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BIOENERGY: POINTING TO THE FUTURE

Composed of five stand-alone pieces, this Issue Paper highlights the current science, processes, and potentials for energy production through agriculture and outlines future research needs.

A **Introduction to the Bioenergy Issue**: As Congress debates the need to expand and diversify U.S. energy supplies, nonfossil sources of energy, including bioenergy, must be considered. Perennial biomass crops could become important, environmentally sound feedstocks for power, liquid fuel, and chemical production, creating new income opportunities for farmers.

B **Technology of Bioenergy**: Successful future research depends on accurate assessments of past information, adequate funding, both broad and specific research focus, clear and consistent research priorities, and multi-institutional, interdisciplinary cooperation to assure effective design and evaluation.

C **Economics and Rural Development of Bioenergy**: Research in biomass and traditional crop conversion technology could decrease the cost of bioenergy and industrial products and broaden the resource base for import substitution.

D **Environmental Effects of Bioenergy**: Although there is proven technology to convert biomass to energy, a major challenge is to make sure that implementation is carried out in an economical and resource-conserving manner. Potential effects on land use, air quality, and wildlife must be addressed.

E **Penetrating the Commercial Marketplace with Bioenergy**: The process of bringing new products to market may be viewed as consisting of links in a causal chain extending from the research bench to its product prototypes to market acceptance and penetration.

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Bioenergy: Pointing to the Future

A. Introduction to the Bioenergy Issue

Reliable, low-cost energy is important for a prosperous U.S. economy. For more than a century, fossil sources have satisfied the majority of the nation's energy needs. But there is growing awareness and concern that reliance on fossil resources for the majority of the large, ever-increasing U.S. energy consumption needs is not sustainable and potentially has serious security, environmental, and economic consequences. The United States currently imports 56% of its oil. As recent worldwide events have shown, energy-source diversity is important not only for energy security but also for national security. Dependence on any single source of energy, especially a foreign source, leaves the United States vulnerable to price shocks, supply interruptions, and economic blackmail.

An important theme of the Bush Administration's National Energy Policy Development Group's recommendations and of the energy legislation now being debated in Congress is the need to expand and diversify U.S. energy supplies. Nonfossil sources of energy, including bioenergy, must be considered. *Bioenergy* is energy contained in material produced by photosynthesis (including organic waste) that may be used directly or indirectly to manufacture fuels and substitutes for petrochemicals and other energy-intensive products. Bioenergy is being mentioned more frequently and is playing a more important role both in the Administration's recommendations and in congressional debate.

Fossil Fuel Concerns

The U.S. Department of Energy's (DOE) Energy Information Administration reports that in 2002 the United States consumed 97.7 quadrillion British thermal units, 86% of which came from fossil sources. This amount included 136 billion gallons of gasoline and 36 billion gallons of diesel fuel, 60% of which came from imported oil (USDOE 2004). Consumption of fossil fuels has grown to its present level because oil is a low-cost raw material and because a well-developed infrastructure is in place to extract, transport, and refine oil, as well as to distribute and market liquid fuels (primarily gasoline and diesel fuel) made from oil. Because the consequences of a disruption in U.S. access to its imported oil supply are extensive (as evidenced during the oil embargo of the 1970s when 30% of U.S. petroleum needs were met by imports), significant amounts of money and effort are spent to maintain an uninterrupted flow of oil.

Even if domestic and imported oil is adequate to meet U.S. needs, there are other concerns. Each gallon of gasoline and diesel fuel burned emits into the atmosphere nearly 2.5 kilograms of carbon, previously stored underground. The cumulative effect of emissions from burning fossil fuels for transportation, heat, and power is the main cause of the recent large increase in carbon dioxide concentrations in the atmosphere. The potential climate-modifying consequences of this increase are of great concern.

Air and water quality concerns also motivate interest in bioenergy. The current U.S. Clean Air Standards require oxygenates for the wintertime carbon monoxide program and the reformulated gasoline programs, all of which are national programs designed to decrease carbon monoxide and smog pollution. Oxygenates are fuel additives that add extra oxygen to gasoline so when burned, carbon monoxide and smog are decreased. But the petroleum-based oxygenate called methyl tertiary butyl ether (MTBE) has been found to leak into groundwater, leaving an odor and foul taste (USEPA 1999). As a result, MTBE has been banned in 17 States. Ethanol, a biobased oxygenate, does not have similar contamination problems and when mixed with a special blendstock of gasoline, meets the standards for reformulated gasoline. Certain policymakers have asked whether ethanol can replace MTBE adequately. A study conducted by the Office of Energy Policy and New Uses (OEPNU) for Senator Harkin from Iowa showed that a 4-year adjustment period is sufficient to enable ethanol production and distribution capacity to expand to meet the projected increase in demand (Glickman 1999;

Shapouri, Duffield, and Wang 2002). Current ethanol production increases bear out the findings of the OEPNU study. The U.S. Department of Agriculture (USDA) is predicting 3.5 billion gallons of ethanol will be produced in 2004. The Harkin study projects that the ethanol production increase would raise net farm income by approximately $12 billion, cumulatively, over an 11-year period.

The use of bioenergy will decrease adverse greenhouse gas (GHG) emissions compared with the use of fossil fuels. An analysis by Argonne National Laboratory in Illinois showed that in the near future, corn ethanol production and use could decrease GHG emissions by 30% versus gasoline, and the use of cellulosic ethanol could decrease emissions by more than 80% (Wang, Smicks, and Santini 1999). A joint USDA–DOE study showed that biodiesel use decreases net carbon dioxide emissions by 78% compared with petroleum diesel use (USDA/USDOE 1998). Linked to this research is the fact that corn ethanol has a positive net energy balance. A recent study by Shapouri, Duffield, and Wang (2004) shows corn ethanol with a positive net energy balance of 67%.

