Chapter 2

INTRODUCTION

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In recent years, rapidly rising fuel prices, depleting domestic oil and gas reserves, the deficit in the U.S. balance of trade, and the possibility of political interruption of oil supplies have led to a search for less expensive, more reliable domestic energy sources. In addition, a number of factors, such **as uncertain energy** demand growth, soaring construction costs, difficulty in plant siting, and the environmental problems associated with coal, have led some energy producers and consumers to question the appropriateness of the large centralized energy systems that have been developed over the last 30 years.

All these concerns have focused attention on energy from biological processes, or biomass—primarily energy uses of plant material and of municipal, industrial, and animal wastes. Biomass represents a renewable domestic source of liquid and solid fuels that can be used in relatively small decentralized energy systems. In addition, if biomass resources and conversion processes are managed properly, they have a much lower potential for environmental damage than coal and coal-based synfuels.

This report analyzes the potential of biological processes as a renewable domestic source of solid, liquid, and gaseous fuels and chemical feedstocks. The report assesses the bioenergy resource base, conversion technologies, and end uses; analyzes the environmental and social impacts that could accompany the widespread use of bioenergy; and identifies policy options that would promote commercialization and proper resource management. I n addition, the report highlights research and development needs and bioenergy's potential for displacing premium fuels.

Because of the large number of biomass fuel cycles (one recent study identifies more than 1,000 such cycles), not all of them could be analyzed in this report. Rather, a detailed analysis is presented of four fuel cycles that are likely to contribute significant amounts of energy within the next 20 years, will contribute to energy self-sufficiency within a particular economic sector, or will provide a source of liquid fuels. These four fuel cycles are: 1) wood for gasification, alcohol fuels production, and direct combustion; *2)* grain and sugar crops for alcohol fuels production; *3)* grass and legume herbage and crop residues for combustion or alcohol fuels production; and 4) animal manure for anaerobic digestion (biogas). (A fifth fuel that could contribute substantial amounts of energy — municipal solid waste— is analyzed in another OTA report and is not discussed here.)

Volume I of this report is organized as follows:

- chapter 3 highlights the central issues surrounding bioenergy and summarizes OTA's findings on those issues;
- chapter 4 presents an overview of the four fuel cycles, including their technical features, economics, environmental impacts, and social implications, and their potential to displace conventional fuels; and
- chapter 5 analyzes policy options that would encourage the introduction of the four fuel cycles into U.S. energy supplies.

Contents of Volume II

Volume II presents a detailed analysis of the technical features of the four fuel cycles as well as other forms of bioenergy; these include the resource base, conversion technologies, and end use. The subjects covered in volume II include:

Resource Base

- **Forestry:** estimates of the standing timber inventory, current harvests, potential growth, harvesting costs, factors affecting wood availability, practical energy potential, environmental impacts, and research, development, and demonstration (RD&D) needs.
- **Agriculture:** estimates of plant growth and crop yields, cropland availability, current

farming practices and yields, energy potential including crop switching, crop residues, environmental impacts, and RD&D needs.

- **Unconventional biomass approaches:** discussions of genetics, crop yields, unconventional land-based crops (lignocellulose, starch and sugar, and oil and hydrocarbon crops), aquiculture (freshwater plants), mariculture (ocean water crops), and other unconventional approaches including multiple cropping, chemical inoculation, energy farms, biophotolysis, inducing nitrogen fixation in plants, and greenhouse cultivation.
- **Biomass wastes:** analyses of the byproducts of biomass processing that are suitable for energy, including forest products industry byproducts, agricultural product processing wastes, and manure.

Conversion Technologies and End Use

- **Thermochemical conversion:** discussions of general aspects, reactor types, optimum size, biomass densification, direct combustion, gasification, liquid fuels synthesis (including methanol, pyrolytic oil, and ethanol), environmental impacts, and RD&D needs.
- **Fermentation:** analysis of ethanol from starch and sugar crops including energy use, process byproducts, costs, and onfarm distillation; discussion of cellulosic feedstocks including general aspects, processes under development, and plausible future costs; environmental impacts; and process innovations.
- **Anaerobic digestion:** analysis of general aspects, reactor types, costs, environmental impacts, and RD&D needs.
- **Use of alcohol fuels:** discussion of spark ignition engines using gasohol, straight ethanol, methanol-gasoline blends, and straight methanol; diesel engines; gas turbines; and environmental impacts.
- **Energy balances for alcohol fuels:** analysis of energy use in producing ethanol from grains and sugar crops, methanol from wood and plant herbage, and general considerations.
- **Chemicals from biomass:** a brief description of various possibilities for chemicals synthesized by plants and chemical synthesis from wood and plant herbage.

