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ESTIMATES OF U.S. BIOFUELS CONSUMPTION 1990

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Energy Information Administration
Office of Coal, Nuclear, Electric and Alternate Fuels
U.S. Department of Energy
Washington, DC 20585

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Preface

This report is the sixth in the series of publications developed by the Energy Information Administration to quantify the amount of biofuel-derived primary energy used by the U.S. economy. It provides preliminary estimates of 1990 U.S. biofuels energy consumption by sector and by biofuels energy resource type. The objective of this report is to provide updated annual estimates of biofuels energy consumption for use by Congress, Federal and State agencies, and other groups involved in activities related to the use of biofuels.

For additional data on biofuels energy consumption, refer to the Energy Information Administration publication, *Annual Energy Review*, DOE/EIA-0384. Information on the potential future for renewable energy can be found in the in the Energy Information Administration publications, *Renewable Energy Excursion: Supporting Analysis for the National Energy Strategy*, SR/NES/90-04, and *Annual Energy Outlook 1991*, DOE/EIA-0383(91).

Contents

Tables

Page

Figures

Highlights

Summary of Findings

In 1990, an estimated 2.8 quadrillion British thermal units (Btu) of biofuels (wood, waste, and alcohol fuels) were consumed in the United States, representing about 3.3 percent of total U.S. energy consumption.[1] By comparison, hydroelectric power contributed 3.5 percent of total energy consumption in 1990 (Figure ES1). Biofuels energy consumption in 1989 amounted to 2.9 quadrillion Btu.

Biofuels, primarily wood, were the major energy source in the United States until the end of the 19th century. With the development of low-priced coal, oil and natural gas reserves, wood energy consumption declined rapidly in all end-use sectors. This decline continued until the mid-1960's and 1970's, when environmental regulations and skyrocketing prices for fossil fuels led to a resurgence in the use of biofuels for energy.

Biofuels energy consumption in the United States grew by 15 percent between 1981 and 1984, but remained relatively constant over the 1984 through 1990 period, varying between 2.8 and 2.9 quadrillion Btu annually. The growth during the early part of the 1980's was due to a number of factors, including escalating prices of the conventional fuels that were in direct competition with biofuels used for energy production, the expansion of economic activity in the Paper and Allied Products and Lumber and Wood Products industries, and the expansion of municipal solid waste facilities that burn waste to reduce its volume and to generate electricity.

The abatement of growth in biofuels energy use in the late 1980's was due principally to reductions in wood energy use in the residential and industrial sectors as the prices of fossil fuel alternatives decreased. Additionally, a warm winter contributed significantly to the decline of wood consumption in the residential sector during 1990. This decline was partially counter-balanced by increased consumption of municipal solid waste in 1990.

During 1990, energy from wood accounted for 84 percent of total biofuels consumption, while energy from solid waste and ethyl alcohol (ethanol) made up 14 percent and 2 percent of the total, respectively (Table ES1). Most of the biofuels consumption in 1990 occurred in the South (48 percent), while the smallest share of consumption occurred in the Northeast (14 percent).[2]

Over the next two decades, biofuels consumption could increase significantly. The rate and magnitude of future growth will depend on a number of factors. For example:

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

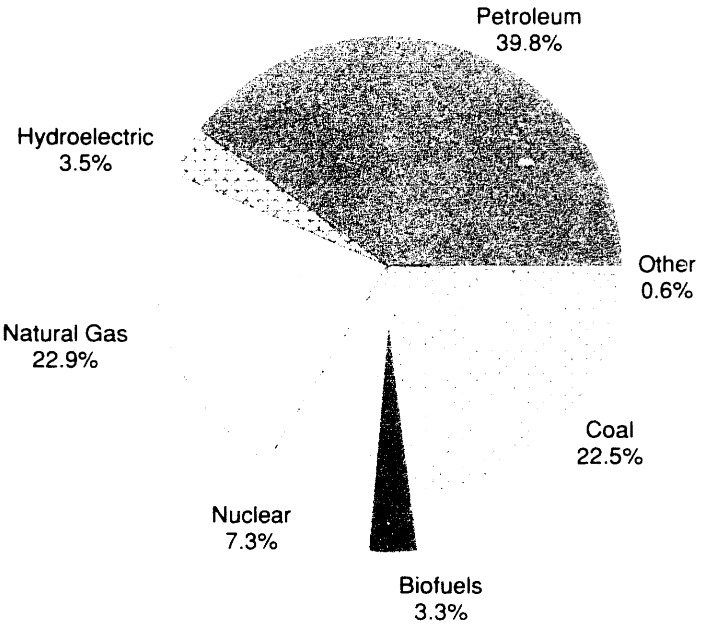
- Wood energy consumption in the residential sector will be influenced by the continued population migration from rural to urban areas, the availability of inexpensive fuelwood, environmental restriction on the burning of wood especially in populated areas, and the availability and the relative cost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

- The use of municipal solid waste (MSW) as a source of energy 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.

[1]Total U.S. primary energy consumption in 1990 was 84.6 quadrillion Btu, estimated by adding nonutility renewable energy consumption to the energy consumption reported by EIA, 81.4 quadrillion Btu (see Energy Information Administration, *Annual Energy Review*, DOE/EIA-0384(90) (Washington, DC, May 1991), Tables 3 and 104), using revised biofuels estimates from this report.

[2]Appendix A provides a map of the four U.S. Census regions. Appendix B provides a discussion of the procedures used for estimating consumption levels.

Figure ES1. U.S. Consumption of Energy by Source, 1990



Note: Based on total energy consumption of 84.6 quadrillion Btu.
Source: Energy Information Administration, *Annual Energy Review 1990*, DOE/EIA-0384(90) (Washington, DC, May 1991), Tables 3 and 104, using revised biofuels estimates from this report.

Table ES1. U.S. Biofuels Consumption by Sector, Type, and Region, 1990
(Trillion Btu)

	Wood				Other Than Wood			
Region	Industrial	Residential	Utility	**Subtotal**	Solid Waste	Alcohol	**Grand Total**	**Share of Grand Total** (Percent)
Northeast	118	147	1	**266**	119	1	**386**	14
South	1,014	211	0	**1,224**	114	23	**1,361**	48
Midwest	90	251	2	**343**	89	34	**465**	17
West	340	178	8	**526**	73	6	**605**	21
Total	**1,562**	**786**	**12**	**2,359**	**394**	**63**	**2,817**	**100**
Share of Wood Total (percent)	66	33	1	100	--	--	--	--
Share of Grand Total (percent)	55	28	<1	84	14	2	100	--

Note: Totals may not equal sum of components because of independent rounding.
Source: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels (August 1991).

In an analysis of the potential for biomass-derived energy, the Energy Information Administration (EIA) estimates that biomass consumption could increase from the current 2.8 quadrillion Btu to 6.3 quadrillion Btu in 2010, when its share of total energy consumption would be 5.9 percent.[3]

Energy from Wood

An estimated 2,359 trillion Btu of energy from wood was consumed in the United States by the industrial (66 percent), residential (33 percent), and utility (1 percent) sectors. Commercial wood energy use is not included in this report because there are no current data sources to provide reliable estimates. However, from the 1986 Nonresidential Buildings Energy Consumption Survey conducted by EIA, it is estimated that annual wood energy use in the commercial sector is on the order of 20 to 40 trillion Btu. Within the industrial sector, the Paper and Allied Products industry consumed the majority of the wood energy. The largest amount of wood energy was consumed in the South, while the smallest amount was consumed in the Northeast.

Energy from Solid Waste

An estimated 394 trillion Btu of energy from solid waste was consumed in the United States, consisting of mass burning of municipal solid waste (73 percent), burning of manufacturing waste (19 percent), and landfill gas recovery (8 percent). The largest amount of energy from solid waste was consumed in the Northeast (30 percent) and the smallest amount was consumed in the West (18 percent).

Energy from Alcohol

Ethanol is currently produced from the fermentation of agricultural crops, primarily corn and used as a fuel supplement in the transportation sector. During 1990, an estimated 750 million gallons of ethanol (63 trillion Btu) were utilized as a supplement with automotive gasoline supplies. The majority of ethanol consumption occurred in the Midwest, where most of the distil'eries are located in the vicinity of the corn feedstock.

Other Biofuels

The consumption of agricultural waste and manure, commercial sector fuelwood consumption, and the use of biogas from sewage treatment were examined. However, data were not available to make statistically sound estimates of energy production from these sources. Data available indicate that these are relatively small sources of energy compared to other biofuels.

Data Limitations

This report provides estimates of biofuels consumption in the United States during 1990 based on data collected by the Energy Information Administration (EIA), other Federal agencies, and private organizations. In cases where EIA data are used, the surveys were not specifically designed to measure biofuels consumption; therefore, the estimates tend to be less reliable than comparable estimates of fossil-fuel consumption. The uncertainties surrounding data from non-EIA surveys are not known. The EIA estimation methodology and the associated uncertainties are described in the body of the report and in Appendix B.

[3]Energy Information Administration, *Annual Energy Outlook 1991*, DOE/EIA-0383(91) (Washington, DC, March 1991), Table A6.

1. Introduction

Background

Heightened concern over fuel prices and availability in the 1970's and the first half of the 1980's led to a renewed interest in the use of wood and other biofuels, including waste and alcohol fuels. This resulted in increased interest in biofuels-related technical and consumption data. Today, the interest in biofuels-related information remains high. This is primarily due to increased interest in the use of renewable sources of energy, including biofuels, as concerns over energy security and environmental pollution increase.

Historically, biofuels energy consumption in the United States consisted primarily of energy derived from the direct combustion of wood.[1] The energy crises of the 1970's and early 1980's, as well as the decreasing availability of landfill sites have increased the use and awareness of both wood and other biofuels, such as:

- Municipal solid waste (MSW), manufacturing waste, agricultural waste, and landfill gas to produce steam and electricity
- Ethanol, derived from the fermentation of grain, primarily corn, for use in internal combustion engines as a gasoline supplement and octane enhancer.