Biobased Fuels

National security and environmental concerns have prompted increased efforts to replace imported fossil energy with "home-grown" alternatives. Agricultural and forest crops hold promise to become significant feedstocks for the production of liquid fuels and power, as well as for other biobased industrial products. The major impediment to changing from fossil fuels to biobased fuels is cost. The rising price of fossil fuel is an important factor if bioenergy is to become commercially competitive.

As world oil supplies are consumed, the price of oil will rise, and as a result, the price of gasoline and diesel fuel also will rise. As these increases occur, renewable energy will become price competitive. According to Banerjee (2002, p. D9), "Oil companies are eager to find alternatives to fossil fuels because they understand that over the next century they will see their supply dwindling. There are enough proven reserves for oil to last another 37 years or so; natural gas, another 61 years; and coal, 211 more years according to the Edison Electric Initiative, a trade group." In the short run, niche markets and energy, environmental, and agricultural policy will guide the market progress of bioenergy. In the long run, an increasing world demand for energy and a diminishing fossil fuel supply could trigger a large market for bioenergy. The Energy Information Administration predicts that prices for natural gas, petroleum, and coal will rise little, if any, during the next 20 years (USDOE 2004). A study by Shell predicts that renewables such as bioenergy will become commercially competitive in 2020 (Kassler 1994).

As Gallagher and colleagues (2003) note, bioenergy from agriculture could displace 25 to 30% of U.S. petroleum imports. To supply that amount, the DOE study estimates that 1 billion dry tons of lignocellulosic feedstock (i.e., material from plants with cell walls consisting of cellulose intimately associated with lignin to provide strength) will be required annually (USDOE 2003). Production of that quantity of biomass will require development of a significant infrastructure to produce, gather, and handle these feedstocks sustainably and convert them into energy, as well as to distribute the liquid fuel and other energy produced. The amount of biomass that will be made available for conversion to energy depends significantly on the price paid for the feedstocks.

Perennial biomass crops (e.g., poplar, willow, or switchgrass) could become important feedstocks for power, liquid fuel, and chemical production and could be produced on land that was considered inappropriate for annual crops and idled for conservation measures during the past few years. Work by the USDA and Oak Ridge National Laboratory in Tennessee indicates that expanding biomass crop production beyond approximately 12.1 million hectares (30 million acres) will make the competition for land between biomass and traditional agricultural crops an important factor (De La Torre Ugarte et al. 2000). Successful biomass research programs that increase crop yields and decrease costs for production, harvesting, delivery, and utilization are key to making biomass commercially competitive.

Biomass has lower energy density than fossil feedstocks and is distributed over large land areas. For liquid fuels, energy-efficient, low-cost technology must be developed to gather and convert biobased feedstocks into liquid fuels. This geographically dispersed technology must be implemented in ways that conserve soil resources and maintain the capacity to produce food, feed, fiber, and energy reliably to satisfy U.S. needs.

Public Policy

Research to enhance biomass crop yields and improve conversion and power generation technologies will allow bioenergy to compete more effectively with fossil fuels. But unless government policies are put in place to include the indirect energy security and environmental costs of fossil fuel consumption in the price consumers pay for fuels, bioenergy will continue to be too costly for the foreseeable future. The reason policies are needed is because the net positive externalities of bioenergy are not accounted for in the marketplace (Champ, Boyle, and Brown 2003).

Some policymakers cite the federal assistance that ethanol receives as evidence of the fuel's high cost. Although it is true that ethanol received a tax credit of 52 cents a gallon in 2003, imported gasoline also received significant financial assistance. Energy security is a major national concern. Four top policymakers, including the former Chair of the Joint Chiefs of Staff Admiral Thomas H. Moore, wrote to Congress that the United States positions approximately one-third of its military forces, directly or indirectly, to ensure the free flow of oil (Butler et al. 1997). In a 1990 study for Congress, the U.S. General Accounting Office (GAO) reckoned that the additional cost of imported gasoline that consumers do not see at the pump is approximately $3 per gallon (USGAO 1991). Another GAO report documents the fact that the U.S oil industry received tax benefits of $134 billion (in year-2000 dollars) from 1968 to 2000 (USGAO 2000). Even the American Petroleum Institute estimates that ethanol blending has decreased the price of finished gasoline by 0.27% (USGAO 1997).

Environmental Benefits

In the aftermath of the 1989 Exxon Valdez oil spill in Alaska, the United States has learned that a discharge of millions of gallons of oil at sea is an extraordinary environmental emergency that is difficult and costly to clean up. Indications are that biobased fuels and bioproducts such as hydraulic fluids and lubricants are biodegraded more easily, have lower toxicity, and have higher flash points than petroleum-based products. Therefore, bioproducts likely will be easier to clean up and less harmful to the environment than their petroleum competitors. Testing is needed to confirm their lighter environmental "footprint."

For example, consider electricity transformer cooling fluids used in the Great Lakes region that are composed of harmful polychlorinated biphenyls, or PCBs. A potentially effective strategy for accomplishing hazardous chemical removal is to replace fossil-based fluid with biobased transformer fluid made from oilseed crops. Testing is needed, however, to verify environmental benefits of the biobased fluid. Successful testing is an important step in a process that could ultimately result in the U.S. Environmental Protection Agency granting greater regulatory flexibility for biobased products and bioenergy that meet their environmental standards successfully.

