Agricultural Energy Crops 2

The agricultural sector has the potential to produce large quantities of renewable energy in the form of bioenergy crops,[2] which can be converted to electricity, heat, or liquid or gaseous fuels.[3] Producing these crops can potentially improve the environment, increase rural incomes, reduce federal budget expenditures, and reduce the U.S. trade imbalance. To realize this broad potential will require continuing research, development, demonstration, and commercialization efforts. It will also require considerable planning and coordination because of the numerous issues that bioenergy crops impact. Haphazardly implementing large-scale bioenergy programs without a sufficient foundation could damage the environment and reduce potential economic benefits.

What Has Changed?

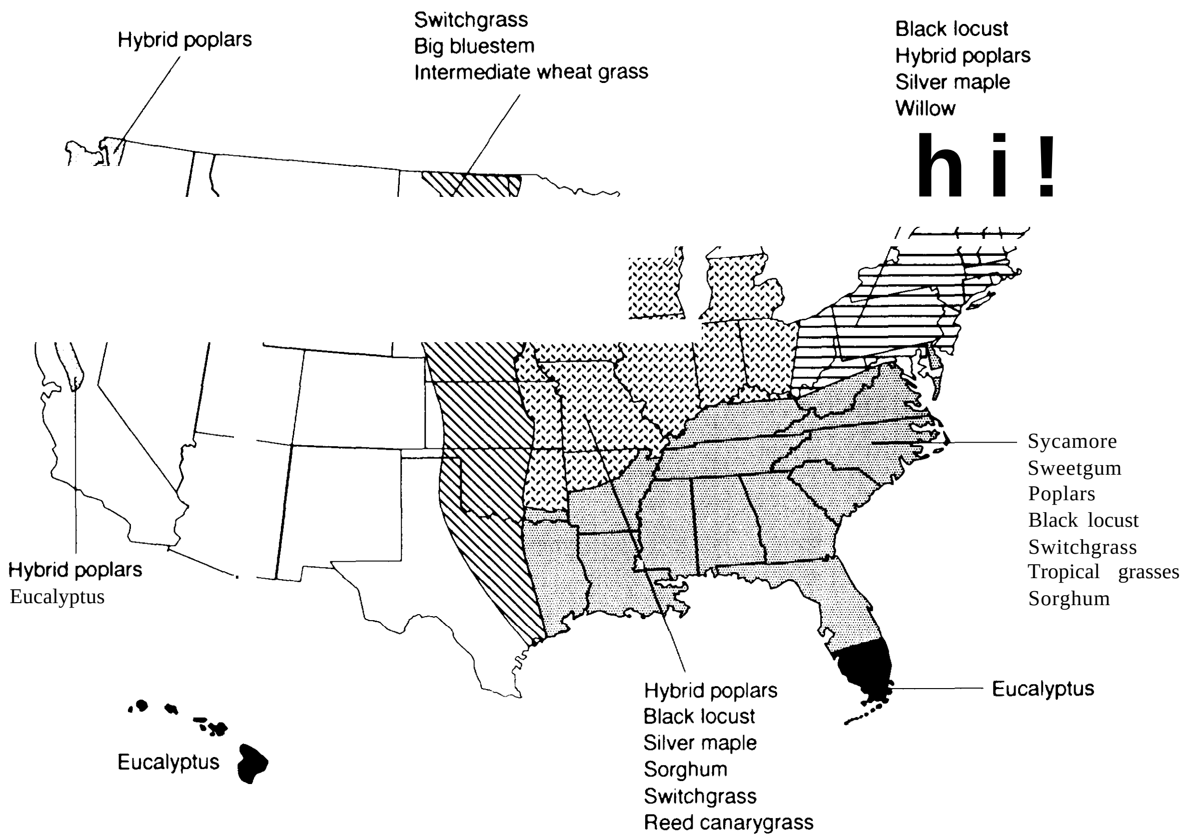
Bioenergy cropping has advanced significantly since 1980. More than 100 woody species and 25 grassy species have been examined by Oak Ridge National Laboratory and others for their suitability as energy crops; six species of woody crops and one specie of grassy crop were selected as models for intensive devel -

[1] Much of the discussion here might also be applied to the forestry sector. Because of certain differences between the agricultural and forestry sectors in environmental considerations, economic and budget impacts, market challenges, and policy issues, however, the focus here is limited to the agricultural sector. Future work should consider extending the analysis to the forestry sector.

[2] Only lignocellulosic energy crops such as trees and grasses are discussed in this chapter.

[3] See chapters 4 and 5 for a discussion of technologies for converting bioenergy crops to useful fuels and electricity.

FIGURE 2-1: Potential Energy Crops and Regions Applicable in the United States



NOTE: A limited set of potential energy crops is shown, along with willow and the regions within the United States where they might be grown. Many other species might be considered as well, including alder, ash, kenaf, mesquite, etc.

SOURCE: Oak Ridge National Laboratory, n.d.

opment.[4] Advances in genetic engineering and breeding techniques have allowed rapid improvements in crop productivity, with biomass yields increasing 50 percent and more over this period for the two principal crops, poplar and switchgrass, on which detailed work has been done.[5] Methods of establishing and maintaining these crops have also been developed and improved. In the 1970s, short rotation woody crops, which can be harvested repeatedly and regrown from the stump,[6] were little more than a scientific curiosity. Today, they are in commercial use. For example, more than 25,000 hectares (62,000 acres) of hybrid poplars have been established in the Pacific Northwest for pulp (paper) and energy use. The

[4] Lynn Wright, Oak Ridge National Laboratory, personal communication, Apr. 7, 1994.

[5] Anthony Turhollow, Consultant, personal communication, May 11, 1994.

[6] With the current rapid pace of crop improvement, replanting may sometimes be preferable to regrowth in order to realize higher yields with new crop strains.

BOX 2-1: National Policies That Influence the Use of Energy Crops

Several national policies reflect the growing interest in bioenergy, A variety of excise tax and other exemptions, tax credits, and other supports are available at both the federal and state levels. Some federal incentives for bioenergy are listed in table 2-1.

Recent legislation related to bioenergy includes

- The 1988 Alternative Motor Fuels Act encouraged the use of methanol, ethanol, and natural gas transport fuels
- The Clean Air Act Amendments of 1990 limited sulfur emissions from powerplants (potentially benefiting bioenergy because it contains little sulfur), set requirements for the use of oxygenated fuels (potentially benefiting ethanol and methanol production—see chapter 4), and established credits for the use of renewable energy,
- The Energy Policy Act of 1992 established federal, state, and private light-duty vehicle fleet mandates for the use of alternative fuels, a variety of tax exemptions and credits for alternate fuel vehicles (including electric vehicles), and a 1 5¢/kWh credit for closed-loop, biomass-fired electricity generation

Finally, the United States, along with 153 other nations, signed the United Nations Framework Convention on Climate Change at the Rio de Janeiro "Earth Summit" in June 1992, and the U. S. Senate ratified it in October 1992 This Framework Convention established the objective of stabilizing "greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic Interference with the climate system " The Climate Change Action Plan, announced in October 1993, has the goal of returning "U S. greenhouse gas emissions to 1990 levels by the year 2000 with cost effective domestic actions " Bioenergy can potentially play a significant role in providing energy with little or no net greenhouse gas emissions

SOURCE Off Ice of Technology Assessment 1995

costs of such energy crops are declining to the point of being competitive as energy resources, and a variety of these crops can be grown across the United States, depending on the region and climate (figure 2-1).

Bioenergy conversion technologies have also advanced significantly over the past two decades. Roughly 8,000 megawatts (MW) of bioenergy - fueled electricity generating capacity is currently connected to the electricity grid, compared with less than 200 MW in 1979; additional bioelectric capacity is operated offgrid.[7] New classes of efficient bioelectric technologies are emerging that can help make biomass competitive over a wider range of conditions (see chapter 5). Similarly, significant advances have been made in converting biomass to liquid fuels such as ethanol and methanol (chapter 4). For example, the cost of converting cellulosic biomass to ethanol has declined from \$3.60/gallon (\$0.95/liter) in 1980 to \$1.20/gallon (\$0.32/liter) in 1993.[8] Several national policies now encourage greater use of bioenergy resources (see box 2-1 and table 2-l).

[7] In comparison, total U.S. electricity generating capacity was about 700,000 MW in 1992. American Solar Energy Society, *Progress in Solar Energy Technologies and Applications* (Boulder, CO: January 1994), p. 36.

[8] Costs are based on 1990 dollars. S.R. Venkateswaran, Energetics Inc., and John Brogan, U.S. Department of Energy, personal communication, May 12, 1994.

TABLE 2-1: Selected Federal Incentives for Biomass Energy

Exemption from excise taxes on motor fuels	5. 4¢/gal
Alternative fuels production tax credit	$5,35/barrel
Tax credit for ethanol fuels	54¢-60¢/gal
Credit for small ethanol producers	10¢/gal
Electricity production credit for closed-loop biomass systems	1.5¢/kWh
Income tax deduction for alcohol fuel-powered vehicles (maximum)	$2,000 deduction

SOURCE: Salvatore Lazzari, Congressional Research Service, "Federal Tax Incentives for Biomass Energy, Including Provisions in the Energy Policy Act of 1992," n.d.

I Potential Roles

Biomass is an already stored form of solar energy and so can be used to generate electricity as needed, rather than as available as is the case for wind and solar energy. Biomass may therefore play an important role in the electricity sector, providing baseload and load following capabilities (see box 5-2), complementing intermittent generation by wind and solar systcms (see chapters 5 and 6). It can be burned directly to provide industrial or commercial process heat or space heat for buildings (chapter 3). Liquid fuels[9] from biomass offer a relatively high-energy-density,[10] high-performance alternative to imported petroleum for powering transport (see chapter 4).

| Principal Themes

Five broad themes are addressed in this chapter: 1) the potential supply and cost of bioenergy; 2) the potential environmental impacts of large-scale bioenergy production; 3) the potential economic impacts of bioenergy production; 4) research, development, and demonstration (RD&D) needs and market challenges in commercializing bioen - ergy prroduction and conversion technologies; and 5) policy issues associated with further development of bioenergy.

BIOENERGY SUPPLIES

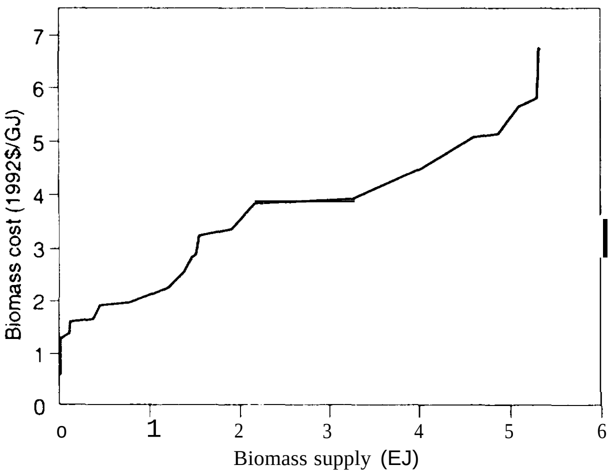
Bioenergy resources include agricultural and forestry residues (see figure 2-2), animal waste, municipal solid waste, and dedicated energy crops. Residues and wastes are often collected at central sites, such as agricultural processing plants, pulp and paper mills, animal feedlots. or municipal waste dumps; their use for energy may then be very cost-effective, particularly as an alternative to trucking them away for disposal. Although limited in quantity, these are the primary bioenergy resources now used (table 2-2). For large-scale energy use, dedicated energy crops are necessary and are the focus of this chapter.

[9]Biomass can also be gasified to produce hydrogen for fuel.

[10]Methanol and ethanol have energy densities of 17 megajoules/liter (MJ/l) (61,000 Btu/gal) and 22 MJ/l (80,000 Btu/gal) respectively, compared with gasoline's energy density of 34 MJ/l (122,000 Btu/gal) on a higher heating value basis. (See appendix A for unit conversion factors.) The fuel efficiencies of ethanol and methanol can be somewhat higher than gasoline in internal combustion engines and are potentially much higher in advanced vehicle technologies such as fuel cells. Higher efficiencies can offset part or all of the impact of lower energy densities on vehicle range. In contrast, gaseous fuels such as methane (natural gas) and hydrogen have much lower energy densities, even in pressurized cylinders. See chapter 4 for details.

[11]For a discussion of bioenergy from agricultural and forestry residues, animal waste, municipal solid waste, and other sources, see the following: U.S. Congress, Office of Technology Assessment, *Energy from Biological Processes*, OTA-E-124 (Washington, DC: U.S. Government Printing Office, July 1980); *Energy from Biological Processes: Volume II—Technical and Environmental Analyses*, OTA-E-128 (September 1980); *Energy from Biological Processes: Volume III—Appendixes Part A: Energy from Wood* (September 1980); *Energy from Biological Processes: Volume III—Appendixes Part C: Select Conversion Technologies and End Use* (September 1980); and *Facing America's Trash: What Next for Municipal Solid Waste*, OTA-O-424 (October 1989). Also see K.H. Lee et al., *Biomass State-of-the-Art Assessment*, Report GS-7471, 2 volumes (Palo Alto, CA: Electric Power Research Institute, September 1991).

