Introduction 2

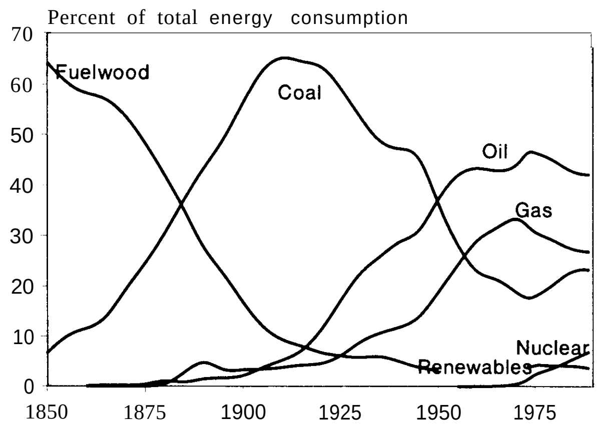
Biomass is mankind's oldest energy resource. It has been periodically misused throughout history, sometimes with serious environmental and other consequences. Cyprus provided the bronze needed by the ancient Greeks for weaponry; wood shortages are a likely cause of the reduction in bronze smelting there by 1300 BC which forced rationing on the Greek mainland and weakened the Mycenaens to outside attack. Aristotle and Plato documented the destruction of forests in Greece itself and the resulting environmental degradation. The Remans were forced to import wood from North Africa, France, and Spain to keep their industries, public baths, and military operational. England suffered severe deforestation in many areas during her early industrial period—citizens even rioted over rising wood prices; eventually the transition to coal was made.] The United States went through a similar transition among energy resources over the past 150 years (figure 2-l).

Today, a variety of concerns has prompted a new look at biomass as an energy resource. Biomass, in combination with advanced combustion and/or conversion technologies, has the potential to contribute needed energy resources for transport, electric power, and industry. Bioenergy may provide economic benefits to the rural economy and possibly to the Nation. By substituting for imported oil, bioenergy also may provide some national security benefits. These potential economic, budgetary, and security values of bioenergy must be weighed, however,

Today, a variety of concerns has prompted a new look at biomass as an energy resource.

[1] John Perlin and Boromir Jordan, "Running Out—4200 Years of Wood Shortages," *Convolution Quarterly,* Spring 1983, pp. 18-25; Erik P. Eckholm, *Losing Ground: Environmental Stress and World Food Prospects (New* York, NY: W.W. Norton and Company, 1976).

Figure 2-l —U.S. Energy Consumption Patterns from 1850 to 1990



This figure shows the generational shift from one fuel to the next for the United States, from wood in the 1800s to coal by the turn of the century, and then to oil and gas from the 1950s on.

SOURCES: Office of Technology Assessment; J. Alterman, *A Historical Perspective on Changes in U.S. Energy-Output Ratios,* EPRI EA-3997 (Palo Alto, CA: Electric Power Research Institute, June 1985).

against alternative uses of the land and other means of meeting these needs.

THE U.S. ENERGY SECTOR AND BIOENERGY

In the United States,[2] bioenergy accounts for roughly 4 percent of total energy use, or about 3 Exajoules (EJ).[3] Oil, coal, and natural gas contribute 41 percent (35 EJ), 23 percent (20 EJ), and 25 percent (21 EJ) respectively (figure 2-2).[4] The primary uses of bioenergy in the United States are industrial cogeneration, primarily in the pulp and paper industry, and for residential heating by wood stoves. Municipal solid waste and ethanol provide most of the remaining bioenergy (table 2-1).5

The Transport Sector

Transportation consumes about one-fourth of total U.S. primary energy use and nearly two-thirds of oil use. Of U.S. oil consumption—which provides 42 percent of the total U.S. energy consumption of about 85 EJ—roughly half is now imported and this share is increasing. With current policies, U.S. imports of oil are likely to increase dramatically over the next several decades (figure 2-3).

Renewable energy resources and technologies—particularly bioenergy-offer the potential to reduce these trends in the longer term. Technologies for biomass feedstock conversion and use in the transport sector are given in box 2-A. Whether or not this potential can be realized, however, remains uncertain and depends on the details of their cost and performance compared

Table 2-1—U.S. Biofuel Production and Use, 1989

Fuel	ExaJoules
Wood	2.6
Industrial	(1.7)
Residential	(0.9)
Utility	(0.01)
Biofuels from waste	0.36
Municipal solid waste combustion	(0.23)
Manufacturing waste	(0.10)
Landfill gas	(0.03)
Ethyl alcohol	0.075
Total	3.04

SOURCE: Energy Information Administration, "Estimates of U.S. Biofuels Consumption 1989," U.S. Department of Energy, Washington, DC, April 1991.

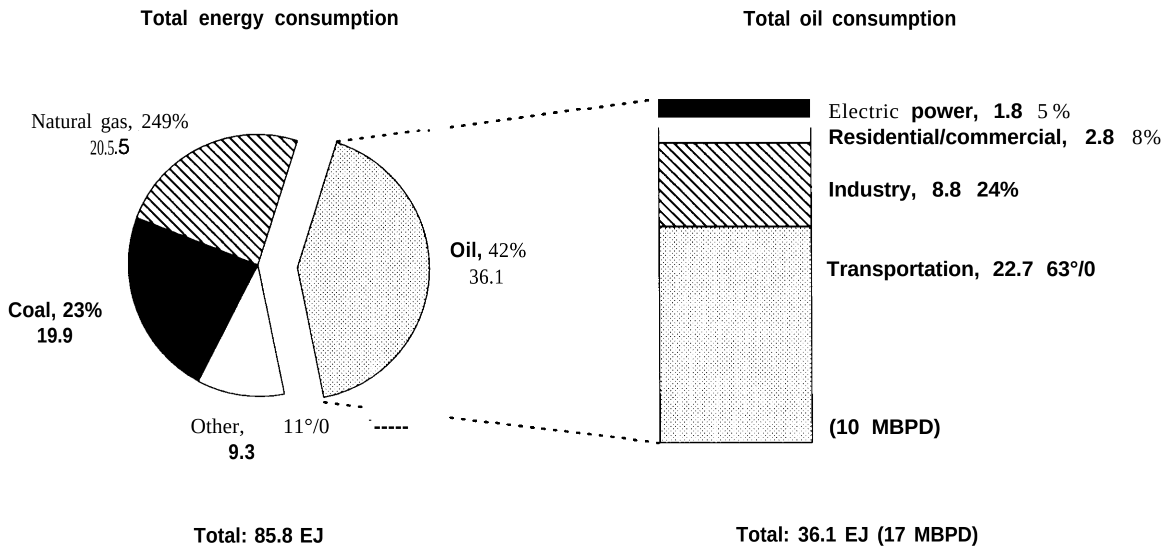
[2] Bioenergy is critical to the economies of developing countries, particularly in rural areas. See, for example: U.S. Congress, Office of Technology Assessment, Energy *in Developing Countries, OTA-E-486* (Washington, DC: U.S. Government Printing Office, January 1991); U.S. Congress, Office of Technology Assessment, *Fueling Development: Energy Technologies for Developing Countries, OTA-E-516* (Washington, DC: U.S. Government Printing Office, April 1992).