Economic Concerns

In addition to providing significant environmental and energy security benefits, bioenergy development can create new income opportunities for farmers, more jobs in rural communities, and an enhanced economy for rural America. The indirect social cost benefits of an improved rural economy also must be taken into account in the comparative prices the consumer pays for fossil-based versus biobased fuels. Economic conditions and new technological developments as well as public policy will determine whether or not bioenergy plays a more significant role in the future. For example, if the ethanol production facilities that currently use natural gas to power the ethanol plant were to use biomass and cogenerate, the net energy gained would increase significantly. Ethanol production from sugarcane in Brazil is so net-energy-positive because the sugarmill and ethanol facilities are powered by the biomass bagasse (sugarcane residue remaining after sugar extraction). Possibly, in the future, corn ethanol plants could cogenerate and burn the distilled dry grains or corn stover to enhance the positive net energy balance further.

The 2002 Farm Bill provided income support for commodities through programs such as direct payments, counter-cyclical payments, market assistance loans, and loan deficiency payments. Increased demand from new bioenergy and bioproduct markets likely will increase commodity prices to farmers and in turn decrease the need for farm program payments. Higher prices for corn, soybean, and other grains will decrease the need for ad hoc supplemental emergency payments and decrease loan deficiency and marketing loan gains when prices are low. For example, the USDA estimates that each 10-cent increase in corn prices could lower farm program outlays by approximately $1 billion per year (Collins 2000). The annual average market price for corn in 2003 was $2.45 per bushel. The marketing loan benefit for the 2003 corn crop was $39 million. Increased demand for ethanol to replace MTBE helped to boost corn prices and decrease the need for farm program payments in 2003.

Creating a market demand for bioenergy and bioproducts would be positive for rural development because of the strategic placement of bioenergy facilities. For example, work done by the OEPNU found that increasing the demand for soy-based biodiesel and bioproducts would create new jobs in the farm, food-processing, manufacturing, and service sectors (Duffield et al. 1998). A 1.5 billion-pound annual average increase in soybean oil demand is projected to induce an increase of more than 13,000 jobs throughout the rural economy, largely in rural areas (Collins 2001).

It is not the purpose of this paper to discuss monetary policy; however, monetary policy does influence agricultural policy. When the U.S. dollar is strong relative to other currencies, U.S. exports are expensive and imports inexpensive. Currently, Canada, Brazil, Australia, New Zealand, and Argentina enjoy inexpensive exports but expensive imports relative to the United States.

In such situations, U.S. agricultural exports are less competitive; therefore, reliance on bioenergy to balance supply and demand is even more important.

The development and expansion of a biofuel industry founded on a strong agricultural sector can play a role in enhancing energy security, cleaning our environment, and promoting farm and rural economic growth. Economic factors will determine the possibilities for expansion. Critical economic determinants to biofuel growth are petroleum and fossil fuel prices; feedstock costs; coproduct markets; policies on agriculture, energy, and the environment; and advances in technologies.

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This paper is one of five stand-alone pieces comprising CAST Issue Paper No. 27, titled *Bioenergy: Pointing to the Future*. Section A was prepared by task force members Roger K. Conway and Don Erbach. Additional copies of the complete issue paper are available for $5.00 from the Council for Agricultural Science and Technology, 4420 W. Lincoln Way, Ames, Iowa 50014; Phone: 515-292-2125; Fax: 515-292-4512; E-mail: <cast@cast-science.org> Linda M. Chimenti, Managing Scientific Editor. World Wide Web: <http://www.cast-science.org>

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Bioenergy: Pointing to the Future

B. Technology of Bioenergy[1]

The concept of using carbon-carbon linkages in optimal ways is fundamental to providing food and fuel for life on this planet. Scientists need to think, discuss, disagree, plan, conduct, and reassess if goals are to allow for serendipitous findings. Therefore, it is essential to devise research directions that will ensure successful future studies built on basic information.

Constraints to selected commercialization goals may include the need to analyze the commercial, technical, economic, social, and political environments in which the specific objective is to be accomplished. Constraints also may include lack of basic knowledge about the physical, chemical, biological, economic, and social phenomena associated with production and use of any selected product.

Hypothetically, the use of cellulosic biomass (normally considered waste or used as ruminant foodstuffs) for the production of fuel ethanol and other coproducts is sound and environmentally appropriate. Using selected enzymes and genetically modified organisms as well as recycling agricultural and forestry residues are practices of national importance and decrease the vulnerability of the U.S. economy to disruptions of energy supplies. Using renewable resources for production of liquid fuels also will aid in decreasing the release of carbon dioxide into the atmosphere. Additionally, growing plants will sequester carbon from carbon dioxide. By the process of photosynthesis, plants absorb carbon from the atmosphere, turning it into usable carbon-containing compounds including amino acids, fatty acids, and carbohydrates.

Several things must be considered in the progression from fundamental ideas to basic research, then to developmental research, adaptive research, technology transfer, and finally to bioenergy commercialization:

- Basic research generates basic knowledge without regard to economic value.
- Subsequent developmental research must lead to applied research.
- Applied research projects must be designed to provide background information on conducting scale-model evaluations.
- Scale models must be developed to include economic assessments before full-scale commercialization.

Often a change in federal policy is required to motivate scientists to initiate coordinated, cooperative, and multidisciplinary research projects. Adequate funding must be available for research and development programs that are performance based and modeled as public–private partnerships. A policy program needs to be established to assist companies in purchasing energy from renewable resources while concurrently receiving recognition for the environmental benefits of their participation.