FIGURE 2-2: Supply Curve for Whole Tree Chips



NOTE Biomass supplies from conventional wood sources (whole tree chips, logging residues, mill resdues, and others) are estimated to be from 13 EJ (1 2 quads) at $2/GJ ($2 10/MBtu) up to 56 EJ (5 3 quads) at $5/GJ ($5 25 MBtu) Most mill residues shown as part of this supply curve are already used for energy The estimates for whole tree chips were made in the mid- 1980s and more strict environmental rules and scrutiny may lead to decreased availability of this resource Excluded from these supplies is fuelwood used in the residential sector, which amouted to about O 8 EJ (O 75 quads) in 1990

KEY EJ = exajoules (1 EJ = O 948 quads) GJ = gigajoules (1 GJ = 0948 mllion Btu)

SOURCE Anthony F Turhollow and Steve M Cohen, Oak Ridge National Laboratory Data and Sources Biomass Supply, " draft, Jan 28, 1994

Bioenergy crops include annual row crops such as corn and sorghum, perennial grasses (herbaceous energy crops, or HECs)[12] such as switchgrass, and short rotation woody crops (SRWCs) [13] such as poplar and willow. [14] HECs are analogous to growing hay, with the crop harvested for energy rather than for forage. SRWCs typically consist of a field of closely spaced—2 to 3 meters (2 to 3 yards) apart on a grid-trees that are harvested on a cycle of three to 10 years. After harvest, HECs regrow from the remaining stubble and SRWCs regrow from the remaining stumps. Such harvesting may continue for 10 to 20 years or more without replanting; fertilizer, other inputs, and maintenance may be required more regularly, however. HECs, because they are grown like forage crops, may be grown by farmers with only modest changes in farming practices. SRWCs use conventional farm equipment for site preparation and weed control, but they require specialized equipment for harvest. [15] Only HECs and SRWCs are considered here for energy cropping. [16] Typical growing regions for selected energy crops are shown in figure 2-1.

The conversion of sunlight to biomass energy is an infficient process typically with an efficiency of less than 1 percent under field condi-

[12] HECs are typically grasses (e.g., switchgrass, big bluestem, intermediate wheatgrass, tall fescue) that are planted, maintained, and harvested like hay. Grasses such as these are currently used in the Conservation Reserve Program to provide erosion control and wildlife habitat. These crops regrow from their roots and stubble and require replanting only every 10 or more years. Because they are hay crops, they can be grown by farmers with only modest changes in farming practices, and equipment is relatively low cost.

[13] SRWCs are typically hardwoods (e.g., poplar, cottonwood, sycamore, silver maple) with planting density ranging from 1,600 to 5,000 trees/hectare (650 to 2,000 trees/acre). The silvicultural management of SRWCs is typically more intense than conventional forestry, but less intense than conventional agriculture. To obtain good yields requires site preparation, weed control during the first two years after establishment (before canopy closure), and the application of fertilizers. These operations employ conventional agricultural equipment. Harvest requires specialized equipment. Coppicing (i.e., regrowth from the stumps after harvest) is possible. Currently, some SRWCs are grown for pulp.

[14] Other potential bioenergy crops include microalgae.

[15] Such equipment might be owned and leased out by the conversion facility purchasing the bioenergy feedstock, by harvest equipment vendors, by cooperatives, or through other arrangements.

[16] Annual row crops used for energy (such as corn) are grown in essentially the same manner as their food crop counterparts and consequently offer few or no environmental benefits over conventional agricultural practices, For this reason, they are not examined further in this report. There are also energy crops (often annual row crops) that produce starches, sugars, oils, and other specialty plant products for energy. Nationally, however, their energy production potential is much lower and their costs are likely to be higher in the long term than those for HECs or SRWCS. Consequently, they are not considered further in this report. Some of these crops and fuels, such as biodiesel, may nevertheless offer important opportunities and have potentially valuable roles to play.

TABLE 2-2: U.S. Biofuel Production and Use, 1989

Fuel	Energy production (in exajoules)
Wood	2.6 EJ
Industrial	17
Residential	09
Utility	001
Biofuels from waste	036
Municipal solid waste combustion	O 23
Manufacturing waste	0.10
Landfill gas	003
Ethyl alcohol	0075
Total	3.04

NOTE EJ - exajoules, 1 EJ -0948 quads

SOURCE U S Department of Energy Energy Information Administration *Esfimates of U S Biofuels Consurnption 1989* (Washington DC April 1991)

tions. As a result, biomass must be collected from large areas.[17] For example, Producing 15 to 20 EJ (14 to 19 quads) of biomass energy annually would require energy cropping on 45 to 60 mill ion hectares (110 to 150 million acres) of land, if a high average yield is assumed. Sixty million hectares (150 million acres) is equivalent to roughly one-third of current total U.S. cropland; it is about 1.7 times more than the 36 million hectares (89 million acres) of cropland currently idled through various conservation and other programs. Crop productivity, harvest, handling, and transport are therefore important determinants of overall bioenergy costs [18] and key areas for further RD&D. Large collection areas also raise the specter of land-use conflicts: fuel versus food, fuel versus wildlife habitat, and others (see below).

Estimates of potential bioenergy crop production typically range up to around 25 EJ/year (24 quads/year) by 2030. '9 Projections based on current policy, however, are that nonliquid biomass fuels will provide 4 to 8 EJ per year (or 3.8 to 7.6 quads/year) in 2030.[20]

The specific land used for energy crops, however, may in some cases be prime cropland rather than currently idled or marginal lands. The use of any particular parcel of land will depend on its highest value use (food, feed, fiber, or fuel), environmental considerations, market access and conditions, and other factors. For example, prime crop land near a powerplant might best be used for producing energy crops in order to minimize transport needs. These factors will be determined by the respective markets operating within the agricultural sector. In many cases, multiple uses will be served.

Although producing large amounts of bioenergy will thus require large land areas (potentially greater than currently idle cropland), some argue that additional cropland will be idled by productivity improvements over the next several decades. For example, in the Intenmediate Future Scenario of the Second Resources Conservation Act (RCA) Appraisal, productivity increases are

[17] These large areas can consist of many small patches, depending on economic. env ironmental, and other considerations.

[18] Obviously land Prices are also important, but they are outside the range of issues considered here.

[19] Additional bioenergy resources are available from other sources such as municipal sol id waste and agricultural or forestry residues. Lower or higher production levels are possible. Various estimates are g iven by: J. W. Ranney and J.H. Cushman, "Energy from Biomass," *The Energy Sourcebook: A Guide to Technology, Resources, and Policy.* Ruth Howes and Anthony Fainberg (eds.) (New York, NY: American Institute of Physics, 1991); and Solar Energy Research institute et al., *The Potential of Renewable Energy: An Interlaboratory White Paper,* SERI/ TP-260-3674 (Golden, CO: March 1990).

[20] Oak Ridge National Laboratory, Resource Modeling and Technology Economics Group, "Projections of Wood Energy Use In the United States," draft, July 2, 1990.

projected to allow an additional 46 million hectares[21] (114 million acres) of current cropland to be idled by 2030 for a net idled capacity of 64 million hectares (158 million acres) .22 In addition, some of the 54 million hectares (133 million acres) of pasture or other lands might be suitable for energy crops (see table 2-3).

Alternatively, some have recently argued that the Uruguay Round under the General Agreement on Tariffs and Trade (GATT), the North American Free Trade Agreement (NAFTA), and other factors could increase the demand for agricultural products and largely absorb lands currently idled through various agricultural programs in the near to mid-term.[23] In this case, energy crops would then be competing more directly with conventional agricultural commodities, and the market penetration of energy crops would depend on their relative return to the grower, the level of agricultural supports for their competitors, the credit given for their environmental benefits, and other factors. In the longer term. it is not known how competition for use of this land to produce food, feed. fiber. or fuel might evolve, particularly given technological advances, increasing crop productivities, and growing agricultural trade.

Figure 2-3 illustrates one estimate of the cost—for planting, maintenance, harvest. transport, etc.-of bioenergy as a function of crop yield and total production (see box 2-2). In the high-yield case of 18 dry metric tonnes/hectare (8 tons/acre) per year, roughly 10 EJ (9.5 quads) of biomass are available for $2/GJ ($2.10/million Btu—MBtu) or less and 17 EJ (16 quads) for $3/GJ ($3.15 /MBtu) or less. In comparison, the low-yield case gives essentially no biomass for less than $2/GJ and 10 EJ for $3/GJ or less. Thus, costs are quite sensitive to crop productivity, reaffirm ing the importance of RD&D into improved crop varieties to increase yields and decrease produc-

TABLE 2-3: Major Cropland Usage, 1992

Crop	Area planted (million hectares)
Corn	308
Wheat	259
Hay	25.5
Soybeans	235
Other small grains	77
Cotton	57
Sorghum	49
Other field crops	53
Orchards	20
Vegetables	16
Total active	1329
Idled	138
Short-term set-aside	77
Long-term set-aside	142
Total cropland	170.4
Total pastureland	539
Total rangeland	1644
Total agricultural land	3887

NOTE 1 hectare -247 acres

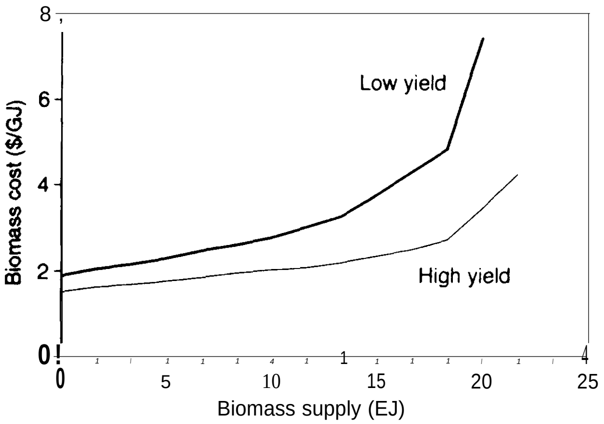
SOURCE Steven Shafer Air Quality Impacts from Agriculture Biomass Production and Residue Utilization as Energy Feed Stocks report prepared for the Off Ice of Technology Assessment May 13 1993

[21]Ctilculated by assuming a base cropland area of 170 million hectares, minus the 36 million hectares currently idled and the estimated (intermediate scenario) 88 million hectares actively cropped by 2030. See U.S. Department of Agriculture, *The* Second *RCA Appraisal: Soil, Water, and Related Resources on Nonfederal Land In the United States, Analysis of Conditions and Trends* (Washington, DC: U.S. Government Printing Office, June 1989), figure 4, p. 10.

[22]Conversion of cropland to urban uses reduces the gross available area from 82 million hectares by another 18 million hectares, leaving roughly 64 mi II ion hectares of idled cropland. Total potentially available idle croplands, not including losses (o urban ization, are estimated at 30 to 105 million hectares (ibid.).

[23]See, e.g., U.S. Department of Agriculture. Office of Economics, Economic Research Serv ice, *Effects of the Uruguay Round Agreement on U.S. Agricultural Commodities* (Washington, DC: March 1994).

FIGURE 2-3: Biomass Supply Curve for Energy Crops on Agricultural Lands



NOTE The potential supply and cost of energy crops grown on agricultural lands are shown The low-yleid case assumes an average productivity of 13.4 dry metric tonnes/hectare/year (6 tons/acre), the high-yield case assumes an average productivity of 179 dry metric tonnes/hectare/year (8 tons/acre) These productivities are believed to be readily attainable, particularly in the Southern United States, by 2020 or sooner with continued RD&D and have already been realized in a number of experimental plots

SOURCE Burt C English and Anthony Turhollow, Department of Agricultural Economics and Rural Sociology, University of Tennessee, Knoxville, "Estimation of the United States Potential To Produce Biomass for Energy, 2005 " 1994

(ion costs. This comparison also suggests that the economics of bioenergy crops may be less attractive on lower quality land.[24]

These estimates are preliminary. The unique local conditions for biomass production, detailed field demonstrations, and commercial purchase and use patterns have largely not been rigorously evaluated. Numerous questions remain concerning bioenergy crop management, procurement, regulatory constraints, market development, scaleup, and other factors. Nevertheless, these preliminary estimates and current fieldwork suggest a substantial bioenergy potential.

In comparison with the bioenergy crop costs shown in figure 2-3, current wholesale costs of coal, natural gas, and oil, respectively, are roughly $ 1.30/GJ ($1 .40/MBtu), $3.70/GJ ($3,90/MBtu), and $3 .00/GJ ($3. 15/MBtu), and are destined to increase over time (see box 1-1).[25] Total national energy use is roughly 87 EJ (83 quads), of which bioenergy currently accounts for roughly 4 percent, or about 3 EJ (2.8 quads) (see appendix 1 -A). Thus 20 EJ (19 quads) of bioenergy would be a substantial contribution to national energy needs.