[3] See appendix B for units, their definition, and their equivalences.

[4] U.S. Department of Energy, Energy Information Administration, *Annual Energy Review, 1992,* Report No. DOE/EIA-0384(92), June 1993.

[5] For a detailed bibliography, see: United States Department of Agriculture, "Biofuels: January 1986-August 1992," National Agricultural Library Quick Bibliography Series QB 92-63, September 1992.

Figure 2-2—U.S. Energy and Oil Consumption, 1989



This figure shows U.S. energy consumption for oil, coal, natural gas, and others, and breaks oil consumption down by its end use. About 42 percent of U.S. energy consumption is in the form of oil and nearly two-thirds of this oil is used for transport.
SOURCE: Energy Information Administration, *Annual Energy Review* 1992, U.S. Department of Energy, DOE/EIA-0384(92), June 1993.

with alternative fuels and technologies, as well as the larger context of urban design, the development of transport infrastructures, and internalizing the external costs of fossil fuel use and transport generally.[6]

The Electricity Sector

Coal, nuclear, hydro, and natural gas are the principal sources of electricity in the United States. Bioenergy, primarily wood and wood wastes in the forest products industry, is an important fuel for industrial cogeneration. Independent power producers are also turning frequently to bioenergy resources, including wood, municipal wastes, and landfill gas, for power production (table 2-2). More than 8 GW of biomass-fired capacity are now installed in the United States.[7]

Utilities are becoming increasingly interested in biomass as a fuel for power production. Factors contributing to this interest include: improved technologies for burning/gasifying biomass and generating power (see box 2-A);[8] pressure to reduce emissions under the Clean Air Act Amendments of 1990; the 1.5 cent/kWh credit authorized under the Energy Policy Act of 1992 for closed loop biomass systems; and others.

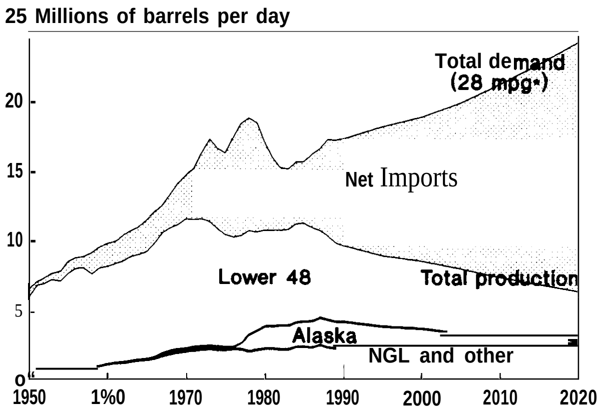
In addition, biomass-fueled electricity generation may play a particularly important role if there is a greater emphasis in the future on using renewable forms of energy. In contrast to intermittent

[6] A forthcoming Office of Technology assessment charts a variety of future renewable energy resource and technology paths for transport; analyzes their relative economic, environmental, and technological performance vis a vis conventional fossil-fueled systems; and examines the key RD&D and commercialization issues that must be addressed if their potential is to be realized. Technologies examined include ethanol, methanol, and hydrogen used in internal combustion engines and fuel cell vehicles. Broader issues of urban design, infrastructure development, and the externalities of transport are also reviewed there.

[7] National Wood Energy Association, *National Biomass Facilities Directory,* Arlington, VA, 1990.

[8] Robert H. Williams and Eric D. Larson, "Advanced Gasification-Based Biomass Power Generation," Thomas B. Johansson, Henry Kelly, Amulya K.N. Reddy, and Robert H. Williams (eds.), *Renewable Energy: Sources for Fuels and Electrcity* (Washington, DC: Island Press, 1993).

Figure 2-3—U.S. Oil and Supply Demand Futures



U.S. domestic oil production is declining, while U.S. oil demand is rising with population and economic growth. Shown here is the projected rise assuming that the new cars and light trucks in the United States have their fuel efficiencies frozen at 1990 levels (28 mpg). "Lower 48" represents oil production in the lower 48 states; "Alaska" is the oil production from Alaska, and NGL and other are Natural Gas Liquids and other sources of liquid fossil fuels.

SOURCE: Office of Technology Assessment. Baselines adapted from Energy Information Administration, *Annual Energy Outlook 7997,* U.S. Department of Energy, DOE/EIA-0383(91), March 1991.

renewable such as solar (available when the sun shines) and wind (available when the wind blows), biomass energy comes as an already stored solar energy resource. It can thus be used as needed rather than as available. Although the intermittancy of solar and wind energy can be moderated by gathering them over a large geographic region, they still require dispatchable backup power such as can be provided by biomass.[9]

The Industrial Sector

The industrial sector uses roughly one-third of primary energy in the United States. Wood as a fuel contributes about 8 percent of total industrial sector primary energy use, mainly in the pulp and paper industry where it contributes as much as three-quarters of energy needs (figure 2-4).[10]

Table 2-2—U.S. Winning Competitive Bidsfor New Capacity, 1984-1992

	Capacity MW
Natural gas	**6,628**
Coal	**1,969**
Refurbishment	**1,127**
Coal wastes	**720**
Oil	**340**
Coke	**165**
Total fossil	*10,949*
Geothermal	**825**
Wood and biomass	**776**
Municipal waste	**564**
Hydro	**125**
Wind	**63**
Landfill gas	**28**
Total other	*2,381*

Note that these include only winners from competitive bidding solicitations. Many other power plants, primarily fossil-fueled, were built outside of competitive bidding solicitations.

SOURCE: *Robertson's Current Competition, vol. 3, No. 2,* May 1992.

Industry is interested in increasing use of these fuels. For example, the typical pulp and paper operation has three principal waste streams which can provide energy: hog fuel, black liquor, and forest residues. Hog fuel is the bark, sawdust, and other scrap produced in reducing logs to feedstock for the pulping process. Hog fuels could supply about 3 GJ[11] per tonne of pulp produced (GJ/tp). Black liquor, from the chemical pulping process, averages an energy content of about 13 GJ/tp. Other residues are currently left in the forest when harvesting the trees. A portion of these forest residues might be collected, but the long-term impact this would have on forest soils would need to be examined closely (see ch. 3). If fully recovered, the estimated energy content of forest resi-

9 Other renewable energy resources that can similarly provide baseload power include geothermal and hydropower.

10 This is the energy used at the site and does not include energy losses in generation, transmission, and distribution of electricity from offsite to the plant, the refinery losses of converting crude oil to fuel oil and transporting it to the site, or other such offsite losses.

