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Estimates of U.S. Biomass Energy Consumption 1992

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Preface

This report is the seventh in a series of publications developed by the Energy Information Administration (EIA) to quantify the biomass-derived primary energy used by the U.S. economy. It presents estimates of 1991 and 1992 consumption. The objective of this report is to provide updated estimates of biomass energy consumption for use by Congress, Federal and State agencies, biomass producers and end-use sectors, and the public at large.

For additional data on biomass energy consumption, refer to the EIA publications, *Annual Energy Review 1992* (DOE/EIA-0384(92), June 1993) and *Annual Energy Outlook 1994* (DOE/EIA-0383(94), January 1994), which present summary biomass energy data within the context of a total energy profile.

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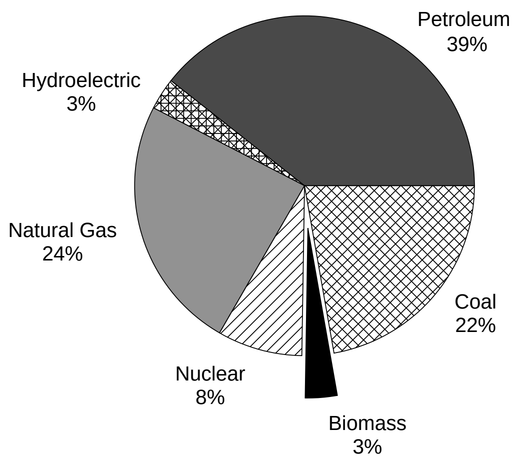
In 1992, an estimated 2,785 trillion British thermal units (Btu)[1] of biomass fuels (wood, waste, and alcohol fuels) were consumed in the United States, representing about 3 percent of total U.S. energy consumption.[2] In comparison, nuclear electric power contributed approximately 8 percent to total energy consumption in 1992 (Figure H1).

Figure H1. U.S. Consumption of Energy by Source, 1992



Note: Since biomass energy consumption is excluded from total energy consumption in the source listed below, percentages are based on the sum of total energy consumption (82,360 trillion Btu) in 1992 plus total biomass energy consumption (2,785 trillion Btu) in 1992.

Sources: Energy Information Administration, *Annual Energy Review 1992*, DOE/EIA-0384(92) (Washington, DC, June 1993), p. 9; and Office of Coal, Nuclear, Electric and Alternate Fuels.

During 1992, energy produced from wood accounted for 81 percent of total biomass energy consumption, while energy produced from solid waste and ethyl alcohol (ethanol) made up 16 percent and 3 percent of the total, respectively (Table H1). Most of the consumption in 1992 occurred in the South (49 percent), while the West consumed 21 percent, and the Northeast and Midwest each consumed 15 percent of the total biomass energy consumed in the United States.

Over the next two decades, biomass energy consumption could increase significantly. The rate and magnitude of future growth will depend on several factors, including the following:

- Wood energy consumption in the industrial sector will be affected by a growth in the demand for domestically produced paper and wood products, the technologies used in the production of fiber and other products, the cost and availability of conventional energy sources, the level of imports, and environmental factors, including those that restrict logging and wood burning.

- Wood energy consumption in the residential sector will be influenced by the continued population migration from rural to urban areas, the availability of inexpensive woodfuel, environmental restrictions on the burning of wood, and the availability and relative cost of conventional fuels.

- Municipal solid waste (MSW) has considerable potential as an energy source. Policy decisions on siting, environmental control issues, recycling, and ash disposal will play a role in determining where and how much MSW will be used for energy.

In an analysis of the potential for biomass-derived energy, the Energy Information Administration (EIA) estimates that biomass consumption could increase from the current 2,785 trillion Btu to 4,770 trillion Btu in 2010, when its share of total energy consumption could be almost 5 percent.[3]

Energy from Wood

Total woodfuel consumption during 1992 is estimated at 2,249 trillion Btu. The industrial sector was the larg-

Table H1. U.S. Biomass Energy Consumption by Sector, Type, and Region, 1992
(Trillion Btu)

Region	Wood				Solid Waste	Alcohol	Grand Total	Share of Grand Total (Percent)
	Industrial	Residential	Utility	Subtotal				
Northeast	119	143	1	264	148	<1	**412**	15
South	1,027	206	0	1,234	128	13	**1,375**	49
Midwest	96	186	5	286	84	55	**425**	15
West	350	111	5	466	100	10	**576**	21
Total	**1,593**	**645**	**11**	**2,249**	**457**	**79**	**2,785**	**100**
Share of Wood Total (percent)	71	29	<1	100	--	--	**--**	--
Share of Grand Total (percent)	57	23	<1	81	16	3	**100**	--

Note: Totals may not equal sum of components due to independent rounding.
Source: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels.

est woodfuel consumer, accounting for almost 71 percent of the U.S. total. Within the industrial sector, the "Paper and Allied Products" industry accounted for the majority of woodfuel use (79 percent), mainly in the form of black liquor. The residential sector accounted for 29 percent, and the utility sector accounted for less than 1 percent of total woodfuel consumption. The largest proportion of woodfuel use occurred in the South (55 percent), and the Northeast consumed the least woodfuel (12 percent).

Continued growth in output from both the paper and lumber industries, escalation in the cost of waste disposal, and the trend toward more complete utilization of timber have contributed to the increase in woodfuel consumption. U.S. wood consumption, accounting for 81 percent (2,249 trillion Btu) of the total U.S. biomass energy consumption (2,785 trillion Btu) in 1992, is expected to maintain this proportion while rising to 3,864 trillion Btu in 2010.[4]

Energy from Solid Waste

Thermal energy can be recovered from many types of biomass waste. Biomass waste can be divided into two key categories—municipal solid waste (discarded or discharged by residential, commercial, and industrial waste generators) and manufacturing waste (processed or scrapped wastes originating from manufacturing, construction, and agricultural operations.) Although current technologies for converting waste into thermal energy have developed slowly, new conversion technologies continue to be tested.

In 1992, an estimated 457 trillion Btu of energy produced from solid waste was consumed in the United States, consisting of mass burning of municipal solid waste (68 percent), burning of manufacturing waste (17 percent), and landfill gas recovery (15 percent). The largest amount of energy produced from solid waste was consumed in the Northeast (32 percent); the smallest amount was consumed in the Midwest (18 percent).

Some waste-to-energy plants do not convert MSW to energy directly by combustion; instead it is converted to a value-added product called refuse-derived fuel (RDF). RDF can be stored, transported, and fed into combustion systems automatically, and it can be used as a primary fuel or co-fired with other fuels.

Energy from Alcohol

Alcohols, such as ethanol and methanol, can be produced from biomass feedstocks or fossil-based feedstocks, such as crude oil, natural gas, and coal, through various chemical conversion processes. Biomass-derived alcohols are renewable in nature, since the resources used to produce them can be naturally regenerated in a relatively short period of time. Ethanol is typically used as a gasoline extender, octane enhancer, and oxy-

[4]Energy Information Administration, *Annual Energy Outlook 1994*, p. 73.

genate in gasoline blends. Ethanol is receiving increased attention as a gasoline additive as a result of the Clean Air Act Amendments of 1990.

During the early 1990s, the amount of ethanol consumed fluctuated. A large increase was seen in 1990, when ethanol consumption reached 82 trillion Btu (1,075 million gallons)—an increase of 28 trillion Btu from 1989. In 1991, however, consumption returned to the levels of the late 1980s, decreasing to 65 trillion Btu (851 million gallons). Consumption then increased to 79 trillion Btu (1,036 million gallons) in 1992.

Other Biomass Fuels

The consumption of agricultural waste and manure, commercial-sector woodfuel consumption, and the use of biogas from sewage treatment plants were examined by EIA. Reliable data were not available, however, to make statistically sound estimates of energy consumption from these sources. The data indicate that these are relatively small sources of energy compared with other biomass fuels.

Data Limitations

This report provides estimates of biomass energy consumption in the United States during 1992 based on data collected by the EIA, other Federal agencies, and private organizations. In cases where EIA data are used, the surveys were not specifically designed to measure biomass energy consumption; therefore, the estimates tend to be less reliable than comparable estimates of fossil-fuel consumption. The uncertainties surrounding data from non-EIA sources are unknown. The EIA estimation methodology and the associated uncertainties are described in the body of the report and in Appendix C.

1. Introduction

Background

Biomass includes a broad range of materials (agricultural and forestry products, farm and wood waste products, selected garbage, and animal wastes such as manure) which are biological in nature and can be used to produce various forms of energy. These products may be used for direct combustion, gasified, and/or processed into biomass fuels, such as ethanol, methanol, or methane.[5]

Biomass is a desirable source of energy; the Nation's biomass resource is large, contains vast amounts of energy, and is renewable. Humans have long used biomass not only for food and shelter but also for electric power generation. Toward the middle of the 19th century, direct combustion of wood and other biomass energy resources provided 90 percent of the energy needs for the United States. By the end of that century, a wood shortage created a national energy crisis. With the advent of widespread fossil fuel use, the use of biomass energy dropped to 20 percent of U.S. energy consumption by 1940. Biomass energy consumption continued to decrease until the energy crisis of the 1970s revived interest in wood and other renewable forms of energy.[6] Since then, consumption of biomass energy has grown steadily at a modest rate. In 1992, biomass energy represented approximately 3 percent of national energy consumption.[7]

Biomass energy is derived from or synthesized by a variety of processes and takes several diverse forms, ranging from landfill methane (a gaseous biomass fuel) to biomass-derived ethanol and methanol (liquid biomass fuels) and wood or waste pellets and briquettes (solid biomass fuels). Some types of biomass fuels are commercially viable, while others are not yet competitive with more established fuels.

The biomass energy industry largely uses residues and wastes from industry, society, and agriculture. Because these resources are limited in supply, the growth of biomass energy industries may be constrained. One solution to this problem is the development of dedicated tree and crop plantations, which would provide reliable sources of fuel and supplies of feedstocks for conversion to biomass fuels.

Consumption patterns associated with biomass energy will probably continue to be characterized by modest growth. Several factors, such as the environmental benefits that can be derived from the use of some biomass fuels (for example, ethanol), have increased the rate of consumption. Biomass fuels, such as wood, contain little or no sulfur (a component of acid-rain-producing emissions from power plants). While a limited number of wood-fired power plants are currently in operation, new interest is developing in the use of wood both as a primary fuel source and in co-firing operations as a means of limiting sulfur emissions. Diminishing landfill space may be a major determinant in the future growth of waste-to-energy (WTE) plants, even though the rate of recycling and material recovery is increasing. This publication reports current consumption and discusses some of the factors that are present determinants or are likely to change future consumption patterns.

The Importance of Biomass Energy

The common components of biomass are carbon, hydrogen, and oxygen. These elements can be burned directly to produce thermal energy for heat or steam, or they can be processed into biomass fuels, which store chemical energy for convenient use (e.g., fuel for vehicles). Biomass has several beneficial qualities: it is regionally diverse, renewable, and environmentally benign. Also, biomass-derived energy that is domestically produced offers the opportunity to lower the national balance-of-payments deficit by replacing imported oil.

Fossil fuels, such as coal and petroleum, are nonrenewable and release carbon dioxide (CO_2)—a major green-

[5]Thyrele Robertson and Hosein Shapouri, "Biomass: An Overview in the United States of America," *First Biomass Conference of the Americas: Energy, Environment, Agriculture, and Industry,* NREL/CP-200-5768, Vol. I (National Renewable Energy Laboratory, August 1993), p. 2.

house gas—into the atmosphere during combustion. CO_2 is also released when biomass decomposes or when biomass fuels are burned. Trees and vegetation absorb CO_2 from the atmosphere while they are growing. The amount of CO_2 released when biomass is burned is essentially equal to the amount that is absorbed by new growth that is cultivated. Therefore, biomass used for energy contributes very little net gain to atmospheric CO_2.

Factors That Influence Consumption

Several factors influence the amount of consumption of biomass-derived energy, a subcategory of renewable energy. Renewable energy is expected to experience an annual growth rate of about 2 percent from 1990 to 2010.[8] Biomass energy, like other forms of energy, is affected by the price of crude oil. If the prices of crude oil and natural gas increase with the national demand for energy, as expected,[9] other forms of biomass energy may also become profitable for entrepreneurs.

Currently, wood, wood waste, and municipal solid waste are the most economically attractive forms of biomass energy. Ethanol is the only biomass fuel with a well-established manufacturing and marketing infrastructure. Wood and biomass waste are commercially viable because they are low-cost or negative-cost resources. (Wood used for fuel is, in most cases, wood of the lowest commercial quality. Municipal solid waste is usually a negative-cost fuel resource, because a monetary charge is involved in its acceptance for disposal.) The commercial viability of ethanol is partly due to tax exemptions, although it has now developed market vitality as an oxygenate for gasoline.

Allowances for the environmental and social benefits of biomass energy may also be a factor in the commercial introduction of some biomass-derived fuels. Such allowances may be in the form of higher taxes on fossil fuels, the creation of a comparative advantage for alternative fuels, or tax exemptions and production credits for renewable energy. The Federal motor fuel excise tax exemption for ethanol is one example which illustrates the recognition of an environmental benefit. Ethanol blended into gasoline has been shown to reduce carbon monoxide, a toxin, in vehicle exhaust emissions.

Another example of recognizing a public benefit of biomass energy is the Federal law that guarantees WTE plants a market for their electricity. Combustion of garbage for electricity by WTE plants supplies energy for public use and reduces the volume burden on landfills.

Technological advances in the production of biomass energy and biomass fuels promise to be a stimulus for growth for both biomass fuels that are currently marketed and those of the future.

Outlook

Until the use of dedicated energy crops becomes practical, the supply of feedstocks will remain relatively limited. Nonetheless, areas can be found in almost every region of the country where the potential for biomass energy crop production is good. The production of energy crops can reduce erosion, sediment loadings to surface water, and agricultural chemical loadings to ground and surface water; provide wildlife habitat; provide a more sustainable agricultural resource base; and increase income and employment opportunities in rural areas. For example, extra equipment will be required to transform biomass into energy, and additional jobs will be created in order to use that equipment.[10]

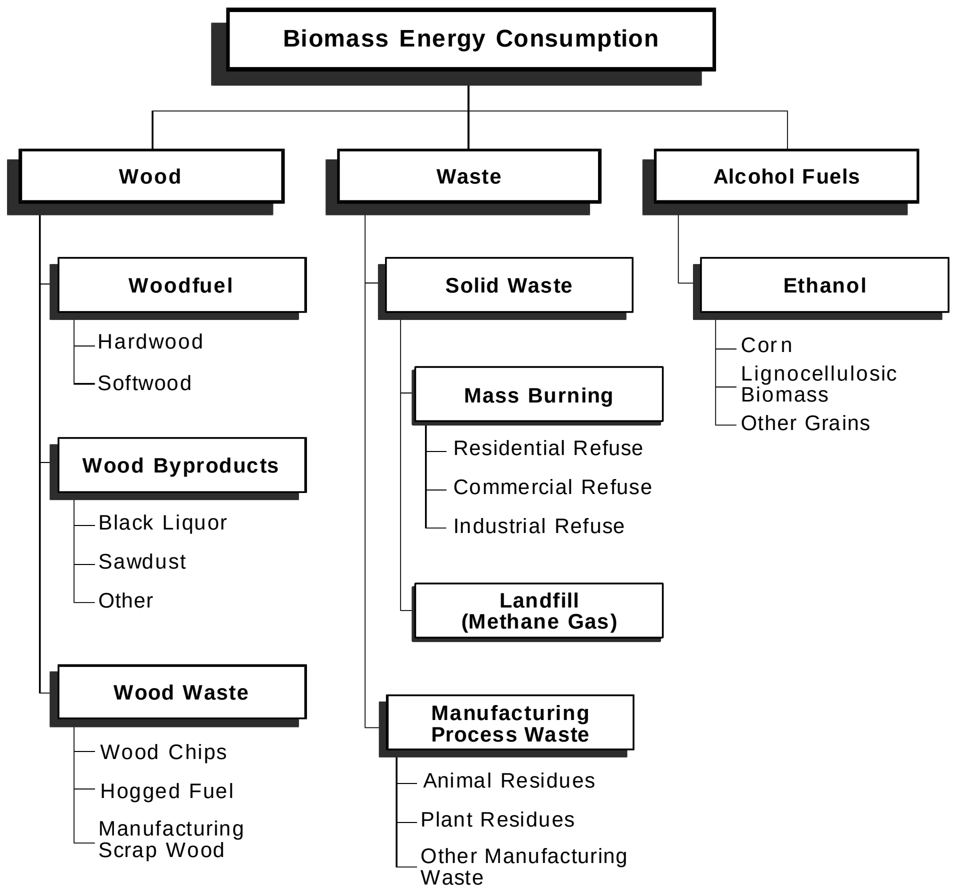
The promotion of biomass energy production will also provide an economic use for current and projected surplus agricultural lands, assuming that biomass can be produced at a rate of return comparable to that for alternative crops. Advanced technology projects are well underway to make biomass fuels as easy to use as today's petroleum-based gasoline and diesel fuels.