Estimation Methodology

Four EIA reports concerning biofuels consumption provide the methodological background for this report:

- *Estimates of U.S. Wood Energy Consumption 1980-1983*,[2] which provides regional estimates of wood energy consumed by the industrial, residential, commercial, and utility sectors
- *Estimates of U.S. Biofuels Energy Consumption, 1981-1984*,[3] which includes estimates for energy consumption of wood, municipal solid waste, alcohol, and agricultural waste
- *Estimates of Biofuels Consumption in the United States During 1987*,[4] which updated the previous report (agricultural waste data were not included)
- *Estimates of Biofuels Consumption in the United States During 1989*,[5] which updated the previous report, and provided a discussion of biofuels consumption in the agricultural sector and a discussion of sewage sludge digestion. Agricultural energy consumption and sewage sludge digestion are discussed but no data were published.

A qualitative review of agricultural waste energy consumption continues to be presented in this report. Because the estimates of agricultural waste for energy are negligible and available data is of poor quality, these estimates are again not included in the summary tables. For the same reasons, sewage sludge consumption is also discussed, but no estimates are developed in this report.

Definitions

Biofuels energy consists of three main segments: wood, waste, and alcohol fuels (Figure 1). Wood energy is derived from: roundwood, used in the industrial and utility sectors; fuelwood, used predominantly in the residential and commercial sectors; wood byproducts and waste wood used predominantly in the industrial sector, although used by some residential, commercial and utility consumers. Waste energy is derived from: mass burning of garbage; conversion of garbage to refuse-derived fuel pellets for eventual burning; collection of methane gas from landfills; and burning or

[1]Energy Information Administration, *Estimates of U.S. Wood Energy Consumption from 1949-1981*, DOE/EIA-0341 (Washington, DC, August 1982).

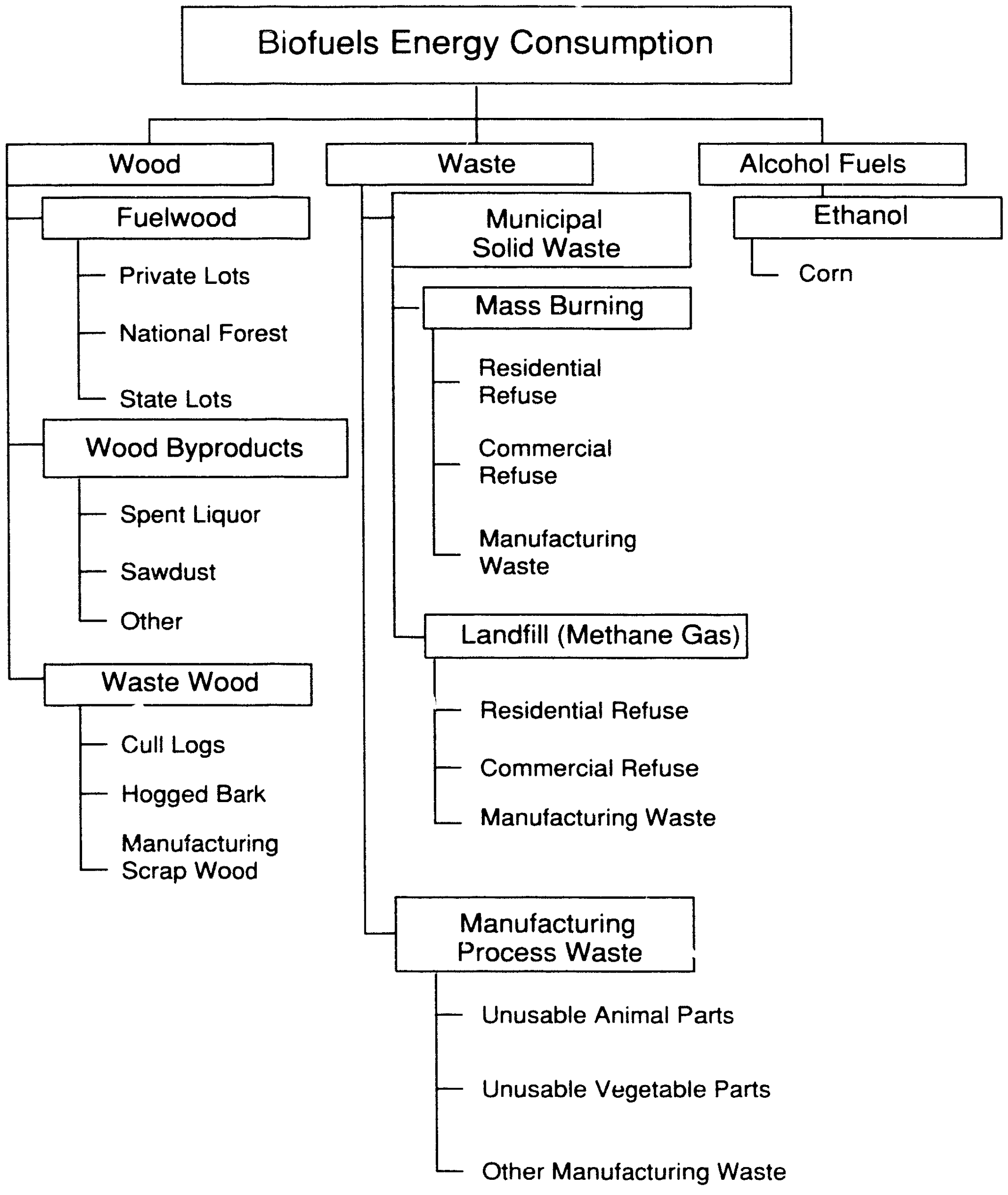
[2]Energy Information Administration, *Estimates of U.S. Wood Energy Consumption 1980-1983*, DOE/EIA-0341(83) (Washington, DC, November 1984).

[3]Energy Information Administration, *Estimates of U.S. Biofuels Energy Consumption 1981-1984*, unpublished report (November 1985).

[4]Energy Information Administration, *Estimates of U.S. Biofuels Energy Consumption 1987*, unpublished report (March 1989).

[5]Energy Information Administration, *Estimates of U.S. Biofuels Energy Consumption 1989*, SR/CNEAF/91-02 (Washington, DC, April 1991).

Figure 1. Biofuels Resource Hierarchy



Source: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels (August 1991).

anaerobic digestion of manufacturing process waste. Alcohol fuel in this report refers to ethanol, typically derived from corn.

The industrial sector includes manufacturing industries in the Standard Industrial Classification (SIC) Codes 20 through 39. The residential sector includes all residences: single-family, multifamily, and mobile homes. The utility sector includes all types of utilities providing electric power to the public, regardless of ownership characteristics. The transportation sector is referred to only in connection with ethanol, which is used in gasoline powered vehicles—mostly cars and light trucks.

Commercial sector data are not included in this report because there are no current data sources available to provide acceptable estimates. However, from the 1986 EIA Nonresidential Buildings Energy Consumption Survey[6] it is estimated that wood energy use in the commercial sector is on the order of 20 to 40 trillion Btu annually.

The use of terms and units of measure relating to wood energy differs among the sectors. The industrial and 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 spent liquor. The unit most often used in measuring the amount of woodfuel consumed by these sectors is *oven-dried short tons*. In the residential sector, wood energy is referred to as *fuelwood* (i.e., firewood). *Cord* is the most common unit of measure for fuelwood.

Report Organization and Coverage

Each of the biofuels is discussed in separate chapters as described below:

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

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

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

Appendix A provides a map of the U.S. Census regions, outlining the boundaries of the geographical regions in this report. Appendix B contains descriptions of the procedures used in developing the energy consumption estimates. Appendix C provides additional information about biofuels consumption by independent power producers.

Data Quality

The biofuels data utilized and presented in this report were collected from nonuniform sources due to the lack of a comprehensive survey of biofuels consumption. As such, data for each type of biofuel was derived from different sources each using different methodologies to obtain the information. For this report, further modifications and estimates were made as appropriate. Discussion of the data quality for the various biofuels is addressed below.

- **Wood Energy:**

  - *Industrial:* Estimates for the industrial sector are based on data derived from the 1988 Manufacturing Energy Consumption Survey (MECS).[7] In MECS, woodfuel use is included under the category of "Other—Specify." The relative standard error for total U.S. woodfuel consumption was 3 percent.[8] The relative standard errors associated with total woodfuel consumption in SIC 24 (Lumber and Wood Products Industry) and SIC 26 (Paper and Allied Products Industry) were 16 percent and 4 percent, respectively. The relative standard error for each SIC increases further where regional level data are considered. The assumptions and the procedures used to estimate 1990 consumption data from the 1988 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 EIA through the 1987 Residential Energy Consumption Survey (RECS). There is a relative standard error of 13 to 17 percent associated with the fuelwood consumption data on the national level in 1987. This margin of error increases on a regional level. The precise relative standard errors associated with estimates in this report are not known because 1987 data were adjusted to obtain estimates for 1990.

  - *Utility:* Utility data are based on a census survey, the EIA "Monthly Power Plant Report" (Form

[6]Energy Information Administration, *Nonresidential Building Energy Consumption Survey—Commercial Buildings Consumption and Expenditures 1986* (Washington, DC, May 1989).

[7]Energy Information Administration, *Manufacturing Energy Consumption Survey—Consumption of Energy 1988* (Washington, DC, May 1991).

[8]Relative standard error (RSE) is a measure of the precision of the estimate derived from the survey sample. Variability occurs in survey statistics because the different samples that could be drawn produce different values for survey statistics. An RSE of 50 percent means that the standard error is half as large as the survey estimate. The RSEs presented for estimates from the MECS are based on the 1985 survey.

EIA-759), and for that reason have no relative standard error.

- **Waste Energy:**

  - Municipal solid waste (MSW) combustion and methane gas recovery from landfills are estimated from industry surveys.[9] For MSW, actual 1990 survey data were used as published by Government Advisory Associates, Inc. For methane gas recovery, the 1988 data, from the same source, were used as a proxy. These surveys are considered to be comprehensive. However, the source said that their survey data may be on the high side because of the hesitancy of industrial organizations to report facility downtime to private surveying organizations.

  - Manufacturing waste energy consumption data are derived from the 1988 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:**

  - Agricultural waste energy consumption is small and too uncertain to estimate, but has been described qualitatively.

- **Sewage Sludge Digestion:**

  - Sewage sludge digestion energy consumption is also small and too uncertain to estimate, but has been described qualitatively.

- **Fuel Alcohol:**

  - National-level ethanol consumption data are based on industry estimates of U.S. ethanol consumption, and do not contain the approximate 100 million gallons of ethanol produced in the United States and exported to other countries.