11 Fifty kilos of dry wood have an energy content of about 1 gigajoule (GJ).

Box 2-A--Bioenergy Conversion Technologies

Biomass can be **used directly to generate** electricity or it can be converted to a liquid (or gaseous) transportation fuel.

The physical and chemical composition of biomass feedstocks varies widely, potentially requiring the tailoring of particular conversion technologies to specific biofuels (with corresponding negative impacts on habitat if narrowly specified monoculture must be used—-see ch. 3). The relatively low bulk densities of biomass and large required collection areas limit the amount of biomass transported to any given site. This constrains the size of individual conversion facilities and limits the extent to which economies of scale in capita! and other costs can be captured.[1]

Electricity. Virtually all existing biomass electric plants use steam turbine technology and, **due to use of old, Inefficient, and small-scale technologies, their** efficiency tends to be low-l **7 to 23 percent** in California, **for example. in comparison, modem coal plants run** at efficiencies of perhaps 35 percent. Steam turbine technology is fairly mature and few advances are foreseen for biomass. Improvements are possible, however, in biomass handling. Whole-tree energy systems, for example, use the flue **gas for** drying, reduce the required handling, increase net energy efficiencies slightly (in part through a higher pressure steam cycle), and avoid chipping costs.

Of greater potential is to gasify the biomass and use the gas generated to **power a** gas turbine. Gasifiers **and gas turbines** are relatively insensitive to scale and can operate at much higher efficiencies than steam turbines in the range of sizes suitable **for biomass systems.**

In a biomass gasifier/gas turbine system, biomass is gasified in a pressurized air-blown reactor and the products cleaned of particutates and other contaminants before being burned in an efficient power cycle based on gas turbines, such as the steam injected gas turbine (STIG), intercooled STIG (ISTIG), or a combined cycle.[2] Hot gas cleanup avoids cost and efficiency penalties, and pressurized gasification avoids energy losses **associated with compressing** the fuel gas after gasification. It is necessary, however, to **remove** trace amounts of alkali vapor from the gas before it enters the gas turbine. There appears to be a basic understanding of the means for adequately cleaning gases **for gas turbine applications with either fluidized** bed gasifiers[3] or updraft gasifiers, although there has **been no commercial demonstration of alkali removal. A demonstration 6** MWe pressurized fluidized **bed** plant, however, has recently gone on **line in** Sweden.

Biomass gasifier/gasturbines (BIG/GTs) are characterized by high conversion efficiencies and low expected unit capital costs ($/kW) in the **5 to** 100 MWe size range.[4] The upper end of this range is probably near the

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[1] **Typical rates of biomass fuel production, or use at individual sites, range up to a maximum of some** 300 **to 400 MW**$_{fuel}$ &4 **to** 72 dry **tonnes per hour) at large factories that produce biomass as a byproduct and use it for energy (e.g., cane sugar and kraft pulp factories). This can be compared with the 800 to** *4,000 MW* **of coal consumed at central station electric power plants. Larger concentrations of biomass could be made available, e.g., from plantations dedicated to producing biomass for energy. Under such schemes, transportation costs and land availability will be limiting factors on the quantity of biomass that** can be concentrated **at a single site.**

[2] **See E.D. Larson and R.H. Williams,** 'steam-injected **Gas Turbines,"** ***ASME Journal Of Engineering for Gas Turbines and Power,*** **vol. 109, 1987, pp. 55-83; R.H. Williams and E.D. Larson, "Expanding Roles for Gas Turbines in Power Generation,"** *Electricity: Efficient End Use and New Generation Technologies, and Their **Planning Implications*** **(Lund, Sweden: Lund** University **Press, 1989), pp. 503-53; R.H. Williams and E.D. Larson, "Thermochemical Biomass Gasifier/Gas Turbine Power Generation and Cogeneration," Thomas B. Johansson, Henry Kelly, Amulya K.N. Reddy, and Robert H. Williams (eds.),** ***Renewable Energy:*** *Sources **for Fuels and Electricity*** **(Washington, DC: Island Press, 1993).**

[3] **E. Kurkela, P. Stahlberg, M. Nieminen, and J. Laatikainen, "Removal of Particulate, Alkali, and Trace Metals from Pressurized Fluid-Bed Biomass Gasification Products-Gas Cleanup for Gas Turbine Applications," in Donald L. Klass,** ***Biomass and Wastes XV*** **(Chicago, IL: institute of Gas Technology, 1991).**

[4] **See E.D. Larson and R.H. Williams, "Biomass-Gasifier/Steam-Injected Gas Turbine Cogeneration,"** ***Journal of Engineering*** *for Gas Turbines and Power, vol. 112,* **April 1990, pp. 157-63; P. Elliott and R. Booth, "Sustainable Biomass Energy: Selected Paper (London, England: Shell International Petroleum Co., Ltd., December 1990).**

practical upper limit on the size of a biomass installation. Capita} costa for gasification and gas cleanup may be lower for biomass than for coal due to the lower operating temperatures and greater volatility of biomass.

Transport Fuels. Biomass-derived fuels-methanol, ethanol, biodiesel, and possibly hydrogen--offer an important opportunity to reduce U.S. fossil fuel consumption transport. Of particular interest here are ethanol and methanol

Ethanol. Much of the attention and funding of biomass fuels has been focused on grain-to-ethanol production. In the United States, commercial operations annually produce about 850 million gallons of ethanol from corn by fermentation. This ethanol is blended in a typically 1 to 9 ratio with about 8 percent of U.S. gasoline as an octane enhancer. (Alternatively, minor engine modifications allow ethanol to be used as a full replacement for gasoline.) This production is supported by tax incentives arid low prices for alternative uses of the corn crop. Expansion of supplies sufficient to significantly reduce US. oil imports, however, is not realistic if limited to the use of grain; nor would it be economical.

Ethanol's environmental benefits include: a reduction of carbon monoxide when used in blends; possible reductions in urban ozone;[5] and, if produced from biomass on a renewable basis, no or low net contributions of the greenhouse gas carbon dioxide to the atmosphere.

Advanced bioengineering and other technologies are now enabling researchers at the National Renewable Energy Laboratory (NREL), Tennessee Valley Authority, and elsewhere to convert cellulosic feedstocks (e.g., the corn stalk, not just the grain) to ethanol. This greatly increases the potential volume of feedstock that could be converted to ethanol and reduces its cost. Although substantial technical hurdles remain, particularly scale-up of laboratory processes, researchers hope to lower the cost of ethanol to competitive levels with gasoline by the year 2000.