To promote the production of biomass energy, policy makers must consider the changing structure of the agricultural sector. Policies must also be coordinated with other legislation that protect the Nation's soil, water, and related resources, improve income and employment opportunities in rural areas, and mitigate negative impacts of greenhouse gas emissions.[11]

Biomass Characteristics

Biomass fuels consist of three main segments: wood, waste, and alcohol fuels (Figure 1). Wood energy is derived from the following sources: roundwood, used primarily in the industrial and electric utility sectors; woodfuel, used predominantly in the residential and commercial sectors; and wood byproducts and wood

Figure 1. Biomass Energy Resource Hierarchy



Source: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels.

waste, which are usually used in the industrial sector. Waste energy is derived from the following sources: mass burning of garbage; conversion of garbage to refuse-derived fuel pellets for eventual burning; collection of methane gas from landfills; and burning or anaerobic digestion of wastes. Alcohol fuel in this report refers to ethanol, typically derived from corn and used primarily in the transportation sector.

The transportation sector is referred to only in connection with ethanol, which is used in gasoline-powered vehicles.

The industrial sector includes manufacturing industries with Standard Industrial Classification (SIC)

Codes 20 through 39.[12] The electric utility sector includes all entities providing electric power to the public. The residential sector includes all types of residences: single-family, multifamily, and mobile homes.

The use of terms and units of measure related to wood energy differs among the consuming sectors. The industrial and electric utility sectors use the term *woodfuel* for all types of wood, wood-derived fuels, and wood byproducts burned as fuel, including cord wood, limb wood, and black liquor. The unit most often used for measuring the amount of woodfuel consumed by these sectors is *oven-dried short tons*.

[12]Descriptions of these codes are presented in Appendix A.

Previous Publications

Five EIA reports concerning biomass energy consumption provide the background for this report:

- *Estimates of U.S. Wood Energy Consumption 1980-1983*,[13] which provides regional[14] estimates of wood energy consumed by the industrial, residential, commercial, and electric utility sectors

- *Estimates of U.S. Biofuels Energy Consumption 1981-1984*,[15] which includes estimates of energy consumption for wood, municipal solid waste, alcohol, and agricultural waste

- *Estimates of U.S. Biofuels Consumption 1987*,[16] which updated the previous report (agricultural waste data were not included)

- *Estimates of U.S. Biofuels Consumption 1989*,[17] which updated the previous report and provided a discussion of biofuels consumption in the agricultural sector and sewage sludge digestion (agricultural energy consumption and sewage sludge digestion were discussed, but no data were published)

- *Estimates of U.S. Biofuels Consumption 1990*,[18] which updated the previous report and offered a qualitative review of agricultural waste energy consumption.

Since the term "biofuels" represents only a portion of the data contained in this report, the title has been changed from *Estimates of U.S. Biofuels Consumption* to *Estimates of U.S. Biomass Energy Consumption*.

Report Organization

Each of the biomass fuels is discussed in a separate chapter of this report, as described below:

- Chapter 2, "Wood," provides background information and consumption data on wood energy use in the United States.

- Chapter 3, "Biomass Waste," provides background information and energy consumption estimates for municipal solid waste, manufacturing waste, and methane gas recovery from landfills, as well as a discussion of energy from agricultural waste and sewage sludge.

- Chapter 4, "Alcohol," provides background information and consumption data on ethanol.

A list of Standard Industrial Classification (SIC) Codes 20 through 39, describing industrial groups and selected industries, is presented in Appendix A. Appendix B provides a map of the U.S. Census regions, outlining the boundaries of the geographical regions described in this report. Appendix C contains descriptions of the procedures used in developing the energy consumption estimates.

Data Quality

The biomass energy data presented in this report were collected from various sources due to the lack of a comprehensive survey of biomass energy consumption. As such, data for each type of biomass energy were derived from different sources, each using different methodologies. Procedures for the estimation of biomass energy consumption are presented in Appendix C. For this report, further modifications and estimates were made as appropriate. Discussion of the data quality for the various biomass energy is addressed below.

- **Wood Energy:**

  - *Industrial:* Estimates for the industrial sector are based on data derived from the 1991 Manufacturing Energy Consumption Survey (MECS). In MECS, woodfuel use is included under the category "Other—Specify." The relative standard error for total U.S. woodfuel consumption in the 1991 survey was 2 percent.[19] The relative standard errors associated with total woodfuel consumption in the industrial sector's SIC 24 (Lumber and

[13]Energy Information Administration, *Estimates of U.S. Wood Energy Consumption 1980-1983*, DOE/EIA-0341(83) (Washington, DC, November 1984).
[14]Appendix B contains a map showing the five Census regions used in all referenced reports.
[15]Energy Information Administration, *Estimates of U.S. Biofuels Energy Consumption 1981-1984*, unpublished report (November 1985).
[16]Energy Information Administration, *Estimates of U.S. Biofuels Consumption 1987*, unpublished report (March 1989).
[17]Energy Information Administration, *Estimates of U.S. Biofuels Consumption 1989*, SR/CNEAF/91-02 (Washington, DC, April 1991).

Wood Products) and SIC 26 (Paper and Allied Products) were 13 percent and 4 percent, respectively.[20] The relative standard error for each SIC increases further when regional level data are considered. The assumptions and the procedures used to estimate 1992 consumption data from the 1991 MECS survey data further impact the accuracy of the published estimates.

- *Residential:* The residential wood energy consumption data presented in this report are based on data developed by the EIA through the 1990 Residential Energy Consumption Survey (RECS).[21] A relative standard error of 10 percent is associated with the survey's 1990 woodfuel consumption data on the national level.[22] This margin of error increases on a regional level. The precise relative standard errors associated with estimates in this report are unknown.

- *Electric Utility:* Wood data from the electric utility sector are based on a census survey, Form EIA-759, "Monthly Power Plant Report."

- **Waste Energy:**

  - Municipal solid waste (MSW) combustion and methane gas recovery from landfills are estimated from industry surveys.[23] While these surveys are considered to be comprehensive, the survey data may be overstated because industrial organizations are hesitant to report facility downtime to private surveying organizations.

  - Manufacturing waste energy consumption data are derived from the 1991 MECS survey. This category is a component of the fuel category "Other—Specify" and carries a large relative standard error at the national and regional levels.

- **Agricultural Waste and Sewage Sludge Digestion:**

  - The use of agricultural waste and sewage sludge is sparse, rendering energy statistics difficult to develop. Because there are no known sources that collect data on a regular basis to estimate the consumption of energy from agricultural waste and sewage sludge digestion, data are not included in this report.

- **Alcohol Energy:**

  - National-level ethanol consumption data are based on production data from the Bureau of Alcohol, Tobacco, and Firearms (BATF), export data from the U.S. Bureau of the Census, and data from Form EIA-819M, "Monthly Oxygenate Telephone Report." Since data from the BATF are only available at the national level, estimated fuel alcohol consumption figures are not exact.

[20]Energy Information Administration, *Manufacturing Energy Consumption Survey: Consumption of Energy 1988,* p. 79.

2. Wood

Background

Most quality timber resources (growing stock[24] and roundwood[25]) are used in value-adding operations, such as furniture and paper making and structural product manufacturing. Consequently, the wood available for use as a fuel to industry, electric utility, and some commercial users is often chipped or ground from limbs, bark, and wood residues from timber harvesting and forest management. In addition to traditional primary sources of wood (such as harvesting operations), secondary processors (such as construction and demolition operations) generate or reclaim wood that can be used for fuel. Nearly 500 million new pallets (portable platforms used for storing or moving cargo), reels, and wood containers are manufactured each year from over 100 million tons of wood.[26] An increasing number of landfills ban or charge high tipping fees for these items. To compensate, an infrastructure has recently developed in which discarded pieces of wood are being reclaimed and processed for fuel. (See box on right for additional sources of wood waste.)

In 1992, wood provided less than 3 percent of the total primary energy consumed in the United States.[27] Wood is a significant fuel in the industrial sector, accounting for 81 percent (2,249 trillion Btu) of total U.S. biomass energy consumption (2,785 trillion Btu) in 1992. Within specific industries, such as "Paper and Allied Products" and "Lumber and Wood Products," woodfuel (wood used as a fuel), including black liquor, accounts for a majority of the energy consumed.

Although wood residues and reclaimed wood are commonly termed "wood waste," both are included in

Sources of Wood Waste

- **Harvested Wood**
  - Loggers
  - Chippers
  - Landclearers
  - Development companies
  - Forest and park agencies
- **Mill Residue**
  - Sawmills
  - Planing mills
  - Flooring mills
  - Pulp and paper mills
  - Boat builders
  - Fence makers
  - Structural member mills
    Trusses, Timbers, Arches
  - Container manufactures
    Cable, Skids, Barrels, Reels, Boxes, Baskets, Pallets, Shook, Tubs
  - Reconstituted building products
    Flakeboard
  - Cooperage mills
  - Cabinetmakers
  - Veneer and plywood mills
  - Log cabin manufacturers
  - Partition manufacturers
  - Furniture makers
- **Pallet Waste**
  - Furniture movers
  - Common carriers
  - Harbor and port authorities
  - Distribution companies
  - Major department and retail stores
  - Shipping lines
  - Warehouses
- **Construction and Demolition Wood**
  - General contractors
  - Roofing contractors
  - Carpenters
  - Pier construction
  - Demolition contractors
- **Other Wood Waste**
  - Residential yard waste
  - Orchards and nurseries
  - Landscaping businesses
  - Utility companies

(Christine Donovan, "Wood Waste Recovery and Processing," Resource Recycling *(March 1991), p. 86.)*

[24]Growing stock consists of commercial quality trees greater than 5 inches in diameter at breast height. U.S. Department of Agriculture, Forest Service, *Forest Resources of the United States, 1992*, General Technical Report RM-234 (Fort Collins, CO, September 1993), p. 118.

[25]Roundwood consists of commercial quality trees less than 5 inches in diameter at breast height. U.S. Department of Agriculture, Forest Service, *An Analysis of the Timber Situation in the United States: 1989-2040*, General Technical Report RM-199 (Fort Collins, CO, December 1990), p. 253.

the data presented in this report, as is waste produced from wood-pulping operations (black liquor).

The availability of wood has diminished as a result of the restrictions placed on logging activity in protected wildlife habitats. Consequently, the quantity of sawdust, mill, and other wood residues available for recovery has also decreased. In Oregon, the country's top lumber-producing State, lumber production in 1992 totaled a mere 50 percent of previous peak year production.[28] As a result, woodfuel is being recovered from construction and demolition projects, pallets, containers, old railroad ties, and other sources.

In addition to using recovered wood for combustion, value-added products, such as densified wood fuels (fuels that are made by processing mill or forest residues into a dry standardized form), are finding wider use. Pellets and briquettes represent two examples of densified wood fuels.[29] Pellets, which are cylindrically shaped and average about 1/2 inch in length and 1/8 inch to 3/8 inch in diameter, must be kept dry to avoid swelling and disintegration. Briquettes, larger than pellets but smaller than manufactured fireplace logs, range between 1 and 4 inches in length and 2 to 4 inches in diameter. Dry storage is also required for briquettes, since their moisture content is below 10 percent.[30] Pellets and briquettes can be burned efficiently in both furnace/boiler units and wood stoves by industrial, commercial, or residential consumers.

In 1992, energy from wood accounted for 3 percent of total U.S. energy consumption.

Historical Perspective

Until the end of the 19th century, wood was the major source of energy in all sectors of the U.S. economy. Much of the industrial energy in boilers and burners was derived from wood. In the commercial and residential sectors, wood was used for cooking, water heating, and space heating. Wood was also used for transportation to propel steam locomotives and steam-powered ships.

With the increased popularity of low-priced coal, oil, and natural gas, woodfuel consumption declined rapidly in all end-use sectors. After the turn of the century, the use of wood in the industrial sector became limited to the paper- and lumber-producing industries. In the past 50 years, these two industries have accounted for virtually all wood energy consumption in the industrial sector. These industries often use residual wood and waste products to fire boilers for steam, process heat, and electricity generation. The paper industry has increasingly used internally generated black liquor as an energy source. Continued growth in output from both the paper and lumber industries, escalation in the cost of waste disposal, and the trend toward more complete utilization of timber have contributed to the increase in woodfuel consumption.

Table 1 summarizes historical woodfuel consumption for 1949 through 1992 in the industrial, residential, and electric utility sectors. The total woodfuel consumption during 1992 is estimated at 2,249 trillion Btu. In 1992, the industrial sector was the largest woodfuel consumer, accounting for almost 71 percent of total woodfuel consumption (Figure 2). The residential sector accounted for 29 percent, and the electric utility sector

Table 1. U.S. Consumption of Wood Energy by Sector, 1949-1992
(Trillion Btu)

Sector	1949	1954	1959	1964	1969	1974	1979	1984	1989	1990[a]	1991	1992	1992 Percent of Total
Industrial	468	576	692	827	1,014	1,159	1,405	1,679	1,556	1,562	1,528	1,593	71
Residential	1,055	800	647	499	415	371	728	923	918	581	613	645	29
Electric Utility	6	3	3	1	1	1	2	9	13	12	10	11	([b])
Total[c]	**1,529**	**1,379**	**1,342**	**1,327**	**1,430**	**1,531**	**2,135**	**2,611**	**2,487**	**2,155**	**2,150**	**2,249**	**100**

[a]EIA's Residential Energy Consumption Survey (RECS) originally reported total 1990 wood energy consumption as 786 trillion Btu. The figure was subsequently revised to 581 trillion Btu.

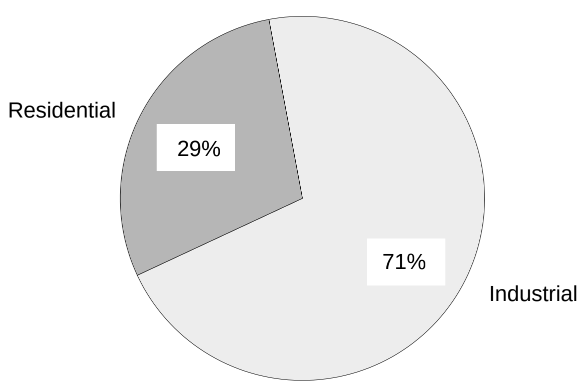
[b]Less than 1 percent.

[c]Commercial wood energy use is not included in this report because there are no accurate data sources for reliable estimates. However, from EIA's Nonresidential Buildings Energy Consumption Survey (NBECS), annual consumption of wood energy in the commercial sector is estimated to be between 20 and 40 trillion Btu.

Note: Totals may not equal sum of components due to independent rounding.

Sources: 1949-1979—Energy Information Administration, *Estimates of U.S. Wood Energy Consumption from 1949-1981*, DOE/EIA-0341 (Washington, DC, August 1982). 1984—Energy Information Administration, *Annual Energy Review 1989*, DOE/ EIA-0384(89) (Washington, DC, May 1990). 1989—Energy Information Administration, *Estimates of U.S. Biofuels Consumption 1989*, SR/CNEAF/91-02 (Washington, DC, April 1991). 1990—Energy Information Administration, *Estimates of U.S. Biofuels Consumption 1990*, DOE/EIA-0548(90) (Washington, DC, October 1991). 1991-1992—Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels (January 1993).

Figure 2. U.S. Consumption of Wood Energy by Sector, 1992



Note: The electric utility sector accounted for less than 1 percent of total U.S. wood energy consumption in 1992.

Source: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels.

accounted for less than 1 percent of total woodfuel consumption.

Differences in regional woodfuel consumption are due to the location of wood resources and wood-consuming industries. In 1992, the largest share of total U.S. woodfuel consumption occurred in the South (55 percent), followed by the West (21 percent), Midwest (13 percent), and Northeast (12 percent) (Table 2).

Industrial Sector Woodfuel Consumption

Woodfuel consumption in the industrial sector is dominated by two industries: the "Paper and Allied Products" industry, SIC 26, and the "Lumber and Wood Products" industry, SIC 24.[31] These industries include facilities (cogenerators) that produce electricity and another form of useful thermal energy, such as heat or steam.

In the "Paper and Allied Products" and the "Wood and Lumber Products" industries, self-generated wood waste is a convenient and cost-effective fuel source for both heat and electricity. On a much smaller scale, selected manufacturers within other industries also use wood waste for energy.

Sector Characteristics

The majority of woodfuel used in the industrial sector consists of wood waste. Very little industrial woodfuel

[31]Standard Industrial Classification (SIC) codes are assigned by the U.S. Bureau of the Census.

Table 2. U.S. Consumption of Wood Energy by Region, 1992

Region	Trillion Btu	Percent of Total
Northeast	264	12
South	1,234	55
Midwest	286	13
West	466	21
Total	**2,249**	**100**

Note: Totals may not equal sum of components due to independent rounding.