[9]Government Advisory Associates, Inc., *Resource Recovery Yearbook* (New York, NY, 1991), and *Methane Recovery from Landfill Yearbook* (New York, NY, 1989).

2. Energy from Wood

Historical Perspective

Until the end of the 19th century, wood was the major energy source in all sectors of the U.S economy. Much of the industrial power in boilers and burners were derived from wood. In the commercial and residential sectors, wood was the predominant fuel, used for cooking, water heating and space heating. Wood was also used in the transportation sector to propel steam locomotives and steam powered ships. With the increased popularity of low-priced coal, oil, and natural gas, wood energy consumption declined rapidly in all end-use sectors. In the U.S. transportation sector, wood as a source of power has disappeared.

After the turn of the century, the use of wood in the industrial sector became confined to the paper and lumber producing industries. In the past half a century, these two industrial groups accounted for virtually all industrial wood energy consumption. These industries often use residual wood and waste products to fire boilers for steam, process heat, and for electricity generation. The paper industry increasingly has used internally generated spent pulping liquor as an energy source. Continued growth in the output of these industries, escalation in waste disposal costs, and the trend toward more complete utilization of timber resources have combined to increase woodfuel use in these industries.

Consumption of wood in the residential sector steadily declined until the late 1970's because fossil fuels were abundant, cheap, and more convenient than fuelwood. However, disruption of crude oil supplies and the curtailment of natural gas deliveries, as well as rising crude oil and natural gas prices in the 1970's revived interest in wood as a fuel for residential space heating. Wood use in homes for heating increased until the mid-1980's, when again declining conventional fuel prices led to a decrease in wood use during the latter part of the 1980's. Fuelwood use for water heating and cooking did not regain popularity and has just about disappeared.

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

Background

Data used and developed in this report show that in 1990 wood provided 2.8 percent of the total primary energy consumed in the United States. It is a significant fuel in the industrial sector and within specific industries, such as Paper and Allied Products and Lumber and Wood Products, woodfuel (including pulp liquor) accounts for a majority of their energy consumed.[10]

Wood is also a significant fuel in the residential sector. It contributes approximately 9 percent of all energy consumed by U.S. households, and is the fourth largest source of energy within the sector after natural gas, electricity and fuel oil. Wood is also the most popular secondary heating fuel, with 22.5 million households reporting using the fuel as a source of heat in 1987. Of these, 5 million households regarded wood as their primary heat source, using primarily wood burning stoves as the heating appliance. Fireplaces were reported to be used by more than 15 million households, making it the most popular secondary heating appliance used in 1987. Also, approximately 200,000 thousand households reported using wood for water heating—making it the least popular water heating fuel.[11]

Total wood energy consumption during 1990 is estimated at 2,359 trillion Btu (Table 1 and Figure 2). The industrial sector is the largest wood energy consumer, accounting for almost 66 percent of the total wood energy consumption. The residential sector accounts for almost 33 percent, and the utility sector 0.5 percent.

[10]Energy Information Administration, *Manufacturing Energy Consumption Survey: Consumption of Energy 1985*, DOE/EIA-0512(85) (Washington, DC, November 1988).

[11]Energy Information Administration, *Housing Characteristics, 1987: Residential Energy Consumption Survey*, DOE/EIA-0314(87) (Washington, DC, May 1989).

Table 1. U.S. Consumption of Wood Energy by Sector, 1949-1990
(Trillion Btu)

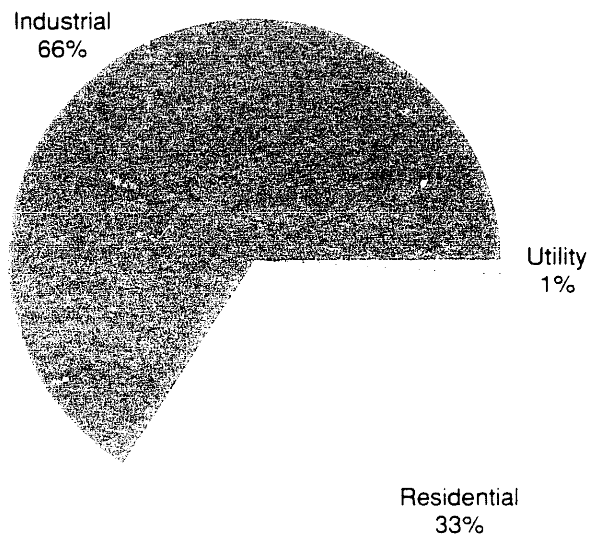
Sector	Consumption										
	1949	1954	1959	1964	1969	1974	1979	1984	1989	1990	1990 Percent of Total
Industrial	468	576	692	827	1,014	1,159	1,405	1,679	1,556	1,562	63
Residential	1,055	800	647	499	415	371	728	923	918	786	37
Utility	6	3	1	1	1	1	2	9	13	12	1
Total[a]	**1,529**	**1,379**	**1,340**	**1,327**	**1,430**	**1,531**	**2,135**	**2,611**	**2,487**	**2,359**	**100**

[a]Commercial wood energy use is not included in this report because there are no accurate data sources to provide reliable estimates. However, from the 1986 Nonresidential Buildings Energy Consumption Survey conducted by the EIA, it is estimated that annual wood energy use in the commercial sector is on the order of 20 to 40 trillion Btu.

Note: Totals may not equal sum of components because of 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, Office of Coal, Nuclear, Electric and Alternate Fuels (August 1991).

Figure 2. U.S. Consumption of Wood Energy by Sector, 1990



Source: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels (August 1991).

The regional distribution of wood consumption was estimated to be 52 percent in the South, 22 percent in the West, 15 percent in the Midwest, and 11 percent in the Northeast (Table 2). This distribution is due to the location of wood resources and wood-consuming industries. Figure 3 presents a graphical comparison of U.S. wood energy consumption by both region and sector.

Industrial Sector Woodfuel Consumption

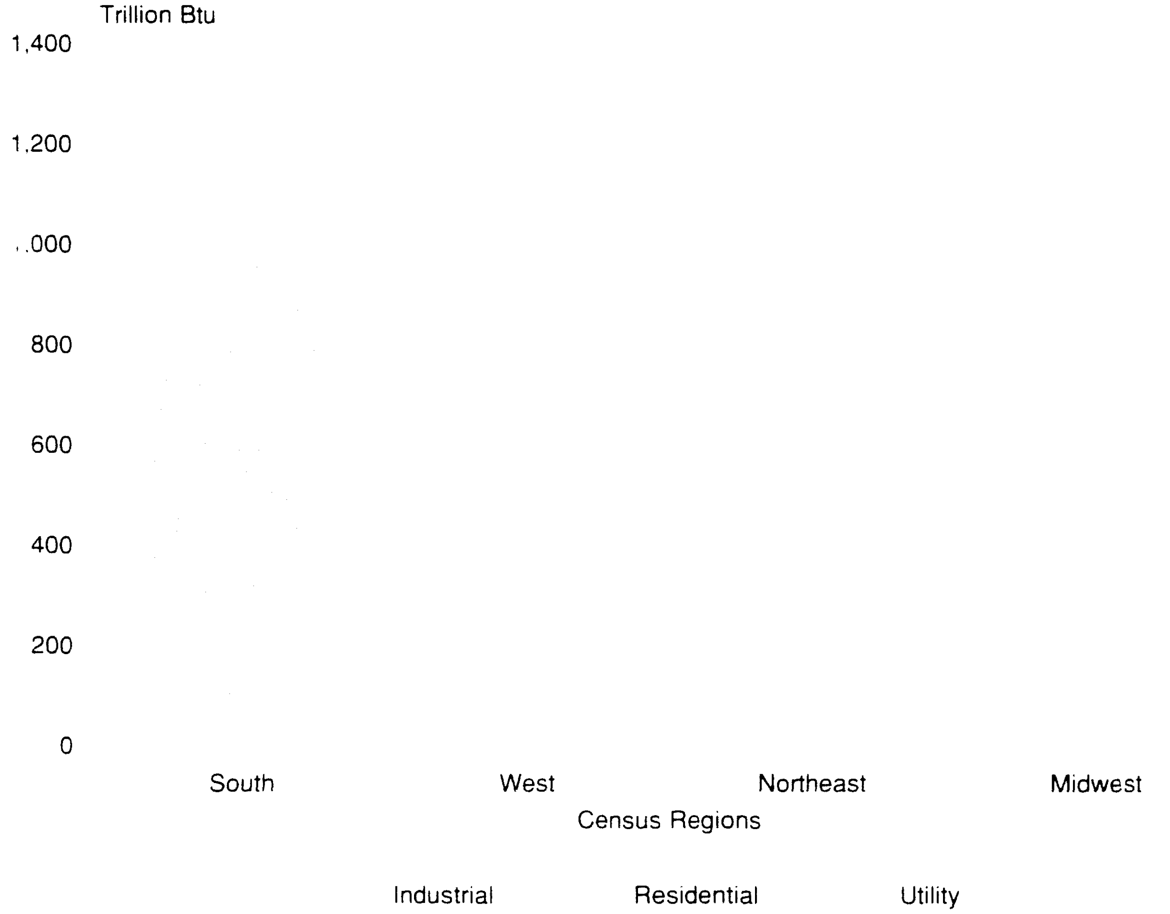
The industrial sector consumed two-thirds of the total woodfuel used in the United States during 1990. Woodfuel consumption in this sector is dominated by two industries: the Paper and Allied Products industry, Standard Industrial Classification (SIC) 26, and the Lumber and Wood Products industry (SIC 24). These industries consumed approximately 79 percent and 18

Table 2. U.S. Consumption of Wood Energy by Region, 1990

Region	Consumption	
	Trillion Btu	Percent of Total
Northeast	266	11
South	1,224	52
Midwest	343	15
West	526	22
Total	2,359	100

Note: Totals may not equal sum of components because of independent rounding.
Source: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels (August 1991).

Figure 3. U.S. Consumption of Wood Energy by Region and Sector, 1990



Note: During 1990, no utilities in the South reported woodfuel consumption.
Source: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels (August 1991).

percent, respectively, of the total woodfuel consumed within the industrial sector (Table 3). These industries include industrial organizations who, in addition to their primary business activities, are nonutility cogenerators of electricity and process heat. Their woodfuel consumption is reflected in these estimates, even though some of the electricity or steam was sold to a utility or other organizations. However, this section does not reflect any wood consumed by nonindustrial organizations that generate electricity, commonly known as independent power producers (IPP). These are generally set up exclusively or predominantly to produce and sell electricity and steam to the utility or other users. These nonindustrial IPPs have reported their energy consumption data to the EIA in a recent survey of nonutility generators. Those data are not yet available. Appendix C contains additional information about consumption of biofuels by independent power producers.