To commercialize biofuels from renewable resources, both broad and specific research priorities should be identified. Broad research areas should include

- economic assessments,
- producer and consumer needs,
- genetic engineering,
- alternative conversion processes,
- milling,
- fermentation,
- coproduct evaluation, and
- usage.

Specific research areas should include

- enhanced technologies for separation of raw materials, in conjunction with improved catalytic

[1]This paper focuses on sugar-based technologies and does not comment in depth on gasification and other reliable forms of bioenergy processing.

monomer conversion;

- explanation of isolation technologies for polymers from energy crops;
- development of high-efficiency enzyme systems for conversion of hexoses and pentoses into fuels;
- improved biomass gasification technologies for direct production of electricity, and in conjunction with improved enzymes/catalysts for production of fuels and chemicals; and
- assessment of transportation and storage issues.

Research priorities must include

- understanding of conversion of solar energy to plant materials;
- modification of plants to enhance photosynthesis;
- development of cultural practices for plants that produce higher levels of bioavailable carbohydrate, protein, lipid, and minerals;
- optimization of biomass productivity;
- development of equipment necessary for planting, growing, and harvesting renewables;
- facilities for fractionation of the renewables;
- enzymes for efficient conversions of raw materials and coproducts;
- separation methods to purify the multiple products resulting from renewables;
- environmental impacts of agricultural and forest-based feedstocks and products; and
- assessment of economic feasibility and impacts.

Conducting multi-institutional, interdisciplinary investigations, evaluations, and assessments will enhance research endeavors. Establishing consortia that include those individuals with appropriate training, experience, and interest would be an initial step in directing research with a market-driven perspective. To achieve commercialization, there must be industry involvement in all phases of planning and prioritization; research endeavors driven by market needs (i.e., demand pull); a systems approach to problem solving; and flexible, goal-oriented consortia members. To ensure close cooperation throughout the process of research, development, testing, and retailing, the use of Industry Advisory Boards (IABs) is a way to design, prioritize, and evaluate programs. If IABs meet regularly during the course of the studies, appropriate redirections can be accomplished on a timely basis.

Conversion of plant and forest materials will require biological, chemical, mechanical, and thermal processes. For example, genetically engineered trees with high cellulose content and concomitant low lignin must be developed to make conversions with the use of less lignin-degrading chemicals and energy. Because lignin is a polymer that plants use to bind fibers together and to confer structural rigidity, there is a need to characterize the essential lignin structure. From this information, lignin biosynthetic pathways can be regulated to provide a higher percentage of cellulose in plant stems while maintaining stem strength.

Biorefineries that produce ethanol and other chemicals from lignocellulosic biomass (i.e., material from plants with cell walls consisting of cellulose intimately associated with lignin to provide strength) will need technologies to release the potentially fermentable sugars and to convert polymers of monosaccharides enzymatically to readily fermentable sugars. Biorefineries also will need additional or improved microbes that can convert both 5- and 6-carbon sugars to ethanol and other oxygenated chemicals. The required synergies for use of multiple raw materials for continuous processing plant operation also must be characterized.

Although production of fuel ethanol and coproducts from cellulosic biomass is technically sound and environmentally sustainable, there are significant economic barriers to commercialization. Overcoming these barriers will require devising, supporting, and carrying out effective research programs that build on the current knowledge base. These programs must generate fundamental ideas and basic knowledge, progress through developmental and applied research to verify economic viability, and then transfer the technology effectively so that the technology is put into practice.

This paper is one of five stand-alone pieces comprising CAST Issue Paper No. 27, titled *Bioenergy: Pointing to the Future*. Section B was prepared by task force member M. E. Tumbleson. Additional copies of the complete issue paper are available for $5.00 from the Council for Agricultural Science and Technology, 4420 W. Lincoln Way, Ames, Iowa 50014; Phone: 515-292-2125; Fax: 515-292-4512; E-mail: <cast@cast-science.org> Linda M. Chimenti, Managing Scientific Editor. World Wide Web: <http://www.cast-science.org>

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Bioenergy: Pointing to the Future

C. Economics and Rural Development of Bioenergy

During the past two decades, per capita energy consumption in the United States has doubled (Figure C.1). America's import dependency ratio for energy also has doubled (Figure C.2). Imports have grown because the domestic supply growth did not match the demand increase. One reason for lagging supply growth is the dwindling availability of mainstream national energy sources (coal, petroleum, and natural gas). Also, clean air regulations discourage the use of more abundant domestic energy resources and shift demand toward imports. When the U.S. Environmental Protection Agency (EPA) placed emissions standards on motor fuels, industry used additives made from natural gas or natural gas by-products to meet demand increases. Similarly, coal technology for electric power now is clean but expensive, so recent capacity expansions in the 1990s favored what were then less-costly natural gas plants. Growing energy imports likely will continue unless there is a major policy change or a new energy source.

The emerging bioenergy and biobased industrial products industries offer the prospect of decreased energy imports with renewable and environmentally friendly fuels. Currently, the U.S. ethanol industry uses domestically supplied corn. Plant-derived feedstocks for production of plastics and industrial materials also substitute for imported petroleum (NRC 2000). Emerging processing technologies that make fuel and chemicals from biomass could decrease the cost and extend the energy resource base to include residues from crops and trees, biomass energy crops (grasses and trees) grown on marginal land, and recycled paper. Fuel and chemical processing that use residue in conjunction with corn also would improve the net energy balance for corn processing. Another example is an electric power industry that uses crop residues to provide some of rural Denmark's electricity and heating needs (Larsen 1997). An important reason that bioenergy and biobased industrial products are beginning to develop is the decline in the relative price of agricultural versus petroleum inputs (Figure C.3).