Throughout this report, an effort was made to use consistent units of measure but this was not always possible. Consequently, table 1 presents the conversion factors between various common units of measure. It should be kept in mind that in some cases the conversion is only approximate because no exact equivalence exists (e. g., between cubic feet and dry tons of wood).

Table 1.—Select Conversion Factors

Wood	
1 cord wood	= 1 dry ton
1 green ton (50% moisture)	= 0.5 dry ton (50% moisture)[a]
1 dry ton (50% moisture)	= 16 million Btu
1 dry ton (0% moisture)	= 18 million Btu
1 ft^3 wood	= 34 dry lb (solid)
	= 11 dry lb (chips)
Grass	
1 dry ton grass	= 13 million Btu
Grain and sugar	
1 bu corn	= 56 lb
1 bu wheat	= 60 lb
1 bu barley	= 40 lb
1 bu oats	= 32 lb
1 bu grain sorghum	= 56 lb
1 ton (fresh) sugarcane	= 0.1 ton sugar
Ethanol	
1 ton sugar	yields 137 gal ethanol
1 ton grain	yields 93 gal ethanol
1 ton wood	yields 70-120 gal ethanol (estimated)
1 ton grass	yields 70-120 gal ethanol (estimated)
1 gal ethanol	= 84,300 Btu (higher heat)
	= 76,200 Btu (lower heat)
Methanol	
1 ton wood	yields 120 gal methanol
1 ton grass	yields 100 gal methanol (estimated)
1 gal methanol	– 63,500 Btu (higher heat)
	= 55,700 Btu (lower heat)
oil	
1 gal gasoline	= 125,000 Btu (higher heat)
	= 117,000 Btu (lower heat)
1 bbl crude oil	= 5.9 million Btu
Energy	
1 million Btu	= 1 million Btu
1 Btu	= 1,055 joule
1 watt	= 1 joule/see
1 kWh	= 3.6 million joules
1 kWh	= about 10,000 Btu (net heat input, no cogeneration)
1 kWh	= about 3,500 Btu (heat input with cogeneration)
1 Quad/yr	= 464,000 bbl/d of oil
1 million bbl/d of oil	= 2.15 Quads/yr
Land use	
1,000 dry ton/d of wood (enough for 60-MWe generation) can be obtained as a steady Yield from	180,000-360,000 acres of average forest land as now managed
	90,000-180,000 acres of more intensively managed average forest land

A net premium fuel displacement of 1,000 gal/yr of gasoline can be achieved from	'About 1.4 acres of new cropland put into production with corn, distillery fueled with coal, byproducts used fully to replace soybean production and increase corn production further, and ethanol used as octane-boosting additive to gasoline[b]
	About 2.7 acres grown in grass converted to methanol or ethanol used as an octane-boosting additive to gasoline
	About 3.3 acres of new cropland grown with corn, distillery fueled with coal, byproducts used fully to replace soybean production and increase corn product ion further, ethanol used as standalone fuel.
	About 6.4 acres grown in grass converted to methanol or ethanol used as standalone fuel
	About 7.4 acres grown with corn, distillery fueled with coal, no byproduct utilization, ethanol used as octane-boosting additive to gasoline.
	About 25 acres grown with corn distillery fueled with coal, no byproduct utilization, ethanol used as standalone fuel.
	About 330 acres in grain sorghum, distillery fueled with coal, ethanol used as standalone fuel.
	Infinite acres grown in corn or other grain if oil used as distillery boiler fuel and ethanol used as standalone fuel.
Photosynthetic efficiency	
Average U.S. forest as now managed	0.07 to 0.1 50/0
Average U.S. forest under intensive management	0.15 to 0.370
Average U.S. corn (108 bu/acre, 1979)	0.9°/0 during growing season 0.5% averaged over entire year
Record corn yield in United States (340 bu/acre)	3.0% during growing season 1.5% averaged over entire year
Other solar efficiencies	
Array of photovoltaic cells	10 to 12%
Flat plate collector	30 to 40%

[a] Dry ton refers to the weight of wood (less the moisture). Thus, 1 dry ton (50% moisture) contains 1 ton of wood plus 1 ton of water thereby weighing 2 tons One green ton (50% moisture) weighs 1 ton

[b] Th. energy savings at th. refinery attributed t. ethanol's octane.boosting ability is an Important variable in this calculation OTA estimates. based on the available evidence. that the energy equivalent of O 4 gal of gasoline can be saved for each gallon of ethanol used as an octane. boosting additive If the actual savings are less than this, then the acreages required to save 1 000 gal/yr of gaoline will Increase See box D for a discussion of the uncertainty associated with the estimate of the energy saving

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