Woody and herbaceous biomass, referred to generally as lignocellulosic materials, consist of three chemically distinct components: cellulose (about 50 percent), hemicellulose (25 percent), and lignin (25 percent).[6] Most proposed ethanol production processes involve separate processing of these components. in the first step, pretreatment, the hemicellulose is broken down by acids or enzymes into its component sugars and separated out.[7] The lignin is also removed. The remaining cellulose is then converted into fermentable glucose through hydrolysis, Following fermentation, the products are distilled to remove the ethanol. Byproducts of the separation process, such as furfural and lignin, can be used as fuel or sold separately.

Methanol, Methanol is a liquid fuel that can be produced from natural gas, coal, or biomass via gasification and catalysis. Methanol does require somewhat greater fuel-system material modifications than ethanol, but flexible-fueled vehicles, which can operate on methanol, ethanol, gasoline, or a mixture of these fuels, are already being produced in limited numbers in the United States.[8] The use of such vehicles could ease the transition away from gasoline.

Biomass-to-methanol plants would typically convert 50 to 60 percent of the energy content of the input biomass into methanol, though some designs have been proposed with somewhat higher conversion efficiencies. Three basic thermochemical processes are involved in methanol production from biomass:[9]

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5 US. Congress, Office of Technology Assessment, *Replacing Gasoline: Alternative Fuels for Light-Duty Vehicles,* p. 108.

6 J.D. Wright, "Ethanol from Lignocellulose: An overview,'" *Energy Progress,* vol. 8, No. 2, 1988, pp. 71–78.

7 C.E. Wyman, N.D. Hinman, and R.L. Bain, "Ethanol and Methanol from Cellulosic Materials," Thomas B. Johansson, Henry Kelly, Amulya K.N. Reddy, and Robert H. Williams (eds.), Renewable *Energy:* Sources *for Fuels and Electricity* (Washington, DC: island Press, 1993); P.W. Bergeron, J.D. Wright, and C.E. Wyman, "Dilute Acid Hydrolysis of Biomass for Ethanol Production," *Energy from Biomass and Wastes XII* (Chicago, IL: Institute for Gas Technology, 1989), pp. 1277-96; M.M. Bulls, J.R. Watson, R.O. Lambert, J.W. Barrier, "Conversion of Cellulosic Feedstocks to Ethanol and Other Chemicals Using TVA's Dilute Sulfuric Acid Hydrolysis Process," *Energy from Biomass and Wastes XIV* (London, England: Elsevier Applied Science, 1991).

8 U.S. Congress, Office of Technology Assessment, Replacing Gasoline, OTA-E-364 (Washington, DC: U.S. Government Printing Office, September 1990), p. 25.

9 C.E. Wyman, N.D. Hinman, and R.L. Bain, "Ethanol and Methanol from Cellulosic Materials," in Thomas B. Johansson, Henry Kelly, Amulya K.N. Reddy, and Robert H. Williams (eds.), *Renewable Energy; Sources for Fuels and Electricity,* (Washington DC: Island Press, 1993).

- Production of a “synthesis gas” (a close relative of producer gas) via thermochemical gasification, but using oxygen rather than air in order to eliminate dilution of the product gas with nitrogen (in air). Oxygen plants have strong capital cost scale economies, which contributes to most proposed biomass-to-methanol facilities being relatively large (typically 2,000 tonnes/day or more input of dry biomass). Biomass gasifiers designed for methanol production are not commercially available but research and pilot demonstrations are in planning or underway.[10]
- The synthesis gas is cleaned and its chemical composition is adjusted to produce a gas consisting purely of hydrogen (H_2) and carbon monoxide (CO) in a molar ratio of 2:1. The specific equipment configuration in the second step in methanol production will vary depending on the gasifier **used, A reactor common to all systems is a “shift”; reactor** used to achieve the desired 2:1 ratio of H_2 to CO by reacting steam with the synthesis gas. **The** shift reactor is a commercially established technology.
- **The** gas is compressed and passed through a pressurized catalytic reactor that converts the CO and H_2 into liquid methanol. A variety of commercial processes can be used.

Tests of methanol’s potential to reduce air pollution have yielded mixed results.[11] Potential greenhouse gas benefits of methanol depend on the feedstock: renewably produced biomass feedstocks would make little or no net contribution to greenhouse gas emissions; fossil fuel feedstocks would increase them for coal and decrease them for natural gas. Methanol does have some environmental disadvantages, particularly greater emissions of formaldehyde, which could require special emission controls. Today’s production vehicles, however, are certified as meeting California’s formaldehyde emissions standards.[12]

10&3@ **A.A.C.M. Beenackers and W.P.M. van Swaaij, “The Biomass to Synthesis** *Gas* **Pilot Plant Programme of the CEC: A First Evaluation of Results,”** *Energy from Biomass, 3rd EC Conference* **(Essex, United Kingdom: Elsevier Applied Science, 1985), pp. 120-45; E. C), Larson, P. Svenningsson, and L Bjerle, “Biomass Gasification for Gas Turbine Power Generation,”** *Electricity: Efficient End-Use and New Generation* **Technologies,** *and their Planning Implications* **(Lund, Sweden: Lund University Press, 1989), pp.** *697-739;* **R.J. Evans, R.A. Knight, et al.,** *Development of Biomass Gasification to Produce Substitute Fuels,* **PNL-6518 (Richland, WA: Battelle Pacific Northwest Laboratory, 1988); Chem Systems, “Assessment of Cost of Production of Methanol from Biomass,” draft (Golden, CO: Solar Energy Research Institute, December 1989).**

11 U.S. Congress, Office of Technology Assessment, Replacing Gasoline, OTA-E-364 (Washington, DC: U.S. Govemment Printing Office, September *1990).*

12 Roberta Nichols, Ford Motor Company, J) **rsonal communication, Sept. 1, 1993.**

dues would be about 25 GJ/tp. Combined, these energy resources total some 41 GJ/tp.[12]

Most kraft pulp mills current] y use black liquor for cogenerating steam and electricity onsite. High-efficiency steam-injected gas turbines, combined cycles, or other high-performance generation technologies might be able to generate as much as 4000 kWh of electricity per ton of pulp produced if all of the hog fuel, black liquor, and recoverable forest residues were used. After meeting onsite needs,[13] this would leave a substantial amount of power—worth nearly half the value of the pulp-that could be sold to the grid.[14]

12 Eric D. Larson, “Prospects for Biomass-Gasifier Gas Turbine Cogeneration in the Forest Products Industry: A Scoping Study,” Center for Energy and Environmental Studies Working Paper No. 113, (Princeton, NJ: Princeton University, February 1990).

13 Onsite needs today are typically about 740 kWh/tp of electricity plus some 4,300 kg/tp Of Steam, with the potential for significant reductions.

14 Assuming $0.07/kWh. See: Eric D. Larson, “Biomass-Gasifier/Gas-Turbine Applications in the Pulp and Paper Industry: An Initial Strategy for Reducing Electric Utility CO_2 Emissions,” Conference on Biomass For Utility Applications, Electric Power Research Institute, Tampa, FL, Oct. 23–25, 1990; Eric D. Larson, “Prospects for Biomass-Gasifier Gas Turbine Cogeneration in the Forest Products Industry: A Scoping Study,” Center for Energy and Environmental Studies Working Paper No. 113, (Princeton, NJ: Princeton University, February 1990).