Source: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels.

is suitable for merchandising.[32] Within the industrial sector, wood waste serves as a fuel for a variety of wood energy conversion systems, including boilers, electricity generators, kilns, dryers, and gasifiers. Boilers and electricity generation systems are usually fueled by wood chips (clean, bark-free chips of wood), bark, or hogged fuel (whole wood wastes chopped into large chunks). Kilns, dryers, and gasifiers are generally fueled with bark and dirt-free sawdust or wood chips. The burning of wood waste for energy is partly a result of extensive efforts to reduce the industries' dependence on natural gas and oil.[33] Also, in industries where wood is a natural byproduct, it is a convenient fuel and reduces the cost of waste disposal.

Pulp and Paper

The pulping process, used to break wood down into fibers that can be used to make paper and paperboard, yields a combustible byproduct called black liquor (also called spent or pulping liquor), which can be used as a source of energy. Black liquor is a concentrated spent reagent solution (a paper processing liquid waste) containing lignin. Energy from black liquor is used on site and sold for process heat and electricity. The American Paper Institute estimates the energy density of black liquor to be over 12 million Btu per ton.

Research on the pulping process has shown that the strength of paper products increases when the products are made from mechanically pulped wood.[34] Research has also shown that the pretreatment of wood by the *Ceriporiopsis subvermispora* fungus can save 40 percent of the energy used in making mechanical pulps. If this pretreatment gains market acceptance, the characteristics of black liquor will change.

Data and Analysis

Industrial woodfuel consumption in 1992 totaled 1,593 trillion Btu (Table 3). The majority of this was consumed by the "Paper and Allied Products" industry, SIC 26, which accounted for 1,258 trillion Btu (almost four-fifths) of the total woodfuel consumed by the industrial sector. The "Lumber and Wood Products" industry, SIC 24, accounted for 18 percent (287 trillion Btu) of the total wood energy consumption in the industrial sector. Wood consumption data for individual SICs other than SIC 24 and SIC 26 are aggregated because they are not reliable at the two-digit SIC level. During 1992, industries other than SIC 24 and SIC 26 consumed the remaining 3 percent (48 trillion Btu) of the total woodfuel used in the industrial sector.

Table 3. Industrial Woodfuel Consumption by Sector, 1992

Industrial Sector	Trillion Btu	Percent of Total
Paper and Allied Products (SIC 26)	1,258	79
Lumber and Wood Products (SIC 24)	287	18
Other Industries	48	3
Total	**1,593**	**100**

Note: Totals may not equal sum of components due to independent rounding.

Source: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels.

Table 4 and Figure 3 show the regional distribution of woodfuel consumption for the industrial sector during 1992. The South consumed 64 percent, followed by the West (22 percent), the Northeast (7 percent), and the Midwest (6 percent).

Residential Sector Woodfuel Consumption

As described above, wood was a major source of energy for heating and cooking in the residential sector between the turn of the century and 1940. The use of

Table 4. Industrial Woodfuel Consumption by Region, 1992

Region	Trillion Btu	Percent of Total
Northeast	119	7
South	1,027	64
Midwest	96	6
West	350	22
Total	**1,593**	**100**

Note: Totals may not equal sum of components due to independent rounding.

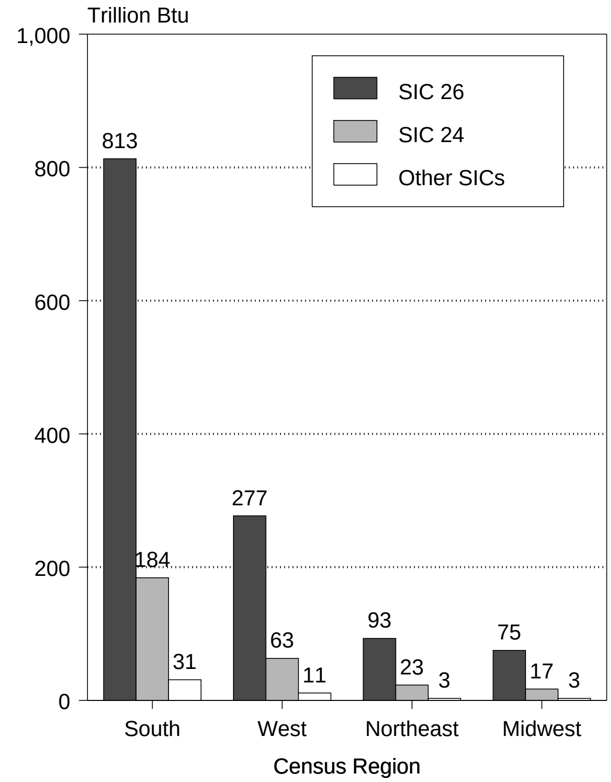
Source: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels.

woodfuel as the primary source of heating fuel in households declined from approximately 22 percent in 1940 to about 2 percent in 1970.[35] The decline can be attributed to the fact that fossil fuels were abundant, cheap, and more convenient than woodfuel during this period. In the 1970s, however, disruption of crude oil supplies and the curtailment of natural gas deliveries, as well as rising crude oil and natural gas prices, revived interest in wood as a fuel for residential space heating.

By 1978, the use of woodfuel as a primary source of heat had increased to approximately 2 million households, representing 3 percent of all U.S. households. Significant increases in the use of wood as a main heating fuel also occurred between 1978 and 1984. By 1981, over 5 million households reported wood to be the main heating fuel, representing 6 percent of all U.S. households. This trend continued through 1984, when 7 million households (8 percent) reported wood as the main heating fuel.[36] The use of wood as a main heating source peaked between 1984 and 1987.

By 1987, only 5 million U.S. households (6 percent) reported wood to be the main heating fuel, representing a decrease of 23 percent from the number of households consuming woodfuel in 1984.[37] This decrease resulted from environmental concerns about the use of

Figure 3. Industrial Woodfuel Consumption by Region and Sector, 1992



Source: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels. Data derived from Tables 3 and 4.

wood stoves during certain periods, as well as the declining prices of conventional fuels, such as heating oil and natural gas. For example, the nominal prices of heating oil and natural gas decreased by 10 and 26 percent, respectively, from 1984 to 1987.

Sector Characteristics

This section reflects the 1990 status of wood burning in the U.S. residential sector. The principal source of this section's statistical information is EIA's *1990 Residential Energy Consumption Survey* (RECS).[38] Other information is derived from industry literature, as referenced.

[35]U.S. Department of Commerce, Bureau of Census, *Residential Energy Uses,* H-123-83-1 (Washington, DC, 1983), Chart 1.

Equipment Used

The following five types of residential wood-burning equipment are currently in use: fireplaces, fireplace inserts, free-standing stoves, central heating equipment for houses, and large boilers for apartment buildings. Each type of equipment is produced in different sizes, has different performance parameters, and is made from a variety of construction materials (steel, iron, and alloys).

Fireplaces are the most common type of wood-burning equipment used in the residential sector. They are rarely used for heating an entire home because of low energy efficiency and fast woodfuel consumption characteristics. Only 7 percent of all households using wood as the main heating fuel reported the use of fireplaces for heating an entire home.[39] More frequently, fireplaces are used for aesthetic reasons and as a temporary source of heat for a room or for part of a house. Depending on the type of fireplace used and draft characteristics of the house, burning wood in fireplaces may actually result in a net heat loss. This occurs because many fireplaces draw a large amount of air from the interior of the house, which is replaced by cold air from outside.

Free-standing stoves are the principal type of wood-burning equipment used for home heating. A variety of stoves exist, including airtight stoves, radiant stoves, circulators, and cast iron units. Airtight stoves have become popular as a result of their relatively high efficiency and long-burning characteristics. In 1990, airtight stoves were used by 3 million households (74 percent) using wood as the main heating fuel.[40]

Free-standing woodstoves, such as this cast iron unit, are the principal type of wood-burning equipment used for home heating.

Several types of wood-burning and dual-fired boiler central heating equipment are also available for application in houses and multifamily units, such as apartment buildings. These units are designed to provide heat for an entire structure, rather than for individual rooms, and consume relatively large quantities of wood at high efficiencies.

In some areas, particularly those at high altitudes and those having large urban populations, environmental restrictions for residential wood burning exist. The U.S. Environmental Protection Agency (EPA) has developed standards for stove construction which address this problem. Because pellet stoves have clean-burning characteristics, consumer demand for them has increased in certain areas. Pellet stoves may often be used on days when traditional wood stoves and fireplaces are banned because of air quality problems. Consumption of wood pellets in Colorado alone is estimated to be 42,000 tons annually.[41]

In addition to equipment characteristics, a number of other factors affect the quantity of woodfuel consumed. Woodfuel consumption in the residential sector depends on consumer decisions to use woodfuel as a source of heat, the type and frequency of maintenance of the wood-burning equipment and chimney, the moisture content, the type of wood used (different types of wood have different Btu contents), and operational parameters, such as air supply (internal and external).

Wood-Burning Demographics

In the residential sector, 23 to 25 million households burned wood in 1990. Of these households, wood was reported as the primary heating fuel in 4 million households and as a secondary source for aesthetic purposes in 19 to 21 million households.[42]

In the residential sector, as in the industrial sector, wood is burned mostly in areas close to the resource. Wood burners in rural areas consume more than 26 percent of the woodfuel consumed in the residential sector. Approximately 18 percent of all wood burners are located in central city areas, consuming a disproportionately small quantity of the woodfuel (7 percent). Of those that use wood as the main heating fuel, only 5 percent are central city dwellers.[43]

The number of households using wood as the primary heating fuel and the quantity of wood consumed are inversely related to income and heating area. The lower income strata are more sensitive to the cost of fuel; therefore, more rural low-income households consume wood for energy than other sectors of the population. RECS reports that less than half of the wood burned is purchased. The availability of wood as a free or low-cost resource can make wood the fuel of choice for low-income rural households.

Data and Analysis

Wood contributes approximately 6 percent of all energy consumed by U.S. households and is the fourth largest source of energy within the sector, following only natural gas, electricity, and fuel oil.[44] Wood is the most popular secondary heating fuel. The majority of households using wood as the primary heat source use wood-burning stoves as the primary heating appliance.

Residential wood consumption in 1992 is estimated at 645 trillion Btu (Table 5). Woodfuel consumption in the residential sector is distributed geographically as follows: the South consumed 206 trillion Btu (10 million cords), followed by the Midwest, which consumed 186 trillion Btu (9 million cords). The Northeast consumed 143 trillion Btu (7 million cords), and the West consumed even less, 111 trillion Btu (6 million cords). The methodology and conversion factors used to develop these estimates are discussed in Appendix C.

Table 5. Residential Woodfuel Consumption by Region, 1992

Region	Trillion Btu	Million Cords[a]	Percent of Total
Northeast	143	7	22
South	206	10	32
Midwest	186	9	29
West	111	6	17
Total	**645**	**32**	**100**

[a]One cord of wood is equivalent to 1.163 oven-dried short tons, containing approximately 20 million Btu.

Note: Totals may not equal sum of components due to independent rounding.

Source: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels.

Electric Utility Sector Woodfuel Consumption

Due to the localized availability of woodfuel and its generally unfavorable economics, the electric utility industry has never relied heavily on woodfuel as an energy source. In several selected locations, however, electric utilities find it suitable to use wood exclusively or in combination with other fuels to generate electricity.

Woodfuel consumption by electric utilities has varied considerably since the 1950s. For example, electric utility woodfuel consumption decreased from 461,000 short tons[45] in 1952 to 85,000 short tons in 1956. Consumption increased to 141,000 short tons in 1972, and then decreased to 11,000 short tons in 1975.[46] After this drop, consumption grew to almost 800,000 short tons in 1989, but then declined to 600,000 short tons in 1992.

Sector Characteristics

The electrical generating capacity of a typical steam plant is 300 megawatts or larger, while wood-burning units are much smaller, usually a maximum of 50 megawatts. Since most new electricity generating capacity is projected to be met through small capacity additions, some electric utilities may now be considering wood-fired power among their options. The two types of wood-burning facilities used in the electric utility sector are wood-dedicated (100 percent wood burning) and wood co-fired with other fuels. All wood-burning electric utility facilities in the Midwest region co-fire wood with another fuel, such as coal or refuse. Wood-fueled power plants represent a small fraction (less than 1 percent) of the total electric plant capacity in the United States.[47]

Data and Analysis

Table 6 lists 1992 woodfuel consumption in the electric utility sector by region. Electric utilities reported a total of 11 trillion Btu of woodfuel use. Electric utilities located in the West consumed 45 percent (5 trillion Btu) of the total wood used in the electric utility sector. Woodfuel use at these plants is dependent on factors such as the availability of free wood waste and the availability of surplus hydropower (water resources for energy production). These plants burn pine, fir, larch, hemlock, alder, and other types of green wood. One plant burns hogged fuel, while another plans to use natural gas to co-fire with wood. During 1992, however, wood-burning plants in the West did not co-fire any fossil fuels.

Electric utilities in the Midwest consumed 45 percent (5 trillion Btu) of the total wood consumed by electric utilities in 1992. One plant burns bark waste from lumber operations, while another burns oak, sawdust, and bark from area sawmills. A third plant receives pine and fir waste from a large window manufacturer.

One plant located in the Northeast consumed 9 percent (1 trillion Btu) of the total woodfuel consumed by electric utilities in 1992. This plant buys green hardwood and softwood for power plant consumption and has the ability to co-fire wood with other fuels. During 1992, no electric utilities in the South reported woodfuel consumption.

Nonutility generators of electricity that consume woodfuels are difficult to account for accurately.[48] Those which cogenerate electricity and steam have been included in the section on industrial woodfuel consumption, since the cogeneration facilities consume electricity

Table 6. Electric Utility Woodfuel Consumption by Region, 1992

Region	Trillion Btu	Million Short Tons[a]	Percent of Total
Northeast	1	0.1	9
South	0	0.0	0
Midwest	5	0.3	45
West	5	0.3	45
Total	**11**	**0.6**	**100**

[a]One short ton of wood has the oven-dried equivalent of approximately 17.2 million Btu.

Note: Totals may not equal sum of components due to independent rounding.

Source: Energy Information Administration, Form EIA-759, "Monthly Power Plant Report" (1992).

on site prior to selling any net generation into the electricity distribution grid.

Future Outlook

In 2010, wood consumption is expected to remain at approximately 81 percent (3,864 trillion Btu) of total U.S. biomass energy consumption (4,770 trillion Btu).[49] The expected increase in the use of wood in the industrial sector is related to anticipated growth in the output of the "Paper and Allied Products" and "Lumber and Wood Products" industries.

Consumption in the residential sector is expected to increase because the price of conventional heating fuels, particularly heating oil and natural gas, is expected to rise. This rise, coupled with the growth in population and number of housing units, is expected to contribute to increased wood consumption within residences. Although total consumption is expected to increase by 2010, the residential sector is expected to account for a smaller share of total U.S. woodfuel consumption. Electricity prices are expected to remain constant, in real terms, through 2010, which will reduce the growth in the use of wood-burning stoves to replace electric heat.[50]

[47]Energy Information Administration, *Inventory of Power Plants in the United States 1992*, DOE/EIA-0095(92) (Washington, DC, October 1993), p. 12.

3. Biomass Waste

Background

Thermal energy can be recovered from many types of biomass waste. Biomass waste can be divided into two key categories—municipal waste (centrally collected wastes that are discarded or discharged by residential, commercial, and industrial waste generators) and manufacturing waste (processed or scrapped wastes originating from manufacturing, construction, and agricultural operations.)

In 1992, the total waste energy consumption in the United States amounted to approximately 457 trillion Btu (Table 7). Of this amount, 83 percent was from the combustion of municipal solid waste and landfill gas, and 17 percent was from the combustion of manufacturing waste.

The main contributors to energy from municipal waste are:

- Municipal solid waste (MSW) processed by waste-to-energy plants
- Municipal waste (landfill gas) processed by landfills
- Municipal sludge processed by digesters.

Municipal waste was used to produce approximately 380 trillion Btu of energy in 1992.[51]

Manufacturing waste consists of biological byproducts from manufacturing processes. In 1992, manufacturing waste produced almost 77 trillion Btu of energy.

Table 7. U.S. Consumption of Biomass Waste Energy by Type of Waste and Region, 1992
(Trillion Btu)

	Type of Waste[a]				
Census Region	**MSW Combustion**	**Manufacturing Waste**	**Landfill Gas[b]**	**Total**	**Percent of Total**
Northeast	126	4	18	**148**	32
South	102	15	11	**128**	28
Midwest	53	18	13	**84**	18
West	30	40	30	**100**	22
Total	**310**	**77**	**70**	**457**	**100**
Percent of Total by Waste Type	68	17	15	**100**	--

[a]Energy from agricultural waste is reported to be about 100 trillion Btu annually. Data are not available on a regional basis; therefore, agricultural waste is not included in the total estimate of waste energy consumption shown here.

[b]Landfill gas data for 1992 are not yet available; however, GAA estimates that by the beginning of 1994 landfill gas energy consumption had increased by 25 percent from 1990 levels.