Some of this bioenergy could potentially be converted to fuels for transport, which would reduce U.S. dependence on imported oil. Unless coupled with very aggressive efforts to improve vehicle fuel efficiency, however, biomass fuels will not be sufficient to completely displace imported oil (see chapter 4). Alternatively, biomass can be converted to electricity (chapter 5).

POTENTIAL ENVIRONMENTAL IMPACTS

Intensively cropping large areas for energy inevitably raises concerns about potential environmental impacts. A detailed review of potential soil, water, air, and habitat issues by the Office of Technology Assessment (OTA) shows that the net environmental impacts depend on the previous use of the land, the particular energy crop, and crop management.[26] For example, as a substitute for conventional agricultural row crops such as corn or soybeans, properly managed HECs and SRWCs can help stabilize erosive soils and

24This, of course, will also depend on whether some consideration or credit is given bioenergy crops for the extent to which they provide environmental or other benefits, or offset other subsidies or supports.

25The difference in cost between fuels reflects the additional processing or different conversion equipment that may be required, depending on each case. The costs are substantially lower than those charged to the final consumer.

26U.S. Congress, Office of Technology Assessment, *Potential Environmental Impacts of Bioenergy Crop Production+-Background Paper*, OTA-BP-E-1 18 (Washington, DC: U.S. Government Printing Office, September 1993).

BOX 2-2: Developing Energy Crop Supply Curves

The energy crop supply curves shown in figure 2-3 are calculated by using a linear programming model of the U S agricultural sector called the Agricultural Resources Interregional Modeling System The model is currently operated from the University of Tennessee

In this model the country is divided into 105 crop production regions, and each crop production region has eight land quality classes Crops Included in the model are barley, corn grain, corn silage, cotton, legume hay nonlegume hay oats, sorghum, sorghum silage, soybeans, wheat, and the energy crops switchgrass and short-rotaton hybrid poplar Grains, silage and hay also serve as inputs for livestock—beef hogs and milk and poultry production Switchgrass serves as a proxy for all warm-season thin - stemmed grasses, and hybrid poplar as a proxy for all hardwoods grown on a short (three- to 12-year) rotation using agricultural-type practices

Land available for crop production is restricted to exsting cropland, and cropland avaiability is assumed to decrease over time Demands for crops and livestock for food, industrial use, and export are he'd constant

The objectve functon of the model is to minimize the cost of producing food, livestock and energy crops, by varying the type and quanity of crops grown in each region

To develop a supply curve energy crop production levels (after losses in harvest and storage) were varied from O 16 to 24 EJ Supply curves were estimated for two energy crop national average yields, 134 dry metric tonnes hectare (6 tons 'acre) and 179 metric tonnes/hectare (8 tons 'acre), before losses Estimated losses ranged from 19 to 24 percent National average yields were determined by modeling energy crops with the EPIC (Erosion Productivity Index Calculator) model and setting average yields across all regions and land quality classes Over this range of production, delivered prices for energy crops varied widely from $1. 30/ GJ ($1 37'MBtu) for very small quantities up to $7/GJ ($7.40/MBtu) for very large quantities At higher production levels, yields make a significant price difference

SOURCE Office of Technology Assessment based on Burt C English and Anthony Turhollow, Department of Agricultural Economics and Rural Sociology, University of Tennessee, Knoxville "Estimation of the United States Potential To Produce Biomass for Energy 2005" 1994

perhaps act as filters to prevent agricultural chemicals and sediments from rcaching water supplies .[27] They may help provide habitat directly or serve in buffers around, or corridors between, fragments of natural forest, wetlands, or prairie. (Such habitat benefits will. however. also depend on the particular animal species.) In contrast, substituting energy crops for hay, pasture. or well-managed Conservation Reserve Program lands will generally have r-nixed environmental impacts, both positive and negative. Positive impacts include offsetting fossil fuel use; negative impucts include possibly greater use of agricultural chemicals and habitat disruption during harvesting. At the global level. when grown on a closd-loop basis.[28] these bioenergy crops would make little or no net contribution to rising levels

[27] To serve as a filter and to be harvested periodically for energy, energy crops may require more complex and careful management than is typical for energy crops that do not serve such demanding multiple functions.

[28] *Closed-loop* means that new biomass is grown at the same rate at which it is harvested for use as energy. Thus, carbon dioxide will be taken up by new plant growth at the same rate that it is released by using the harvested biomass for fuel.

Switchgrass growing near Auburn, Alabama This fast-growing, high-ytetd grass can be harvested once or twice each year over many years, whale its deep roots help protect soils and ground water

of atmospheric carbon dioxide ($C0_2$)—a key greenhouse gas.[29]

The potential environmental benefits of energy crops compared with conventional agricultural row crops are due to several factors. The energy crops considered here are perennials; agricultural crops are annuals. Perennial crops require tillage only when being established—perhaps every 10 to 20 years—and then maintain a year-round protective cover over the soil. This greatly reduces soil erosion, which occurs primarily when soils are uncovered during heavy storms, and can reduce compaction as well because of the less frequent use of heavy equipment on the soil. These energy crops also have the potential to be more efficient in the use of fertilizers (i.e., some nutrient retention and cycling occur between growing years that do not occur with annual crops).

The overall inputs required by energy crops are generally lower than in conventional agriculture for several reasons. Energy crops often have heavier and deeper rooting patterns than conventional agricultural crops, which allows the soil to be utilized to a greater depth for water and soil nutrients and provides more time to intercept fertilizers or other agricultural chemicals as they migrate down through the soil. This can also give energy crops greater capacity to intercept fertilizers or other agricultural chemicals flowing from adjacent areas. This capacity may make energy crops a valuable new tool in addressing certain nonpoint water pollution problems; further research on this subject is needed.[30]

Heavier rooting also puts more carbon into the soil and so assists in creating more productive soil conditions, such as enabling the slow continuous release of nutrients or the binding of chemicals so that they are not leached.[31] Energy crops are also selected on the basis of their production of cellulosic biomass, which consumes less input energy (e.g., light) per unit of energy stored than many specialty plant components.

Finally, energy crops can provide greater structural diversity especially if grown in polycultures in the longer term-than conventional agricultural crops, which emphasize large agricultural blocks devoted to a few monoculture cash crops. In general, the more complex the vegetation (with many species, sizes, shapes, and ages of

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[29] Currently, some fossil fuel—typically S to 15 percent of the energy value of the bioenergy crop—is used in the form of agricultural chemicals or diesel fuel. Energy crop cycles such as com to ethanol have much lower net energy production and consequently higher net emissions of carbon dioxide than the SRWC and HEC crops discussed here (see ch. 4). The potential contribution of biomass energy crops to other greenhouse gases, such as methane and nitrous oxide, needs to be examined.

[30] Office of Technology Assessment, op. cit., footnote 26.

[31] This also sequesters additional atmospheric carbon, thereby slightly slowing the increase in atmospheric CO_2 levels.

plants) in an area, the more complex is the community of animals--+, g.. insects,[32] spiders,[33] birds,[34] mammals[35]—that it will support. Conversely, as vegetative structure is simplified, the community supported becomes progressively poorer. For example, the number of insect species in typical agricultural ecosystems such as corn can be half that found in pasture and one-third to one-tenth that found in deciduous forests.[36] It is. in part, the structural poverty of conventional agricultural monoculture that opens an opportunity for using energy crops to improve habitat and biological diversity in a region.

Properly designed, energy crops can be used to manage or direct the regional landscape ecology—potentially serving as buffers around natural habitat, as corridors between fragments of natural habitat, or as habitat in themselves, How effectively the energy crop serves these roles depends on the particular crop, how it is managed (including use of chemicals, equipment, and harvesting cycle), and how the species that it is designed to assist actually respond. There are very few field data on which to base conclusions at this time; further research is required.

Energy crops are not, however, a substitute for natural habitat.[37] Instead, their impact depends on the particular case. In terms of local habitat value, it would often be preferable to let much of the idled cropland or other land return to a more natural state. Should global warming occur as currently projected, however, much of the habitat in the United States and elsewhere may be subject to sufficiently rapid climate change that the species and habitat intended to be protected may be unable to adjust quickly enough for the changed circumstances[38] (figure 2-4). To avoid this and out of more general concern for potential global warming, it may be preferable to use idled cropland to produce greenhouse-gas-neutra1[39] biomass energy. Energy crops are therefore of particular interest to the extent that they can be designed as a compromise between local habitat concerns and greenhouse gas concerns with global habitat implications.

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32 D.R. Strong et al., *Insects on Plants* (Oxford, England: Blackwell Scientific Publications, 1984).

33 C.L. Hatley and J.A. MacMahon, "Spider Community Organization: Seasonal Variation and the Role of Vegetation Architecture," *Environmental Entomology, vol.* 9,1980, pp. 632-639.

34 R. H. MacArthur and J.W. McArthur, "On Bird Species Divers ity," *Ecology*, vol. 42, 1961, pp. 594-598; and G.S. Mills et al., "The Relationship Between Breeding Bird Density and Vegetation Volume, " *Wilson Bulletin, vol.* 103, 1991, pp. 468-479.

35 M. Rosenzweig and J. Winakur, "Population Ecology of Desert Rodent Communities: Habitats and Environmental Complex ity," *Ecology, vol.* 50, 1966, pp. 558-572: and R. Il. Dueser and W.C. Brown, "Ecological Correlates of Insular Rodent Diversity," *Ecology, vol.* 61, 1980, pp. 50-61.

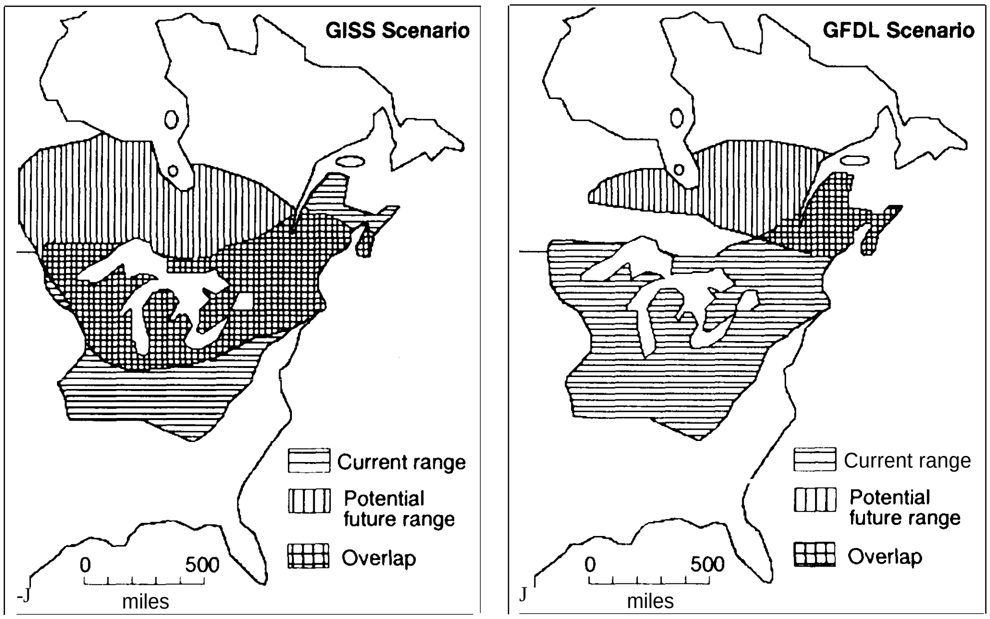
36 David Pimentel et al., "Conserving Biological Diversity in Agricultural/Forestry Systems," *BioScience, vol. 42, No. 5,* May 1992, pp. 354-362; and M.G. Paoletti et al., "Agroecosystem Biodiversity: Matching Production and Conservation Biology," *Agriculture, Ecosystems and Environment, vol. 40,* 1992, pp. 3-23.

37 Defining *natural habitat* may be difficult and controversial] because the past decades to centuries of clear cutting, selective harvesting of economically valuable trees, and tire suppression, for example, have altered many U.S. forests, often leading to an increased concentration of plant species with lower economic or ecological value. Similar alterations have occurred over many other U.S. landscapes, including prairie and wetlands. Although defining how much modification still qualifies as "natural " is thus challenging, the term is used broadly here to include all lands that support a significant quantity and variety of indigenous plants and animals. For this report, only current or former agricultural lands or highly degraded lands are considered for energy crops.

38 U. S. Congress, Office of Technology Assessment, *Preparing for an Uncertain Climate*, vols. *1* and 2, OTA-O-567, OTA-O-568 (Washington, DC: U.S. Government Printing Office, October 1993).

39 If fossil-fuel. based agricultural chemicals, fertilizers, or transport fuels are used, bioenergy is not strictly greenhouse gas neutral. Typically, however, the net energy return (or greenhouse gas equivalence) for HECs and SRWCs varies from 6: 1 to 18: l for biomass energy to fossil energy inputs. In contrast, current com to ethanol production has much lower net energy gains.