The Residential Sector

The residential/commercial sector accounts for about one-fifth of total primary energy use, with electricity and natural gas the primary fuels used. Wood fills roughly 10 percent of the space heating requirements, or roughly 5 percent of the total energy used in the residential sector.[15] Prospects for substantially increasing wood use in this sector are not promising because of the relatively high level of emissions generated by small household wood stoves, and the difficult and expensive logistics of delivering wood fuels to highly dispersed small users.

Impacts of U.S. Energy Demand Patterns and Bioenergy

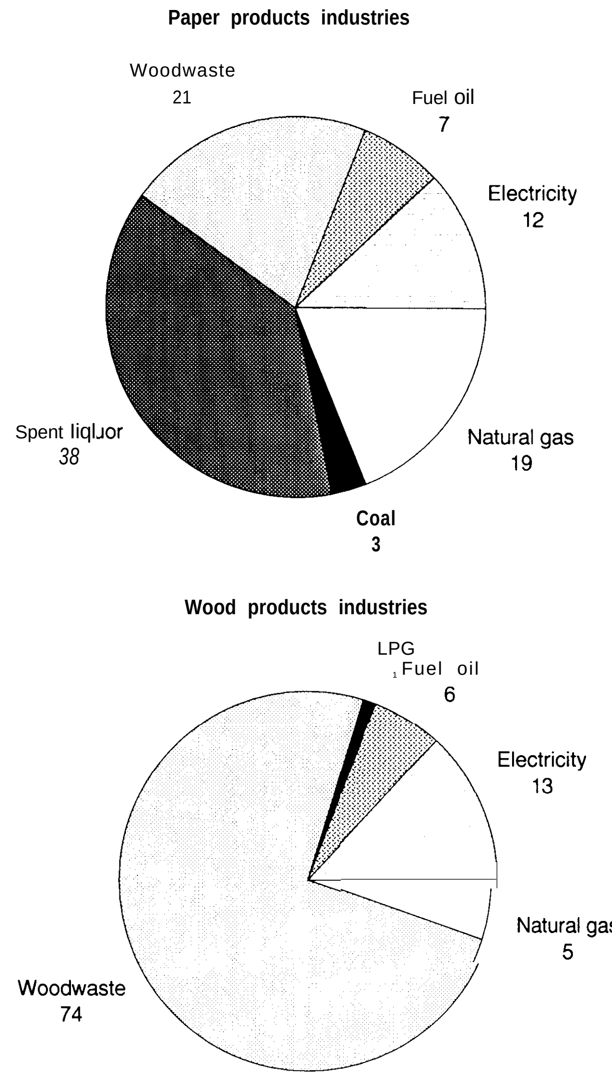
Current U.S. energy demand patterns affect the economy, national security, and the environment (see ch. 3). Bioenergy could reduce these impacts, but by itself cannot eliminate them. Its relative value in meeting these needs will have to be compared with other potential uses for the land, alternative fuels and technologies, and other approaches.

U.S. expenditures on foreign oil are currently running about $50 billion per year and are destined to increase sharply as U.S. oil production continues its decline. Several U.S. electric utilities are also now importing low sulfur coal.[16]

The economic impacts of these imports are hard to assess as they depend on: the manner in which these petrodollars are recycled back into the U.S. economy; changes in the terms of trade; employment in U.S. export industries; and other factors.[17] These economic impacts are also spread unevenly within the United States.

The ready availability of cost-effective and high-performance alternative fuels and technolo-

Figure 2-4-Energy Sources Used by the Wood and Paper Products industries



This figure shows the extensive use of biomass fuels—woodwaste and spent liquor—in the wood and paper products industries. Of total end-use energy consumed, 60 to 75 percent is provided by biomass.
SOURCE: Energy Information Administration, *Estimates of U.S. Biofue/s Consumption 1989,* U.S. Department of Energy, April 1991.

[15] U.S. Department of Energy, Energy Information Administration, "Estimates of U.S. Biofuels Consumption 1989," Report No. SR/CNEAR-91-02, Washington, DC, April 1991.

[16] Jane Turnbull, Electric power Research Institute, personal communication, Sept. 1, 1993.

[17] H.G. Broadman, "The Social Cost of Imported Oil," *Energy Policy, vol. 14, 1986,* pp. *242–52;* H.G. Broadman and W.W. Hogan, "IS An Oil Tariff Justified? An American Debate: The Numbers Say Yes," *Energy Journal, vol. 9, No. 3, 1988,* pp. *7–29;* M. Ethridge, "The Social Costs of Incremental Oil Imports: A Survey and Critique of Present Estimates," Discussion Paper #25, American Petroleum Institute, Washington, DC, February 1982; Daniel Sperling and Mark A. DeLuchi, "Transportation Energy Futures," *Annual Review @Energy,* vol. 14, 1989, pp. 375-424.

gies could help reduce oil price volatility, oil price increases, and oil import costs. In addition, they would reduce the uncertainty and risk associated with price volatility and thus might help reduce the corresponding distortion of investment decisions toward the short term. Fuels derived from biomass feedstocks might provide some of these alternatives.

Reliance on imported oil also poses national security risks. These can be quickly enumerated but defy quantification. Such risks include: future involvement in Middle East or other conflicts; possible pressure on U.S. alliances; economic impacts due to a sudden oil curtailment; and many others. The likelihood and severity of these impacts will depend on the extent to which potential anti-Western factions might gain control of key oil-exporting countries and exercise this power, the discovery and development of oil resources outside the Middle East, improvements in secondary oil recovery from existing fields, and the development of alternative transport fuels and technologies.[18]

THE RURAL ECONOMY AND BIOENERGY[19]

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's 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. Roughly half of the ship-loading grain terminals in the United States are reportedly closed, about to close, or for sale.[20] Due to these pressures, there is a growing need to find alternative crops for rural agricultural communities: to provide employment, to stabilize rural incomes, and to maintain the rural infrastructure of equipment and supplies distribution and service. Bioenergy crops might serve such a role if mechanisms can be found to overcome a variety of market and institutional obstacles to their use.

The rural economy faces several trends; bioenergy may be able to moderate some of their impacts. Demand for conventional agricultural products is likely to grow slowly: U.S. population growth is low[21] and the U.S. consumer is reasonably well fed. At the same time, foreign demand is uncertain.[22] It may be met in the future by new export powerhouses, particularly eastern Europe and the former Soviet Union, Latin America, and elsewhere.[23] Efforts in those regions will be strongly aided by adoption of the modem agricultural techniques and crop varieties pioneered by the United States; thus, U.S. farmers are not

18 U.S. Congress, Office of Technology Assessment, *U.S. Vulnerability to an Oil Import Curtailment: The Oil Replacement Capability,* OTA-E-243 (Washington, DC: U.S. Government Printing Office, September 1984); U.S. Congress, Office of Technology Assessment, *U.S. Vulnerability to an Oil Import Curtailment: The Technical Replacement Capability,* OTA-E-503 (Washington, DC: U.S. Government Printing Office, October 1991).