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

- **SIC 20 — Food and Kindred Products Industry:** consumes roundwood, wood chips, and wood waste
- **SIC 22 — Textile Mill Products Industry:** consumes wood chips
- **SIC 25 — Furniture and Fixture Industry:** consumes wood chips and wood waste
- **SIC 27 — Printing and Publishing:** consumes wood pulp
- **SIC 28 — Chemicals and Allied Products Industry:** consumes wood chips, pulping, or black liquor
- **SIC 30 — Rubber and Miscellaneous Plastic Products:** consumes roundwood and wood chips
- **SIC 32 — Stone, Clay, and Glass Products Industry:** consumes wood chips
- **SIC 33 — Primary Metals Industry:** consumes wood chips
- **SIC 34 — Fabricated Metals Products Industry:** consumes wood chips
- **SIC 38 — Instruments and Related Products Industry:** consumes roundwood.

Wood-consuming companies within these sectors supplement self-generated waste wood with the purchase of woodfuel from nearby wood-product industries (SIC 24 and SIC 26).

The energy conversion technologies used by the industrial sector include: boilers, cogenerators, and burners to produce process heat, steam, and electricity. It is estimated that about half of woodfuel consumption is used in boilers; about one-third is used in cogenerators for the production of steam; about 7 percent in cogenerators for the production of electricity (total of 42 percent for cogenerators); and about 11 percent for process heating.[12]

Sector Characteristics

Within the industrial sector, waste wood serves as fuel for a variety of wood energy conversion systems, including boilers, electricity cogenerators, kilns, dryers, and gasifiers. Kilns, dryers, and gasifiers are generally fueled with bark and dirt-free sawdust or wood chips, while the boilers and electricity cogeneration systems are fueled by wood chips, bark, hogged fuel, or pulping or black liquor. Wood chips are acceptably clean, bark-free chips of wood; hogged fuel generally consists of whole wood wastes chopped to large chunks; and pulping or black liquor is a concentrated spent reagent solution (a paper processing liquid waste) containing lignin. The majority of woodfuel used in industry is comprised of wood waste. Very little industrial woodfuel is suitable for merchandising.[13]

Motivation to burn wood waste for energy is due, in part, to extensive efforts to reduce the industries' dependence on natural gas and oil.[14] In industries where wood is a natural byproduct, it becomes a convenient fuel, reduces the cost of waste disposal, and alleviates or reduces dependence upon other types of fuel sources.

[12]The Gas Research Institute, *Industrial Natural Gas Markets: Facts, Fallacies and Forecasts*, GRI-88/0316 (Chicago, IL, March 1988), p. 110.

[13]Argonne National Laboratory, *Energy and Material Flows in the Production of Pulp and Paper*, NTIS-DE82-000890 (Chicago, IL, May 1981).

[14]T.J. Grant and R.J.H. Slinn, American Paper Institute, *Patterns of Fuel and Energy in the U.S. Pulp and Paper Industry, 1972-1982* (Washington, DC, April 1983).

Data and Analysis

Industrial woodfuel consumption in 1990 totaled 1,562 trillion Btu (Table 3). The majority of this woodfuel was consumed by the Paper and Allied Products industry (SIC 26) which accounted for 1,232 trillion Btu of woodfuel or almost four-fifths of the total woodfuel consumed by the industrial sector. The Lumber and Wood Products industry (SIC 24) accounted for 18 percent or 276 trillion Btu of the total. Wood consumption data for individual SIC's other than SIC 24 and SIC 26 are aggregated because they would not be reliable at the two digit SIC level. During 1990, industries other than SIC 24 and SIC 26 consumed the remaining 3 percent (53 trillion Btu) of the total woodfuel.

Table 4 shows the regional distribution of woodfuel consumption for the industrial sector during 1990. The South consumed 65 percent, the West 22 percent, the Northeast 8 percent, and the Midwest 6 percent. Figure 4 graphically portrays the geographical distribution of industrial sector consumption of woodfuel during 1990.

Table 3. Industrial Woodfuel Consumption by Sector, 1990

Industrial Sector	Consumption: Trillion Btu	Consumption: Percent of Total
Paper and Allied Products	1,232	79
Lumber and Wood Products	276	18
Other Industries	53	3
Total	**1,562**	**100**

Note: Totals may not equal sum of components because of independent rounding.
Source: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels (August 1991).

Residential Sector Fuelwood Consumption

Recent History

From the turn of the century until about 1940, wood was a major source of energy for heating and cooking in the residential sector. The use of fuelwood as the primary source of heating fuel declined from approximately 22 percent of households in 1940 to approximately 2 percent of households in 1970.[15] By 1978, the use of fuelwood as a primary source of heat had increased to more than 1.9 million households representing 2.5 percent of all U.S. households. The use of wood for cooking has all but disappeared.

Significant increases in the use of wood as a main heating fuel occurred between 1978 and 1984. By 1981, 5.4 million households reported wood to be the main heating fuel—representing 6.4 percent of all U.S. households. This trend continued at least through 1984, when 6.5 million, or 7.5 percent of all households

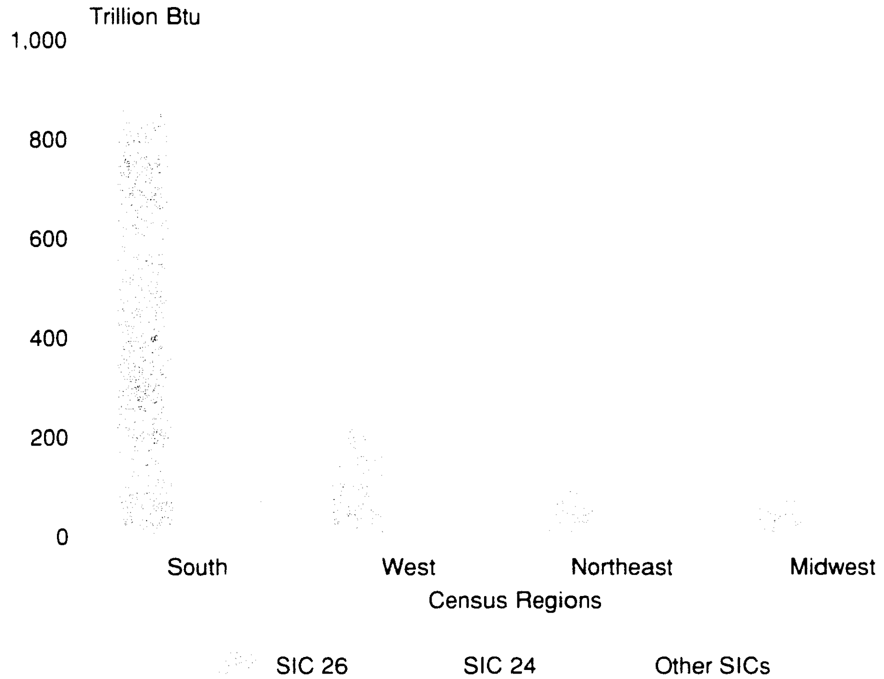
Table 4. Industrial Woodfuel Consumption by Region, 1990

Region	Consumption: Trillion Btu	Consumption: Percent of Total
Northeast	118	8
South	1,014	65
Midwest	90	6
West	340	22
Total	**1,562**	**100**

Note: Totals may not equal sum of components because of independent rounding.
Source: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels (August 1991).

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

Figure 4. Industrial Woodfuel Consumption by Region and Sector, 1990



Source: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels (August 1991).

reported wood as their main heating fuel.[16] Somewhere between 1984 and 1987 wood use as a main heating source peaked. By 1987, only 5.0 million or 5.6 percent of the households reported wood to be their main heating fuel—a decrease of 23 percent from 1984.[17] This decline resulted from the declining prices of the conventional fuel alternatives—heating oil, natural gas and electricity. For example, the nominal prices of heating oil and natural gas decreased by 10 and 26 percent, respectively, from 1984 to 1987.

Sector Characteristics

The principal source of the statistical information in this section is from EIA's 1987 Residential Energy Consumption Survey (RECS). Other information is derived from industry literature, as referenced. It should be noted that relationships shown in this section reflect the 1987 status of woodburning in the U.S. residential sector. The 1990 RECS data, which would provide a more accurate reflection of the industry, will not be available until 1992. The discussion, using the 1987 data, is to be used only as a general understanding of woodburning in the residential sector. It is likely that the specific statistical details between 1987 and 1990 will have changed, and will be more accurately reflected when the RECS data for 1990 become available. However, unlike the statistical details, the general characteristics of woodburning in the residential sector will still likely apply.

This section is divided into three parts: equipment used; woodburning demographics; and energy use. The discussion frequently refers to households burning wood and households burning wood as the main heating fuel. The former refers to all households reporting the use of wood as an energy source. The later refers to households who use wood as the predominant fuel for heating. This differentiation reflects the structure of the information contained in the 1987 RECS.

[16]Energy Information Administration, *Residential Energy Consumption Survey: Consumption and Expenditures, April 1980 Through March 1981*, Parts 1 and 2, "National Data," DOE/EIA-0321(81/1 and 81/2) (Washington, DC, 1982); and *Residential Energy Consumption Survey: Consumption and Expenditures, April 1984 Through March 1985*, Parts 1 and 2, "National Data," DOE/EIA-0321(84/1 and 84/2) (Washington, DC, 1985).

[17]Energy Information Administration, *Housing Characteristics, 1987: Residential Energy Consumption Survey*, DOE/EIA-0314(87) (Washington, DC, May 1989).

Equipment Used

There are five types of residential woodburning equipment in use: free-standing stoves, fireplaces, fireplace inserts, 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 woodburning equipment. They are rarely used for heating an entire home because of their low energy efficiency and fast fuelwood consumption characteristics. Only a small fraction (1.3 percent) of all woodburners report use of fireplaces for this purpose.[18] More frequently, fireplaces are used for aesthetic reasons and as a temporary source of heat for a room or for a part of a house. Depending on the type of fireplace used and on the draft characteristics of the house, burning wood in fireplaces may result in a net heat loss. This results because many fireplaces draw a large amount of air from the house which is replaced by cold outside air. Improvement can be made by adding fireplace enclosures, heat blowers, and outside air source for the fireplace. With the use of a fireplace insert, or other energy saving fireplace equipment, the energy efficiency of a fireplace can be substantially improved.