Note: Totals may not equal sum of components due to independent rounding.

Sources: Energy Information Administration, Office of Energy Markets and End Use, *1988 Manufacturing Energy Consumption Survey, Consumption of Energy*, DOE/EIA-0512(88). Governmental Advisory Associates, 1993/1994 Resource Recovery Database and 1993/1994 Methane Recovery Database (preliminary estimate).

Historical Perspective

The first estimates of energy produced from waste were developed in an unpublished report by the Energy Information Administration for the years 1981 through 1984. By 1981, the total amount of energy produced from waste reached approximately 88 trillion Btu.[52] During the period from 1981 through 1992, waste energy consumption experienced a growth of 369 trillion Btu[53] (Table 8). This increase can be attributed to the expansion in the number of MSW facilities that burn waste with thermal energy recovery due to local and Federal legislative efforts to reduce the amount of waste for disposal at landfills.

The conversion of waste to thermal energy could have either beneficial or adverse economic impacts, depending on a complex set of factors that must be evaluated separately. Economics vary by type of waste (MSW, manufacturing waste, and landfill gas), the location of the waste facilities, electricity price and regulatory requirements, the technology employed for conversion of waste into thermal energy, and the quality of the waste available. In many areas, the economics of MSW-derived energy are made more attractive by imposing large tipping fees, the costs charged for the disposal of MSW. The future growth of the MSW industry depends on evolving environmental legislation and local opposition to the operation of MSW facilities in, or close to, urban centers.

Municipal Solid Waste

Municipal Solid Waste and Waste-to-Energy

The nature of municipal waste combustion has changed significantly over the last decade, and the quantity of energy produced from this source has risen steadily. Legislation against pollution generated from the incineration of solid waste led to the closing of many incinerators with uncontrolled emissions, as well as the implementation of energy recovery technologies designed to meet air pollution standards. Incineration of waste for volume reduction purposes without energy recovery has declined dramatically since the implementation of strict emissions standards requiring expensive air pollution control devices.

Diminishing landfill space has made it imperative for most local and State governments to implement or encourage waste management strategies such as resource recovery, composting, and combustion of waste for energy (Figure 4). Many communities employ these alternatives in combination, a practice referred to as integrated waste management. A MSW facility that employs energy recovery from waste combustion can reduce incoming refuse volume by an estimated 90 percent.[54]

Based on 1990 data, the U.S. Environmental Protection Agency (EPA) estimated that 55 to 65 percent of MSW is generated from residential sources and that 35 to 45

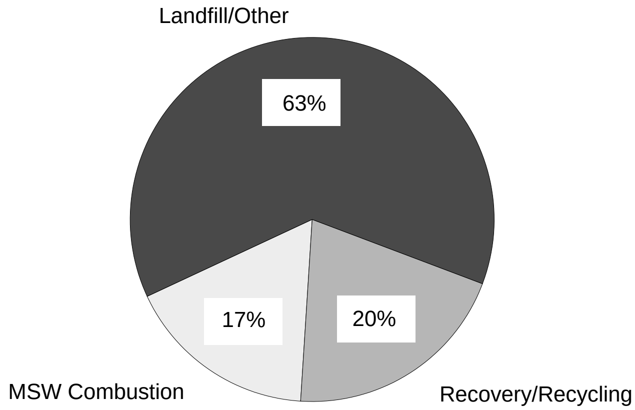
Table 8. U.S. Consumption of Biomass Waste Energy by Region, 1981-1992
(Trillion Btu)

Census Region	1981	1984	1987	1989	1990	1992	1992 Percent of Total
Northeast	16	39	60	84	119	148	32
South	37	57	108	145	114	128	28
Midwest	5	21	47	64	89	84	18
West	30	91	74	51	73	100	22
Total	**88**	**208**	**289**	**344**	**395**	**457**	**100**

Note: Totals may not equal sum of components due to independent rounding.

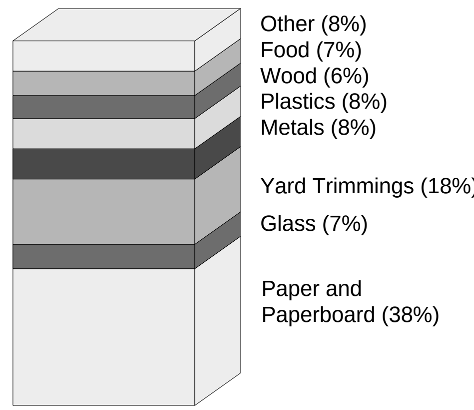
Sources: 1981-1987—Energy Information Administration, *Annual Energy Review 1989*, DOE/EIA-0384(89) (Washington, DC, May 1990). 1990—Energy Information Administration, *Estimates of U.S. Biofuels Consumption 1990*, DOE/EIA-0548(90) (Washington, DC, October 1991). 1992—Governmental Advisory Associates, 1993/1994 Resource Recovery Database and 1993/1994 Methane Recovery Database (preliminary estimate), and Energy Information Administration, *1988 Manufacturing Energy Consumption Survey, Consumption of Energy*, DOE/EIA-0512(88).

Figure 4. Management of MSW in the United States, 1992



Source: U.S. Environmental Protection Agency, *Characterization of Municipal Solid Waste in the United States: 1992 Update*, EPA/530-R-92-019 (Washington, DC, July 1992), p. 4-18.

Figure 5. Materials Generated in MSW by Weight, 1990



Source: U.S. Environmental Protection Agency, *Characterization of Municipal Solid Waste in the United States: 1992 Update*, EPA/530-R-92-019 (Washington, DC, July 1992), p. ES-4.

percent comes from commercial sources.[55] According to the EPA definition, MSW includes nonprocess industrial waste, but excludes industrial process wastes, hazardous wastes, municipal sludge, and construction and demolition debris (C&D), even though C&D is often landfilled. Used tires are also included in the definition of MSW used by the EPA since they are discarded at a continuous rate. Traditionally a disposal nuisance that served as a breeding ground for mosquitos and a fuel for accidental landfill fires, used tires are now being turned into an energy resource in some areas.

In contrast, yard waste (leaves and grass clippings), even though it is organic, is prohibited from disposal as MSW by many municipalities. This is due to its volume, high moisture content, which limits heat production, and high mineral content, which contributes to ash production and refractory slagging problems during combustion.

Figure 5 details EPA's profile of the municipal waste stream. Considered for its potential as a fuel, MSW currently consists, on average, of about 84 percent organic (combustible) material and 16 percent inorganic material, including glass, metals, and miscellaneous inorganics.[56]

In 1992, the United States generated about 201 million tons of MSW, of which 34 million tons (about 310 trillion Btu) were burned with energy recovery (Table 9). This represents a substantial increase from 1990, when 26 million of 196 million tons of MSW were combusted for energy.[57] According to the Governmental Advisory Associates (GAA) 1993/1994 database, the number of operating MSW combustion facilities in the United States increased from 114 in 1990 to 123 in 1992. In 1992, electric generating capacity was about 2,300 megawatts, with generation amounting to 11 million megawatthours. Comparable values for 1990 were 1,810 megawatts and 8 million megawatthours, respectively.[58] The percentage of all operating MSW facilities which produce electricity increased from 60 percent in 1990 to 67 percent in 1992.[59]

The energy content of raw MSW varies by region, sometimes widely, according to the composition of the

[55]U.S. Environmental Protection Agency, *Characterization of Municipal Solid Waste in the United States: 1992 Update*, EPA/530-R-92-019 (Washington, DC, July 1992), p. 5-4.

[56]U.S. Environmental Protection Agency, *Characterization of Municipal Solid Waste in the United States: 1992 Update*, p. 5-4.

[57]Waste generation data were derived from a straight-line interpolation of EPA 1990 waste generation data and 1995 projections for corresponding data. U.S. Environmental Protection Agency, *Characterization of Municipal Solid Waste in the United States: 1992 Update*, Table 34, p. 4-18. Combustion data were obtained from the 1990/1991 and 1993/1994 databases developed by Governmental Advisory Associates.

Table 9. Energy Recovery from MSW, 1990-1992

Year	Total MSW Generated (Million Tons)	Total Discards (Million Tons)	Quantity Combusted (Million Tons)	Energy Recovered (Trillion Btu)
1990	196	162	26	235
1991	198	161	NA	NA
1992	201	160	34	310

Note: Combustion data for 1991 are not available (NA).

Sources: U.S. Environmental Protection Agency, *Characterization of Municipal Solid Waste in the United States: 1992 Update*, EPA/530-R-92-019 (Washington, DC, July 1992). Governmental Advisory Associates, 1993/1994 Resource Recovery Database.

waste stream. Unprocessed MSW is generally considered to have an energy content of between 4,500 and 5,000 Btu per pound (Higher Heating Value).[60] Some portions of the stream (e.g., plastics) have an energy content as much as four times the average.

Table 10 shows the 1992 geographic consumption of MSW by waste-to-energy plants by region in the United States.[61]

There are two types of waste-to-energy combustion facilities: mass burn and modular. Mass burn facilities typically have one combustion chamber and are usually constructed on site to specifically meet the needs of the community. Mass burn systems are usually chosen for larger sites. Modular facilities, in contrast, use two-stage combustion, are usually factory-assembled units, and are chosen for smaller sites. In a modular system, a series of modules are linked together to achieve the required capacity. Economics, space, the need for flexibility, and other factors determine the appropriate modular configuration.[62] In 1991, there were 60 mass burn plants and 50 modular plants in the United States. In 1992, the number of mass burn plants increased to 65, while the number of modular plants decreased to 48.[63]

Theaverage gross power output rating for all resource recovery facilities that produce electricity is about 34 megawatts.[64] For a MSW-fired mass burn boiler with 50 megawatts net capacity, the typical heat rate is approximately 16,400 Btu per kilowatthour.[65] Steam is produced at 700°-850°F and 600-850 psi for large plants and less for small plants. Electricity production from

Table 10. Energy Recovery from MSW by Region, 1992

Region	MSW Combusted[a] (Million Tons)	Energy Recovered (Trillion Btu)	Percent of Total
Northeast	14	126	**41**
South	11	102	**33**
Midwest	6	53	**17**
West	3	30	**10**
Total	**34**	**310**	**100**

[a]The quantity of MSW combusted is based on the higher heating value of 4,500 Btu per pound.

Note: Totals may not equal sum of components due to independent rounding.

Source: Governmental Advisory Associates, 1993/1994 Resource Recovery Database.

[60]Regional sampling of MSW by the Department of Mechanical Engineering, Oregon State University, indicated an average higher heating value for coarse MSW (screened to 6 inches) of 4,677 Btu per pound. For purposes of estimating national consumption, the present report adopted 4,500 Btu per pound.

[61]The regionalization of the total MSW combusted was based on Figure 1, "Regional Breakdown of Operating U.S. Facilities," *Waste Age* (November 1992), p. 32.

[62]Great Lakes Regional Biomass Energy Program, *Biomass Energy Facilities: 1988 Directory of the Great Lakes Region* (Chicago, IL: Council of Great Lakes Governors, 1988), p. 248.

[63]"Municipal Waste Combustion in North America: 1992 Update," *Waste Age* (November 1992), p. 34.

[64]"The Outlook for Resource Recovery Through the 1990s," *Waste Age* (August 1991), p. 106.

Thermal energy can be recovered from many types of biomass waste. The municipal waste shown here is one type of biomass waste.

MSW typically yields less than 1 megawatthour per ton of MSW consumed.[66]

The recent increase in the recycling of waste materials could change the composition of the waste stream. Both the quantity of waste stream combustibles and recycling will continue to expand as the population grows and consumption patterns change. The elimination of plastics in the waste stream through recycling will lower the average Btu per pound of energy feedstocks for MSW combustion. As generation and material recovery patterns change as a result of environmental concerns, the energy density of MSW is also likely to change to some extent.

However, EPA projections indicate that, on a national scale, the combustible fraction of MSW will most likely remain relatively unchanged. For the year 2000, EPA estimates that the combustible fraction of MSW will be 85 percent, a change of only 1 percent in one decade.[67]

Energy production from MSW facilities faces stiff public opposition, and future environmental regulations concerning incinerator emissions are uncertain. These factors increase the uncertainty of the potential contribution of energy from MSW. In contrast, future EPA regulations concerning landfills may escalate waste disposal fees, making waste combustion a more economically attractive alternative.

Some waste-to-energy plants do not convert MSW to energy directly by combustion; instead, MSW is converted to a value-added product called refuse-derived fuel (RDF). RDF is formed from MSW through a process that involves varying degrees of waste separation and size reduction. Noncombustible materials such as glass and metals are removed. These materials represent as much as 30 percent of the original MSW. The remaining refuse is then processed into RDF. RDF can be used as a primary fuel or co-fired with other fuels. The uniform particle size, moisture content, and heating value of RDF is desirable for stable combustion in boilers, easier storage, and economical transportation. There are several types of RDF, and their heating values are substantially higher than those of unprocessed MSW. RDF can be burned on site in a dedicated RDF boiler to produce steam and/or electricity, or it can be sold to a separate facility for energy production.

Landfill Gas

Although not constructed to produce methane, landfills are currently being tapped to release built-up gases. This serves the dual purpose of removing a potential hazard and utilizing a valuable energy resource. At a landfill, municipal solid wastes are layered alternately with soil at a selected site. Over time, the landfill spontaneously generates biogas.[68] Landfill gas or biogas results from the digestion of MSW by anaerobic bacteria. This digestion produces a gas containing methane, carbon dioxide, and other trace products.

Due to the concentration of carbon dioxide in the raw gas, landfill gas is classified as low to medium quality with typical heating values of 400 to 550 Btu per cubic foot. Raw landfill gas can either be burned as a boiler

Characteristics of Landfill Gas

When the oxygen has been depleted in a landfill, buried organic matter undergoes anaerobic decomposition. This process generates methane, carbon dioxide, and trace organic gases, collectively called landfill gas. As pressure develops in the landfill, these gases, if not captured, escape into the atmosphere with adverse environmental impact. Various methods of containment and capture are used to process landfill gas and dispose of it by converting it to fuel or flaring it. In either case, carbon dioxide is released into the atmosphere. Carbon dioxide is considered a greenhouse gas (i.e., a global warming agent), but it is proportionally much less harmful than methane.

One pound of dry organic material can generate as much as 7 to 10 cubic feet (405 to 598 liters) of gas over the life of the landfill. Actual gas production rates range from 0.05 cubic feet per pound (3 liters per kilogram) to 0.20 cubic feet per pound (13 liters per kilogram). Site histories indicate that landfills can have a gas production lifetime of 10 to 15 years or more, although peak production rates occur within the first few years.

Characterized by highly complex processes, the decomposition of landfill matter can be described in three phases. First, degradable wastes react with trapped oxygen, releasing heat and producing mainly carbon dioxide and water. In the second phase, oxygen has been depleted; therefore, aerobic organisms die off and anaerobic organisms proliferate. In the third phase, anaerobic microorganisms generate gases consisting primarily of methane (about 60-70 percent) and carbon dioxide (about 30-40 percent). This reaction continues until decomposition is complete.

The energy density of landfill gas is typically about 500 Btu per cubic foot (19 megajoules per cubic meter). It can be used for boiler fuel once part of the moisture is removed. Moisture removal may be accomplished by pretreatment scrubbers or dehydration by a triethylene glycol process. Preliminary water removal by chillers can raise the energy content to about 530 Btu per cubic foot (20 megajoules per cubic meter). When landfill gas is sent to a natural gas pipeline, condensers can be used to raise the energy content to about 700 Btu per cubic foot (26 megajoules per cubic meter). Upgrading the gas to pipeline quality, which is about 1,000 Btu per cubic foot (37 megajoules per cubic meter), can be accomplished by a variety of methods and entails the removal of all or part of the carbon dioxide, heavy hydrocarbons, and trace contaminants. After the process, the landfill gas is essentially the same as natural gas.

fuel to obtain usable energy (steam, hot water, electricity), converted into high heat value gas (around 950 Btu per cubic foot) via carbon dioxide removal, and/or used as a fuel to produce electricity from generators.

Gas recovery at landfills started in the 1970s in California as a result of smog problems, energy shortages, and high energy prices.[69] There were 108 facilities operating with methane combustion in 1990.[70] During 1992, approximately 70 trillion Btu of landfill gas was consumed, almost one-half of which was consumed in the West.[71]

The landfill gas industry experienced a constant growth until about 1983, when it slowed due to the low prices for electricity and natural gas feedstocks.

U.S. landfill gas collection facilities have between 333 and 400 megawatts of installed nameplate capacity for the generation of electricity,[72] consuming over 50 billion cubic feet of gas (about 26 trillion Btu) annually. About 4 billion cubic feet per year (4 trillion Btu) of high-Btu gas are refined at eight facilities.[73] About 20 methane gas recovery projects in the United States consume landfill gas in boiler operations for space heating.[74] Table 11 presents estimated total landfill gas production data.