FIGURE 2-4: Current and Projected Range of Sugar Maple Under Two Models of Global Warming



NOTE GISS = Goddard Institute for Space Studies, GFDL = Geophysical Fluid Dynamics Laboratory

SOURCE Off Ice of Technology Assessment, 1993, adapted from M B Davis and C Zabinski, "Changes in Geographical Range Resulting from Greenhouse Warming Effects on Biodiversity in Forests, " *Global Waming and Bilological Diverrsity* B J Peters and T E Lovejoy (eds) (New Haven, CT Yale University Press, 1992)

Although large land areas would be devoted to bioenergy crops, in most cases they are not likely to dominate the landscape. For typical electricity or ethanol production facilities with processing capacities of 1,000 to 2,000 dry metric tonnes (1 ,100 to 2,200 short tons) of biomass per day, roughly 4 to 8 percent of the land in a 40-kilometer (25-mile) radius around the plant would be required.[40] In terms of land area, energy crops would then rank third or fourth in overall importance in most areas.[41]

Bioenergy can potentially also improve urban and regional air quality by reducing sulfur oxide (SO_x) and other emissions. SOx, emissions can be reduced by cofiring biomass with coal or by substituting biomass-fired for coal-fired powerplants. If poor-quality equipment or controls are

[40] This assumes the high yield of roughly 18 dry metric tonnes/hectare (8 tons/acre) shown in figure 2-3. At lower yields, the percentage of land devoted to energy crops would increase proportionately.

[41] R.D. Perlack et al. Oak Ridge National Laboratory, "Environment] Emissions and socioeconomic Considerations in the Production, Storage, and Transportation of Biomass Energy Feedstocks," ORNL/TM- 12030, 1992.

used, however, emissions of particulate and certain organic compounds could be increased by the substitution of bioenergy for conventional fuels.

Under the Clean Air Act Amendments of 1990, oxygenates arc required in gasolines used in urban areas that exceed carbon monoxide and ozone limits. Ethanol and methanol, which can be derived from renewable resources,[42] could serve that purpose. However, a 1994 government directive that 30 percent of oxygenates be derived from renewable fuels was recently overturned by a federal court. More importantly. by developing an infrastructure in support of ethanol or methanol fuel in the near term, mid- and longer term use of advanced vehicle technologies may be possible, with much greater potential reductions in emissions and substantial increases in fuel economy (see chapter 4).

Biomass can be used in place of fossil fuels to avoid the emission of carbon dioxide from fossil fuel combustion.[43] In addition, biomass energy crops may provide a net increase in soil carbon as well as in standing biomass, depending on the previous use of the land.[44] The ability of bioenergy to offset the emission of greenhouse gases is an important potential benefit from its use. Details of these issues are discussed elsewhere.[45]

Conversely, the potential impact of likely climate change on energy cropping is uncertain and may require some adaptation. These issues have been explored in depth in a recent OTA publication.[%]

ECONOMIC IMPACTS[47]

Rural economies in the United States have been hard pressed for many years. Between about 1980 and 1990, the U.S. share of the world total agricultural trade dropped from 28 to 21 percent. At the same time, the European share grew from about 13 to 19 percent. China is now the world's second largest corn exporter and Brazil is a major exporter of soybeans. Some expect that parts of Eastern Europe and the former Soviet Union could become food exporting powerhouses in the future.[48] In late 1992, roughly half of the shiploading grain terminals in the United States were reportedly closed, about to close, or for sale.[49]

~2.Again the focus here is on ethanol and methanol from cellulosic biomass. Ethanol from Com presents a different set of issues and is not examined here.

43D.O. Hall et al., "Alternative Roles for Biomass in Coping with Greenhouse Warming. " *Science and Global Security, vol.* 2, 1991, pp. 113-151 .

44L.L. Wright and E.E. Hughes, "U.S. Carbon Offset Potential Using Biomass Energy Systems," *Journal of Water, Air and Soil Pollution*, in press.

45For more information, see Off Ice of Technology Assessment, op. cit., footnote 26.

46Office of Technology Assessment, op. Cit., footnote 38.

47The primary source for this section is K, Shaine Tyson and Randall A. Reese, Windy Peaks Associates, "Economic Impacts of Biomass Energy, " report prepared for the Office of Technology Assessment, Jan. 15, 1994. For other reviews of the economic impacts of bioenergy crops, see: Southeastern Regional Biomass Energy Program, Tennessee Valley Authority, and Meridian Corp., *Economic Impact of Industrial Wood Energy Use in the Southeast Region of the .0'. S., 4* vols. (Muscle Shoals, AL and Alexandria, VA: November 1990); J.W. Onstad et al.. National Renewable Energy Laboratory and Meridian Corp., *Analysis of the Financial and Investment Requirements for the Scale-Up of Biomass Energy Crops (Alexandria,* VA: September 1992); Ed Wood and Jack Whittier, "Biofuels and Job Creation: Keeping Energy Expenditures Local Can Have Very Positive Economic Impacts," *Biologue*, vol. 10, No. 3, September-December 1992, pp. 6-1 I: Meridian Corp. and Antares Group, Inc., "Economic Benefits of Biomass Power Production in the U.S.," *Biologue, vol. 10, No.* 3, September-December 1992, pp. 12-18. R.L. Graham et al., "Biomass Fuel Costs Predicted for East Tennessee Power Plant," *Biologue*, vol. 10, No. 3, September-December 1992, pp. 23-29; and U.S. Department of Energy, Office of Solar Energy Conversion, Solar Thermal and Biomass Power Division, *Electricity from Biomass: A Development Strategy*, DOE CH 10093-152 (Washington, DC: April 1992).

48In the longer term, population growth in some developing countries may surpass agricultural productivity growth and increase the demand for food imports. Some of this demand may be supplied by the United States. No one knows, however, what the net effect is likely to be.

49Scott Kilman, "U.S. Is Steadily Losing Share of World Trade in Grain and Soybeans. " *Wall Street Journal*, Dec. 3, 1992, p. Al.

These pressures have resulted in a growing need to find alternative crops and/or markets for U.S. agricultural communities: to provide employment, to stabilize rural incomes, and to maintain the rural infrastructure of equipment and supply distribution and service. Bioenergy crops offer one such alternative.

The rural economy faces several trends: bioenergy may be able to moderate some of their impacts. Domestic demand for conventional agricultural products is likely to increase slowly: U.S. population growth is low[50] and the U.S. consumer is reasonably well fed. At the same time, foreign demand is uncertain and will depend on how fast agricultural productivity increases compared with population growth, the impacts of trade agreements such as GATT and NAFTA (see above),[51] and other factors. Foreign demand might also be met in the future by new export powerhouses, particularly Eastern Europe and the former Soviet Union. Latin America. and elsewhere.[52] Efforts in those regions will bc strongly aided by adoption of the modern agricultural techniques and crop varieties pioneered by the United States. Thus, U.S. farmers are not assured of a continuing comparative advantage. at least not of the magnitude they have enjoyed in the past.

The trend to farming as an agribusiness is likely to continue as well. This is an inevitable result of the need to maintain some competitive advantage, and it will require increased use of modern chemistry, biology, and computer and telecommunication technologies, creating a production unit with sophisticated stocks and flows of goods and scrvices.[53]

The production of bioenergy may also be impacted by such agribusiness considerations. For example, large conversion facilities requiring an assured supply of feedstock might: 1) buy or lease land sufficient to supply their biomass feedstock needs; 2) negotiate a limited number of larger contracts to provide the feedstock while minimizing overhead; and 3) use these supplies to keep market prices down and supplies up—all of which could significantly influence bioenergy markets in a region. This scenario is a rather different vision from that of many small farmers entering a huge market. Further analysis of the possible evolution of these markets would be useful.

Environmental considerations may play an increasing role in farming practice as well. Indirectly, increasing attention to environmental considerations on public lands may push fiber and other production activities more to private and marginal lands.[54] At the same time, increasing attention to environmental issues on private lands (e.g., soil erosion, water quality, habitat) may also have an impact on cropping practices.

Energy crops may provide alternative sources of income and help diversify risk for the farmer. Energy crops have the potential to redirect large financial flows from foreign oil or other fossil energy resources to the rural economy while simultaneously reducing federal agricultural expenditures. Realizing this potential, however, will require further development of economically and environmentally sound energy crops; their successful commercialization; and carefully crafted federal, state, and local policies to ease the transi-

[50] U.S. population growth is one of the highest in industrial countries. however.

[51] U.S. Department Of Agriculture, 0p. cit.. footnote 23.

[52] Of course, this will require heavy investment to develop the needed infrastructure of farming equipment, roads, storage facilities, and shipping terminals. Such investment capital is now very limited in these countries.

[53] U.S. Congress, Office of Technology Assessment, *A New Technological Era for American Agriculture, OTA-F-474* (Washington, DC: U.S. Government Printing Office, August 1992); and William E. Easterling, "Adapting United States Agriculture to Climate Change," report prepared for the Office of Technology Assessment, February 1992.

[54] This is beginning t. occur in the pacific Northwest now, with SRWCs being grown on pasture or cropland to supply fiber for paper products.

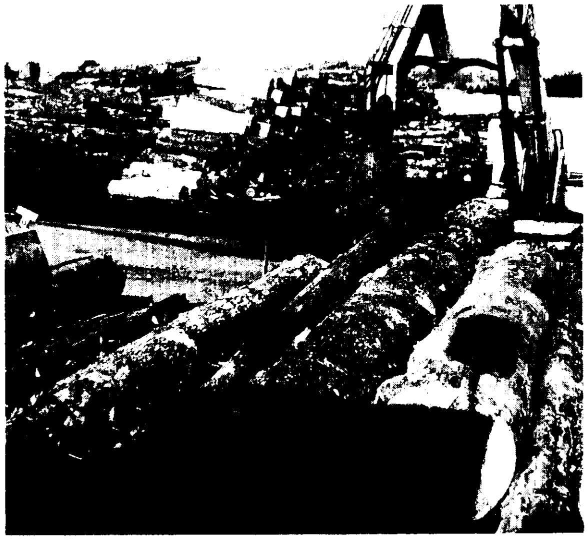
(ion to energy crops without injuring the farm sector or exposing it to undue risk during this period. It will also depend on the relative value of other uses of this land and the costs and benefits of other fuels and technologies.

Electricity

Several efforts have been made to model the potential economic impacts of bioenergy crop production.[55] For the electricity sector. job creation in rural agriculture must be measured against fewer jobs created or even job losses in coal production.[5b] Various estimates place net job creation—including both direct and indirect impacts across the entire economy—with bioenergy development at about 9,500 to 13,000 jobs per GW of electricity-generating capacity in the year 2010 and net income generation at $170 million/GW to **$290** million/GW. Much of the projected job creation would be in rural agricultural areas.

These models project bioelectricity capacity in the year 2010 in the range of 12 to 18 GW. Factors influencing this capacity expansion include the design of the particular econometric model and assumptions concerning the costs of competing fuels, the continued availability of tax credits, the growth in electricity demand, and technological advances.

Estimates of federal and state tax revenues on the direct and indirect economic activity stimulated by the bioelectricity generation vary, but typically range in the neighborhood of $70 million/GW before tax credits or other financial supports. In addition, there is the potential to offset some of the roughly $10 billion that the federal government now pays in agricultural commodity support and conservation programs (see below).



WARREN GRETZ NATIONAL RENEWABLE ENERGY LABORATORY

Wheelabrator Shasta Energy Co , near Anderson, California, uses the bark to generate electricity and se//s the hfgh-quality wood chips to a nearby paper mill.

Installing 12 to 18 GW of bioelcctricity-generation capacity by 2010 is a substantial challenge. Feed stock production and powerplant demonstrations must be developed and completed to show the financial viability of these technologies. Detailed business plans must be developed and financial markets tapped. Large-scale dedicated energy crops must be established, infrastructure developed, powerplants built, and regulatory and institutional issues addressed. For capacity on this scale to be installed by 2010, power companies should already have a significant amount of bioenergy powerplant construction in their 10-year plans: they do not.[57] In the longer term, however, bioelectricity production on a very large scale (50 to 100 GW or more) appears feasible with expected crop land availability and bioenergy crop productivity, and with expected advances in

55 Tyson and Reese op. cit., footnote 47; Southeastern Regional Biomass Energy Program, Tennessee Valley Author-it). and Meridian Corp., op. cit., footnote 47; Wood and Whittier, op. cit., footnote 47; and Meridian Corp. and Antares Group, Inc., op. cit.. footnote 47.

56 Over a particular time there may be net increases in jobs in the coal sector even with aggressive bioenergy development, depending on the overall growth of the electricity sector, coal share of electricity) generation, and other factors. Further. other factors such as automation may reduce the number of jobs in coal mining as well as in bioenergy. For example. according to one estimate the coal industry cut its workforce by a net 70,000 jobs between 1980 and 1990 as a result of productivity increases. See Meridian Corp. and Antares Group. Inc., op. cit., footnote 47.

57 Kurt Yeager Electric Power Research Institute, personal communication, Mar. 11, 1994.

biomass-powered electricity-generating technologies (see chapter 5).