Free-standing stoves are the principal type of woodburning equipment used for home heating. Stoves come in several varieties, including radiant stoves, circulators, and cast iron units. Of the free-standing units, airtight stoves have become popular because of their relatively high efficiency and long-burning characteristics. By 1987, airtight stoves were used by 3.9 million or 78 percent of the households that report wood to be the main heating fuel. 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.

Besides equipment characteristics, a number of other factors affect the quantity of fuelwood consumed. Consumer decisions to use the fuelwood as the source of heat, the type and frequency of maintenance of the equipment and the chimney, moisture content and type of wood used (different types of wood have different Btu contents), and operational parameters, such as air supply (internal and external).

Woodburning Demographics

In 1987, wood was reported to be used as a primary heating fuel by 5 million households, and as a secondary source for aesthetic purposes in 17.5 million households.[19]

In the residential sector, as in the industrial sector, wood is burned mostly in areas close to the resource. Woodburners in nonmetropolitan areas and outside central city limits consume more than 91 percent of the fuelwood. Less than 19 percent of all woodburners are located in central city areas, consuming a disproportionately small quantity of the fuelwood (8.6 percent). Of those that use wood as the main heating fuel, only 6 percent are central city dwellers. Predominantly, wood is burned for space heating, although some wood is burned for water heating and some for cooking. The RECS reports that approximately 200,000 households use wood for water heating.[20]

The frequency of fuelwood used as a primary heating fuel, and the amount of wood used is inversely related to income and heating area. Higher sensitivities to the cost of fuel by the lower income strata of the population causes a larger proportion of rural low income households to consume wood for a larger proportion of their needs 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 resource, or a low cost resource, can make wood a low cost alternative and a fuel of choice for low income rural households.

Data and Analysis

Residential wood consumption in 1990 is estimated at 786 trillion Btu (Table 5). Fuelwood consumption in the residential sector is distributed geographically as follows: the Midwest consumed 251 trillion Btu (13 million cords), the South 211 trillion Btu (11 million cords), the West 178 trillion Btu (9 million cords) and the Northeast 147 trillion Btu (7 million cords). The methodology and conversion factors used to develop these estimates are discussed in Appendix B.

[18] Energy Information Administration, *Housing Characteristics, 1987: Residential Energy Consumption Survey*, DOE/EIA-0314(87) (Washington, DC, May 1989).

[19] Energy Information Administration, *Housing Characteristics, 1987: Residential Energy Consumption Survey*.

[20] Energy Information Administration, *Housing Characteristics 1987: Residential Energy Consumption Survey*.

Table 5. Residential Fuelwood Consumption by Region, 1990

Region	Consumption		
	Trillion Btu	Million Cords[a]	Percent of Total
Northeast	147	7	19
South	211	11	27
Midwest	251	13	32
West	178	9	23
Total	**786**	**40**	**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 because of independent rounding.
Source: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels (August 1991).

Utility Sector Woodfuel Consumption

Woodfuel consumption by utilities has varied considerably since the 1950's. For example, woodfuel consumption by this sector decreased from 461,000 short tons in 1952 to 85,000 short tons in 1956, and increased to 141,000 short tons in 1972 and then decreased to 11,000 short tons in 1975.[21] However, in 1989, utility woodfuel consumption grew to almost 800,000 short tons, but declined to 700,000 short tons in 1990.

Sector Characteristics

The electrical generating capacity of a typical steam plant is 300 megawatts or larger, while woodburning units are much smaller, a maximum of 50 megawatts. Two types of wood-burning facilities are used in the utility sector. These are wood dedicated (100 percent) and cofiring wood with other fuel sources. All three woodburning facilities in the Midwest region cofire with wood. Two of these facilities use coal as the alternative fuel and one uses trash. Wood-fueled electric plants represent a small fraction (less than 1 percent) of all electric plant capacities in the United States and generate an even smaller fraction (approximately 0.05 percent) of total electricity in the utility sector.

Data and Analysis

Table 6 lists the utility sector's 1990 woodfuel consumption by region. Eight utilities reported a total of 11.9 trillion Btu of woodfuel use. Utilities located in the West (three plants) consumed 68 percent (8.1 trillion Btu) of the total wood used in the utility sector. Woodfuel use at these plants is dependent upon factors such as the availability of free waste wood and the availability of surplus hydro power. These plants burn pine, fir, larch, hemlock, alder and other types of green wood. One plant burns hogfuel. One plant plans to use natural gas to co-fire with wood. However, during 1990 woodburning plants in the West did not use fossil fuels.

Three plants in the Midwest consumed 21 percent (2.5 trillion Btu) of the total wood used at utilities. One plant burns waste bark from lumber operation in Wisconsin and Minnesota. Another burns oak, sawdust, and bark from area sawmills. The third plant receives pine and fir waste from a large window manufacturer.

One plant in the Northeast consumed 11 percent (1.3 trillion Btu) of total utility woodfuel used. This plant buys green hardwood and softwood for powerplant consumption, and has the ability to cofire. During 1990, no utilities in the South reported woodfuel consumption.

[21]Energy Information Administration, *Estimates of U.S. Wood Energy Consumption from 1949-1981*, DOE/EIA-0341 (Washington, DC, August 1982).

Table 6. Utility Woodfuel Consumption by Region, 1990

Region	Consumption		
	Trillion Btu	Million Short Tons[a]	Percent of Total
Northeast	1.3	0.1	11
South	0.0	0.0	0
Midwest	2.5	0.1	21
West	8.1	0.5	68
Total	**11.9**	**0.7**	**100**

[a]One short ton of wood refers to the oven-dried equivalent, which averages approximately 17.2 million Btu.
Note: Totals may not equal sum of components because of independent rounding.
Source: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels (August 1991).

Nonutility generators of electricity which consume woodfuels are difficult to account for accurately. Those which are cogenerators have been included in the section on industrial woodfuel consumption because the cogeneration facilities consume the electricity at the site of generation prior to putting any net generation into the electricity distribution grid. Data on those which are not cogenerators have been collected but are not yet available for publication.

Future Outlook

U.S. wood consumption in 1990, accounting for approximately 84 percent (2.4 quadrillion Btu) of the total U.S. biofuels consumption (2.8 quadrillion Btu), is expected to maintain this proportion while rising to approximately 4 quadrillion Btu in 2010 (84 percent of 4.9 quadrillion Btu).[22] Of the total growth, 75 percent is projected to occur in the industrial sector, and 25 percent in the residential sector. The expected increase in the use of wood in the industrial sector is due to anticipated growth in the output of the Paper and Allied Products, and Lumber and Wood Products industries.[23]

The increase in the residential sector is expected 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. By 2010, the residential sector is expected to account for a smaller share of total U.S. wood energy consumption, 28 percent as compared with 33 percent in 1990. Electricity prices are expected to remain almost constant in real terms through 2010, which will reduce the growth in the use of woodburning stoves to replace electric heat.[24]

[22]Energy Information Administration, *Annual Energy Outlook 1991*, DOE/EIA-0383(91) (Washington, DC, March 1991), Table A6, p. 50.

[23]Nuclear and Alternate Fuels Division; detailed tables supporting Table A6 of Energy Information Administration, *Annual Energy Outlook 1991*, DOE/EIA-0383(91) (Washington, DC, March 1991).

[24]Nuclear and Alternate Fuels Division; detailed tables supporting Table A6 of Energy Information Administration, *Annual Energy Outlook 1991*.

3. Energy from Solid Waste

Background

Waste energy considered in this report is either from municipal solid waste (MSW) or manufacturing waste. MSW includes residential solid waste (ordinary household trash); commercial waste from office buildings, restaurants and supermarkets; and some nonhazardous industrial waste disposed of in the same manner as residential waste. Manufacturing waste includes biological byproducts from manufacturing processes. Waste resources are converted to usable energy by combustion or biochemical (anaerobic digestion) processes.

Waste energy is divided into three key categories, municipal solid waste, manufacturing waste and landfill gas. Total waste energy consumption amounted to 394 trillion Btu in 1990 (Table 7). Of this total, 73 percent was from the combustion of municipal solid waste, 19 percent was from manufacturing waste, and 8 percent was from landfill gas (Figure 5). The largest amounts of waste were consumed in the Northeast, (30 percent) and the South at 29 percent.

Historical Perspective

The first estimates of energy from waste were developed by the Energy Information Administration for the years 1981 through 1984 in an unpublished report.[25] Prior to that time, the method of converting waste into energy developed slowly, and by 1981 reached approximately 88 trillion Btu. This was primarily energy derived from mass burning facilities. During the period from 1981 through 1990, waste energy consumption has grown to almost 400 trillion Btu (Table 8).[26] Much of the increase is attributable to expansion in the number of MSW facilities that burn waste for energy, mostly steam and electricity, and to reduce the amount of waste to be disposed at landfills.

The economics of converting waste to energy depends on a complex set of factors. Economics vary by type of waste (MSW, manufacturing waste, and landfill gas); location of the waste facility which affects the cost of waste disposal, price of electricity, and regulatory requirements; technology employed to convert waste into energy; and quality of the waste available. In many localities the economics of MSW-derived energy consumption are made attractive by imposing large tipping fees.[27] In other areas where tipping fees are moderate, the economics of MSW facilities are marginal. The future of MSW facilities are somewhat clouded by evolving environmental legislation and local opposition to operating these facilities in or close to urban centers, close to the source of most of the municipal solid waste.

Municipal Solid Waste (MSW)

Raw MSW combustion, or mass burning, involves minimal processing of the waste before combustion. This processing usually involves the removal of oversized and difficult to combust materials (e.g., large metal objects, tree stumps, mattresses). Specially designed incinerators are used for mass burning with the heat converted into steam, electricity, and other usable forms of energy.