Several laws and regulations influence the energy production from landfill gas. The Energy Policy Act of 1992 provides credits, in some instances, for the production of energy from landfills (see box above).[75] Sections IIIb and IIId of the Clean Air Act (CAA) affect

[69]"Methane Gas from Landfill Used to Heat AT&T Plant," *PR Newswire* (June 25, 1992), p. 1.
[70]1990/1991 Methane Recovery database developed by Governmental Advisory Associates.
[71]Data for 1992 are derived from the 1993/1994 Methane Recovery Database developed by Governmental Advisory Associates (preliminary estimate).
[72]*Power*, Vol. 136, No. 2 (February 1992), p. 15.
[73]*Pipeline Industry* (February 1993), p. 15.
[74]"Methane Gas from Landfill Used to Heat AT&T Plant," *PR Newswire* (June 25, 1992), p. 1.

The Federal Tax Incentive for Recovery of Landfill Gas

The National Energy Policy Act of 1992, signed into law on October 4, 1992, extended the fuel credit for gas production from biomass. This fuel credit was originally authorized by the Crude Oil Windfall Profits Tax Act of 1980 and implemented by §29 of the Internal Revenue Code (IRC) to promote energy production from "nonconventional sources." Without the extension, the credit would have been eliminated for facilities placed in service after December 31, 1992. Facilities that produce gas from biomass and are placed in service by December 31, 1996, may now qualify for the credit. A termination date of January 1, 2008, is stipulated by the new law.

The IRC §29 credit is based on the barrel-of-oil equivalence for the fuel produced, adjusted annually for inflation. The 1991 credit per barrel was $5.35. In 1992, this credit increased to $5.53 per barrel equivalent. To qualify for the IRC §29 credit, a biomass fuel facility must produce a combustible gas from biomass and sell this gas to an "unrelated" party. Two companies may be considered "unrelated" if there is less than 80 percent common ownership between the two companies. In a parent-subsidiary corporate structure, the parent company can own no more than 50 percent of the subsidiary.

The following two methods of gas production qualify for the credit: (1) biomass pyrolysis and (2) collection of the gas released by the bacteriological decomposition of biomass (i.e., landfill methane).

The Internal Revenue Service (IRS) has issued several rulings which provide guidance with respect to IRC §29. In one ruling, a boiler system was retrofitted with a biomass gasification unit. The boiler was owned by one party and the gasifier was owned by another party. The owner of the gasifier produced and sold the biomass gas to the owner of the boiler, and the gas was used to fire the boiler and generate steam. The IRS ruled that the owner of the gasifier qualified for the credit based on gas sales to the boiler owner. The credit was computed by measuring the Btu content of the steam produced by the boiler.

The IRS has also ruled that the sale of methane gas from landfills qualifies for the credit. Credit is given if methane gas from a landfill drilling facility is sold to an "unrelated" company and is used to produce electricity.

The credit will not offset alternative minimum tax but will offset regular tax liability only to the extent that regular tax exceeds tentative minimum tax. Any unused credit in a particular year may not be carried back or forward to any other year. The credit is designed to be phased out if oil prices exceed a certain price level, which is adjusted annually for inflation. The 1991 credit would have begun to phase out if oil prices had exceeded $42 per barrel and would have been discontinued if they had exceeded $53 per barrel. The credit is reduced by the amount of grants or subsidized financing used to fund a particular project.

Table 11. Energy Recovery from Landfill Gas by Region, 1992
(Trillion Btu)

Region	1992	Percent of Total
Northeast	18	26
South	11	16
Midwest	13	19
West	30	43
Total	**70**	**100**

Note: Totals may not equal sum of components due to independent rounding.

Source: Governmental Advisory Associates, 1993/1994 Methane Recovery Database (preliminary estimate).

landfills. EPA landfill regulations,[76] which implement the CAA and its amendments (CAAA), may have the ancillary effect of stimulating the production of energy by requiring broader emissions control and monitoring.

Agricultural Waste

Agricultural waste and sewage sludge digestion are also sources of waste energy. Their use, however, is sparse (rendering energy statistics difficult to develop) and historically insignificant to the total biomass waste-to-energy contribution. Currently, there are no known sources that collect data on a regular basis to estimate

After this wheat field is harvested, the small grain straw (agricultural waste) can be used as waste energy.

the consumption of energy from agricultural waste and sewage sludge digestion. However, these energy sources are reported to be around 100 trillion Btu annually.[77]

Agricultural wastes include plant and animal residues. Plant residues consist of materials such as corn stover or husks, soybean stalks and pod shells, small grain straw, sunflower shells, oat and rice hulls, sugar beet seeds, sugar cane bagasse, and orchard prunings.

By one estimate, about 200 million tons of corn and soybean crop residues are produced annually in the Midwest alone and are potentially available for conversion to energy.[78] While most agricultural residues dry to a low moisture content, a good fuel trait, some contain high concentrations of minerals which require special considerations in combustion technology.

Agricultural waste data typically exclude those materials used in the food processing industry (SIC 20), usually reported as manufacturing waste. This exclusion encompasses the vast majority of agricultural residues, including cotton gin, citrus, sugar cane bagasse, nut shells, and rice hulls being used for energy in the manufacturing sector.

The real potential for using residues is limited by the following factors:

- The availability of residues is usually seasonal, which presents a storage problem if they are to be used for anything other than a supplementary fuel.
- Collection and transportation costs can be prohibitive.
- Labor and equipment may not be available during the harvest season.
- Many residues are already being used for animal feed, as soil amendments, and other purposes that may have a greater value than their energy content.
- The animal residues (manures) that can be used for energy come from animals that are raised in confinement, thus facilitating the collection of the manures. This effectively limits this available resource to manures from dairy cattle, beef cattle feedlots, hogs, and poultry.

Energy generally is recovered from animal residues by anaerobic digestion to produce methane gas. The manure is biologically converted in digester vessels or anaerobic lagoons (covered ponds). This methane gas is usually used for space heating, as a boiler fuel, or as fuel for electricity production by generators. Dried manures can also be used in combustion systems. Methane is sometimes recovered for energy from manure from feedlot or dairy operations.

The energy recovery from animal residues is constrained by limited markets. Most animal farming operations do not have a need for energy that can be satisfied by either methane gas derived from manure or the direct combustion of manure. The exception is large dairy farms that process and bottle their own milk. The alternatives are to generate electricity for sale to the grid or to produce pipeline quality methane gas, which would only be practical for large feedlots.

Environmental Issues Related to Biomass Waste

With public attention increasingly focused on environmentalism and climate change, there is enormous potential for the commercial use of biomass to accelerate. The use of fuel derived from biomass waste has a very high environmental benefit because it both substitutes for fuels that produce more toxic emissions during combustion, and utilizes a feedstock that in itself is environmentally damaging. The biomass feedstock with the lowest marginal cost is commercial waste. Waste imposes substantial and well recognized environmental costs, what economists refer to as “negative externalities.” Recognition of these externalities is reflected in tipping fees and costs imposed by regulation.

There are many benefits and few costs associated with using waste as a feedstock, whether it is industrial, agricultural, or municipal. MSW landfills account for the largest single source of anthropogenic methane emissions in the U.S. Both MSW landfills and unprocessed manure can result in leachate that contaminates surface water, causing fishkills and oxygen deprivation in aquatic ecosystems. The leachate also contains high levels of organic nitrates and bacteria that pose human health hazards.

Since there is value in keeping some crop residue on the land after harvest, the opportunity cost associated with leaving less than the optimal amount can be construed as the “cost” of its alternative use. Some agricultural waste left in the field increases rhizome activity and the soil's ability to retain nutrients and water, as well as decreasing erosion. Too much residue, however, can lead to depressed crop growth due to lower soil temperatures, reduced nitrate formation, and the harboring of pests and diseases. The amount of residue that is beneficial to leave on the ground after harvest varies by type of farming system.

Other environmental benefits also accrue from burning MSW or other types of waste to produce electricity. Combustion of MSW reduces its volume up to 90 percent. Though the ash from MSW combustion can be used as a fertilizer in some locations, it is generally disposed of in landfills dedicated to ash waste. The leachate from ash monofills is generally less than from ordinary landfills. It also has a lower metal concentrate. Most metals dissolve more slowly in ash monofills because the ash (and accompanying scrubber lime) is relatively basic.

Substituting waste for coal or petroleum oil eliminates the toxic emissions and other residues that would result from burning coal or petroleum oil to generate electricity. Air emissions for all types of biomass tend to be low relative to air emissions from coal and petroleum oil, particularly with respect to sulfur and carbon dioxide. Biomass is frequently co-fired with coal in order to reduce sulfur emissions. Even though nitrogen oxide emissions also tend to be lower for biomass than for coal, they are of some concern. Biomass combustion can produce problematic amounts of particulate matter and nitrogen oxides so that without adequate emission controls, one form of pollution is simply substituted for another.

(Excerpted from “Environmental Issues Related to Biomass: An Overview,” presented by Merritt Hughes of the U.S. Department of Agriculture, Office of Energy, and Jack W. Ranney of Oak Ridge National Laboratory at the First Biomass Conference of the Americas: Energy, Environment, Agriculture, and Industry, August 30-September 2, 1993.)

Sewage Sludge Digestion

Sludge is defined as solids that settle out from water but contain 55 to 99 percent water and are formed from industrial and public water treatment. Use of industrial sludge for energy is included in estimates of energy from manufacturing waste. The discussion below addresses energy from public water treatment sludge, also known as sewage sludge.

Energy can be recovered from the sludge from public water treatment operations in several ways. Gases are generated when sludge is composted to produce mulch, soil conditioners, and fertilizers. These gases include methane, which can be collected for use as a gaseous fuel. To date, however, sewage sludge gas recovery has been employed only by demonstration facilities.

Sludge can be disposed of by direct combustion. However, this process results in a net energy loss, requiring more energy to burn it than can be regained as output energy.

Biogas can be produced from sewage sludge through anaerobic digestion. In this process, the volume of solids is reduced by half, while methane gas (about 60 to 70 percent), carbon dioxide (30 to 40 percent), and trace gases are produced.

At water treatment facilities where gas volume is large enough to be cost-effective, the gas is collected to heat the digester tanks, to provide space heat to the treatment facility, and, in a some instances, to power an engine / generator to produce electricity.

Water treatment operations are energy-intensive. Self-generated energy represents only about 30 percent of total consumption by these facilities. The resulting biogas and electricity are rarely sold off-site.

Manufacturing Waste

Manufacturing waste refers to biomass byproducts from manufacturing processes. In general, manufacturing waste that is not disposed as MSW nor contained under woodfuel includes the following: food matter, such as nonconsumable animal parts or organs; residue from food processing operations, such as fats and oils; and packaging material, including paper, cardboard, and straw. Industries that consume process waste-derived energy include: Food and Kindred Products (SIC 20), Furniture and Fixtures (SIC 25), Paper and Allied Products (SIC 26), Petroleum and Coal Products (SIC 29), and Electronic and Other Electric Equipment (SIC 36). During 1992, approximately 77 trillion Btu of manufacturing waste was consumed, with more than half consumed in the West.

At one time, industrial use of farm and forest products was widespread. In the early part of the industrial revolution, nearly all industrial feedstocks were plant- or animal- based. In 1925, plant materials accounted for about 35 percent of industrial feedstocks. By 1989, plant material accounted for less than 16 percent of industrial inputs, most of which was used in paper manufacturing.[79] Today, the pulp and paper industry still consumes more biomass energy than any other industry group, especially through the burning of black liquor.

Future Outlook

The Federal government has found that regulatory requirements and acquisition practices are effective in levering into commercial viability some activities deemed necessary for the common good. In this vein, Executive Order 12873[80] promotes Federal in-house recycling and waste prevention. It directs the use of recycled and environmentally preferable products and services, without mentioning how these externalities will be funded. This order directly affects the future of MSW.

By any standard, modern municipal solid waste-to-energy facilities qualify as providing environmentally preferable products and services. Environmentally preferable means products or services that have a lesser or reduced adverse effect on human health and environment than comparable competing products or services. The comparison may consider raw materials acquisition, production, manufacturing, packaging, distribution, reuse, operation, maintenance, or disposal of the product of service.[81]

The Order creates jobs in each Federal agency to oversee the implementation of this Order, including a multi-agency group within the EPA. This group is tasked with the collection and dissemination of electronic information concerning methods to reduce waste, materials that can be recycled, waste prevention and recycling costs and savings, and current market sources of products that are environmentally preferable or produced with recovered materials.[82]

4. Alcohols

Background

Alcohols can be produced from biomass feedstocks or fossil-based feedstocks, such as crude oil, natural gas, and coal, through various chemical conversion processes. Biomass-derived alcohols are renewable, since the resources used to produce them can be naturally regenerated in a few years or less. In contrast, once the resources, which have developed over tens of millions of years, have been consumed by the production of fossil-based fuels, they can never be replaced.

In the past, alcohols, such as methanol and ethanol, were used as transportation fuels. The first automobiles manufactured by Henry Ford were powered by methanol. Before methanol was found to be valuable as a fuel, however, it was a coproduct recovered from the manufacture of charcoal (used in iron smelting). Ethanol, or grain alcohol, was used as a fuel and industrial solvent before 1862, when a tax was levied on it for those particular applications.[83] Ethanol also played an important role as a fuel extender in the United States during both World Wars, when petroleum products were scarce.

Traditionally, ethanol has been produced from biomass through the processes of hydrolysis, fermentation, and distillation, which are similar to the processes used to make alcohol spirits. About 95 percent of the U.S. production of fuel ethanol is derived from corn; 5 percent is produced from other grains, such as milo, sorghum, barley, and oats.[84] For industrial use, ethanol is produced from ethylene.

Methanol is currently receiving increased attention as a transportation fuel. Before the 1920s, methanol was produced through the pyrolysis (heating in the absence of air) of wood or agricultural crops. Current technology uses the catalytic conversion of natural gas to produce methanol most cost-effectively. Methanol can also be produced from biomass feedstocks, primarily wood, by gasification, followed by catalytically driven processes.

Biomass-derived methanol is used, only in limited quantities, to fuel demonstration fleets. It is not considered in this report because, currently, all methanol consumed as a fuel is produced from natural gas. Other alcohols that can be used as fuel oxygenates, such as TAME (tertiary amyl methyl ether) and TBA (tertiary butyl alcohol), are also produced from natural gas or manufactured by refinery processes.

Ethanol is commonly used as a gasoline extender, an oxygenate for carbon monoxide mitigation, and an octane enhancer in a gasoline blend containing 7 to 10 percent ethanol and 90 to 92 percent gasoline (by volume). In this form, the blend—commonly referred to as "gasohol" in the 1970s—is used in smaller internal combustion engines. Ethanol is also being used experimentally as a "neat" fuel (nearly 100 percent ethanol) for vehicles of all sizes.

Ethanol can be produced from any feedstock that can be reduced to fermentable sugars. Current U.S. technologies used in the production of ethanol rely on

Sweet sorghum can be used as a renewable energy source in the production of ethanol.

agricultural food crops, primarily corn. The feedstock is first prepared by converting starch to sugars. Yeast then ferments the sugars into ethanol. The ethanol is concentrated through a distillation process that yields a hydrous solution of ethanol and water. A final purification step can produce dry (anhydrous) ethanol.

Ethanol can also be produced from lignocellulosic biomass. Examples of lignocellulosic biomass include existing resources such as underutilized wood and logging residues, agricultural residues, municipal solid waste, and industrial waste.[85] Research and development in the conversion of wastes and nonfood crops to ethanol holds promise for reducing the cost of ethanol, but this development is not considered in this report because it is not commercially viable at present.

Historical Perspective

As a result of the 1973 petroleum embargo, alcohol fuels were the subject of public attention during the 1970s. During the early 1980s, however, petroleum prices and public concern with the development of alternative fuels declined. Nevertheless, ethanol consumption grew steadily during this period as a result of Federal and State incentives,[86] rising from 7 trillion Btu (92 million gallons) in 1981 to 56 trillion Btu (737 million gallons) in 1985.[87]

With the decline of gasoline prices in the mid-1980s, ethanol became economically less attractive. However, large producers with high production capabilities were able to keep ethanol production at fairly constant levels during the latter part of the 1980s. Consumption remained in the range of 50 to 60 trillion Btu (654 to 785 million gallons) throughout the late 1980s.

During the early 1990s, ethanol consumption fluctuated (Table 12). A large increase was seen in 1990, when ethanol consumption reached 82 trillion Btu (1,075 million gallons)—an increase of 28 trillion Btu from 1989. Additionally, at least 132 million gallons of ethanol were exported in 1990.