Biomass Resources and Technologies

Provided that biomass technologies are developed and adopted successfully, they could provide a significant

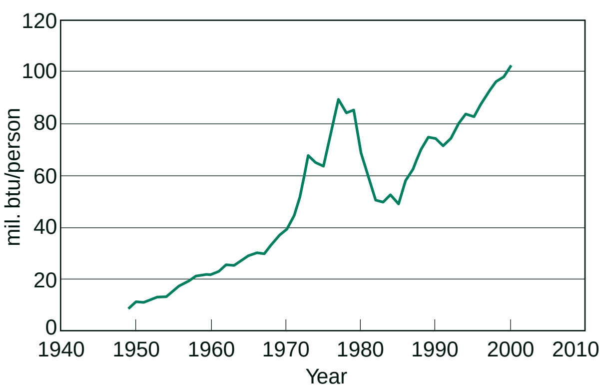

Figure C.1. U.S. energy consumption per capita (adapted from USDOE–EIA 2002).

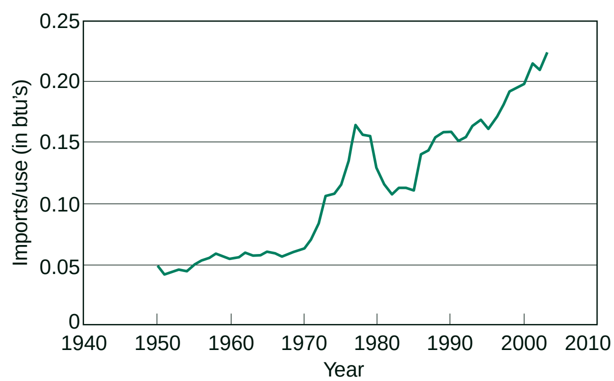

Figure C.2. U.S. import dependency ratio for energy (adapted from USDOE–EIA 2003).

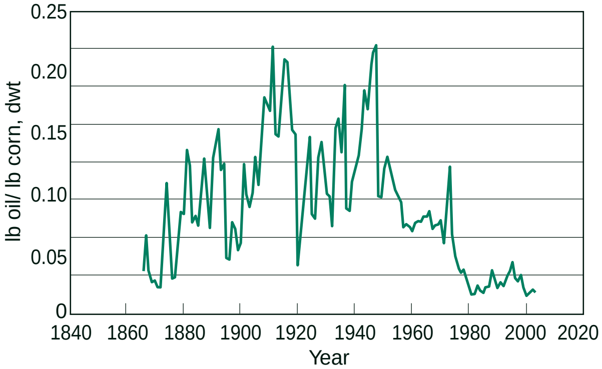

Figure C.3. Corn/Petroleum price ratio (adapted from IMF 2004; U.S. Bureau of the Census 1975; USDA–NASS 2003).

share of U.S. fuel needs. Economically accessible and environmentally sustainable use of crop residues could substitute for 13% of current petroleum imports (Gallagher et al. 2003). A smaller estimate of crop residues uses relatively conservative residue yield and erosion control assumptions (Graham 2003). Also, energy crops could be planted on 8.1 to 16.2 million hectares (20 to 40 million acres) of land in the Conservation Reserve Program or diverted from traditional crops with plausible energy crop prices, replacing another 16% of petroleum imports (Walsh et al. 2003). Therefore, according to the Gallagher and Walsh studies, bioenergy from agriculture could displace 25 to 30% of U.S. petroleum imports with fully developed biomass ethanol technology. Biofuels would help the United States with its energy supply problems, and the food supply would be affected minimally because waste streams and energy crops on marginal land are the feedstocks. Improvements in yield through research would increase the potential of biomass for energy.

Environmental Benefits

Biobased energy provides environmental benefits. For example, ethanol currently has the highest octane and oxygen content of gasoline additives. Octane creates a potential health benefit as a lead replacement (Kitman 2000). Oxygen decreases carbon monoxide from combustion; ethanol can be blended with vapor-decreasing additives (alkylates) to comply with the EPA's air quality requirements. Similarly, biomass for power lowers emissions of sulfur dioxide and nitrous oxides below the coal-burning reference level (Nikolaisen et al. 1998). Finally, biofuels decrease global warming relative to fossil fuels, because carbon dioxide consumed and oxygen produced during photosynthesis and plant growth offset carbon dioxide produced in fuel consumption (Wang, Smicks, and Santini 1999).

Reasons for Bioenergy Market Intervention

Although bioenergy markets are developing after a half-century of declining (real) agricultural prices, in order for the full potential to be realized several factors must be internalized in the marketplace by public policy:

- The environmental benefit from using a biofuel is an externality; that is, it is not included in the profit calculations of firms and decisions of consumers looking for the cheapest fuel in an unregulated market.
- There is a national security benefit: to the extent that increased fuel supply stems a foreign supply disruption, there is a public benefit associated with the improved price stability.
- Bioenergy investments typically are located in the rural areas of middle America; the employment and income gains to state economies are not included in private sector calculations.
- Potential investors in bioprocessing enterprises face an exceptionally risky decision environment, which limits the size of the industry. Bioenergy profits can look very attractive on the high side of the petroleum market and the low side of the farm markets, but prolonged periods of meager profits can occur with other market conditions. Also, investors have some risk of owning an obsolete plant because processing technology is evolving at an uncertain rate.
- The profitability of bioenergy investments is tied to shifting government regulations, which can be unpredictable when compared with income growth and the business cycle that define the success of alternative investments.