Liquid Fuels

Technologies are under development to convert energy crops such as HECs and SRWCs to liquid fuels such as ethanol and methanol that can be used for transport[58] (see chapter 4). The econom ic impacts of large-scale production of liquid fuels are similar to those for the production of bioelectricity. Net income and job gains in the agricultural sector must be weighed against possible long-term slower growth or even job losses in the oil and refinery sectors. The impact of biofuels on the oil and gas sector is, however, likely to be far less important than that of ongoing changes within the oil and gas sector: declining domestic resources in many areas, refinery operations shifting offshore, volatile prices impacting independent developers, and many others. Further, because oil and petroleum products have a well-developed global market, a large share of any domestic oil production or refinery capacity displaced by the production of biofuels may ultimately be redirected toward other markets, with little overall job or income loss. Additional investment in infrastructure may be required, however, to move these products efficiently to new markets.

Estimates of direct and indirect job creation in the agricultural and conversion sectors are roughly 20,000 jobs per billion gallons of ethanol (BGOE) and $350 million of direct and indirect income per BGOE.[59]

Potential production levels of ethanol and methanol vary widely with assumptions about the cost of oil, the availability of tax credits and other financial supports, constraints on the availability of manpower and finance, growth in the demand for transport fuels, technological advances (see chapter 4), and many other factors. One model projects production levels of 15 to 50 BGOE per year by 2030, depending on these and other factors.[60] A level of 50 BGOE is the equivalent of roughly 2 million barrels of oil per day, or about 10 percent of our current total oil use. Before 2010, the potential for producing ethanol is limited by the need for continued RD&D of the technology and the lead time required for large-scale commercialization. Further work to understand the potential economic impacts of biomass-ethanol strategies would be useful.

Fluctuations in the price of oil have been a significant risk for ethanol producers. Between 1979 and 1987, the corn-ethanol industry constructed some 140 facilities of which 60 percent failed and were closed, at least in part due to the oil bust in the mid-1980s. Oil price fluctuations similarly pose substantial risk to future development of biomass-to-ethanol production.

Federal Budget Impacts

Federal agricultural expenditures play a noted role in the rural economy. The federal budget is under great pressure, however, and agricultural programs—like everything else—are undergoing increased scrutiny for savings. Currently, federal programs to prevent soil erosion[61] and various commodity support programs to strengthen crop prices together cost roughly $10 billion per year, and considerable debate about the future of these programs is under way. If, for example, the Conservation Reserve Program (CRP) is reduced in scope in the future, unintended costs may be im-

[58] These energy crops have a much greater resource potential than com to ethanol, much better overall energy *Conversion ratios,* and fewer (or beneficial) environmental impacts.

[59] Tyson and Reese, op. cit., footnote 47.

[60] Ibid.

[61] An example is the Conservation Reserve program (CRP), which pays farmers to take lands out of production of a marketable crop for 10 years in order to protect more erodible or fragile soils with permanent cover. Similar soil protection can be obtained from bioenergy crops on CRP land, but harvesting of energy crops may reduce the wildlife habitat value of this land.

posed on the commodity support programs as farmers put previously idled CRP lands back into production. More generally, as agricultual productivity continues to increase, means of idling additional acreage may be necessary.

Bioenergy crops area potential alternative cash crop that could protect fragile soils or could be grown on lands previously idled in order to strengthen commodity crop prices. If grown on fragile soils or marginal lands. however, energy crop productivities would 1ikely be low and might require additional supports to be cost competitive. Bioenergy represents a huge potential market. Americans use food at the equivalent of roughly 100 watts,[62] while energy is used at the rate of 10,000 watts. U.S. energy demands are far greater than the energy likely to be produced by bioenergy crops.

Earnings from energy crops might then be used to ease federal supports while maintaining farm income. Of course, the relative environmental benefits of energy crops versus current soil conservation programs such as CRP would again depend on the specific energy crops grown and how the land was managed. The relative economic and budgetary value of producing bioenergy crops would have to be compared with potential alternative uses of the land. Designing federal programs to achieve such ends while minimizing disruption and risk to farmers presents challenges.

The federal government also provides significant crop insurance support in response to flood, drought, or other natural disasters. Some bioenergy crops may be naturally more resistant to such disasters than food or feed crops. For example, in contrast to food or feed crops, certain trees normally found in frequently flooded bottonlands-sweetgum. sycamore, willow, and others-may survive partial inundation for weeks without significant damage. Harvesting of food or feed crops must also be done within a narrow window of time; severe weather or natural disasters may limit such harvesting. In contrast, the harvest of SRWC bioenergy crops can be delayed for months with no damage to the crop. The extent to which such bioenergy crops can cost-effectively substitute for traditional food or feed crops while potentially reducing federal crop insurance expenditures needs to be examined in detail.[63]

Trade Balance Impacts[64]

U.S. expenditures on foreign oil are currently running about $45 billion per year and are destined to increase sharply as domestic oil production continues to decline. Several U.S. electric utilities are also now importing low-sulfur coal. As noted above, bioenergy crops could potentially offset some of these imports. Although biocnergy by itself is unlikely to eliminate fuel imports unless combined with dramatic improvements in vehicle efficiency (see chapter 4), it could make a substantial contribution to our energy needs.

RD&D AND COMMERCIALIZATION

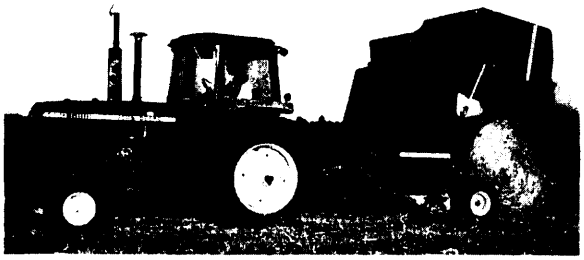
If bioenergy is to make a substantial contribution to the U.S. energy mix, several issues must be addressed. Examined briefly here are RD&D of environmentally sound energy crops and market challenges that may substantially slow commercial adoption of these technologies.

62 This does not account for transport, storage, processing, and other losses, or for the low conversion efficiency of feed to meat. In addition, only a small portion of the plant is useful food, while most of the plant carl be converted to energy.

63 This might include consideration of both the risk of crop loss and the offsetting of federal or other crop insurance payments.

64 Some note that Japan imports all of its oil, yet still maintains a sizable trade surplus for various reasons. Thus, the role Of energy in the trade balance is just one facet of a very complex issue. Reducing the (). S. trade deficit mayor may not be a worthwhile goal at this time, depending on a variety of factors; reducing the trade deficit and creating jobs at home--all else remaining the same—are likely [o help domestically.

LAB



Baling switchgrass near Auburn, Alabama.

Research, Development, and Demonstration

Research, development, and demonstration may be useful at all levels of biomass energy systems, including high-productivity crop varieties; their planting, maintenance, and harvesting; their environmental impacts; their transport and storage; and their conversion to fuels or electricity (see chapters 4 and 5).

- *High-productivity crop varieties.* RD&D to improve energy crop productivity and performance remains in its infancy. Crop productivities have increased 50 percent in the past decade, but substantial further improvement appears possible. Because of the sensitivity of biomass costs to crop yield (figure 2-3), improving crop productivity can play a particularly important role in the economic viability of energy crops. In the longer term, the development of complementary polycultures may also be of interest (see below).
- *Crop operations.* Crop planting, maintenance, harvesting, transport, and storage represent the bulk of the costs—and thus opportunities for cost reduction—in producing biomass. Much research remains to be done in these areas, but early indications suggest substantial opportunities for productivity improvement and overall cost reduction in several of these steps.
- *Environmental impacts.* Relatively little R&D has been done on the environmental impacts of energy crops in the United States. Most studies have been short term, limited in scope, and confined to small scales. Although careful studies have been conducted at a handful of sites across the United States, the results tend not to be readily transferable to significantly different sites, crops, or management practices. Consequently, most practices in the field have been developed by analogy with conventional agriculture or forestry. This approach has significant limitations: for example, energy crops can have much deeper and heavier rooting patterns than conventional agricultural crops, affecting soil carbon balance, water balance, and the fate of agricultural chemicals. Even less is known about the habitat impacts of energy crops; some of the first studies are just under way at a few locations. Virtually all proposed habitat practices are based on ecological theory and by analogy with conventional crops. A detailed list of possible environmental RD&D is provided in box 2-3, and prototype principles for structuring energy crops are provided in box 2-4.
- *Demonstrations.* There have been few demonstrations to establish pilot energy conversion facilities such as bioenergy to electricity or to liquid or gaseous fuels (or to other petrochemical substitutes); to clarify issues of how best to develop supporting infrastructure and to address overall management and regulatory issues; or to determine how to structure energy crops for maximum environmental (soil, water, air, habitat) value or determine what their environmental value actually is by field observations. Demonstrations are most useful if they are of sufficient scale to clarify the characteristics of a fully functional infrastructure and thus to reliably and cost-effectively link feedstock production activities to energy conversion processes.[65]

[65] The U.S. Department of Energy is making awards for feasibility studies for bioenergy crop and conversion demonstration projects.

The structure of the farm sector also plays a role in determining environmental impacts and needs to be examined carefully. For example, roughly one-third of farms having fertilizer expenditures and one-quarter having pesticide expenditures in 1986 paid for some custom application procedures. Training such specialists in the timing and application of agricultural chemicals to minimize misapplication, potential groundwater leaching or runoff, or other problems may require one set of extension activities; reaching the two-thirds or more of the farms that use on-farm hired laborers to do it may require a different approach.[66] Extension efforts will also vary between very large farms and small part-time farms. Tenants and part-owners are operating an increasing proportion of farms and farmland acres, and may be less concerned about the environmental costs and benefits of various crops and management systems than owners.[67]

Some research is already under way for many of the above and related topics. In addition, the Electric Power Research Institute. National Audubon Society, and others have organized a National Biofuels Roundtable to develop a set of principles and guidelines for minimizing negative environmental and socioeconomic impacts associated with the development of bioenergy crops and conversion facilities.[68]

Energy crops must be cost-effective to producers and users. This will require careful balancing of environmental considerations—including near-term local and long-term global environmental impacts—within the overall bioenergy economics. It may also require trading off local versus global environmental impacts. Detailed integrated analyses of the economics and environmental impacts of various bioenergy fuel cycles are needed. The economics of bioenergy crops might also be improved if the potentially significant environmental services of energy crops were recognized and valued, where appropriate. This may be quite difficult in practice.

Finally, and as noted above, energy crops may also provide greater habitat value than con\' entional agricultural monoculture. Providing habitat has traditionally been of 1ittle concern to and is largely not addressed by conventional agriculture. In contrast, the National Biofuels Roundtablc has identified habitat improvement as a guideline for bioenergy development.[69] The extent to wh ich the habitat value of bioenergy crops is actively encouraged is a policy choice, however, and will be influenced by a variety of factors. including the particular region, crop, and wildlife species; overall bioenergy crop economics: and the value (if any) credited the energy crop for its habitat benefits. The extent to which bioenergy crops can address habitat concerns without significant} reducing their economic viability —particularly vis-à-vis agricultural crops or fossil fuels. wrhich carry little or no such consideration-is unknown.

If the potential habitat value of energy crops is identified as an important policy goal, several issues are then raised, including the follow in::

- *Disrupting life-cycle processes.* Biomass planting, maintenance, harvesting, and other activities may sometimes interfere with key

[66] New technologies may also help avoid some Of these problems. For example, the development Of time-re!e~ie fertilizer\ (or other agricultural chemicals) would allow farmers to continue the common labor-saving practice of spreading fertilizer (or other chemicals) only once per year while reducing the amount that must be applied to ensure that the nutrients arc available late in the growth cycle. See David O. Hall et al. "Biomass for Energy: Supply Prospects," *Renewable Energy: Sources for Fuels and Electricity*, Thomas B. Johansson et al. (eds.) (Washington, DC': Island Press, 1993).

[67] U.S. Congress, Office of Technology Assessment, *Beneath the Bottom Line: Agricultural Approaches To Reduce Agrichemi '(]/ [']) ttami-nation of Groundwater*, OTA-F-418 (Washington, DC: U.S. Government Printing Office, November 1990).

[68] National Biofuels Roundtable, Electric Power Research Institute, and National Audubon Society, "Principles and Guidelines for the De~ elopment of Biomass Energy Systems" draft, May 1994.

[69] Ibid.