19 For broader reviews of the economic impacts of bioenergy crops, see Southeastern Regional Biomass Energy Program, Tennessee Valley Authority and Meridian Corporation, "Economic Impact of Industrial Wood Energy Use in the Southeast Region of the U.S.," four volumes, Muscle Shoals, AL, and Alexandria, VA, November 1990; J.W. Onstad, M.S. Lambrides, B.S. McKenna, "Analysis of the Financial and Investment Requirements for the Scale-Up of Biomass Energy Crops," National Renewable Energy Laboratory and Meridian Corporation, 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. 6-11; Meridian Corporation 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, B.C. English, R.R. Alexander, M.G. Bhat, "Biomass Fuel Costs Predicted for East Tennessee Power Plant," *Biologue, vol. 10, No. 3,* September/December 1992, pp. 23–29; "Electricity from Biomass: A Development Strategy," Solar Thermal and Biomass Power Division, Office of Solar Energy Conversion, U.S. Department of Energy, DOIYCH1OO93-152, April 1992.

20 Scott Kilman, "U.S. 1, Steadily Losing Share of World Trade in Grain and soy beans," *Wall Street Journal,* Dec. 3, 1992, p. Al.

21 U.S. population growth is one of the highest of the industrial countries, however.

22 In the longer term, Population growth in developing countries may surpass agricultural productivity growth and increase 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.

23 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.

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 will be an inevitable result of the need to maintain some competitive advantage, and will require increased use of modem chemistry, biology, computer, and telecommunication technologies, creating a production unit with sophisticated stocks and flows of goods and services.[24]

Environmental considerations are likely to 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 toward private and marginal lands. At the same time, increasing attention to environmental issues on private lands 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 policies to make the transition to energy crops without injuring the farm sector or exposing it to undue risk. It will also depend on the relative value of other uses of this land and the costs and benefits of other fuels and technologies.

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 under increased scrutiny for savings. Currently, Federal programs to prevent soil erosion (see box 2-B) and various commodity support programs to strengthen crop prices together cost roughly $10

Box 2-B-Conservation Compliance Programs

Conservation compliance was enacted under the 1985 Food Security Act, as amended in 1990, in which all farmers cultivating highly erodible land must fully implement an approved conservation plan by 1995 or risk losing certain farm benefit programs. At the same time, the Conservation Reserve Program (CRP) 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 are enrolled in CRP, with annual payments averaging roughly $110 per hectare. At the end of the contract, land that is highly erodible 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; any Farmers Home Administration loans that will contribute to erosion on highly erodible lands; and several other types of assistance.

Conservation compliance affects some 55 million hectares, 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 conflict with soil erosion concerns (see ch. 3).

For more information, see Jeffrey A. Zinn, "Conservation Compliance: Status and Issues," Congressional Research Service, 93-252 ENR, Feb. 24, 1993.

24 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); William E. Easterling, "Adapting United States Agriculture to Climate Change," contractor report prepared for the Office of Technology Assessment, February 1992.

billion per year. Bioenergy crops are a potential alternative cash crop that could protect fragile soils or could be grown on lands previously idled in order to strengthen commodity crop prices. Earnings from the energy crop might then allow Federal supports to be eased while maintaining farm income. Of course, the relative environmental benefits of energy crops versus current soil conservation programs such as the Conservation Reserve Program 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 also presents challenges.

BIOENERGY RESOURCES

Biofuels currently provide about 3 EJ, or 4 percent of U.S. primary energy. Some researchers estimate that biofuels have the potential to provide 15 EJ of energy annually by 2010 and perhaps 25 EJ by 2030.[25] Recent detailed econometric studies estimate that the agricultural sector could support the production of roughly 10 EJ of delivered ethanol from cellulosic biomass (not from grain, sugar cane, etc.) by the year 2030 with net benefits to the agricultural economy.[26] Projections based on a business-as-usual estimate nonliquid biomass fuels will provide 4-8 EJ in 2030.[27] These projections will not be critiqued here. Instead, the focus of this report is to examine the environmental implications if such large land areas are converted to energy crops.

Three sets of biomass resources could be used: municipal solid wastes (MSW); agricultural and forestry residues; and bioenergy crops. Each of these resources has unique characteristics and considerations, and differing quantities of material available at a particular price.

Municipal Solid Wastes

Generation of heat or electricity from MSW can be technically difficult under some circumstances due to the variety of materials handled and the need to control emissions of the numerous toxic trace materials found in MSW. Nevertheless, more than 70 waste-to-energy plants are in operation or under construction and roughly 50 are in an advanced stage of planning. By one estimate, U.S. MSW could provide the energy equivalent of more than 10 GW on a continuous basis.[28] Recycling, the slow economy, and other factors, however, have reduced the availability of MSW for some incinerators, increasing costs above those originally projected.[29] In other areas, landfills are filling rapidly yet new sites are controversial, making the prospects for use of MSW brighter.[30] MSW is not considered further in this report.

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25 J. W. Ranney and J.H. Cushman, "Energy from Biomass," Ruth Howes and Anthony Fainberg (eds.), *The Energy Sourcebook: A Guide to Technology, Resources, and Policy,* (New York, NY: American Institute of Physics, 1991); another set of estimates is given in Solar Energy Research Institute et al., *The Potential of Renewable Energy: An Interlaboratory White Paper, SERUTP-260-3674,* March 1990 (now known as the National Renewable Energy Laboratory).

26 Randall A. Reese, Satheesh V. Aradhyula, Jason F. Shogren, and K. Shaine Tyson, "Herbaceous Biomass Feedstock Production: The Economic Potential and Impacts on U.S. Agriculture," *Energy Policy,* July 1993, pp. 726-734,

27 Resource Modeling and Technology Economics Group, "Projections of Wood Energy Use In the United States" (Oak Ridge, TN: Oak Ridge National Laboratory, July 2, 1990, draft).

28 R.E. Barrett et al., "Municipal Waste-To-Energy Technology Assessment," EPRI TR-1OOO58 (Palo Alto, CA: Electric Power Research Institute, January 1992).

29 Jeff Bailey, "Fading Garbage Crisis Leaves Incinerators Competing for Trash," *Wall Street Journal,* Aug. 11, 1993, p. A1; and Jeff Bailey, "Poor Economics and Trash Shortage Force Incineration Industry Changes," *Wall Street Journal,* Aug. 11, 1993, p. A2.