In 1991, however, consumption returned to the levels of the late 1980s, decreasing to 65 trillion Btu (851 million gallons). Consumption then increased to 79 trillion Btu (1,036 million gallons) in 1992.[88]

The increase during the early 1980s can be attributed to three major factors: the passage of the Energy Tax Act of 1978; the escalating gasoline prices of the early 1980s;

Table 12. U.S. Consumption of Ethanol by Region, 1985-1992[a]
(Trillion Btu)

Census Region	1985	1986	1987	1988	1989	1990	1991	1992	1992 Percent of Total
Northeast	([b])	([b])	([b])	([b])	([b])	([b])	([b])	([b])	<1
South	20	26	21	19	13	17	11	13	17
Midwest	32	41	33	35	35	55	45	55	70
West	4	4	4	6	6	10	9	10	12
Total	**56**	**70**	**58**	**60**	**54**	**82**	**65**	**79**	**100**

[a]This historical data series differs from those presented in previous publications because different data sources were used. See Appendix C for an analysis of the various data sources.
[b]Less than 1 trillion Btu.
Note: Totals may not equal sum of components due to independent rounding.
Sources: 1985-1991—Bureau of Alcohol, Tobacco and Firearms, fuel ethanol production and import data; and U.S. Bureau of the Census. The 1992 estimate was derived from ethanol production, change in stocks, and net imports reported on Form EIA-819M, "Monthly Oxygenate Telephone Report." Regional distributions were based on U.S. Department of Transportation, Federal Highway Administration, *Monthly Motor Fuel Reported by States*, FHWA-PL-92-0111 (Washington, DC, January 1993).

[85]B.J. Goodman and C.E. Wyman, "Near Term Application of Biotechnology to Fuel Ethanol Production from Lignocellulosic Biomass" (NREL, September 1993), p. 151.
[86]U.S. Department of Agriculture, Economic Research Service, *Ethanol: Economic and Policy Tradeoffs*, Agricultural Economic Report No. 585 (Washington, DC, April 1988), p. 1.

and the passage, by many States, of State ethanol tax credits and other incentives (Table 13). The Energy Tax Act exempted ethanol from a large portion of the Federal excise tax on gasoline, which amounted to an exemption of 54 to 60 cents per gallon of ethanol. Additionally, the average price of unleaded gasoline in the United States increased from $0.93 per gallon in 1978 to $1.38 per gallon in 1981, making ethanol more economically attractive.

Table 13. State Incentives for Fuel Ethanol (in Addition to Federal Tax Incentives), 1992 and 1993
(Cents per Gallon)

State	Retailer Gasohol Excise Tax Exemption		Change, 1992-1993
	1992	1993	
Alaska	8	8	0
Connecticut	1	1	0
Idaho	4	0	-4
Iowa	1	1	0
Nebraska	2	0	-2
New Jersey	4	0	-4
Oregon	5	0	-5
South Dakota	2	2	0
Washington	2	2	0
Wyoming	4	4	0

Source: U.S. Department of Transportation, Federal Highway Administration, *Monthly Motor Fuel Reported by States*, FHWA-PL-92-0111 (Washington, DC, January 1993).

These three factors led to an increase in the U.S. ethanol operational production capacity.[89] In 1990, production capacity was estimated to be slightly over 1 billion gallons.[90] The ethanol industry appears to be capable of doubling or tripling production, to more than 3 billion gallons annually, by the year 2000, based on the following assumptions: the availability of land, increased production of corn at current prices, and the ability of the ethanol industry to distribute the fuel outside of local markets.[91] While the industry may be capable of supporting an increased level of production, prices need to be competitive to encourage expansion.

Comparing the cost of ethanol with the costs of gasoline and other blending agents is made difficult by the complicated and interrelated patterns of petroleum and ethanol production and distribution, environmental regulation, and Government incentives. Ethanol's competitive position depends on the distribution system configuration, the use of ethanol as an octane enhancer, an oxygenate, or a fuel extender, volatility restrictions, the age of the motor vehicle stock, and State and local incentives. In general, ethanol cannot be price-competitive with petroleum as long as petroleum prices are below $25 per barrel without incentives. Ethanol could be competitive, however, if credits for byproducts exceeded the cost of corn.[92]

The extension of Federal tax benefits for ethanol producers to the year 2000 and the passage of the Clean Air Act Amendments of 1990, which mandates the reduction of mobile source emissions, could assist in the growth of ethanol consumption. Ethanol consumption could also grow as a result of the successful development of commercial processes based on wastes and nonfood crops. Future developments will also depend on the prices of corn, gasoline, and other alternative fuels.

Data and Analysis

Gross Production and Consumption

Table 12 indicates an increase in consumption between 1991 and 1992 which, in part, reflects a moderate industry response to a greater demand for ethanol. This demand was created by the first season of EPA's mandatory oxygenated fuel program during the winter of 1992-93.

Consumption of fuel ethanol in the United States is more difficult to estimate than production of ethanol (see Appendix C, “Methodology”). Historically, virtually all ethanol production has been consumed as gasohol.[93] In 1991, ethanol imports and exports totaled about 12 million gallons and 43 million gallons, respectively. Brazil was the largest customer for U.S. fuel ethanol. In 1992, imports totaled 37 million gallons, and exports dropped to about 6 million gallons, due primarily to a drop in exports to Brazil (see box below).

[89]Production capacity data are not included in this report, because they are not available on an annual basis.
[90]Information Resources, Inc., *Oxy-Fuel News*, Vol. II, No. 38 (January 7, 1991), p. 4.
[91]U.S. General Accounting Office, *Alcohol Fuels: Impacts from Increased Use of Ethanol Blended Fuels*, GAO / RCED-90-156 (Washington, DC, July 1990), p. 3.
[92]S.M. Kane and J.M. Reilly, U.S. Department of Agriculture, Economic Research Service, *Economics of Ethanol Production in the United States*, Agricultural Economic Report No. 607 (Washington, DC, March 1989), pp. 17-18.

The Ethanol Shortage in Brazil

In the 1980s, Brazil launched a major program to develop ethanol as a substitute for gasoline. Since most of the country's petroleum was imported, the Brazilians wanted to use a domestically available fuel. During 1990, the Brazilian government took a variety of actions to alleviate a serious fuel ethanol shortage that began in late 1989, due to higher world sugar prices, which diverted sugar use from ethanol production. As a result, in 1990, reported U.S. exports of ethanol totaled 132 million gallons, most of which was shipped to Brazil. Prices paid to ethanol producers in Brazil were raised in 1991 to bring them more closely in line with world prices, and producers' debts were renegotiated. Credits were made available for expansion of sugar cane planting, because a rebound in world sugar prices had placed ethanol production in competition with sugar production. In 1992, Brazil imported no U.S. ethanol.

(U.S. General Accounting Office, Alternative Fuels: Experiences of Brazil, Canada, and New Zealand in Using Alternative Motor Fuels, *GAO/RCED-92-119 (Washington, DC, May 1992), pp. 53-55.)*

Imports and exports have been very small factors in the U.S. ethanol industry, except during 1990.

During 1992, ethanol production increased by 8 trillion Btu, reaching 73 trillion Btu. Despite this growth, however, production was still less than the 82 trillion Btu produced in 1990. Despite the greater demand for oxygenates up to November 1992, industry response (in the form of fuel ethanol production) to the demand was moderate. Analysis of EIA data shows that in 1992, from the beginning of the year through November, producers' cumulative stocks were at a very low level.[94] In spite of the widely anticipated increase in oxygenate demand which began in November 1992, producers did not substantially augment their inventories.

Overall, ethanol contributed approximately 0.7 percent of the total fuel consumption of gasoline-powered vehicles in 1990. This figure does not include the approximately 132 million gallons of ethanol that were exported, primarily to Brazil, but does include the consumption of imported ethanol. In 1992, ethanol contributed about 0.9 percent of the total fuel consumption by gasoline-powered vehicles.

The Midwest region has consistently accounted for more than half of annual U.S. ethanol consumption. During 1992, ethanol consumption in the Midwest totaled 55 trillion Btu (720 million gallons), while 13 trillion Btu (170 million gallons) were consumed in the South. Ten trillion Btu (131 million gallons) were consumed in the West, and less than 1 trillion Btu were consumed in the Northeast (Table 12).

In the Northeast region, there is relatively little grain production, and few tax credits exist for ethanol. The Midwest (Illinois and Iowa in particular) has more large ethanol producers than other regions in the country due to the availability of corn feedstock. Local production in the Midwest region results in reduced transit expenses from the producer to the blender to the retailer. It also leads to greater consumption of gasohol. In the West, distribution is difficult, and freight costs generally lower the cost-competitiveness of ethanol.

The variations in regional ethanol consumption, as discussed above, are attributable to the following factors:

- **State tax credits** are currently provided in only 10 States (Table 13). State producer incentives for fuel ethanol have shown a decline in number and size over the past several years. This is due to several factors, including tight State budgets and the perception that ethanol is now well-established in the fuel market because of its qualities as an oxygenate.

- **Transportation costs** include the distance between ethanol producers and areas of high grain (corn) production.

- **Limitations of the distribution infrastructure**, such as pipelines and storage facilities, exist.

Factors That Influence Fuel Ethanol Consumption

The following three major U.S. policy concerns contribute to the importance of ethanol: environmental quality, energy security, and agricultural income stabilization.[95] The U.S. Department of Agriculture has estimated that farm income could increase by as much as $1 billion by the year 2000 as a result of expanded ethanol production.[96] The expansion of ethanol production from current levels to 2 billion gallons annually would also displace an additional 41 million barrels of imported oil and improve the country's balance-of-payments account by $1 billion.[97]

Legislation

Major forces behind the evolution of ethanol as a transportation fuel include a series of Federal laws that began in 1978 (see box below), as well as the Clean Air Act (CAA) of 1963 and its subsequent Amendments (CAAA), enacted in 1970, 1977, and 1990.

During 1990, gasoline blends containing at least 10 percent ethanol (gasohol) received a Federal tax exemption of 6 cents per gallon of blend. This exemption provided ethanol with a market subsidy of approximately 60 cents per gallon.[98] The current subsidy equals about $25 per barrel of ethanol. When the energy difference is considered, the subsidy equals about $40 per barrel of gasoline displaced.[99] In addition, individual State incentives, primarily in the form of tax exemptions, were made available to producers and/or retailers. The tax exemptions range from 1 cent per gallon of fuel blend to 8 cents, equal to an ethanol-equivalent market incentive of 10 to 80 cents per gallon of ethanol (Table 13). Mandated by the Miscellaneous Tax and Budget

A History of Legislation Affecting Ethanol as a Fuel

The following legislative acts have contributed to the use of ethanol as a fuel:

- The **Energy Tax Act of 1978**, Section 4081, defined gasohol as a blend of 90 percent gasoline and 10 percent renewable-derived alcohol and established a motor fuel excise tax exemption of 4 cents per gallon for it through October 1, 1984.
- The **Energy Security Act of 1980** authorized funds for building alcohol fuel production plants.
- The **Crude Oil Windfall Profit Tax of 1980** extended the 4-cents-per-gallon tax exemption for gasohol to December 31, 1992, and established a blender's tax credit of 40 cents per gallon of fuel blend for the use of alcohol in any proportion other than 10 percent alcohol/90 percent gasoline.
- The **Omnibus Reconciliation Tax Act of 1980** placed a tariff on imported fuel ethanol/gasoline blends that was equivalent to the blender's tax credit established by the Crude Oil Windfall Profit Tax of 1980.
- The **Surface Transportation Act of 1982** raised the gasoline tax from 4 cents per gallon to 9 cents per gallon and increased the exemption for gasohol to 5 cents per gallon.
- The **Deficit Reduction Act of 1984** increased the tax exemption for gasohol to 6 cents per gallon and increased the blender's tax credit to 60 cents per gallon of blend.
- The **Alternative Motor Fuels Act of 1988** encouraged the use of alternative fuels, including ethanol, and addressed national energy policy concerns.
- The **Budget Reconciliation Act of 1990** reduced the gasohol tax exemption to 5 cents per gallon and the blender's tax credit for ethanol to 54 cents per gallon. It extended these incentives to the year 2000. The law provided a credit of 10 cents per gallon for the first 15 million gallons of ethanol manufactured by qualified small producers with annual outputs of less than 30 million gallons.
- The **Energy Policy Act of 1992** set guidelines and established incentives to encourage the increased use of alternative fuels and alternative-fueled vehicles in Federal, State, and private fleets. It preserved the 5-cents-per-gallon Federal motor fuel excise tax exemption for gasohol and the 54-cents-per-gallon blender's income tax credit for ethanol.

A series of Federal laws, beginning in 1978, contributed to the evolution of ethanol as a transportation fuel.

Reconciliation Act of 1990, the Federal tax exemptions were extended through December 31, 2000, and the level of exemption was decreased from 6 to approximately 5 cents per gallon of ethanol / gasoline blend.

The Energy Policy Act of 1992 (EPACT) established guidelines for the development of a more extensive alternative transportation fuel and vehicle infrastructure. In addition to its goal of improving energy security through the development of alternatives to oil, EPACT also reinforces the Clean Air Act by promoting clean alternative fuels, such as ethanol. Additionally, EPACT preserved the Federal motor fuel excise tax exemption for ethanol and the blender's income tax credit for the use of ethanol in blends. The law also expanded the definition of gasohol to include 7.7 percent (by volume) and 5.7 percent (by volume) ethanol blends[100] and allowed them exemptions of 4 cents per gallon and 3 cents per gallon, respectively.[101] Without these Federal and State tax subsidies, ethanol would be unable to compete with petroleum-based products in the transportation fuels sector.

Environmental Considerations

The Clean Air Act Amendments (CAAA) of 1990 directed the U.S. Environmental Protection Agency (EPA) to establish National Ambient Air Quality Standards (NAAQS). The NAAQS designated four categories for air quality characterization: EXTREME, SERIOUS, SEVERE, and MODERATE. EPA measures several “mobile source” (vehicle) related ambient air toxics, including carbon monoxide (CO) and ozone. Using NAAQS as a gauge, EPA designated some areas of the country as “CO nonattainment areas.”

Several regulations concerning exhaust and evaporative emissions have been issued by EPA. In 1971, the agency established a standard for CO emissions: 9 parts per million (ppm) CO may be emitted, on average, for an 8-hour period; 35 ppm may be emitted for a 1-hour period. These standards may not be exceeded more than once a year. From 1976 to 1985, national CO levels declined by 36 percent.[102] In 1987, however, there were still 81 areas of the country that were not in attainment for CO.[103] As of 1990, 39 areas were classified as CO nonattainment areas.[104] This may have been due, in part, to EPA's mandatory winter oxygenated fuel program, which recently completed its first season.

Carbon monoxide emissions result from incomplete combustion of fuel. Adding oxygen to the fuel makes combustion more complete, and CO emissions are reduced as carbon dioxide (CO_2) is produced instead of CO. The CAAA began the oxygenated gasoline program during the winter of 1992. This program requires that oxygenated gasoline containing a minimum of 2.7

[100]On the basis of oxygenating properties, 7.7 percent ethanol contributes 2.7 percent (by weight) oxygen to a gasohol blend and 5.7 percent ethanol imparts 2.0 percent (by weight) oxygen. These are the minimum oxygen contents mandated by the Clean Air Act Amendments of 1990 for carbon monoxide and ozone nonattainment areas, respectively.

percent oxygen (by weight) be used in CO nonattainment areas during the winter months, usually beginning in November. CO emissions are particularly high in the winter, when cold weather increases CO vehicle exhaust emissions. Emissions are especially prominent from the time a car engine is first started until it warms up.

Oxygenated gasoline must be used during the winter months when the specified CO nonattainment areas are prone to high concentrations of CO. The first urban areas, where CO emissions are particularly high during the winter months, to require the use of oxygenated gasoline include Colorado, Arizona, New Mexico, and Nevada.[105] The CO season lasts a minimum of 4 months, but it may be longer in areas where the duration of CO nonattainment is longer.[106] These areas encompass one-third of the country's population, and 31 percent of the gasoline consumed during the winter in the United States is consumed in these areas.[107]

During the first oxygenated gasoline season, virtually the only two oxygenates used were MTBE (methyl tertiary butyl ether) and ethanol. Ethanol has a significantly higher oxygen content than MTBE and is thus more effective in reducing CO on an equal volume basis. The blending octane value of fuel ethanol is slightly higher than that of MTBE, but MTBE has a lower blending Reid Vapor Pressure (i.e., lower volatility) and is more easily transported in existing pipelines. On an MTBE equivalent basis,[108] during the first oxygenated gasoline season, MTBE supplied about 58 percent of the oxygenate blended, while ethanol supplied the remaining 42 percent.[109] It was estimated that over half the ethanol used during the peak season was used as an oxygenate in oxygenated gasoline.

From November 1992 through January 1993, EPA carbon monoxide standards were exceeded only twice (Table 14) in 20 areas using oxygenated fuel. However, during the same period 1 year prior to the introduction of oxygenated fuels into the market, the same areas exceeded Federal standards 43 times. Nevertheless, as Table 14 indicates, there has been a pattern of reduced CO exceedances over the past six winter seasons. While the wintertime oxygenated fuel program clearly appears to have been successful, EPA attributes some of the 1992-1993 reduction to turbulent weather. In 2001, the oxygen level in gasoline may be increased, at the discretion of the EPA, to 3.1 percent (by weight) in the remaining CO nonattainment areas classified as SERIOUS.