BOX 2-3: Environmental Research and Development Needs for Energy Crops

Energy crops raise a variety of Important environmental concerns Research to understand and minimize potential environmental Impacts IS needed across a breadth of Issues, Including the following

- Soil qualify. Key areas of RD&D Include the development of a "minimum data set" of key soil physical, chemical, biological, and other parameters as a means of monitoring soil quality over long periods of time for different crops and management regimens. nutrient cycling, particularly of biochemical processes, the return of organic matter to the soil under various intensive energy crops and cropping systems, and the impacts of necessary equipment and various tillage systems on soil quality It may also be necessary to conduct this RD&D in parallel with the study of adjoining land uses to improve understanding of the interaction of energy crops with the larger environment.
- Agricultural ***chemicals.*** Research on the impact of agricultural chemicals on soil flora and fauna and on wildlife is needed. This includes research on the Impacts on wildlife behavior and reproductive processes Chemical pathways, decay processes, and Impacts need to be better understood, particularly when they affect more than the target species or when they move out of the target area The dynamics of chemical use on energy crops, how to reduce the movement of chemicals offsite, and how to reduce their use generally are important Issues.
- ***Water quality.*** Research is needed on the impact of erosion/sedimentation and agricultural chemicals from energy crops, especially on riparian zones, and on the potential of various energy crops to serve as filters and buffers for riparian areas Studies are also needed on how to best minimize potential Ieaching of agricultural chemicals into groundwater. Energy crops might be a useful tool for reducing nonpoint agricultural pollution, but data are needed to verify this and to provide better crop guidelines for realizing that end,
- Air ***quality.*** Research on the total fuel cycle emissions of various bioenergy crops, conversion, and end-use systems is necessary to minimiae impacts on air quality This Includes better understanding of both rural and urban air quality issues and how to best trade them off to maximize benefits Comparing the potential air quality Impacts of bioenergy systems with those of a wide range of other fuel and energy technology options is a key issue
- ***Habitat.*** Box 2-4 lists a number of prototype principles for structuring energy crops to maximize their value as habitat, buffers, or corridors Each of these principles needs to be examined through extensive research in dedicated large-scale field trials and modified as necessary Such research must consider the impacts of energy crops in the context of the regional landscape ecology over the near and the long term Establishing overall goals for the desired habitat impacts (which species should be helped) of energy crops in the larger landscape WI I also require extensive analysis.

life-cycle processes for wildlife. If such potential conflicts are to be minimized, biomass harvesting and other activities may need to be restricted during nesting and other critical times. (Harvesting may also be limited at times, for example, during peak growing periods or inclement weather.) This could require storage of sufficient biomass to keep the conversion plant operating during this period: it may also require idling capital equipment and labor used for harvesting and transport. Alternatively, electricity generation, for example, might be powered during such periods by the use of natural gas (chapter 6). On the other hand, a well-established biomass industry may have a sufficient variety of crops and rotation cycles to moderate this disruption. Field trials arc needed to determine the extent of these potential disruptions and means of moderating them.

BOX 2-3 (cont'd.): Environmental Research and Development Needs for Energy Crops

- ***Restoration of degraded soils and ecological functions.*** Energy crops may reverse soil deterioration from human abuse in certain cases This might Include problems of soil structure, loss of topsoil or organic content, salinity, acidity or alkalinity, or even chemical or heavy-metal pollution. [1] It might also Include restoration of some water purification or wetland functions, including moderating flood damage. Research is needed to Identify such opportunities, to design systems that make the best use of this potential, and to verify performance in the field Realizing the possible restorative potential of energy crops while providing landowners with adequate income (where yields are low) poses additional challenges
- ***Greenhouse gases.*** The total fuel cycle (from crop production to end use) impact of energy crops on greenhouse gases (including carbon dioxide, methane, isoprenes, and nitrous oxide) needs to be evaluated for various energy crops, conversion processes, and end uses. The development and use of a "minimum data set" of key emission factors would be useful for determining these Impacts. Related effects (e g , on soil carbon balances or vehicle refilling station volatile organic compounds emissions) should be Included These fuel cycle emissions can then be compared for agricultural or energy crops and for fossil or biomass fuels
- ***Crops and multiple cropping.*** The potential risks and impacts of various genetically modified energy crops WilI need to be examined A variety of multiple cropping systems should be evaluated to determine how to ensure soill quality, habitat benefits, crop productivity, crop disease resistance, and other key economic and environmental criteria At the same time, research is needed to determine how to convert agricultural lands to tree crops and vice versa, the soils and microflora and fauna are often quite different

[1] Growing plants will take up a variety of chemical or heavy metal toxins, depending on the precise substance and the particular plant species This poses a problem for food crops because it concentrates the toxins and allows them to enter the food chain In contrast for energy crops these toxins may be removed in the energy conversion process (e g destroyed by combustion or remaining in the ash) and so may allow a gradual cleansing o! the soil

SOURCE U S Congress, Off Ice of Technology Assessment *Potential Environmental Impacts of Bioenergy Crop Production*, OTA-BP-E-1 18 (Washington DC U S Government Printing Off Ice September 1993)

■ *Polycultures.* In the longer term, it may be useful to research the value of polycultures (a mixture of species as well as various ages. sizes, and shapes) to provide both energy and environmental benefits. According to ecological theory and a few limited field tests, a mixture of species can have higher biomass productivity and greater resistance to environmental stress than a monoculture.[70] From this perspective, a polyculture would benefit bioenergy production. On the other hand, it may be easier and cheaper to maintain a monoculture and to harvest, transport, and convert a uniform size

[70] Peter Kareiva, "Diversity Begets Productivity," *Nature*, vol. 368, Apr.21, 1994, pp. 686-687; Shahid Naeem et al., "Declining Biodiversity Can Alter the Performance of Ecosystems." *Nature*, VOI. 368, Apr. 21, 1994, pp. 734-737; and Yvonne Baskin, "Ecologists Dare To Ask: How Much Does Diversity Matter'?" Science, vol. 264, Apr. 8.1994, pp. 202-203.

and type of feedstock.[71] Research in the conversion of polycultures could be useful, particularly if it can be coupled with field research on the habitat and other environmental benefits of particular combinations of crops.

- *Regional landscape planning.* Realizing the benefits of energy crops as habitat, buffers, and corridors may in some cases require a level of regional landscape planning not often seen in this country. This will require much more RD&D on regional landscape ecology and its sensitivity to imperfections. Considerable effort will also be required to develop new policy instruments for encouraging participation in such landscape formation across many public and private properties. These issues are examined further in box 2-4.

Finally, once a substantial market develops for wood fuels, there is the potential risk that owners will be encouraged to harvest poor-quality timber—spared up to that point because of its low commercial value—that is serving as important wildlife habitat, or to plant energy crops on wetlands that are fertile but inappropriate for conventional agriculture. These matters are particularly important in regions such as the Northeast where forests are the primary biomass resource. Means of addressing such unintended side effects maybe needed.

These many issues form a substantial near-, mid-, and longer term RD&D agenda. Which of these issues should be pursued and when depend on the policy goals that are established.

Commercialization

As for any new technology, agricultural production of energy crops faces a variety of market challenges that may slow the speed of adoption.[72] These challenges include slow technology adoption in the agricultural sector, competitor prices (low and/or volatile fossil fuel prices), production scaleup, ways to level the playing field, and infrastructure development. Energy crops also must contend with a variety of existing support programs for other crops (box 2-5). Each of these factors may play an important role in determining the pace of market penetration by bioenergy crops. Issues unique to bioenergy crop development and commercialization are discussed here.

Technology Adoption

Technology adoption in the agricultural sector has been relatively slow in the past. This is changing, however, as agricultural production becomes increasingly technology-based and business-oriented,[73] and because of the competitive pressures and rigid market fluctuations farmers have experienced in recent years.

Farmers typically make *production* decisions within short timeframes while maintaining flexibility, which discourages investments in potentially longer term and less flexible energy crops. Market prices, support levels, credit availability, and debt load are critical considerations at the individual farm level.

[71] For example, some species in a polyculture may not be easily converted to ethanol by current enzymatic hydrolysis processes. In the near term, it maybe more important to verify the cost and performance of these conversion processes by using R&D already in progress for narrowly specified (monoculture) feedstocks. For the longer term, it may be useful to begin R&D now to adapt these enzymatic hydrolysis processes to mixed feedstocks as needed in order to increase habitat benefits. Some research on mixed feedstocks is under way at the National Renewable Energy Laboratory. It tends to focus, however—and rightly so at this early stage-on a few common farm species that might be mixed with the primary feedstock by accident, rather than on a much wider range of plants that might be considered on the basis of their habitat value. Arthur Wiselogel, National Renewable Energy Laboratory, personal communication, Sept. 8, 1993.

[72] The specific issues of commercializing transport fuels are addressed in chapter 4 and of commercializing electricity-generation technologies in chapters 5 and 6. See also U.S. Congress, Office of Technology Assessment, *Replacing Gasoline." Alternative Fuels for Light-Duty Vehicles, OTA-E-364* (Washington, DC: U.S. Government Printing Office, September 1990).

[73] U.S. Congress, Office of Technology Assessment, *A New Technological Era for American Agriculture, OTA-F-474* (Washington, DC: U.S. Government Printing Office, August 1992).

BOX 2-4: Prototype Ecology-Driven Principles for Structuring Energy Crops

Plant species under consideration for use as bioenergy crops are primarily native species that evolved in the regions where they may be used These crops can provide greater structural diversity on a landscape level than typical agricultural crops and thus can enhance wildlife habitat The extent to which such habitat benefits are realized, however, depends on the careful application of ecological principles, as outlined below These principles should be considered merely a starting point, requiring much further research Further, these principles are drawn from studies of natural ecosystems and of highly simplified agricultural systems there are few or no empirical data for energy crops themselves Conducting dedicated field trial research on the ecological Interact Ions of natural systems with energy crops would be useful in guiding the development of large-scale energy cropping Finally, the extent to which these principles can be pursued WiIl be highly dependent on the local situation and the economics of the particular energy crop

Ecology-driven principles for structuring energy crops might Include the following

- Site. Energy crops should be concentrated on current, idled, or former agricultural, pasture, or other "simplified" or "marginal' lands Energy crops should not be grown on naturally structured primary - growth forest land, wetlands, prairie, or other natural lands [1]
- Species. Energy crops should combine two or more species in various ways to improve species diversity. This would preferably include the use of leguminous species or others with nitrogen-flxlng capabilities to reduce the need for artificial fertilizers, and other comb; nations to reduce potential losses from disease or Insects and thus reduce pesticide use Noninvasive species that will not escape from cultivated plots are also preferred
- ***Structure.*** Energy crops should combine multiple vegetative structures to enhance landscape diversity as needed by particular wildlife species This could include various combinations of SWRCs, perennial grasses, and other dedicated energy crops, Ieaving small to large woody debris and other ground cover, as well as Inclusions of natural habitat, as needed These energy crops could also be used to provide structure to conventional agricultural monoculture through the addition of shelterbelts and fencerow plantings Similarly, monoculture of energy crops should have shelterbelts or fencerows of other types of vegetation
- ***Lifetime.*** Landscape structure can also be made more diverse by harvesting adjacent stands on different rotation cycles, Including Ieaving some stands for much longer periods if possible.
- ***Native species.*** Energy crops should use locally native species rather than exotics to the extent possible Native species or close relatives wiIl harbor richer insect and other faunas
- Chemicals. Crops should be chosen to minimize application of agricultural chemicals such as herbicides, insecticides, fungicides, and fertilizers, as discussed earner
- ***Unique features.*** Unique habitats and features such as small natural wetlands, riparian or other corridors, "old-growth" inclusions, and shelterbelts should be preserved and enhanced by the energy crop
- Habitat ***assistance.*** Artificial nesting structures and other additions to or supplements of habitat features should be provided where appropriate
- Research. Energy crops should be studied carefully at all appropriate scales and on a long-term basis to better understand the means of Improving appropriate habitats for desired species both for the energy crop itself and for related agricultural, managed forest, and natural lands This should also be done on a regional basis, as appropriate

[1] See footnote 37 in this chapter on defining *natural habitat*

SOURCE U S Congress Off Ice of Technology Assessment *Potential Environmental Impacts of Bioenergy Crop Production* OTA BP-E-1 18 (Washington DC U S Government Printing Off Ice September 1993)

BOX 2-5: Existing Farm Support Programs

Most farmers participate in federal farm commodity programs, These programs have a significant influence on which crops farmers plant and how the crop is managed, Program crops include wheat, corn, sorghum, barley, oats, cotton, and rice. Depending on how many acres a farmer has planted with such crops and the crop yield, a farmer establishes “base” acreage and yield over a period of time. Each year, farmers receive deficiency payments based on the difference between the market price and the target price (established by Congress and the Administration) and the number of base acres and program crop yields. Farmers are required to grow the specific program crop on the appropriate number of base acres or lose a portion of their base acreage (with some exceptions)

Some flexibility has been added in recent years. With flexible base acreage (15 percent mandatory and 10 percent optional), a farmer may plant any crop (with some exceptions) including trees. On the mandatory flexible base, deficiency payments are received; if another crop is planted there are no deficiency payments, but also no loss of base,

The economic attractiveness of energy crops to the farmer is potentially much greater on the mandatory flexible base acres than on other base acres Under the 0/85 program for wheat and feed grains (corn, sorghum, barley, oats), producers with base acres plant 15 percent or more of their maximum payment acres (base acreage minus conservation reserve acreage—base acres that farmers are required to take out of production—and mandatory flexible base) to a conserving use. The producers maintain their base acres and can receive 85 percent of the deficiency payments on land planted with the conserving crop as if it were planted with the program crop, Energy crops would have to be declared a conserving use for this to apply

Because soil conserving energy crops would be perennial, farmers would need some assurance that the 0/85 program would continue for a number of years Haying is presently not allowed during the five months of the principal growing season to avoid competing with forage markets No trees are allowed on 0/85 land,

SOURCE Office of Technology Assessment, 1995

Outside their normal range of cropping practice, farmers prefer to make changes slowly. Farm *management* changes, even relatively minor ones, are not decisions made overnight. The adoption of relatively simple, highly profitable technologies such as hybrid corn has taken as long as nine years on average. The decision to change farming practices requires a considerable degree of deliberation, and maintaining new practices frequently necessitates on-farm experimentation and adaptation beyond that conducted during initial technology development.