30 See, for example, U.S. Congress, Office of Technology Assessment, *Facing America's Trash: What Next for Municipal Solid Waste?* OTA-O-424 (Washington, DC: U.S. Government Printing Office, October 1989); R.E. Barrett et al., "Municipal Waste-To-Energy Technology Assessment," EPR1 TR-1OOO58 (Palo Alto, CA: Electric Power Research Institute, January 1992); D. Longwell et al., "Waste-to-Energy Permitting Sourcebook," EPRI TR-1OO7I6 (Palo Alto, CA: Electric Power Research Institute, October 1992); Marjorie J. Clarke, Maarten de Kadt, and David Saphire, "Burning Garbage in the U. S.: Practice vs. State of the Art" (New York, NY: INFORM, Inc., 1991).

Agricultural and Forestry Residues

As with MSW, agricultural and forestry residues can often be obtained at low or no cost: they may have already been trucked to a central processing site such as a sugar mill or sawmill and are available in large quantities. Burning them onsite usually costs less than hauling them away for disposal. More of this resource might be collected and used for energy production,[31] and more efficient energy conversion systems could be used. Residues are an important part of the forest ecosystem, however, and must be carefully guarded from overuse or misuse (see chapter 3).[32]

Energy Crops

Energy crops can be divided into three broad categories: annual row crops such as corn, herbaceous perennial grasses (herbaceous energy crops—HECs) such as switchgrass, and short-rotation woody crops (SRWCs) such as poplar.

Annual row (energy) crops are grown in essentially the same manner as their food crop counterparts and consequently offer few or no environmental benefits over conventional agricultural practices. Because of this, annual row crops are not examined further in this report.

Crops (often annual row crops) have also been used to produce starches, sugars, oils, and other specialty plant products as energy feedstocks. On a national basis, however, their energy production potential is much lower and their costs higher than for cellulosic bioenergy crops (HECs and SRWCs). Consequently, they are not considered further in this report either.

HECs are analogous to growing hay, harvesting the crop instead for energy. SRWCs typically consist of plantations of closely spaced (2 to 3 meters apart on a grid) trees that are harvested on a cycle of 3–10 years. Following harvest, HECs regrow from the remaining stubble and SRWCs regrow from the remaining stumps. Such harvests may continue for 15 to 20 years or more without replanting (fertilizer and other inputs, and maintenance may be required annually, however).

These crops can be planted in a variety of configurations with each other and with agricultural crops to maximize their economic and environmental benefits. Five key variables govern the viability of woody and herbaceous energy crops: technical feasibility; availability of suitable land; economic viability; implementation; and environmental impacts. The first three are described briefly below and implementation issues are described briefly in ch. 4. The potential environmental impacts are examined in detail in ch. 3.

Technical Feasibility

Research and development on plant species and methods of planting have greatly enhanced the technical feasibility of energy cropping. One of the most important technical characteristics of energy crops is their ability to perform well in varying environments. Some energy crops, such as switchgrass and sweetgum, are no more site-specific than a conventional agricultural crop such as corn. Others can be extremely site-specific if very high yields are to be realized. In some cases, species that respond well under research conditions may not do well under actual site conditions during operational trials.[33]

31 It may also be possible to increase forest productivity, allowing additional biomass to be extracted, For example, modest applications of nitrogen and phosphorus increased incremental growth severalfold in Scandinavian forests. See, for example, Sune Linder, "The Relationship Between Nutrition and Biomass Production in Swedish Coniferous Stands," Department of Ecology and Environmental Research, Swedish University of Agricultural Sciences, Uppsala, Sweden, no date.

32 More intensive use of forests for energy may be controversial, however, and use of public lands for biomass energy supply could be strongly opposed by the environmental community. James H. Cook, National Audubon Society, personal communication, Aug. 26, 1993.

33 A number of factors contribute to this change in response. The new site may be substantially different than the test plot, and conditions may vary across the site itself. These include differences with respect to soil quality, the availability of nutrients and moisture, the presence of weed competitors or of pests and disease, and others. This ha.. implications for the selection of plants, the management of stands, the areas planted, and the regional distribution of plantings. Jack Ranney, Oak Ridge National Laboratory, personal communication, Sept. 1, 1993.

Other desirable characteristics of cellulosic energy crops include fast growth; efficient use of nutrients and water; high density (of wood—high heat value per unit of volume); robustness (ability to withstand weather, pests, and disease); nitrogen-fixing capability (a trait that reduces the need for fertilizer); and good potential for regrowth from stubble (HECs) or stumps (SRWCs). Since the 1970s the USDOE and USDA Forest Service have supported research and development of SRWCs that incorporate most of these features.[34]

Bioengineering eventually may further improve energy crops, such as by increasing productivity or reducing vulnerability to pests and environmental stress. Desirable characteristics, such as nitrogen fixation and fast growth,also may be enhanced through bioengineering. Bioengineering technologies that have proven successful in some cases are cloning and hybridization.[35] For example, USDOE supported research has produced hybrid black cottonwoods that have yields that exceed those of the parent stock by a factor of 1.5 to 2.[36] Genetic engineering of trees is a relatively new field compared with agricultural biotechnology. Technology transfer from agriculture will speed SRWCs genetic engineering, but only to a point; trees and shrubs have unique characteristics, including long generation times. Nonetheless, the potential to increase yields through biotechnology is enormous—according to one researcher, even more significant than the successes already achieved in agricultural genetic engineering.[37]

Suitable trials and controls, however, will be needed to ensure that these engineered cultivars do not injure people, animals, or plants directly or injure them indirectly by becoming a weed to agriculture or more invasive of natural habitats than unmodified cultivars. They must also not transfer their genes (e.g., via pollination) to wild relatives whose offspring might become more injurious, weedy, or invasive. Current USDA guidelines require evidence[38] that transgenic crops pose no greater risk to the environment than unmodified plants from which they were derived.[39]

Availability of Suitable Land

To be reliable and substantial sources of energy, energy crops will require significant amounts of land.[40] Estimates of the area available for growing energy crops in the United States vary widely, depending on the underlying assumptions about the types of land to be considered, possible alternative uses for the land, the likely demand for food or other exports, the projected increases in agricultural productivity, economic constraints, environmental constraints, the time frame considered, and many others. Estimated areas potentially available for energy cropping range from roughly 15 to 100 million hectares.[41] At yields

34 David Dawson, Forest Policy Consultant, personal communication, Aug. 18, 1993.

35 Edwin H. White et al., "Bioenergy Plantations in Northeastern North America," paper presented at the Conference Energy from Biomass and Wastes XV, Washington, DC, Mar. 25, 1991, p. 10.