Energy recovery from municipal solid waste is rapidly growing as the number of operational sanitary landfills decreases. Combustion of MSW produces steam or electricity and reduces incoming refuse volume by an estimated 90 percent.[28] However, newly-developing environmental regulations may limit the growth in the mass burning of MSW. Also, in the future, increased recycling of waste materials could change the waste stream. Both waste stream combustibles and recycling will continue to expand as the population grows and consumption patterns change. The elimination of plastics through recycling will lower the average Btu per pound of the energy feedstocks to MSW combustion. However, it is expected that the net effect will be a growth in the energy recovered from MSW.

[25]Energy Information Administration, *Estimates of U.S. Biofuels Energy Consumption 1981-1984*, unpublished report (November 1985).

[26]Estimates of waste energy consumption for the years 1981 through 1984 did not include energy from manufacturing waste. The first time energy consumption from manufacturing waste was reported was for the year 1987, with an estimated consumption of 93 trillion Btu.

[27]Tipping fees are the costs charged for the disposal of MSW. These fees typically range from $20 to $100 per ton.

[28]Government Advisory Associates, Inc., *Resource Recovery Yearbook* (New York, NY, 1989).

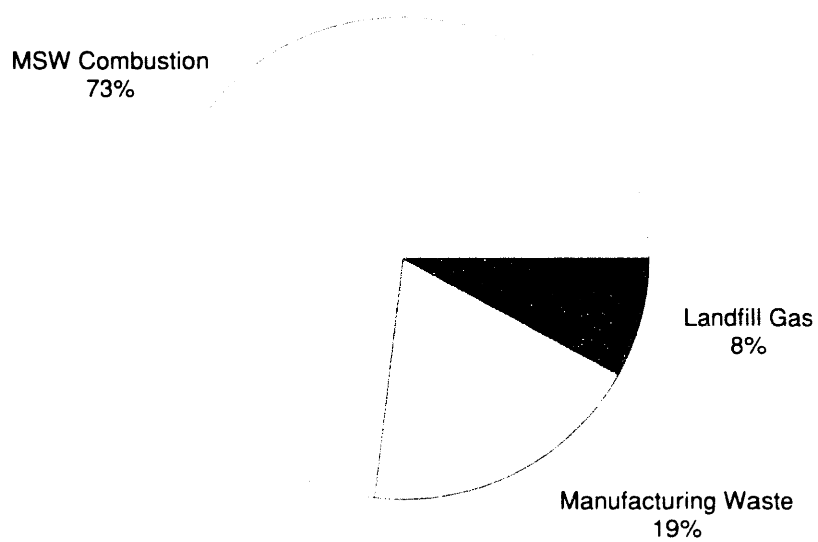
Table 7. U.S. Consumption of Energy by Type of Waste and Region, 1990

Region	Energy Type (Trillion Btu)			Total (Trillion Btu)	Percent
	MSW Combustion	Manufacturing Waste	Landfill Gas		
Northeast	110	4	5	**119**	30
South	95	15	4	**114**	29
Midwest	66	17	6	**89**	22
West	18	39	16	**73**	18
Total	**289**	**75**	**31**	**394**	**100**
Percent	73	19	8	**100**	--

Notes: Conversion factors used to convert the quantities of waste and waste-derived biogas into Btu are different for each type of waste. The conversion factors are provided in Appendix B. Totals may not equal sum of components because of independent rounding.

Source: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels (August 1991).

Figure 5. U.S. Consumption of Waste Energy by Category, 1990



Source: See Table 7.

Table 8. U.S. Consumption of Waste Energy by Region, 1981-1990
(Trillion Btu)

Region	1981	1984	1987	1989	1990	1990 Percent of Total
Northeast	16	39	60	84	119	30
South	37	57	108	145	114	29
Midwest	5	21	47	64	89	22
West	30	91	74	51	73	18
Total	**88**	**208**	**289**	**344**	**394**	**100**

Sources: • **1981-1987**: Energy Information Administration, *Annual Energy Review 1989*, DOE/EIA-0384(89) (Washington, DC, May 1990). • **1990**: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels (August 1991).

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

Refuse-derived fuel (RDF) is formed from MSW in 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 processed into RDF. The uniform particle size, moisture content, and heating value of RDF is desirable for stable combustion in boilers, easier storage, and economical transportation. RDF also possesses a higher energy value per pound than unprocessed refuse. RDF can be burned on-site in a dedicated RDF boiler to produce steam and/or electricity, or sold to a separate user facility for energy. The energy consumption data on RDF in this report reflect the energy content of this biofuel after processing.

Utilization of waste for energy is an option that is increasingly being considered as landfill disposal capacity becomes scarce and expensive. Furthermore, incineration of waste for volume reduction purposes without energy recovery has declined dramatically since the implementation of strict emission standards requiring expensive air pollution control devices.

Manufacturing Waste

Manufacturing waste refers to biomass (biologically produced) byproducts from manufacturing processes that are converted to energy in the manufacturing sector. In general, manufacturing waste that is not disposed of with MSW and is not included under woodfuel includes the following: food matter, such as nonconsumable animal parts or organs; residue from food processing operations, such as fats and oils; packaging material, including paper, cardboard, and straw. Industries that consume process waste-derived energy are: Food and Kindred Products (SIC 20), Furniture and Fixtures (SIC 25), Paper and Allied Products (SIC 26), Petroleum and Coal Products (SIC 29), and Electric and Electric Equipment (SIC 36). During 1990, approximately 75 trillion Btu of manufacturing waste was consumed, and more than half of this was consumed in the West.

Landfill Gas

Landfill gas results from the digestion by anaerobic bacteria of MSW in landfills. This digestion produces a gas which contains methane, carbon dioxide, and other trace products. This gas is collected through a network of pipes. Due to the concentration of carbon dioxide in the raw gas from landfills, this gas is classified as low to medium quality with typical heating values of 400 to 550 Btu per cubic foot. Raw landfill gas may be burned as a boiler 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, or used as a fuel to produce electricity. Internal combustion, gas turbine, and boiler steam turbine methods to generate electricity are all used. During 1990, approximately 31 trillion Btu of landfill gas was consumed, with about one-half of this being consumed in the West.

Agricultural Waste

Agricultural waste and sewage sludge digestion are also sources of waste energy. However, their use is sparse (rendering tracking very difficult) and or insignificant to the total waste to energy contribution. Since there is no acceptable data source available to estimate the consumption of energy from agricultural waste and sewage sludge digestion, they are only mentioned in this report.

Agricultural waste includes two components: crop and animal residues (manures), and excludes those materials used in the food processing industry (SIC 20), which are 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.

Crop residues include: corn cobs, husks and stalks; straw from wheat, oats, barley, and sorghum; and orchard clippings. The real potential of using these residues is limited by several factors, including:

- The availability of residues is usually seasonal, which presents problems of storage if they are to be used for anything other than a supplementary fuel.
- Collection and transportation costs can be prohibitive and the labor and equipment to do this may not be available during the harvest season.
- Many residues are already being used for animal feed, soil amendment, 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 enclosed, 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. 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.

The recovery of animal residues is constrained by the limited markets for the energy that can be recovered. 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 only would be practical for large feedlots.

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 energy from manufacturing waste. The discussion below addresses energy from public water treatment sludge, also known as sewage sludge.

Sludge can be composted to produce mulch, soil conditioners, and fertilizers. During the composting process moisture is driven off the sludge and the end product has potential as a combustible fuel. However, at present, combustion of composted sludge only occurs at a few demonstration facilities for use as a fuel for heating and electricity generation. Sewage sludge can be disposed of by combustion but the process results in a net energy loss, having the disadvantage of requiring greater energy input than can be regained and applied as output energy.

Biogas can also be produced from sewage sludge through anaerobic digestion. In this process, the volume of sludge solids is reduced by about 50 percent through microbial digestion. Methane gas is produced as a byproduct of this volume reduction. As with landfill gas, the biogas is about 60 percent methane and 40 percent carbon dioxide. At water treatment facilities where biogas formation is large enough to be cost-effectively collected, it is often used by the plant in heat exchangers to heat the digester tank or the offices, and occasionally in engine generator sets to produce electricity.

Since water treatment is a very energy-intensive process, self-generated power from sludge represents at most 30 percent of the energy required at these facilities. Consequently, sewage sludge generated electricity and biogas is rarely sold off-site.

Future Outlook

Combustion of municipal solid waste for the production of electricity, steam, and other forms of energy is expected to increase from the current 0.4 quadrillion Btu to 1.5 quadrillion Btu by 2010.[29] Most of the additional 1.1 quadrillion Btu, is projected to be used for electricity generation in a nonutility ownership mode. The nonelectric energy is projected to be consumed by the industrial and commercial sectors in the form of steam. This growth projection is based on the assumption that, by 2010, 55 percent of municipal solid waste will be combusted, compared to approximately 18 percent of the waste combusted in 1990.

The number of facilities generating electricity from landfill gas grew in the 1980's, with 86 currently operating landfill gas facilities, half of which are in California. An additional 68 facilities are in various stages of development.[30] However, planned additions have slowed considerably since many municipalities have found the low Btu landfill gas to be less efficient than anticipated for their completed facilities. Flaring of landfill gas is currently used to dispose of the methane formed through the anaerobic digestion of the waste.

[29]Nuclear and Alternate Fuels Division; detailed tables supporting Table A6 of Energy Information Administration, *Annual Energy Outlook 1991*, DOE/EIA-0383(91) (Washington, DC, March 1991).

[30]American Public Power Association, *Public Power Weekly*, August 26, 1991, p. 3.

4. Energy from Alcohol

Background

In the United States, energy from alcohol is primarily derived from ethyl alcohol (ethanol). Ethanol can be produced from any feedstock that can be reduced to fermentable sugars. Current technologies used in the United States for producing ethanol rely on agricultural feedstocks, primarily corn. The feedstock is first prepared by converting carbohydrates to sugars that are then fermented into ethanol by yeast. The ethanol is then removed by a distillation process that yields a (hydrous) solution of ethanol and water. A final chemical and distillation process produces dry (anhydrous or water-free) ethanol. The most common use of ethanol is as a gasoline supplement and an octane enhancer, in a gasoline blend containing 10 percent ethanol and 90 percent gasoline by volume. In this form the blend is commonly known as gasohol, and is used in smaller internal combustion engines. Ethanol is also being experimented with as a neat fuel, 100 percent ethanol, for all sizes of vehicles including urban transit buses.