Some energy crops may reduce the flexibility of farmers. For example, typical SRWC stands require 3 to 10 years to mature. Farmers may then be reluctant to make the investment because of this long lead time and the need for interim cash flow, particularly with current low and uncertain prices for other forms of energy. It may be difficult to quickly plow under a tree crop and plant the land with something else should crop productivity, market conditions, or other factors limit the return on the farmer’s investment of labor, land, and capital.

Thus, although the Conservation Reserve Program encouraged U.S. farmers to convert 12 million hectares (30 million acres)[74] of marginal

[74]The total now stands at approximately 15 million hectares (37 million acres). Thyrele Robertson, U.S. Department of Agriculture, Soil Conservation Service, personal communication, Aug. 26, 1993.

BOX 2-6: Conservation Compliance Programs

Conservation compliance was enacted under the 1985 Food Security Act as amended in 1990, which requires all farmers cultivating highly erodible land to fully Implement an approved conservation plan by 1995 or risk losing certain farm benefit programs At the same time, the Conservation Reserve Program pays farmers with highly erodible or otherwise environmentally fragile or sensitive land to take it out of production under 10-year contracts At present, some 15 million hectares (38 milllion acres) are enrolled in the CRP, with annual payments averaging roughly S124~hectare ($50/acre) At the end of the contract, land that is highly erodilble must meet conservation compliance conditions

Failure to comply with the conservation plan results in the potential loss of a variety of benefits, including eligibility for price supports and related programs, farm storage facility loans, crop Insurance, disaster payments, storage payments, certain Farmers Home Administration loans, and several other types of ass stance

Conservation compiance affects some 57 milionon hectares (140 million acres), more than one-third of U S cropland A key aspect of about three-quarters of the conservation compliance plans to date is the use of agricultural residues to control erosion Use of such residues for energy may then confilict with SOil erosion concerns

SOURCE Jeffrey A Zinn *Conservation Compliance Status and Issues*, 93-252 ENR (Washington, DC Congressional Research Service Feb 24 1993)

corpland to permanent cover during the 1986-89 period, only 1 million hectares (2,5 million acres) of this was planted with trees (box 2-6).[75] More gcnerally, of land planted in tree crops, the majority has been in the southern United States, where relatively short tree rotation ages and some longer landowner planning horizons have intersected.[76] Conversely, grasses generaly do not reduce flexibility.

On the other hand, farm labor needs are determined largely by the intense effort required to plant, harvest. and transport conventional agricultural crops during a narrow window of time, usually spring and fal1. Once planted, however. perennial herbaceous or woody energy crops may last 10 to 20 years, and harvesting may take place over a relatively long period of time. Adding such energy crops to the farmer's portfolio might then case the burden during spring and fall, allowing better use of labor and capital equipment overall and thus increasing certain aspects of farmer flexibility.

Farmers are most likely to adopt technologies with certain characteristics. Favored technologies are those that: 1) have relative advantage over other technologies (e.g., lower costs or labor, higher yields): 2) are compatible with current management objectives and practices: 3) are easy to implement: 4) are capable of being observed or demonstrated; and 5) can be adopted on an incremental or partial basis. The complexity of systems-oriented changes will likely slow their adoption. which may pose particular problems if regional landscape planning is pursued to maximize the habitat benefits of energy crops. Mechanisms for incrementally realizing habitat benefits may be needed should these programs go forward.

[75] R Neil Sampson, "Biomass Opportunities in the United States To Mitigate the Ef'feet\ of Global Warm " *Energy from Biomass and Wastes XV*, Donald L. Klass (ed.) [Chicago, IL. Institute of Gas Technology). 1991).

[76] Thomas Kroll, Minnesota Department of Natural Resources, personal communication. Apr. 13, 1994.

Individual and farm characteristics appear to explain only a small portion of behavior associated with adopting new crops or farming practices; institutional factors (e.g., farm programs, credit availability) are highly influential. Research on individual farm characteristics (e.g., size, specialization, land tenure) and farmer traits (e.g., age and education) and their relation to conservation adoption has yielded mixed results. Most researchers consider institutional factors to be much more influential, but few studies have been conducted on these to date.

Finally, farmers are a heterogeneous group with unequal abilities, access to information, and resources for decisionmaking; different degrees of willingness to take risks; and a wide range of objectives in practicing farming. For example, farmers objectives may include the following: making a satisfactory 1iving (as either an owner-operator, a tenant, or an employee); keeping a farm in operation for family inheritance or other personal reasons, perhaps while working at an off-farm job; obtaining a satisfactory return on investments in land, labor, and equipment; obtaining tax benefits; and obtaining recreation or aesthetic enjoyment. These objectives influence the portfolio of crops, including energy crops, that a particular farmer chooses to grow.

Strategies to encourage bioenergy crop adoption might include the following:

- *Demonstrations.* Local demonstrations would allow area farmers to observe first-hand what works and what does not and thus provide some familiarity with the technology in the local context. Demonstrations are similarly important for bioenergy feedstock users such as fuel producers (chapter 4) or electricity generators (chapter 5).
- *Long-term contracts.* The development of long-term contracts with local feedstock users, such as electric powerplants or ethanol producers, would provide greater market certainty to the farmer (see below).
- *Business plans.* The development and demonstration of high-quality business plans and related supporting materials might improve the credit worthiness of bioenergy cropping and assist farmers in gaining needed financial support.

Competitor Prices

As noted in chapter 1, fossil fuel prices are very low and can be quite volatile. These factors make it difficult to compete against fossil fuels in the near term and increase the risk of long-term investments in alternative energy systems. Strategies for dealing with low fossil fuel prices and high volatility might include the following:

- *RD&D.* Maintaining stable long-term RD&D programs in bioenergy crops irrespective of low or volatile energy prices might allow more rapid development of competitive bioenergy crop and energy conversion technologies.
- *Nonmarket values.* Recognizing and valuing the potential environmental and energy diversity benefits of bioenergy crops could improve their competitiveness. Environmental benefits potentially include reducing soil erosion, improving water quality by reducing sedimentation and agrichemical runoff or leaching from adjacent food and feed crops, improving air quality, reducing the emission of greenhouse gases, and providing habitat benefits. Energy crops might be used to help restore degraded lands, providing some financial incentive to plant and maintain the land.[77] Energy diversity benefits result from increasing the variety of energy resources that can be tapped and thus limiting the dependence on any one resource (see chapter 6). Approximate values for these benefits might then be incorporated through

IT@ degraded lands, yields are likely to be lower. Remaining economically competitive with low yields may then necessitate valuation Of some of the environmental or other benefits that the energy crop offers.

various environmental taxes on fossil fuels and/or credits for biofuels. When even crude financial valuations of these bcnefits (s prove difficult, techniques such as point systems or competitive set-asides may be useful (see chapter 6).

- *Federal supports.* The competitiveness of bioenergy crops might be improved by including a portion of the federal soil conservation and/or agricultural commodity support payments that would be offset by producing the bioenergy crop. Properly structured. it might then be possible to make the bioenergy crop competitive, improve farmer income. and reduce federal agricultural expenditures. Careful examination of the potential costs and benefits of such an approach is needed.

Production Scaleup

As noted in chapter 1, a key difficulty faced by many new technologies is the chicken-and-egg problem of developing a market. In the case of biomass energy, farmers cannot afford to grow biomass unless electric power or fuel conversion facilities---g.,., producing electricity and liquid fuels—are in place to purchase it. Conversion facilities cannot be built unless the biomass feedstock is available at a reasonable price and an end-use market is ready. An end-use market is difficult to develop without assured supplies of fuel.

Strategies to enable production scaleup might include the following:

- *Niche markets. Niche* markets for bioenergy crops might include cofiring biomass with coal in conventional power-plants. Cofiring works well for perhaps up to 5 to 15 percent wood input into the powerplant fuel mix. Cofiring is also a means for utilities to reduce their emission of SO_x. Cofiring can provide an early market, begin the development of biomass infrastructure, and provide electric utilities with early experience in procuring. transporting, and using biomass. As a substitute for coal in a conventional powerplant, however, the delivered costs of bioenergy should be roughly comparable to those of coal. limiting the quantity of biomass that can be tapped economically. Credits for SO_x reduction may improve these economics. (See also chapters 4 and 5.)
- *Partnerships.* As noted above, long-term contracts might be developed between farmers and end users such as electric utilities, ethanol/ methanol producers. or others such as pulp and paper producers. This would provide greater certainty to both partners. The high levels of capital investment required of feedstock users might also encourage them to be the prime movers of such a strategy. Such partnerships may also help address the ● ’nuisance” factor of needing numerous (small) contracts to provide sufficient feedstock.
- *Multiple uses.* Bioenergy crops might best serve a variety of end uses simultaneously. In particular, the initial establishment of bioenergy crops might be assisted by coupling energy production with higher value uses of the feedstock. For example, an energy crop might be established initially to serve a higher value purpose such as the production of pulp and paper and only secondarily for energy .[78] The experience gained through such multiple uses may provide a foundation for further energy crop development and cost reductions.

Bioenergy crops will naturally move to their highest value use. This might be as a transport fuel. as a baseload backup to intermittent renewable, for industrial chemicals or fiber, or perhaps for environmental benefits. Evaluating more completely the full range of costs and benefits for each potential use of bioenergy crops, including budget and trade balance impacts. across the entire production and use cycle would be an important next step in determining the potential competitiveness of these crops vis-à-vis various competing uses of the land and other sources of energy.

[78] Even if SRWCs are used for pulp and paper, roughly 25 to 40 percent of the harvested biomass would be available for energy use.

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Eight-year old hybrid poplars grown by James River Corp. in Oregon These fast-growing trees can be harvested repeatedly and regrow from the stump More than 25,000 hectares (62,000 acres) of these trees have been established in the Northwest to provide both fiber and energy

Studies of how best to address these issues might be conducted in parallel with demonstrations.

Leveling the Playing Field

Existing soil conservation and commodity support programs, as well as other factors. may discourage financial investment in alternatives such as energy crops. The extent to which this occurs needs to be examined and is an important area for further analysis.

Infrastructure Development

A wide range of infrastructure development is required to support bioenergy programs. This includes, in particular, harvesting and transport equipment, energy conversion facilities (electricity generation, ethanol production), energy transmission (high-voltage electric power lines) and transport (pipelines or tanker trucks) systems, financial services, extension services, trained manpower, and many others.

Much of this infrastructure will develop with the industry. In some cases, however, existing infrastructure—such as electricity transmission systems or liquid or gaseous fuel pipelines—might be used effectively if plants can be sited appropriately. Geographic information systems could assist such analysis.

POLICY OPTIONS

Several economic incentives and other supports of biomass fuels are already law (box 2-1; table 2-1). These supports target primarily the transport fuel and electricity sectors, however, and tend to ignore the substantial market challenges at the crop production stage. As a consequence, a significant share of the near- to mid-term opportunities for producing and using biomass energy might not be realized because of the market challenges described above and current resource constraints. There has been a significant increase in overall program support for bioenergy in recent years.[79] Bioenergy crop development is, however, a small portion of the total. For feedstock development, the fiscal year 1995 budget is about $4.6 million in 1992 dollars.

Under current funding levels, the ability to develop and demonstrate energy crops and related harvesting and transport hardware is quite limited. Development of high-productivity crop species currently accounts for about half of the Depatiment of Energy (DOE) feedstock development funding. With total costs for developing a single feedstock species in a single region of about $1 million per year, feedstock development has been limited to poplar at three centers[80] and switchgrass at two centers[81]---even with heavy cost-sharing with the private sector, states, and others. At present funding levels, detailed feedstock development is not taking place on other tree spe-

[79] Most of this funding is for feedstock conversion processes such as lignocellulose to ethanol (ch. 4) or electricity generation (ch. 5).

[80] Located in [he pacific Northwest, the Midwest, and the Southeast.

[81] Located in the Midwest and the Southeast.

cies, such as silver maple, black locust, sycamore, and sweetgum, and on grass species, such as big bluestem and wheatgrass. Funding levels of perhaps $6 million to $10 million (1992 dollars) over an extended period (e.g., 10 to 15 years) would provide adequate to good species development for the various regions (see below).

Current DOE funding levels provide essentially no support for the development of harvesting and transport hardware. Since these activities constitute a significant fraction of bioenergy crop costs, development of high-performance hardware is essential if costs are to be reduced to more widely competitive levels. Funding of $1 million to $2 million per year over an extended period (five years or more) maybe sufficient to catalyze private sector interest and cost-sharing to develop such hardware.