Public Policies

Certain benefit-cost evaluations do show a net improvement in economic welfare with public policies in place. For instance, an oxygen standard in the Midwest could function like a local methyl tertiary butyl ether ban; the consumer gains from lower prices with an ethanol blending credit because more fuel is exempt from the federal gasoline tax. The consumer gain, the midwestern gross domestic product increase, and the crop producers' income improvement offset the losses of livestock producers from higher feed costs and excise taxes, for a net welfare improvement (Gallagher, Otto, and Dikeman 2000). Similarly, the increased fuel supply from corn stover-based ethanol would lead to an annual benefit of $3.2 billion in decreased fuel prices and fewer disruptions in the U.S. economy (Gallagher and Johnson 1999). Hence, the corn stover-related benefits justify a $64 billion capital outlay for biomass technology development when the public discount rate is 5%.

Some policies that address market limitations are in place in the world. Denmark's subsidy for biomass power illustrates the idea of an offset for net environmental benefit (Nikolaisen et al. 1998). Similarly, German manufacturers pay for a product's disposal costs, a policy that gives an advantage to biobased plastics and packaging materials given their biodegradability. In the United States, the oxygen standard in reformulated fuel facilitates the pollution decrease associated with ethanol consumption (Rhodes 1998). In addition, the federal tax exemption for ethanol blends decreases investment risks by increasing ethanol's profitability. Certain states also have incentive programs that offset capital costs and encourage local rural development. The United States, however, does not seem ready to date to join the Kyoto Protocol or adopt other policies that provide incentives to decrease carbon dioxide emissions (Hagem and Holtsmark 2001). Once the intervention approach is taken, there always are contentious issues about the appropriate form and extent of government involvement.

Conclusion

Regardless of one's view on environment, rural development, and investment risk, a public investment in technology development for bioenergy deserves consideration. Research in biomass and traditional crop conversion technology could decrease the cost of bioenergy and industrial products and broaden the resource base for import substitution. The technology seems close enough to make the possibility believable. Unassisted private sector initiatives do not seem to be imminent, possibly due to risk, the dilution of returns with research duplication, or the long-run nature of the investment. If conversion technology succeeds, technology development aimed at increasing energy crop yields and decreasing handling costs also would help. Given the U.S. energy habit and dwindling national supplies, a public policy investment in domestically supplied, clean energy at reasonable prices is a good bet in any public budget.

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Bioenergy: Pointing to the Future

D. Environmental Effects of Bioenergy

Bioenergy can be generated from either feedstocks produced specifically for use in energy production or by-products or “waste products” resulting from other production processes. Important energy crops include many traditional ones, such as corn, sugarcane, and sugar beets, which are used in ethanol production. In addition, crops such as fast-growing tree and grass species are being developed and adapted specifically for energy feedstocks.

Much attention has been focused on the capture and use for energy production of what have been considered as waste products. For example, sawmill waste products often are used to provide energy for drying lumber, powering saws, and meeting other mill needs. As another example, the technology necessary to capture and recover methane from animal waste lagoons for use in electrical power generation has been available for at least 10 years but has been adopted by relatively few animal producers. Methane captured from landfills has been used to fire boilers to heat greenhouses and other buildings. Animal waste utilization and disposal issues creating air and water problems have led to expanded research and technology development budgets in the private and public sectors.

There is proven technology to convert biomass to energy. A major challenge is to implement this technology in an economical and resource-conserving manner.

Land Availability

According to the 1997 Census of Agriculture, there are approximately 174.6 million hectares (ha) (431.4 million acres [a.]) of cropland in the United States, of which approximately 103.0 million ha (254.5 million a.) are planted to the eight major crops. The plantings include 11.0 million ha (27.2 million a.) to alfalfa, 13.4 million ha (33.2 million a.) to other hay crops, and approximately 24.4 million ha (60.3 million a.) to pasture. Approximately 13.8 million ha (34 million a.) are in the Conservation Reserve Program (CRP) (USDA 2001b).

Of the approximately 303.6 million ha (750 million a.) of forestland in the United States, roughly 63% is in private ownership (USDA 2001a). Nonindustrial private forests constitute the largest ownership category at 53%; the forest industry owns approximately 9%, the federal government approximately 27.5%, and other public entities, 9.3%. The United States has the land base to produce substantial quantities of biomass, depending on economic, environmental, and social preferences.

Potential Effects on Land Use

Conservation Reserve Program Land Returned to Production

Increased production of plant material for bioenergy production could have a significant effect on land use. One source of this impact could be a change in land use as CRP land comes back into production. The CRP has retired approximately 13.8 million ha (34 million a.) of environmentally sensitive land from crop production. This land has been in permanent vegetative cover for 10 or more years, provides soil erosion control as well as wildlife shelter, and leads to water and air quality benefits.

From the standpoint of bioenergy, CRP land falls into three categories:

1. Approximately 810 thousand ha (2 million a.) of land planted to trees (15- to 20-year CRP contracts) has a substantial potential to provide biomass, both from the biomass grown on the land during the CRP contract and from land use to produce biomass after contract expiration. Much of this forested land comprises pine plantations in the South.
2. CRP cropland returned to production in humid areas also has a strong potential to provide biomass. This land is highly erodible and will require substantial conservation measures to produce biomass sustainably.
3. The majority of CRP land is in semiarid locations and does not have great potential for intensive biomass production.