Methanol is another form of alcohol fuel getting increasing attention as a transportation fuel. The consumption of this fuel is not considered in this report because to date all methanol consumed as a fuel is made from natural gas. Methanol can also be produced from biomass, primarily wood. However, to date it is considered to be less efficient than natural gas based methanol.

During 1990, gasoline blends containing 10 percent or more ethanol (gasohol) received a Federal tax exemption of 6.0 cents per gallon of ethanol. This had the effect of providing gasohol with approximately a 60 cent per gallon market subsidy. In addition individual State incentives, primarily in the form of tax exemptions, were made available to producers and or retailers in 20 States as shown in Table 9 (in some States the subsidies were not in effect from the beginning of 1990). The tax exemptions ranged from 1 cent per gallon of blend to 8 cents, equal to an ethanol-equivalent market incentive of 10 to 80 cents per gallon. As of January 1, 1991, mandated by the Miscellaneous Tax and Budget Reconciliation Act of 1990, the Federal tax exemptions were extended through December 31, 2000, and the level of exemption reduced from 6.0 to 5.4 cents per gallon of ethanol. Without these Federal and State tax subsidies, the ethanol industry would be unable to compete in the transportation fuels sector.

Selected gasohol sales data are maintained by the Federal Highway Administration (FHWA), U.S. Department of Transportation. Sales are reported to the FHWA for claiming credits on ethanol. However, industry estimates of ethanol consumption were used in this report because several States do not maintain records or do not report gasohol sales or commingle gasohol sales data with regular gasoline consumption data.

Historical Perspective

Ethanol consumption increased substantially throughout the 1980's from 7 trillion Btu (85 million gallons) in 1981 to 43 trillion Btu (509 million gallons) in 1984 to 71 trillion Btu (840 million gallons) in 1989, but then dropped to 63 trillion Btu (750 million gallon) in 1990 (Table 10). The general increase during the 1980's can be attributed to three major factors: the passage of the Energy Tax Act of 1978, the escalating gasoline prices of the early 1980's, and the passage, by many States, of State tax credits and other incentives. The Energy Tax Act exempted ethanol from a large portion of the Federal excise tax on gasoline, which amounted to between 40 and 60 cents per gallon of ethanol. Additionally, the price of unleaded gasoline increased from 93 cents per gallon in 1978 to $1.38 per gallon in 1981, and this made ethanol more economically attractive. These two factors led to the expansion of ethanol production facilities and to the construction of additional production capacity. The 1990 U.S. ethanol operational production capacity was estimated to be 1.15 billion gallons.[31] A U.S. General Accounting Office analysis indicates that the ethanol industry is capable of doubling or tripling production over the next 8 years to 2.2 or 3.3 billion gallons annually.[32] This analysis made several assumptions:

[31]Information Resources, Inc., *Oxy-Fuel News*, January 7, 1991.

[32]*Alcohol Fuels: Impacts from Increased Use of Ethanol Blended Fuels*, GAO/RCED-90-156 (Washington, DC, July 1990).

Table 9. State Gasohol/Ethanol Incentives (in Addition to the Federal Tax Subsidy)
(Cents per Gallon)

State	Retailer Gasohol Excise Tax Exemption	Incentive to Ethanol Producers (per Gallon of Ethanol)
Alaska	8	-
Connecticut	1	-
Hawaii	4	-
Idaho	4	-
Illinois	([a])	-
Iowa	1	-
Kansas	-	20
Minnesota	2	20
Missouri	2	[b]20
Montana	-	[b]30
Nebraska	2	20
New Jersey	4	-
North Carolina	-	([d])
North Dakota	-	[b]40
Ohio	-	15
South Carolina	[c]6	-
South Dakota	2	20
Virginia	-	20
Washington	2.9	-
Wyoming	4	-

[a]Retailers of gasohol receive a 2-percent exemption of the price of gasohol.
[b]Producers receive payment if the ethanol is produced from agricultural products of the State.
[c]Exemption from motor fuel tax if the ethanol is produced in the State.
[d]Tax credit for construction of ethanol production capacity.
Note: One gallon of gasohol contains only 0.1 gallon of ethanol.
Source: National Corn Growers Association, *Ethanol Plant Development Handbook*, First Edition (April 1991).

Table 10. U.S. Consumption of Ethanol by Region, 1981-1990
(Trillion Btu)

	Consumption					
Region	1981	1984	1987	1989	1990	1990 Percent of Total
Northeast	([a])	([a])	([a])	<1	1	1
South	1	13	26	26	23	37
Midwest	4	25	38	38	34	54
West	2	5	4	7	6	10
Total	**7**	**43**	**69**	**71**	**63**	**100**

[a]Less than 0.5 trillion Btu.
Note: Totals may not equal sum of components because of independent rounding.
Sources: **1981-1987**: Energy Information Administration, *Annual Energy Review 1989*, DOE/EIA-0384(89) (Washington, DC, May 1990). **1989**: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels (November 1990). **1990**: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels (August 1991).

availability of land, increased production of corn at current prices, and the ability of the ethanol industry to distribute the fuel outside their local markets. While the industry may be capable of supporting that level of production, the prices need to be competitive.

Comparing the cost of ethanol with that of gasoline and other blending agents is difficult because of 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 either an octane enhancer or a fuel extender, volatility restrictions, age of the motor vehicle stock, and State and local subsidies. Without the subsidies and with existing technology, ethanol cannot be competitive with petroleum when petroleum prices are below $25 per barrel, unless byproduct credits exceed the cost of corn.[33]

With the abatement of gasoline prices in the mid-1980's ethanol became economically less attractive. However, the large producers with high production efficiencies have been able to keep ethanol production at fairly constant levels during the latter part of the 1980's. With the extension of the Federal tax benefits in 1990 to the year 2000, and the passage of the Clean Air Act Amendments of 1990, which mandates the reduction of mobile source emissions, there could be further growth in ethanol consumption. However, future developments will also depend on the prices of corn, gasoline, and other alternate fuels.

Data and Analysis

It is estimated that approximately 750 million gallons of ethanol were consumed by the U.S. transportation sector during 1990.[34] 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 100 million gallons of ethanol that was exported, primarily to Brazil, but does include the consumption of imported ethanol.

The Midwest region has consistently accounted for over half of the annual ethanol consumption. Ethanol consumption during 1990 in this region was 34 trillion Btu (405 million gallons), while 23 trillion Btu (278 million gallons) was consumed in the South, 6 trillion Btu (75 million gallons) was consumed in the West, and less than 1 trillion Btu was consumed in the Northeast (Table 10).

In the Northeast there is relatively little grain production and few tax credits for ethanol. Growth in ethanol usage in the South is due primarily to successful marketing by established regional producers and blenders. 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 and consumption result in reduced transit expenses from the producer to blender to retailer, and greater consumption of gasohol in the Midwest region.In the West, distribution is difficult and freight costs generally prohibit the cost-competitiveness of ethanol.

The variations in regional ethanol consumption are attributed to several factors:

- State tax credits — currently provided in only 20 States (Table 9)
- Transportation costs — distance from ethanol producers and areas of high grain (corn) production
- Limitations of the distribution infrastructure, such as pipelines and storage facilities.

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, flowing from the Gulf Coast to the major populations centers and from California to points west of the Rockies. The pipeline system is neither conveniently located nor structured for efficient distribution of ethanol from the major ethanol-producing areas in the Midwest. For example, no major petroleum product pipeline flows out of Nebraska to the East, South or far West.

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

[33]Kane, S.M., and Reilly, J.M., *Economics of Ethanol Production in the United States*, U.S. Department of Agriculture, Economic Research Service, Agricultural Economic Report No. 607, pp. 17-18.

[34]Information Resources, Inc., *Oxy-Fuel News*, January 14, 1991.

Corrosion is not the only problem with alcohol fuels in the petroleum product pipelines. If, as is sometimes the case, water is contained in the pipelines, the alcohol and water will combine and separate out of the petroleum product, causing the finished product to fall below specifications.

As a result of these factors, ethanol is currently transported mostly by truck, barge and rail car; these modes of transportation are far more costly than pipeline transport. As a result, ethanol is often splash blended at bulk stations or into trucks just prior to delivery to gas stations.

The Clean Air Act Amendments of 1990, passed on November 15, 1990, will require the use of additives to boost the oxygen content of traditional gasoline in areas of the United States with air quality/emissions problems. Ethanol has excellent oxygenating characteristics (increases combustion efficiency and decreases emissions) and has the potential for increased use in these problem areas. Several other types of oxygenating additives are being used or considered at this time, and other alternatives using ethanol, most notably ethyl tertiary butyl ether (commonly referred to as ETBE) are being developed and tested.