Fuel Transportation Obstacles

One of the obstacles to the use of ethanol is that it must be "splash-blended" near the point of sale, due to its affinity to water, which interferes with pipeline transportation. If water is contained in the pipelines, which sometimes occurs, the alcohol and water will combine and separate out of the petroleum product, causing the finished product to fall below specifications.

Table 14. Carbon Monoxide Exceedances in Areas with Oxygenated Fuel Programs, 1987-1993
(Number of Occurrences)

Period	November	December	January	Total
11/87-1/88	38	38	56	**132**
11/88-1/89	16	50	31	**97**
11/89-1/90	20	76	17	**113**
11/90-1/91	16	15	25	**56**
11/91-1/92	14	14	15	**43**
11/92-1/93	1	1	0	**2**

Note: Data exclude California, which has an EPA waiver permitting only a 2.0-percent oxygen content (by weight) instead of the 2.7-percent program requirement.
Source: Adapted from U.S. Environmental Protection Agency, *Alcohol Outlook* (March 1993), p. 2.

[105]U.S. General Accounting Office, *Alcohol Fuels: Impacts from Increased Use of Ethanol Blended Fuels*, p. 9.

Because ethanol is typically produced in the Midwest, far from the major refining centers on the Gulf Coast and eastern areas, and cannot be transported by pipeline, it must be carried on land or water to be blended into gasoline. As a result, ethanol is currently transported mostly by truck, barge, and rail car, all of which are far more costly than pipeline transportation. MTBE, on the other hand, can be blended at the refinery and shipped by pipeline.

The current petroleum products pipeline system has been in place for many years and was built before ethanol blending in gasoline was an option. Most of this system is unidirectional for large batches of petroleum products, flowing from the Gulf Coast to the major population centers and from California to points west of the Rockies. The pipeline system is neither conveniently located nor structured for efficient distribution of small batches of ethanol from the major ethanol-producing areas in the Midwest.

Without anticorrosive additives, alcohol fuels are not considered suitable for distribution in the existing oil pipeline infrastructure. New pipelines with corrosion-resistant surfaces may be built, which would eliminate the concern for the pipelines' lifetime integrity; however, this will probably occur slowly, over time, as sections of corroded pipeline are replaced with segments that have new surfaces.

The Oxygenate Market

By November 1992 (the first month of the first season of the oxygenated gasoline program), more than 16 million barrels of MTBE, ethanol's main competitor in the oxygenate market, were in producer stocks.[110] By the end of 1992, total U.S. production of MTBE equaled nearly 37 million barrels (slightly over 1 billion gallons).[111] During the first oxygenated gasoline season, MTBE blending in gasoline increased by more than 400 percent, to 233,000 barrels per day. Although ethanol blending in gasoline increased somewhat during the same period, it did not experience the dramatic increases of MTBE blending. During 1992, ethanol was blended into gasoline at a rate of 69,000 barrels per day.[112] Uncertainty surrounding blending regulations, continuance of the Federal motor fuel excise tax exemption for ethanol, and controversy associated with pending legislation were the major factors responsible for the high degree of industry caution regarding the use of ethanol.

To place these statistics in perspective, total CO-related oxygenate demand is estimated to be 200,000 barrels per day (about 3 billion gallons per year) until 1995.[113] As other oxygenates, such as TAME and TBA, are produced, additional factors in the market share will develop. ETBE (ethyl tertiary butyl ether), which can be made from biomass products, may also become a market participant. At the time of this writing, however, it is not clear whether biomass-derived ETBE would be given a Federal subsidy similar to ethanol's subsidy. In 1995, an additional demand factor will take effect when EPA's Phase I reformulated gasoline program is initiated. This program requires all gasoline sold in NAAQS ozone nonattainment areas to contain a minimum of 2.0 percent (by weight) oxygen. This requirement will necessitate the addition of oxygenates, such as MTBE and ethanol, to gasoline. Although ethanol will undoubtedly participate in the reformulated gasoline market, it is unclear to what degree.

The Market for Ethanol Byproducts

The market for byproducts of ethanol production represents a major determinant in the overall cost-effectiveness of ethanol production. Ethanol byproducts include animal feeds such as gluten feed, gluten meal, and distillers' dried grains.

The European Community (EC) is the major consumer of ethanol feed byproducts, representing about 95 percent of U.S. gluten feed exports.[114] A 1962 trade agreement established a duty-free status for gluten feed. Exports of gluten feed to Europe approached 4 million metric tons annually in 1988.[115] For the past several years, however, the EC has become progressively more restrictive with animal feed imports from the United States. This stance resulted from the difficulty of reaching an agreement on these commodities in recent General Agreement on Tariffs and Trades (GATT) sessions and from disagreements over the acceptable protein content of gluten feed. EC duties on these byproducts or limits on imports reduce the value of the

[110]One barrel is equivalent to 42 U.S. gallons. Energy Information Administration, *Weekly Petroleum Status Report*, DOE/EIA-0208(93-38) (Washington, DC, September 17, 1993), p. 35.
[111]Energy Information Administration, *Petroleum Supply Monthly*, DOE/EIA-0109(93/07) (Washington, DC, July 1993), p. 147.

byproducts. They also increase the cost of fuel ethanol production and diminish producer profitability.[116]

The U.S. Department of Energy has sponsored research on the processes for converting feedstocks, including lignocellulosic biomass, to ethanol more completely. The goal of the research is to produce a higher ethanol yield and a lower byproduct volume. Ethanol feed byproducts compete with soybean meal in the animal feed market. The U.S. Department of Agriculture is finding new applications for soybeans and other products, including the production of biodiesel (see box below), a potential substitute fuel for diesel-powered vehicles. Development of new biomass-derived products may offer solutions to problems such as having limited markets for the byproducts of ethanol production.

Future Outlook

Consumption of ethanol in the United States as a gasoline supplement and octane enhancer is projected to increase to 130 trillion Btu by 2010.[117] The potential for corn-based alcohol production is limited because of relatively high feedstock (corn) and production costs. Reduction of feedstock costs and improvement of the cost and efficiency of conversion processes must be implemented before ethanol can be cost-competitive. Research is being conducted to develop low-cost crops designed for high ethanol yields and new and improved ethanol production processes. These developments, which are expected to evolve over a long period of time, could have a significant commercial impact.

Biodiesel

The Energy Policy Act of 1992 (EPACT) established a goal for the year 2000 of replacing 10 percent of motor fuels with nonpetroleum alternative fuels. At least half this amount must be derived from domestic sources. By 2010, the EPACT goal rises to 30 percent of motor fuels.

In addition to alternative and replacement fuels as defined by EPACT, biodiesel is being considered as a possible substitute fuel to help achieve this goal. Made from vegetable oils, plant oilseeds, or animal tallow, biodiesel has characteristics very much like conventional diesel fuel. It can be burned in conventional diesel engines with minimal or no engine modifications.

Biodiesel's major advantage is that it is environmentally clean. Unlike conventional diesel fuel, biodiesel contains neither sulfur nor aromatics. Aromatics contribute to particulate emissions. These properties are highly desirable in view of:

- New EPA regulations which limit sulfur content in diesel fuel to 0.05 percent.
- California Air Resources Board limits on aromatics content of diesel fuel set at 10 percent. Conventional diesel aromatic content is often 40 to 60 percent.

Additionally, biodiesel is biodegradable. European tests of rapeseed-oil-based biodiesel indicate that it is 99.6 percent biodegradable within 21 days.[1] Within 1 month of spillage, biodiesel should decompose completely.

While biodiesel may have a slight environmental disadvantage regarding NO_x emissions,[2] its principal disadvantage is cost. Biodiesel fuel costs over $2 per gallon, compared to 65 to 70 cents for conventional diesel fuel. For biodiesel to be economically competitive, it would require support roughly equivalent to that currently provided for fuel ethanol.

Currently, biodiesel is produced by a process called transesterification. The input fat or oil is first filtered, then preprocessed with alkali to remove free fatty acids. It is then mixed with an alcohol (usually methanol) and a catalyst.[3] The oil's triglycerides react to form esters and glycerol, which are then separated from each other and purified. Esters, such as rape methyl ester (derived from the seeds of rapeseed plants), can be used as a transportation fuel or an additive to diesel fuel.

[1]Werner Korbitz, *Biodiesel Presentation Outline* (Vienna, Austria, 1993).
[2]Emissions data on biodiesel are very limited. However, it appears that nitrogen oxides emissions are greater with biodiesel than conventional diesel fuel. It is possible this problem can be overcome by engine ignition timing adjustments.
[3]Usually sodium or potassium hydroxide.

Appendix A
Standard Industrial Codes

This appendix contains descriptions of industrial groups and selected industries taken from the *1988 Manufacturing Energy Consumption Survey*.[118]

SIC 20—**Food and Kindred Products:** This major group includes establishments manufacturing foods and beverages for human consumption and certain related products, such as manufactured ice, chewing gum, vegetable and animal fats and oils, and prepared feeds for animals and fowls.

SIC 21—**Tobacco products:** This major group includes establishments engaged in manufacturing cigarettes, cigars, smoking and chewing tobacco, snuff, and reconstituted tobacco and in stemming and redrying tobacco.

SIC 22—**Textile Mill Products:** This major group includes establishments engaged in performing any of the following operations: (1) preparation of fiber and subsequent manufacturing of yarn, thread, braids, twine, and cordage, (2) manufacturing broad-woven fabrics, narrow-woven fabrics, knit fabrics, and carpets and rugs from yarn, (3) dyeing and finishing fiber, yarn, fabrics, and knit apparel, (4) coating, waterproofing, or otherwise treating fabrics, (5) the integrated manufacture of knit apparel and other finished articles from yarn, and (6) the manufacture of felt goods, lace goods, nonwoven fabrics, and miscellaneous textiles.

SIC 23—**Apparel and Other Textile Products:** This major group, known as the cutting-up and needle trades, includes establishments producing clothing and fabricating products by cutting and sewing purchased woven or knit textile fabrics and related materials, such as leather, rubberized fabrics, plastics, and furs.

SIC 24—**Lumber and Wood Products:** This major group includes establishments engaged in cutting timber and pulpwood as well as merchant sawmills, lath mills, shingle mills, cooperage stock mills, planing mills, and plywood and veneer mills engaged in producing lumber and wood basic materials. Establishments engaged in manufacturing finished articles made entirely or mainly of wood or related materials are also included.

SIC 25—**Furniture and Fixtures:** This major group includes establishments engaged in manufacturing household, office, public building, and restaurant furniture. It also includes office and store fixtures.

SIC 26—**Paper and Allied Products:** This major group includes establishments primarily engaged in the manufacture of pulps from wood and other cellulose fibers and from rags. Also included are establishments that manufacture paper and paperboard as well as convert paper and paperboard into products, such as paper coated off the paper machine, paper bags, paper boxes, and envelopes.

SIC 2621—**Paper Mills:** This group includes establishments primarily engaged in manufacturing paper from wood pulp and other fiber pulp. Establishments which also manufacture converted paper products may also be included.

SIC 2631—**Paperboard Mills:** This group includes establishments primarily engaged in manufacturing paperboard, including paperboard coated on the paperboard machine, from wood pulp and other fiber pulp.

SIC 27—**Printing and Publishing:** This major group includes establishments engaged in printing by one or more common processes, such as letterpress, lithography (including offset), gravure, or screen, as well as those establishments that perform services for the printing trade, such as bookbinding and platemaking.

SIC 28—**Chemicals and Allied Products:** This major group includes establishments producing basic chemicals and establishments manufacturing products by predominantly chemical processes. Establishments classified in this major group manufacture three general

[118]Energy Information Administration, *Manufacturing Energy Consumption Survey: Consumption of Energy 1988*, pp. 195-197.

classes of products: (1) basic chemicals, such as acids, alkalies, salts, and organic chemicals, (2) chemical products to be used in further manufacture, such as synthetic fibers, plastics materials, dry colors, and pigments, and (3) finished chemical products to be used for ultimate consumption, such as drugs, cosmetics, and soaps; or to be used as materials or supplies in other industries, such as paints, fertilizers, and explosives.

SIC 2819—**Industrial Inorganic Chemicals, Not Elsewhere Classified:** This group includes establishments primarily engaged in manufacturing industrial organic chemicals, excluding alkalies and chlorine, industrial gases, and inorganic pigments.

SIC 2821—**Plastics Materials and Resins:** This group includes establishments primarily engaged in manufacturing synthetic resins, plastics materials, and nonvulcanizable elastomers.

SIC 2869—**Industrial Organic Chemicals, Not Elsewhere Classified:** This group includes establishments primarily engaged in manufacturing industrial organic chemicals, excluding gum and wood chemicals, and cyclic organic crudes and intermediates, and organic dyes and pigments.

SIC 2873—**Nitrogenous Fertilizers:** This group includes establishments primarily engaged in manufacturing nitrogenous fertilizer materials or mixed fertilizers from nitrogenous materials produced in the same establishment.

SIC 29—**Petroleum Refining and Related Industries:** This major group includes establishments primarily engaged in petroleum refining, manufacturing paving and roofing materials, and compounding lubricating oils and greases from purchased materials.

SIC 2911—**Petroleum Refining:** This group includes establishments primarily engaged in producing gasoline, kerosene, distillate fuel oils, residual fuel oils, and lubricants, through fractionation or straight distillation of crude oil, redistillation of unfinished petroleum derivatives, cracking or other processes.

SIC 30—**Rubber and Miscellaneous Plastics Products:** This major group includes establishments manufacturing products, not elsewhere classified, from plastics, resins, and from natural, synthetic, or reclaimed rubber, gutta percha, balata, or gutta siak.

SIC 31—**Leather and Leather Products:** This major group includes establishments engaged in tanning, currying, and finishing hides and skins, leather converters, and establishments manufacturing finished leather and artificial leather products and some similar products made of other materials.

SIC 32—**Stone, Clay, Glass, and Concrete Products:** This major group includes establishments manufacturing flat glass and other glass products, cement, structural clay products, pottery, concrete and gypsum products, cut stone, abrasive and asbestos products, and other products from materials taken principally from the earth in the form of stone, clay, and sand.

SIC 3241—**Cement, Hydraulic:** This group includes establishments primarily engaged in manufacturing hydraulic cement, including portland, natural, masonry, and pozzolana cements.

SIC 33—**Primary Metal Industries:** This major group includes establishments engaged in smelting and refining ferrous and nonferrous metals from ore, pig, or scrap. Establishments that also engage in rolling, drawing, and alloying metals or manufacturing castings and other basic metal products are also included. Other establishments included are those that manufacture nails, spikes, and insulated wire and cable.

SIC 3312—**Steel Works, Blast Furnaces (Including Coke Ovens), and Rolling Mills:** This group includes establishments primarily engaged in manufacturing hot metal, pig iron, and silvery pig iron from iron ore and iron and steel scrap. Establishments that convert pig iron, scrap iron, and scrap steel into steel or engage in hot-rolling iron and steel into basic shapes, such as plates, sheets, strips, rods, bars, and tubing, are also included.

SIC 3334—**Primary Production of Aluminum:** This group includes establishments primarily engaged in producing aluminum from alumina and in refining aluminum by any process.

SIC 34—**Fabricated Metal Products:** This major group includes establishments engaged in fabricating ferrous and nonferrous metal products such as metal cans, tinware, handtools, cutlery, general hardware, nonelectric heating apparatus, fabricated structural metal products, metal forgings, metal stampings, ordnance (except vehicles and guided missiles), and a variety of metal and wire products, not elsewhere classified.

SIC 35—**Industrial Machinery and Equipment:** This major group includes establishments engaged in manufacturing industrial and commercial machinery and equipment and computers.

SIC 36—**Electronic and Other Electric Equipment:** This major group includes establishments engaged in manufacturing machinery, apparatus, and supplies for the generation, storage, transmission, transformation, and utilization of electrical energy.