Land Currently in Production

In addition to potential effects from CRP land returning to biomass production, bioenergy can have land-use effects on land already in crop or forest production.

An example of this effect is the use of biomass left on fields as a source of energy. Much of the gain in erosion control during the past 15 years has been through the adoption of conservation tillage, which requires management of residue. Actions to collect and use residue as a feedstock for bioenergy have a strong potential for increasing soil erosion unless they are managed carefully. Usually, 30% of the soil surface should remain covered with residue; the rest can be "harvested." In addition to erosion control, it should be noted, conservation tillage results in less energy being used in crop production and enhances carbon sequestration in the soil.

Intensifying biomass production on existing cropland will require the development and implementation of new production and conservation systems. Elements will include selection of specific species; development of nutrient, pest management, and harvesting protocols; and development of soil and water conservation systems. Some biomass crops such as switchgrass, hybrid poplar, and willow use management and conservation practices similar to those used in traditional crop and forest production systems.

There are large acreages in pasture and hayland, some of which could be farmed more intensively for the production of biomass. But if the land is highly erodible, it may be subject to sodbuster provisions that require a conservation plan and production practices limiting soil erosion to tolerable levels. In addition, some of this land is in long-term crop rotations, in accordance with established conservation compliance plans. Bringing this land into production from pasture to cropping probably will require updating of affected plans.

Changes in land use may not always be straightforward. A study by University of Tennessee and Department of Energy scientists simulated the effects of alternative biomass production scenarios on land use (De La Torre Ugarte et al. 2000). The scientists found shifts in acreage of major crops resulting from the introduction of bioenergy crops, with many traditional crops losing acreage to the bioenergy crops. This shift generated higher prices for the traditional crops and provided incentives to convert idle and pasture land to traditional crop production.

Bioenergy also can have land-use effects on land currently in forest production; gathering feedstocks after timber harvest or from actively growing forests can lead to soil erosion. On the positive side, however, removing waste materials and undergrowth can decrease fire, disease, and pest problems.

Potential Air Quality Effects

Increased use of bioenergy will help decrease greenhouse gas emissions. Carbon dioxide emitted from burning returns to the atmosphere for uptake by plants in the carbon cycle. Methane and many other by-products of animal agriculture generally are considered waste products today. Some methane capture occurs in the United States, but there is great potential for expansion. The benefits of expansion will include providing heat and, potentially, electricity for farm and farmstead uses, possibly decreasing farm costs; providing a source of income; and helping to decrease methane emissions into the environment.

Manure is a substantial problem in many locations in the United States where there is insufficient agricultural land for its traditional use as a fertilizer. Work is under way to develop means to capture the energy in manure. The Environmental Protection Agency's AgSTAR program is an example of that work (USEPA 2004). Some progress has been made in poultry manure conversion to energy, and a few electrical generating plants now use this manure as a feedstock.

Potential Wildlife Effects

Bioenergy effects on wildlife stem from several sources. Adverse effects can result from the conversion of land from native habitat to biomass crop production as well as from the intensification and specialization of crop production for biomass. Proper management can help minimize such adverse effects. For example, delaying biomass harvesting until after the bird nesting season can minimize harmful effects on certain birds.

Beneficial effects can result from improved water quality caused by the use of highly erodible cropland for perennial biomass feedstock production as well as from improved nutrient management.

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BIOENERGY: POINTING TO THE FUTURE

E. PENETRATING THE COMMERCIAL MARKETPLACE WITH BIOENERGY

The efforts of agricultural producers and processors to develop and produce new biobased energy and coproducts have matched growing consumer interest in environmentally friendly products. Despite substantial investment in research to improve bioenergy production technology, widespread market penetration for bioenergy has not been realized. This does not mean that money for research has been misspent; rather, it is likely that there has been underinvestment in other steps required to bring new biobased energy and coproducts to market. Those steps are described in this section.

In the past, the development of bioenergy and bioproducts from biomass focused on basic research. There was a need to determine the efficiency and economics of production from nonpetroleum feedstocks to assess their viability and supply. Although basic research provided the information to narrow the focus on feedstock choice and the types of products to produce, it has done little to apply the research to real-world conditions that would allow for investment from the business community.

What, then, is missing? A more systematic approach could result in greater penetration of commercial markets by bioenergy. The process of bringing new products to market may be viewed as consisting of links in a causal chain extending from the research bench and its product prototypes to market acceptance and penetration. Those links include research, testing, regulatory initiatives, product development and commercialization, public sector incentives, and financing issues, as well as education and outreach programs. The following subsections discuss the links in that causal chain and suggest ways to be more successful in creating a demand pull for bioenergy and bioproducts.

RESEARCH

Research remains a key element in bringing all new products to market. Greater knowledge of plant genomics, coupled with the evolving tools of biotechnology, can create an array of plant varieties with high-value characteristics. These new characteristics can provide feedstocks of improved and more uniform quality at lower costs for conversion into energy and bioproducts. New separation technologies that segregate the higher-valued components must be developed to provide the pathway to lower manufacturing costs. Decreased costs for sugars from lignocellulosic biomass (plants with cell walls consisting of cellulose intimately associated with lignin to provide strength) can open new opportunities for developing products from feedstocks currently being wasted. The biorefinery concept—the separation of plants and grains into component parts—can be developed more fully to yield a broader array of product streams from biomass and, as a consequence, to decrease manufacturing costs.