Substantial field demonstration and environmental monitoring of these energy crops will be needed, at a scale sufficient to demonstrate the performance and characteristics of a fully functioning crop production, infrastructure, and feedstock conversion system. Such demonstrations may be needed at some level for each species and region. As an example, a dedicated 50-MW powerplant will require production from perhaps 20,000 hectares (50,000 acres) of energy crops. At a typical cost for crop establishment of $740/hectare ($300/acre), this will have a front-end cost of $15 million, not including the powerplant (see chapter 5). The private sector would share the cost of the demonstration, and a portion of the funds will also be recovered with the sale of electricity or fuel from the faci lit y. To reduce risk further, early demonstrations could be limited to obtaining 15 to 30 percent of their fuel needs from biomass; the rest could be obtained from natural gas or coal.

Environmental monitoring of such demonstrations will also be needed, with costs running into several million dollars per year, to monitor species such as birds and mammals, soil quality, groundwater quality and quantity, and landscape-level impacts.[82]

Thus, while the current funding level provides support for the detailed development of a single tree and a single grass species; it does not support significant development of key harvesting and transport hardware, and it supports only minimally the field demonstration and environmental monitoring of these crops. As a consequence, the development of energy crops is likely to be relatively slow and haphazard, and several current or near-term cost-effective applications of bioenerg y are unlikely to be captured. These include some coal cofiring and biomass-fired electricity-generation opportunities. A significant demonstration program would give farmers, electricity sector planners, financiers, and regulators the confidence to move these biomass-fueled systems forward.

To the extent that current funding fails to fully capture the cost-effective use of bioenergy crops, it misses the opportunity of using these crops to offset federal budget expenditures for soil conservation, commodity support, and/or crop insurance.[83] Maximizing cost-effective production and use of energy crops could also improve the rural economy and generate jobs, while reducing environmental problems such as soil erosion and emissions of greenhouse gases.

The development and demonstration of these energy crops can also reduce farmers' risks by diversifying their crop portfolios and providing more robust crops for flood- or drought-prone re-

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[82] For example, current monitoring of the environment] impacts of several small 400-hectare (1,000 acres in 8 to 15 plots) sites costs about $200,000 to $300,000 per year. Scaleup by a factor of 15 to 25 to a demonstration system of 20,000 hectares would not increase costs commensurately because only portions of this area would have to be sampled. There would. however, be additional environmental monitoring costs associated with landscape-level impacts on habitat diversity and other factors.

[83] The extent t. which these budget expenditures actually occur will depend strongly on the impact of trade agreements—the Uruguay Round of GAIT and NAFTA-and many other factors.

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Harvesting hybrid poplars at the James River Corp. in Oregon, using a "feller buncher "

gions. Energy crops may similarly reduce national energy risks by diversifying the national energy portfolio. For example, large-scale use of these energy crops could offer a mid- to long-term alternative to imported oil.

To capture high-leverage opportunities to significantly expand the production and use of bioenergy, it would be necessary to increase expenditures to some extent. For example, crop development support could be increased to $6 million per year (1992 dollars), providing at least $1 million per year for harvesting and transport hardware development, and supporting several larger scale demonstration and environmental monitoring efforts. This funding would necessarily be leveraged against private sector supports to carry out these efforts adequately.

These costs should be balanced against potential savings in federal expenditures in areas such as soil conservation, commodity support, and crop insurance programs. The timing and magnitude of these potential costs and savings, however, depend on numerous technical, economic, and institutional factors and remain to be determined.

The 1995 Farm Bill may be a potentially useful vehicle for addressing many of the policy options involving higher expenditures than current levels, which are described below. Among other options, a title might be included within the Farm Bill that focuses on energy crop RD&D, planning, commercialization, information, crop insurance, and other programs. Attention could also be given to joint programs between associated departments and agencies, such as DOE, the Department of Agriculture, and the Environmental Protection Agency.

Policies that could be considered as part of a bioenergy development strategy are listed below. RD&D programs might include the following:

- *Collaborative research, development, and demonstrations.* Continuing and expanded support could be provided for high-leverage RD&D opportunities across the breadth of crop production, harvesting, transport, environmental impacts, and other aspects discussed above. These efforts may be significantly leveraged to the extent that they can be conducted in collaboration with private organizations, and they could include the development of multiuse crops to reduce farmer risk. In addition, this might include analysis of the potential infrastructure development requirements and economic impacts of large-scale energy cropping. Various forms of support, particularly through cooperative efforts with the private sector, could be provided for a variety of biomass electric or transport fuel project demonstrations,

Planning and information programs include:

- *Planning.* Support, including the development of geographic information systems and other tools, could be developed in cooperation with state and local governments to establish a local and regional landscape planning capability for optimal design of energy crops. Support could also be provided for the development of local approaches that minimize possible environmental or other impacts of energy crops. Some work in this area is now beginning and could be strengthened.
- *Information programs.* Information programs, including extension efforts to farmers, electric utilities, financiers, and others, might be expanded. Conversely, much information could

be gathered from farmers so as to better design biocnergy programs. Current funding for information and a number of other activities through the Regional Biomass Program is about $4 million per year. These programs conduct regional biomass resource assessments. facilitate technology transfer to the private sector, support public-private projects, and assist other activities. As their scope and outreach activities increase, greater support will be needed for these and related programs. In certain cases, however, it may be possible to capture some savings by combining these with other agricultural information and planning programs.

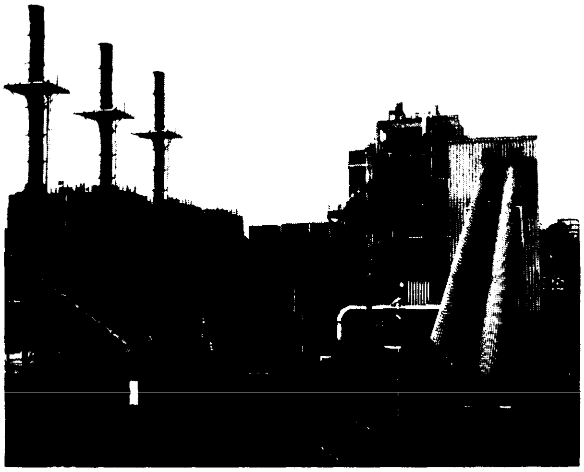
Bioenergy programs might complement existing agricultural programs as follows:

- *Conservation Rrserve Program lands.* Contracts on CRP lands begin to expire in 1995. If Congress decides to alter the CRP, consideration might be given to achieving a transition to bioenergy cropping on some of these lands in order to reduce federal CRP expenditures while increasing farm income and minimizing farmer risk. This, together with commodity support and insurance program considerations listed below. represents a key opportunity that requires further analysis.
- *Commodity support programs.* Energy crops might be considered as substitutes for program crops with a modified or transitional payment schedule so as to reduce federal expenditures and farmer risk. while allowing the farmer to maintain or increase income through energy crop sales. Additional flexibility in commodity support programs might also be considered to allow the growth of energy crops without penalty or risk to the farmer's enrollment in other farm programs.
- *in.surance programs.* Federal crop and other insurance programs for flood. drought, and other natural disasters might be examined to determine if biocnergy crops offer a lower risk alternative to conventional agricultural crops in particular areas. If so, growers in high-risk areas might be encouraged to switch to these crops.

Finance and commercialization programs could include the following:

- *Partnerships.* Mechanisms for brokering or leveraging partnerships between bioenergy growers and users might be examined, including modest financial or institutional support from the federal government in early demonstration or commercialization efforts. Partnerships are also examined in chapters 4 and 5.
- *E.xternality taxes and incentives.* Mechanisms for recognizing and valuing the potential environmental and energy-diversity benefits of bioenergy crops might be examined, including appropriate financial credits,[84] points or other value systems for including environmental and other potential bioenergy benefits when choosing technologies for expanding electricity y capacity, and green set-asides. These mechanisms are examined in chapter 6 for the electricity sector. Such considerations could allow bioenergy's range of costs and benefits-including environmental—to be considered more fully in comparison with those of con\' entional energy systems.
- *Energy production credits.* The National Energy Policy Act of 1992 established a 1.5¢/kWh energy product ion tax credit for electricity y generation with closed-loop bioenergy crops. This credit is available only for plants placed in service before July 1, 1999. Because of the long lead times required to establish many energy crops, such as SRWCs, and powerplants, few will be able to make use of this tax credit. Congress might consider extending the period of eligibility sufficiently for such closed-loop systems to be fully tested and markets to be initiated.
- *Federal procurement.* The federal government. including the Power Marketing Authorities, could establish bioenergy power facilities

[84] Alternatively, various combinations of social cost taxes on conventional energy resources might be considered (see ch. 6).



Wheelabrator biomass electric plant in Mt. Shasta, California.

where cost-effective or near-cost-effective biomass supplies might be obtained. These could serve as useful demonstrations and provide valuable design and scaleup data for commercial efforts. Federal procurement complements the above policy tools by being a more direct mechanism for initiating bioenergy projects.

A strategy involving higher levels of funding could include the following elements:

- *Financial mechanisms.* Innovative financial mechanisms might be examined that reduce farmers' risks in shifting to energy crops while minimizing public costs. These could include interest rate buydowns, cost-sharing, longer term farmer-feedstock-user contracts or risk-sharing agreements, or explicit codevelopment of bioenergy with the expansion of pulp and paper or other facilities. For utilities, this might also include safe harbor rules, cofiring of biomass with coal to provide SO_x reductions, recognition of fuel diversity benefits, and competitive set-asides for biomass energy (see chapter 6). Many of these would be private initiatives with modest federal support. The relative costs and benefits of such mechanisms need to be evaluated to determine which are the most cost-effective.
- *Competitor pricing.* Mechanisms might be considered to protect an embryonic biomass energy industry from short-term fossil fuel price drops below certain thresholds. Effectively, this would be the bioenergy counterpart to agricultural commodity support programs. Again, the relative costs and benefits of such mechanisms would have to be evaluated, mechanisms to minimize and cap costs explored, and means developed for ensuring their phaseout within a reasonable period.

The multiplicity of sectors affected by energy crops--e. g., agriculture, energy, environment, forestry—poses a substantial and, in some ways, unique institutional challenge in developing coherent policy goals, processes, and effective coordination. For any bioenergy strategy, effective means of communication and policy coordination among the many institutional and private-sector participants are required.

CROSSCUTTING ISSUES

Integrating biomass crops with energy conversion facilities and end uses requires careful consideration of total fuel cycle cost, performance, environmental impacts, and other factors, Current bioenergy crop and conversion systems already show considerable promise in simultaneously providing energy, economic, and environmental benefits.

In the longer term, additional gains maybe possible with advanced bioenergy crop and conversion systems, although much research remains to be done. Compared with monoculture, for example, polycultures may provide more wildlife habitat benefits as well as other possible environmental benefits. If polycultures are pursued, energy conversion technologies such as gasifiers may then be preferred for their ability to easily handle a variety of input feedstocks. In turn, gasifiers are better suited to the production of methanol than ethanol, and methanol may allow the use of low-temperature steam reformers and proton exchange membrane fuel cells to power transport (chapter 4).

Conversely, advances in solid oxide fuel cells may encourage the use of ethanol for transport. Capturing the habitat benefits of polycultures may then require further research on the enzymatic hy -

drolysis of polyculture feedstocks. Chapter 4 examines some of these alternative technology paths for transport, including fuel cells and internal combustion engine hybrids. At this early stage, it is important that a broad portfolio of energy crop and conversion technology RD&D and environmental analysis be maintained.

The extent to which such paths can be pursued depends strongly on the relative long-term economics of bioenergy polycultures versus monoculturcs, the value placed on habitat and other benefits, and the means by which these are weighed against the economic or environmental costs and benefits of agricultural crops and/or fossil fuels. These long-term questions should not obscure the potential benefits of currently conceived monoculture energy crops.

CONCLUSION

Energy crops may help address some of our national energy, economic, and environmental problems. Depending on the direction of global agricultural markets, they can potentially provide a significant amount of energy, perhaps 20 EJ (19 quads) or more---equivalent to one-quarter of current U.S. energy USC. The y have potential environ - mental benefits compared with conventional agricultural crops. Energy crops are no substitute, however. for natural habitats on contiguous landscapes. The regional impacts of energy crops will be mixed. Not all crops can be readily grown everywhere. The overall national economic and job impacts of bioenergy cropping may be quite positive, particularly for rural areas.

Energy crops thus show promise to help meet several national needs---conomic. environmental, budgetary, and national security. The extent to which the potential of bioenergy can be realized wil1 depend on how wel1 the many compcting eco - nomic/environmental. rural/urban, and other interests can be balanced. Realizing this potential will require a long. dedicated effort in terms of research, development, demonstration, and commcrcializaticm of these technologies. Implementing large scale bioenergy programs without such a foundation could damage the environmcnt and reducc potential economic- or other benefits.