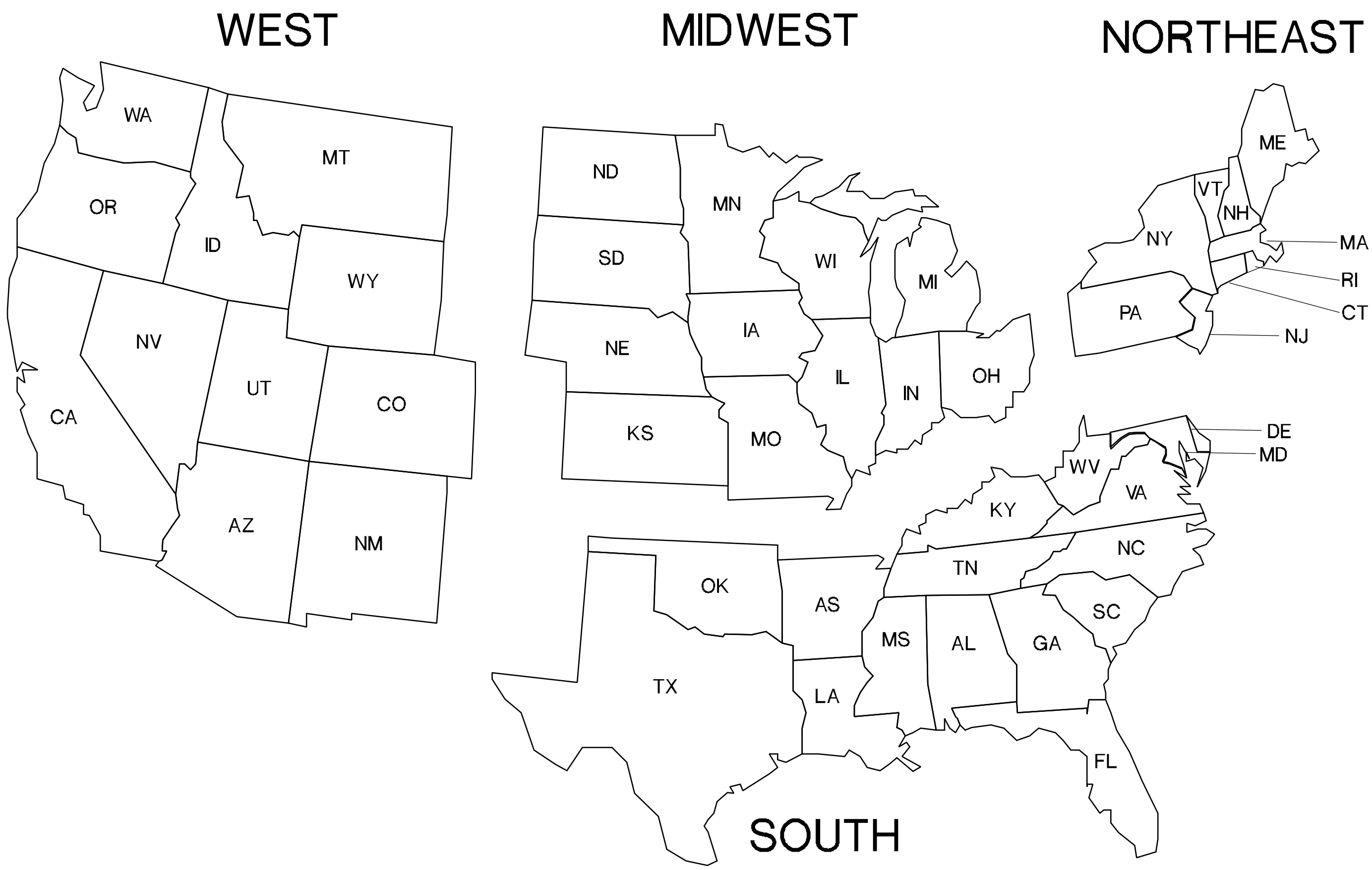
SIC 37—**Transportation Equipment:** This major group includes establishments engaged in manufacturing equipment for transportation of passengers and cargo by land, air, and water.

SIC 38—**Instruments and Related Products:** This major group includes establishments engaged in manufacturing instruments (including professional and scientific) for measuring, testing, analyzing, and controlling and their associated sensors and accessories. Establishments engaged in the manufacturing of optical instruments and lenses, surveying and drafting instruments, hydrological, hydrographic, meteorological, and geophysical equipment as well as search, detection navigation, and guidance systems and equipment are included. Also included are establishments that manufacture surgical, medical, and dental instruments, equipment and supplies as well as ophthalmic goods, photographic equipment and supplies, and watches and clocks.

SIC 39—**Miscellaneous Manufacturing Industries:** This major group includes establishments primarily engaged in manufacturing products not classified in any other major group.

Appendix B
U.S. Census Regions

Figure B1. U.S. Census Region Map



Source: U.S. Department of Commerce, Bureau of the Census.

Appendix C
Procedures for Estimating Consumption Levels

Procedure for Industrial Sector Woodfuel Consumption

Data developed to measure woodfuel consumption in the industrial sector in 1991 are based on the 1991 Manufacturing Energy Consumption Survey (MECS) conducted by the Energy Information Administration (EIA). The data include selected wood inputs of energy for heat, power, and electricity generation consumed in the following fuel categories:

- Waste Materials
- Pulping Liquor
- Roundwood
- Wood Chips, etc.

Regional and sectoral woodfuel consumption values for 1991 were derived by applying the 1990 sectoral and regional distributions presented in *Estimates of U.S. Biofuels Consumption 1990* to the 1991 MECS total wood consumption figure. This procedure was used because significant portions of the 1991 MECS wood consumption data by industrial sector and by region were withheld due to disclosure requirements and/or estimated standard errors that were greater than 50 percent. Applying this method assumes that the industrial sector and regional distributions remain the same as in 1990.

The 1992 industrial woodfuel consumption figures were derived by applying the 1992/1991 ratio of total industrial energy consumption in quadrillion Btu (23.53/ 22.57 = 1.0425) to the estimated 1991 woodfuel estimates.[119]

Procedure for Residential Sector Woodfuel Consumption

Residential woodfuel consumption estimates for 1991 and 1992 could not be obtained from EIA surveys. The most recent data reported in EIA's Residential Energy Consumption Survey (RECS) were for 1990 (582 trillion Btu total). The procedure used for estimating residential fuelwood consumption for 1991 and 1992 consisted of applying the 1991/1990 and 1992/1990 ratios of population-weighted *regional* heating degree days to the 1990 regional RECS values, respectively. The same procedure was employed for *Estimates of U.S. Biofuels Consumption 1990*. Use of this procedure was based on the assumption that the residential sector consumed the same amount of wood per heating degree-day in 1991 and 1992 as in 1990.

The formula used for the 1992 conversion was as follows:

$$C = C' (a/b)$$

where:
C = 1991 estimated consumption
C' = 1990 RECS consumption
= 582 trillion Btu
a = heating degree-days for 1991
b = heating degree-days for 1990.

The same approach was used to estimate 1992 residential woodfuel consumption, except that 1991 heating degree-days were replaced by 1992 heating degree-days.

Procedure for Electric Utility Sector Woodfuel Consumption

The 1991 and 1992 electric utility woodfuel consumption figures were obtained by contacting each electric utility that reported woodfuel use on Form EIA-759, "Monthly Power Plant Report," to determine the number of short tons burned by each facility in each year. For plants that reported consumption in short tons of green wood (tons of wood containing 50 percent or more water by weight), consumption data were converted into oven-dried short tons using the following formula:

[119]Energy Information Administration, *Annual Energy Review 1992*, DOE/EIA-0384(92) (Washington, DC, June 1993), p. 31.

$$ODST = GT \times CF$$

where:
$ODST$ = oven-dried short ton.
GT = green tons consumed
CF = (8,000,000 Btu per green ton) / (17,200,000 Btu per oven-dried short ton) = 0.465 oven-dried short tons per green ton.

Procedure for MSW and Landfill Gas Estimates

Municipal solid waste (MSW) and landfill gas estimates for 1992 were derived from data contained in Governmental Advisory Associates (GAA), *Resource Recovery Yearbook*[120] and *Methane Recovery Yearbook*.[121] The following specific steps were taken to calculate both MSW and landfill gas consumption estimates for 1992.

MSW

Steam Plants. For steam-only plants, the following equation was used:

Thermal output (trillion Btu) = [Steam output (pounds per hour) × Btu per pound of steam × days operating per year × 24 hours per day] / 10^{12}.

Electricity Plants. For electricity-only plants, the following equation was used:

Thermal output (trillion Btu) = [MSW throughput (tons per day) × 2,000 pounds per ton × days operating per year × Btu per pound of MSW] / 10^{12}.

Electricity and Steam Plants. For electricity-and-steam plants, the equation for electricity-only plants was used.

Landfill Gas (Methane)

The following equation was used to derive estimates of consumption for 1990:

Thermal output (trillion Btu) = [Cubic feet of methane produced per day × Btu per cubic foot of methane × (365 days - days shut down)] / 10^{12}.

For plants producing pipeline-quality gas, the Btu per cubic foot value for treated gas was used. Data for 1992 are not yet available; however, GAA estimates that by the beginning of 1994, landfill gas energy consumption had increased by 25 percent from 1990 levels. The estimates for 1990 were increased by 25 percent to obtain 1992 consumption.

Procedure for Manufacturing Waste Estimates

For the previous issue of this publication, *Estimates of U.S. Biofuels Consumption 1990*, estimates for manufacturing waste consumption were based on data obtained from EIA's 1988 Manufacturing Energy Consumption Survey (MECS). For the 1991 MECS, manufacturing waste consumption data were not available because the relative standard error was greater than 50 percent.

The 1991 and 1992 manufacturing waste estimates presented here were derived by applying the 1991 / 1990 and 1992 / 1990 total industrial energy consumption ratios to the estimated 1990 values, respectively.

Procedure for Fuel Ethanol Consumption Estimates

Fuel ethanol consumption estimates for 1985-1991 were compiled from fuel alcohol production and import data collected by the Bureau of Alcohol Tobacco and Firearms (BATF) and fuel ethanol export data collected by the Foreign Trade Office, Bureau of the Census. BATF production data were collected from two statistical releases, “Alcohol Fuel Production” and “Distilled Spirits.” The Bureau of the Census fuel ethanol export data were obtained from Schedule B, Commodity Number 2207.20.0000, “Ethyl Alcohol, Denatured of Any Strength (for Nonbeverage Use).”

Fuel ethanol consumption was derived from the two BATF statistical releases and Bureau of the Census export data as follows:

Fuel Alcohol Production + Imports for Fuel Use - Exports of Ethyl Alcohol.[122]

BATF alcohol fuel production and import data are reported in proof gallons and have been converted to wine gallons. (Two proof gallons are approximately equal to one wine gallon). Census export data were reported in wine gallons prior to 1989 and in liters thereafter. Export data reported in liters have been converted to wine gallons. (One liter is equal to 0.264 gallons). A heating value of 76,400 Btu per gallon was used to convert gallons to Btu.

The 1992 ethanol consumption estimate was derived from the EIA's (Petroleum Supply Division) ethanol production data, change in stocks, and net imports as reported on Form EIA-819M. Specifically, 1992 consumption was derived as:

[Production - Stock Changes + Net Imports].

Regional distributions for all years were based on gasohol sales data published by the U.S. Department of Transportation, Federal Highway Administration.[123]

Appendix D
Data Quality

Wood

Wood energy consumption estimates were developed from data collected by the EIA and the U.S. Department of Agriculture, Forest Service. Since 1992 Forest Service data for wood used as a fuel are not available, 1991 estimates are compared.

Energy Information Administration Estimates

Wood energy consumption was derived from the following surveys: Manufacturing Energy Consumption Survey (MECS), Residential Energy Consumption Survey (RECS), and the Form EIA-759, "Monthly Power Plant Report." Appendix B presents the methodology used to develop these estimates. A total of 943 trillion Btu of wood energy consumption was estimated by EIA in 1991. An additional 1,207 trillion Btu were consumed as black liquor in the paper industry.

Forest Service Estimates

The Forest Service wood energy consumption was derived from data presented in *Forest Resources of the United States, 1992*.[124] The volume of wood harvested for woodfuel in 1991 was obtained from Table 36 for both softwoods and hardwoods. Since the densities of these two types of wood differ, the Forest Service standards of 35 pounds per cubic foot (softwoods) and 40 pounds per cubic foot (hardwoods) were used to convert the volume to the weight of harvested wood. Because the energy content of wood varies with moisture content and the type of wood, an average heating value of 7,000 Btu per pound was used to convert the weight of harvested wood to energy consumed.

In 1991, harvested wood represented about 58 percent of wood energy consumption in the United States. The remaining 42 percent was consumed in the form of bark and wood residues. The weights of bark and wood residues used as a fuel for both softwoods and hardwoods were obtained from Table 37. An average heating value of 7,000 Btu per pound was used to derive wood energy consumption from bark and wood residues.

The total wood energy consumption from the Forest Service data was 1,498 trillion Btu, representing the maximum amount of wood available for fuel use in 1991. This total excludes the consumption of black liquor in the industrial sector. By contrast, the American Paper Institute (API) estimated that, in 1991, 1,155 trillion Btu of black liquor were consumed in the "Paper and Allied Products" industry.

Comparison

Total U.S. wood energy consumption in 1991 ranged from 943 trillion Btu, estimated by the EIA, to 1,498 trillion Btu, derived from Forest Service data. This range in wood energy consumption may be a result of:

- A variation in reporting frequencies and measurement techniques
- The exclusion of nonindustrial firms (e.g., school districts) from surveys
- The inclusion of the consumption of biomass energy, used as a secondary fuel, with the primary fuel's energy consumption
- Assumptions made about wood density, moisture content, and energy density.

Also, a portion of the wood energy that is unaccounted for by the EIA may be trashed or buried, burned in the residential sector, or become industrial scrappage.

Ethanol

Fuel ethanol consumption data have been estimated from data collected by the EIA, the Bureau of Alcohol, Tobacco, and Firearms (BATF), the Bureau of the Census, and the U.S. Department of Transportation (DOT).

[124]U.S. Department of Agriculture, Forest Service, *Forest Resources of the United States, 1992*, General Technical Report RM-234 (Fort Collins, CO, September 1993).

BATF and Bureau of the Census

Fuel ethanol consumption was compiled from fuel alcohol production data, collected by the BATF, and denatured ethanol export data, collected by the Foreign Trade Office, Bureau of the Census. BATF production data were collected from two statistical releases, "Alcohol Fuel Production" and "Distilled Spirits." The ethanol export data from the Bureau of the Census were obtained from Schedule B, Commodity Number 2207.20.0000, "Ethyl Alcohol, Denatured of Any Strength (for nonbeverage use)." Appendix B presents the methodology used to derive ethanol consumption estimates in this report.

Data from the BATF were available only at the national level. Therefore, the regional breakout presented in this report was based on data obtained from the DOT. Since only production and export data were available, changes in fuel ethanol stock balances are unknown; consequently, estimated fuel alcohol consumption figures are not exact. In addition, the Census export data were for "nonbeverage use" and may include denatured ethanol used for other applications, such as cosmetics.

The large increase in ethanol consumption from 1989 to 1990 (Table C1) was due to a sharp rise in both BATF alcohol production data and Census export data. The considerable increase in BATF production may have been due in part to a "bumper" corn harvest in 1989/1990, which resulted in low corn prices to ethanol producers. A sugar crop failure in Brazil over the 1989/1990 period contributed to the substantial increase in exports. Brazil is the largest importer of U.S. fuel ethanol.

Department of Transportation

The DOT ethanol consumption estimates were derived from various issues of *Highway Statistics*, published by the DOT's Federal Highway Administration. Specifically, ethanol consumption was estimated at 10 percent of gasohol sales, as reported by the DOT in the above publication. Regional distributions were based on gasohol sales published by State. Although the DOT publishes the only State-level estimates of ethanol consumption, there are known deficiencies in the data, which are based on State tax records.

Energy Information Administration

The EIA ethanol consumption values up to 1990 were taken from *Estimates of U.S. Biofuels Consumption 1990*. The 1992 ethanol consumption figure was derived from ethanol production, change in stocks, and net imports, as reported on Form EIA-819M, "Monthly Oxygenate Telephone Report." Specifically, 1992 consumption was estimated as the sum of production and net imports less the change in stocks. The regional distribution was based on gasohol sales, by State, published by the DOT.

Table D1. U.S. Ethanol Consumption Estimates
(Trillion Btu)

Data Source	1981	1984	1985	1986	1987	1988	1989	1990	1991	1992
BATF[a]	NA	NA	56	70	58	60	54	82	65	73
DOT[b]	5	41	NA	NA	61	NA	53	57	66	NA
EIA[c]	6	39	NA	NA	62	NA	64	57	NA	79
EIA[d]	7	49	NA	NA	69	NA	71	63	NA	83

[a]Production + Imports - Exports. Based on a heating value of 76,400 Btu per gallon. Export data are from the Bureau of the Census, Schedule B, Commodity Number 2207.20.0000, "Ethyl Alcohol, Denatured of Any Strength."

[b]Ethanol consumption estimated as 10 percent of gasohol sales. Based on a heating value of 76,400 Btu per gallon.

[c]Data for 1981 through 1990 are from *Estimates of U.S. Biofuels Consumption 1990*, adjusted to reflect a heating value of 76,400 Btu per gallon (the published report used a heating value of 84,400 Btu per gallon). The 1992 estimate is derived from ethanol production, change in stocks, and net imports data reported on Form EIA-819M, "Monthly Oxygenate Telephone Report."

[d]Estimates derived using a heating value of 84,400 Btu per gallon. Data for 1981 through 1990 are from *Estimates of U.S. Biofuels Consumption 1990*. The 1992 estimate is derived from ethanol production, change in stocks, and net imports data reported on Form EIA-819M, "Monthly Oxygenate Telephone Report."