TESTING

Testing of new bioenergy and bioproducts and product prototypes seems to be a critically important step in bringing them to market. Unless merchants and customers can be reasonably sure an energy product can meet the performance claims of its manufacturer, it is unlikely such a product will be offered for sale widely or purchased by consumers. Moreover, because an important component of the attributes embedded in these products (such as biodegradability) relates to their effect on the environment, it is important to know whether these products have lower life cycle costs and environmental footprints than the fossil energy-based products they will replace.

Many products currently in use have industry- or user-determined performance standards that represent the threshold performance levels these products must meet. For example, automotive manufacturers have developed the American Society for Testing and Materials' Standards for fuels, lubricants, and greases. When the Defense Logistics Agency of the Department of Defense purchases products for the U.S. military services, it uses minimum performance standards based on the requirements of the equipment in which the product will be used; for example, performance characteristics and quality of fuel for a specific tank or aircraft. It will be important for developers of biobased fuel to submit their products to a similar testing regime. In addition, quantifying the environmental attributes of a fuel adds to its competitiveness, even when its price may be somewhat higher than that of a comparable fossil fuel. Biofuels and their bio-coproducts bring additional value in managing the carbon cycle and improving the environmental sustainability of modern life.

Regulatory Initiatives

Regulatory initiatives can play an important role in encouraging firms to try new technologies and new products. One example is a renewable fuels standard that creates a market for transporting biofuels. Regulatory flexibility can encourage the use of best practices for environmental management, which often will incorporate biofuels. Ideally, it may become possible, with sound scientific information, to encourage environmental regulatory agencies to differentiate clean air and water regulations by recognizing the more benign effects of some biofuels and bioproducts on people and the environment. That differentiation could, of course, materially add to the market competitiveness of biofuels and bioproducts. Regulatory initiatives also may include tax credits or incentives. Life cycle analysis of biobased fuels from "cradle to grave" could provide carbon credits for industry trading, thus lowering the effective cost of biobased fuel production.

Product Development and Commercialization

A critical step in the process of creating new products and bringing them into the market is product development and commercialization. Product development involves refinement and fine-tuning of product prototypes to address specific market demands as well as demonstration projects that test the product in use to determine how effectively it fills a market need. Demonstration projects are a critical step and likely will be an iterative process with research and product testing steps, as the developer seeks to create a product that cost-effectively fills a market need. Product demonstration also can play an educational role as potential customers evaluate the usefulness of a product and learn how it might be used in their applications.

Another important step in commercialization of bioenergy and bioproducts involves procurement preferences for federal, state, and other public sector purchasing. These preferences fill at least three important functions in commercialization:

1. They provide a broader-based and more diverse opportunity to demonstrate the product in use to potential customers.
2. They provide a critically important demand base large enough for suppliers to scale up production, thereby achieving economies of scale and decreasing product cost.
3. Public procurement preferences can stimulate sufficient market demand to bring new suppliers and their competitive efficiencies into the market.

Public Sector Incentives

Public sector incentives to support new industries often extend beyond procurement preferences. Tax credits, such as investment and research tax credits, can be used to decrease both risk and cost to private firms that develop, manufacture, and commercialize a new product, use a new and untried production process, or enter new markets. An incentive based on production levels, such as the Commodity Credit Corporation Bioenergy Program that provides an incentive payment to processors increasing their production of biofuels, is the most effective public sector incentive to achieve the desired result—increased output of the target product. Insurance coverage can be created to support risk management associated with the use of new and untried technology that might be used in producing a new production process, such as cellulosic conversion of plant lignin for use in a new biorefinery, or a new bioproduct.

Sometimes incentives must be tradable to achieve the desired public policy result. This is true for cooperatives engaged in production of biofuels and coproducts, because they return profits to members and typically do not have a tax liability on which to use tax credits.

Financing Issues

Financing is a large concern for firms entering into new business ventures or offering new products to the marketplace. A number of strategies have proved successful in addressing this issue.

Equity capital is difficult to acquire, and the tendency, especially with cooperatively organized business firms, is to go forward with the minimal amount of equity capital necessary to support the debt capital used in the start-up. That action can add unnecessary risk to the new business venture because it means there is little built-in financial resiliency to sustain business setbacks.

An array of private sector and public/private sector partnerships can facilitate financing. It is almost always preferable to own part of a successful venture than to own all of a venture with a high risk of failure. Creating competitive access to venture capital and "angel" capital (individual investors) for new business start-up and expansion is a problem in rural America, and thus, creating investment networks that focus on rural and biobased businesses may be part of the solution. Assistance in preparing a sound business plan is a first step toward attracting either venture or debt capital. Although federal rural development funds are available to some extent, programs need to be developed to address specifically the funding of high-risk technology such as bioenergy and bioproducts.

Overcoming rate of return barriers on new investments in plants and equipment to support biofuels and coproducts production is a particularly difficult issue for private sector firms entering a new and inherently higher-risk market—one that usually has high entrance requirements in terms of capital and technology. Public sector investment partnerships, tax credit plans, and grants can be particularly helpful in enabling the first generation of new production and marketing to gain a competitive foothold.

Access to specialized insurance or other risk-bearing strategies to protect cash flow during periods of business interruptions could prove helpful. Contracts that fix feedstock costs and facilitate market demand also are important for lowering financial risk to levels that business firms are willing to bear.

Educational and Outreach Programs

Educational and outreach programs that provide science-based information on biofuels and bioproducts to policymakers, manufacturers, and consumers can be important in obtaining successful market penetration. Understanding product environmental and performance characteristics is key to a product launch. Bioenergy products have to be more than "green"; they also have to be priced competitively and add more value than the competition.

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