36 Philip A. Abelson, "Improved Yields of Biomass," *Science, vol. 252, No. 5012,* June 14, 1991, p. 1469.

37 Edward A. Hansen, "SRIC Yields: A Look to the Future," *Biomass and Bioenergy,* vol. 1, 1991.

38 There is debate about *how* good the evidence is or should be.

39 Peter Kareiva, "Transgenic Plants on Trial," *Nature, VOL 363,* June 17, 1993, pp. *580-581;* M.J. Crawley et al., "Ecology of Transgenic Oilseed Rape in Natural Habitats," *Nature,* vol. 363, June 17, 1993, pp. 620423.

40 J Warren Ranney et al., "Hardwood *Energy* Crops: The Technology of Intensive Culture," *Journal of Forestry,* vol. 85, pp. 17–28.

41 K.K. Shaine Tyson, "Biomass Resource Potential of the United States," National Renewable Energy Laboratory, October 1990, draft; James L. Easterly, "Overview of Biomass and Waste Fuel Resources," Strategic Benefits of Biomass and Waste Fuels Conference, Washington, DC, Mar. 30, 1993; W. Fulkerson et al., "Energy Technology R&D: What Could Make a Difference? Volume 2, Supply Technology," ORNL-6541/V2/P2 (Oak Ridge, TN: Oak Ridge National Laboratory, December 1989); D.O. Hail, H.E. Mynick, and R.H. Williams, "Alternative Roles for Biomass in Coping with Greenhouse Warming," *Science and Global Security, vol. 2,1991,* pp. 113-151; James H. Cook, Jan Beyea, Kathleen H. Keeler, "Potential Impacts of Biomass Production in the United States on Biological Diversity," *Annual Review of Energy and Environment, vol. 16,* pp. 401-431, 1991; Thomas B. Johansson, Henry Kelly, Amulya K.N. Reddy, Robert H. Williams (eds.), *Renewable Energy: Sources for Fuels and Electricity* (Washington, DC: Island Press, 1993).

of 15–20 tonnes/ha, roughly 8 EJ or 10 percent of current U.S. energy demand could be produced on 30 million ha. Some studies estimate the total bioenergy potential as 15 EJ annually by 2010 and perhaps 25 EJ by 2030.@ Recent econometric studies estimate that the agricultural sector could support the production of roughly 10 EJ of delivered ethanol from cellulosic biomass (not from grain, sugar cane, etc.) by the year 2030 with net benefits to the agricultural economy.[43] Projections based on business-as-usual estimate nonliquid biomass fuels will provide 4-8 EJ in 2030.[44]

These estimates of perhaps 8–25 EJ of bioenergy are roughly 10-30 percent of current U.S. energy use of 85 EJ-of which roughly 20 EJ each is for coal in the power sector and for oil in the transport sector. Thus, bioenergy crops can potentially contribute a significant fraction of U.S. energy needs.

To the extent that large areas of land are cultivated for energy crops, however, concerns are raised about the potential environmental impacts on soil quality and erosion, water use, agricultural chemical use, and habitat. These are explored in the following chapter.

Economic viability

Overall, agricultural residues and wood wastes are available in limited supplies for roughly $0.50-$1.50/GJ.[45] Gathering additional residues would raise these costs. The best energy crop sites can now produce perhaps 15-20 tonnes/year at costs in the range of $2 to $4 per GJ.[46] Conversion of these biomass feedstocks to useful fuels raises these costs. In comparison, crude oil at $20 per barrel is equivalent to $3.30/GJ; coal at the current price to electric utilities of roughly $30/ton is equivalent to roughly $1 .50/GJ.[47]

Even if they are not strictly cost effective compared with fossil fuels, energy crops may still be desirable if other benefits-such as environmental advantages, offsets of oil imports, or financial returns to the rural economy—justify the costs.

CLOSE

Concern over the environmental impacts of fossil fuel use, the rural economy, oil import bills and national security, Federal budget deficits, and other factors have prompted many to take a second look at biomass as an energy resource. Although some initially proposed that biomass be used to store (sequester) carbon released by the burning of fossil fuels; more recently many groups have explored the potential of biomass to substitute for fossil fuels.[48] Technological advances in biomass growth, harvesting, transport, and combustion are lowering costs to where plantation-grown biomass

42 J.W. Ranney and J.H. Cushman, "Energy from Biomass," Ruth Howes and Anthony Fainberg (eds.), *The Energy Sourcebook: A Guide to Technology, Resources, and Policy, (New* York, NY: American Institute of Physics, 1991). Another set of estimates is given in Solar Energy Research Institute et al., *The Potential of Renewable Energy: An Interlaboratory White Paper, SERlJTP-260-3674,* March 1990; see also the references listed in footnote no. 43.

43 Randall A. Reese, Satheesh V. Aradhyula, Jason F. Shogren, and K. Shaine Tyson, "Herbaceous Biomass Feedstock Production: The Economic Potential and Impacts on U.S. Agriculture," *Energy Policy,* July 1993, pp. 726-734.

44 Resource Modeling and Technology Economics Group, "Projections of Wood Energy Use In the United States" (Oak Ridge, ‘N: Oak Ridge National Laboratory, July 2, 1990, draft).

45 U.S. Department of Energy, "Electricity from Biomass: A Development Strategy," DOE/CH10093-152, April 1992.

46 J.W. Ranney and J.H. Cushman, "Energy From Biomass," Ruth Howes and Anthony Fainberg (eds.), *The Energy Sourcebook: A Guide to Technology, Resources, and Policy (New* York, NY: American Institute of Physics, 1991); U.S. Department of Energy, "Electricity from Biomass: A Development Strategy," DOE/CH10093-152, April 1992.

47 U.S. Department of Energy, Energy Information Administration, *Annual Energy* Review *1992,* DOE/EIA-0384(92), June 1993.

48 See, for example: Solar Energy Research Institute et al., *The Potential of Renewable Energy: An Interlaboratory White paper, SERVTP-260-3674,* March 1990; Office of Conservation and Renewable Energy, U.S. Department of Energy, *Renewable Energy Technology Evolution Rationales,* draft, Oct. 5, 1990; U.S. Environmental Protection Agency, *Renewable Electric Generation: An Assessment of Air Pollution Prevention Potential, EPA/400/R-92/005,* March 1992; Thomas B. Johansson, Henry Kelly, Amulya K.N. Reddy, Robert H. Williams (eds.), *Renewable Energy: Sources for Fuels and Electricity* (Washington, DC: Island Press, 1993).

may soon be competitive. As the potential scale of use of biomass energy has become apparent, however, environmental concerns have been raised and have begun to be addressed through several efforts.[49] The potential environmental impacts of large-scale bioenergy production is the primary focus of the following chapter.

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49 This includes "Toward biological Guidelines for Large-Scale Biomass Energy Development," Report of a Workshop Convened by the National Audubon Society and Princeton University, May 6, 1991; and the National Biofuels Roundtable, convened by the Electric Power Research Institute and the National Audubon Society.