Future Outlook

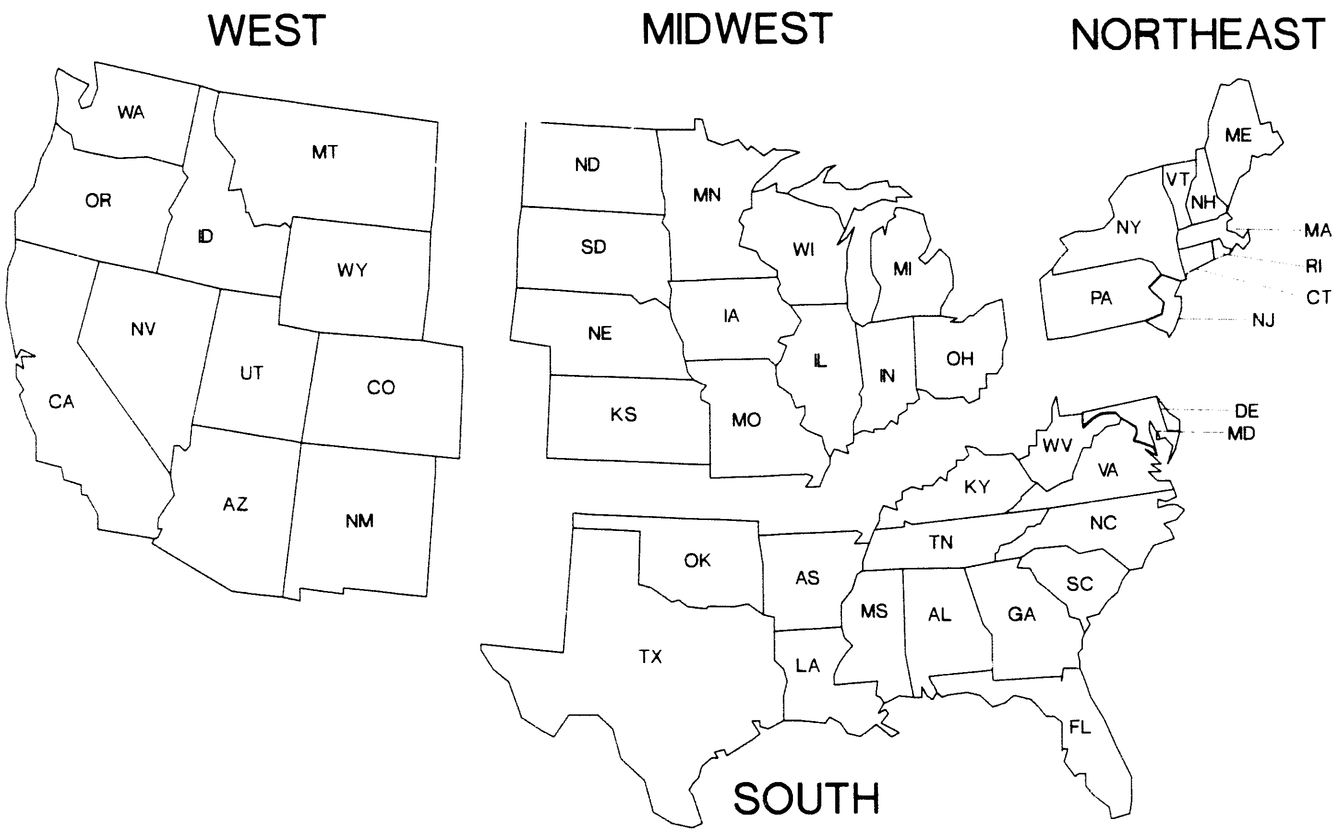
Consumption of ethanol in the United States as a gasoline supplement and octane enhancer is projected to increase to 0.14 quadrillion Btu in 2010.[35] The potential for corn-based alcohol production is limited because of the relative high feedstock (corn) costs and high production costs. Establishment of reliable feedstock supply, reduction of feedstock costs, and improvement of the cost and efficiency of conversion processes need to be implemented before ethanol can be cost competitive. Research is being conducted into developing low cost crops designed for high ethanol yields and into new and improved ethanol production processes. These improvements are expected to evolve over a long period of time and are not likely to have a substantial commercial impact until after the year 2010.

[35]Energy Information Administration, *Annual Energy Outlook 1991*, DOE/EIA-0383(91) (Washington, DC, March 1991).

Appendix A

U.S. Census Region Map

Figure A1. U.S. Census Regions



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

Appendix B

Procedures for Estimating Consumption Levels

Procedure for Industrial Sector Woodfuel Consumption

Data developed to measure woodfuel consumption in the industrial sector are based on the 1988 Manufacturing Energy Consumption Survey (MECS) conducted by the Energy Information Administration.[36] The following fuel categories taken from MECS were used as estimates of 1988 industrial woodfuel consumption:

- **Waste Material**—largely consisting of paper products and packing materials
- **Pulping and Black Liquor**—a residue of the chemical paper pulping process used as furnace fuel, primarily in SIC 26
- **Roundwood**—wood cut specifically for use as fuel
- **Wood Chips, etc.**—includes limb wood, bark, sawdust, forest residue, charcoal, and pulp waste.

For the first time, regional data are based on published and unpublished MECS data for SIC 24, SIC 26, and "Other." The regional data have high relative standard errors, but were regarded to be more accurate than the previously used methodology. The methodology used in the past assumed woodfuel consumption in the industrial sector to be proportional to the regional distributions of all energy forms consumed by SIC 24, SIC 26, and "Other" in MECS.

The 1988 values were inflated by the ratio of total industrial energy consumption in 1990 to total industrial energy consumption in 1988, or 23.042/22.111 = 4.21 percent.[37]

Procedure for Residential Sector Fuelwood Consumption

The procedure used in estimating residential fuelwood consumption is the same as was employed in EIA's last publication on wood energy consumption.[38] A summary of the procedure is provided below.

A sample survey found that short-term shifts in consumption patterns of residential fuelwood use are directly related to heating degree-days.[39] This implies that changes in heating degree days for individual households are the primary cause of change in fuelwood consumption. Therefore, the relationship between fuelwood consumption and heating degree days was used to compute consumption for the calendar year. Regional heating degree days, weighted by population, were obtained from the National Climatic Data Center.

Based on the assumption that the residential sector consumed the same amount of wood per heating degree-day in 1990 as in 1987, 1987 RECS data (published in 1989) were adjusted by the difference in heating degree-days between the 3 years to represent 1990 residential consumption.

The formula used for this conversion is as follows:

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

where:

C = 1990 consumption
C' = 1987 RECS consumption
= 0.85 quadrillion Btu
a = heating degree-days for 1990
b = heating degree-days for 1987.

[36]Energy Information Administration, *Manufacturing Energy Consumption Survey: Consumption of Energy 1988*, DOE/EIA-0512(88) (Washington, DC, May 1991).

[37]Energy Information Administration, *Monthly Energy Review*, DOE/EIA-0035(91/07) (Washington, DC, July 1991), Table 2.2.

[38]Energy Information Administration, *Estimates of Biofuels Consumption in the United States During 1987*, CNEAF/NAFD-89-03 (Washington, DC, March, 1989).

[39]Energy Information Administration, *Estimates of U.S. Woodfuel Consumption, 1980-1983*, DOE/EIA-0341(83) (Washington, DC, November 1984).

Procedure for Utility Sector Woodfuel Consumption

Energy Information Administration Form EIA-759, "Monthly Power Plant Report," was the source for identifying utilities that burn wood. Data reported on these forms were verified and modified as necessary through interviews wi6th facility plant managers.

Each facility reporting woodfuel use on Form EIA-759 was contacted to determine the number of short tons burned during 1990. These interviews also identified the utility's source of wood, future plans for wood consumption for the generation of electricity, and the perceived general trends in woodfuel consumption by utilities.

All plants reported woodfuel consumption data in short tons of green wood (tons of wood containing 50 percent or more water by weight). These data were converted into oven-dried short tons using the following formula:

$$ODST = GT \times CF_i$$

where:

GT = green tons consumed

CF_i = (8,000,000 Btu per green ton) / (17,200,000 Btu per oven-dried short ton)
= 0.465 oven-dried short ton per green ton

$ODST$ = oven-dried short tons.

The average heat content of green wood was assumed to be 4,000 Btu per pound or 8.0 million Btu per ton of woodfuel. These conversion factors are generally accepted by industry and used by EIA.[40]

Procedure for MSW Estimates

Estimates for consumption of municipal solid waste for energy in 1990 were developed from the 1990 *Resource Recovery Yearbook*[41] and the 1988-1989 *Methane Recovery Yearbook*.[42]

These sources provided information on:

- The type of waste fuel—i.e., refuse-derived fuel (RDF), "raw" MSW, and the Btu value of landfill gas collected—used at each facility
- The average operating throughput (in tons for MSW, and cubic feet for landfill gas) per day
- Days per week plants were operated in 1990 for MSW and in 1987 for methane
- Periods of plant down-time for repair and maintenance.

For RDF, an industry standard for unprocessed refuse-to-RDF conversion efficiency of 75 percent was used to calculate tons of fuel obtained. Annual refuse or landfill gas throughput was calculated by multiplying the average daily throughput by the number of days the plant was operating during the year.

Total biofuel consumption was computed by applying industry reported Btu values to processed and unprocessed refuse. For landfill gas, the reported Btu value of the gas at each facility was used. These site-specific data were then combined geographically.

To estimate 1990 consumption of energy from landfill methane, the 1989 data were reported.

Procedure for Manufacturing Waste Estimates

Estimates of energy from manufacturing waste were calculated from published and unpublished 1988 MECS data. A category "biofuels" reported as waste energy, was used as the principle data element. The 1988 values were inflated by the ratio of total industrial energy consumption in 1990 to total industrial energy consumption in 1988, or 23.042/22.111 = 4.21 percent.[43] This is the same as the methodology used to develop industrial woodfuel consumption estimates. The regional distributions for manufacturing waste consumption were partially provided by unpublished the MECS data. For regions where consumption was very small MECS did not provide regional data. For these regions the data were estimated.

[40] Energy Information Administration, *Estimates of Biofuels Consumption in the United States During 1987*, CNEAF/NAFD-89-03 (Washington, DC, March 1989).

[41] Government Advisory Associates, Inc., *1990-1991 Resource Recovery Yearbook* (New York, NY, 1991).

[42] Government Advisory Associates, Inc., *1988-1989 Methane Recovery from Landfill Yearbook* (New York, NY, 1989).

[43] Energy Information Administration, *Monthly Energy Review*, DOE/EIA-0035(91/07) (Washington, DC, July 1991), Table 2.2.

Appendix C

Independent Power Producers Biofuels Consumption

Independent power producers (IPPs) are a subgroup of electric generators, exempt from State and Federal rate regulations. IPPs produce electricity and sell it to State-regulated utilities (i.e., the grid). A subgroup of this category are "qualifying facilities" (QFs). Of the IPPs that use biofuels, most are QFs or industrial cogeneration facilities included in MECS[44] and are covered in this report.

Under the Public Utility Regulatory Policies Act (PURPA), utilities must purchase power from QFs at their (utilities) avoided costs. QFs are cogeneration or small facilities that meet the following criteria: 1) capacity no greater than 80 megawatts; 2) 50 percent or more of total energy consumption derived from biomass, solar, wind, hydro, geothermal, or waste; and 3) aggregate fossil fuel not exceeding 25 percent of total energy input during any calendar year. A majority of the QFs are hydroelectric, and QFs using biofuels are a small subset of all QFs. Most QFs that use biofuels are cogeneration facilities in the paper and pulp and lumber industries (i.e., using woodfuel) or the food processing industry (i.e., using sugar cane).

EIA has initiated a survey of nonutility generators which includes the collection of information from electricity generators using biomass (biologically based, nonfossil) that are not included in MECS. It is expected that there are not many occurrences of this type of facility, but data are not yet available for proper assessment of the situation.

[44]Energy Information Administration, *Manufacturing Energy Consumption Survey: Consumption of Energy, 1988*, DOE/EIA-0512(88) (Washington, DC, May 1991).

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