Biomass Energy Data Book

Edition 2

U.S. Department of Energy

Energy Efficiency and Renewable Energy

Bringing you a prosperous future where energy is clean, abundant, reliable, and affordable

Oak Ridge National Laboratory

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EDITION 2

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ACRONYMS

AEO	Annual Energy Outlook
ARS	Agricultural Research Service, USDA
ASABE	American Society of Agricultural and Biological Engineers
ASTM	American Society for Testing and Materials
Btu	British thermal units
CES	Cooperative Extension Service
CO2	Carbon dioxide
CRP	Conservation Reserve Program
d.b.h.	Diameter at breast height
DOE	Department of Energy
EERE	Office of Energy Efficiency and Renewable Energy
EIA	Energy Information Administration
EPA	Environmental Protection Agency
EPAct	Energy Policy Act
ERS	Economic Research Service
Etoh	Ethanol
FTE	Fuel Treatment Evaluator
FY	Fiscal Year
GAO	United States Government Accountability Office
GHG	Greenhouse Gas
GPRA	Government Performance Results Act
GW	Gigawatt
IEA	International Energy Agency
LFG	Landfill Gas
MJ	Megajoule
MMBtu	Million British thermal units
MW	Megawatt
MSW	Municipal Solid Waste
NASS	National Agricultural Statistics Service
NEMS	National Energy Modeling System
NOAA	National Oceanic & Atmospheric Administration
NREL	National Renewable Energy Laboratory
NRCS	Natural Resources Conservation Service
ORNL	Oak Ridge National Laboratory
PNNL	Pacific Northwest National Laboratory
PPA	Power Purchase Agreement
RPS	Renewable Portfolio Standard
SEO	State Energy Office
SRIC	Short Rotation Intensive Culture
SSEB	Southern States Energy Board
TBD	To Be Determined
TVA	Tennessee Valley Authority
USDA	United States Department of Agriculture
USFS	United States Forest Service

PREFACE

The Department of Energy, through the Biomass Program in the Office of Energy Efficiency and Renewable Energy, has contracted with Oak Ridge National Laboratory to prepare this *Biomass Energy Data Book*. The purpose of this data book is to draw together, under one cover, biomass data from diverse sources to produce a comprehensive document that supports anyone with an interest or stake in the biomass industry. Given the increasing demand for energy, policymakers and analysts need to be well-informed about current biomass energy production activity and the potential contribution biomass resources and technologies can make toward meeting the nation's energy demands. This is the second edition of the *Biomass Energy Data Book* and it is available online in electronic format. Because there are many diverse online sources of biomass information, the Data Book provides links to many of those valuable information sources. Biomass energy technologies used in the United States include an extremely diverse array of technologies - from wood or pellet stoves used in homes to large, sophisticated biorefineries producing multiple products. For some types of biomass energy production, there are no annual inventories or surveys on which to base statistical data. For some technology areas there are industry advocacy groups that track and publish annual statistics on energy production capacity, though not necessarily actual production or utilization. The Department of Energy's Energy Information Administration (EIA) produces annual estimates of biomass energy utilization and those estimates are included in this data book. Information from industry groups are also provided to give additional detail. An effort has been made to identify the best sources of information on capacity, production and utilization of most of the types of biomass energy currently being produced in this country. It is certain, however, that not all biomass energy contributions have been identified. With the rapid expansion in biomass technologies that is occurring, bioenergy production information may not yet be available, or may be proprietary.

It is even more difficult to track the diverse array of biomass resources being used as feedstocks for biomass energy production. Since most of the biomass resources currently being used for energy or bioproducts are residuals from industrial, agricultural or forestry activities, there is no way to systematically inventory biomass feedstock collection and use and report it in standard units. All biomass resource availability and utilization information available in the literature are estimates, not inventories of actual collection and utilization. Biomass utilization information is derived from biomass energy production data, but relies on assumptions about energy content and conversion efficiencies for each biomass type and conversion technology. Biomass availability data relies on understanding how much of a given biomass type (e.g., corn grain) is produced, alternate demands for that biomass type, economic profitability associated with each of those alternate demands, environmental impacts of collection of the biomass, and other factors such as incentives. This book presents some of the information needed for deriving those estimates, as well as providing biomass resource estimates that have been estimated by either ORNL staff or other scientists. In all cases it should be recognized that estimates are not precise and different assumptions will change the results.

ABSTRACT

The *Biomass Energy Data Book* is a statistical compendium prepared and published by Oak Ridge National Laboratory (ORNL) under contract with the Office of the Biomass Program in the Energy Efficiency and Renewable Energy (EERE) program of the Department of Energy (DOE). Designed for use as a convenient reference, the book represents an assembly and display of statistics and information that characterize the biomass industry, from the production of biomass feedstocks to their end use, including discussions on sustainability.

This is the second edition of the *Biomass Energy Data Book* which is available online in electronic format. There are five main sections to this book. The first section is an introduction which provides an overview of biomass resources and consumption. Following the introduction to biomass is a section on biofuels which covers ethanol, biodiesel and bio-oil. The biopower section focuses on the use of biomass for electrical power generation and heating. The fourth section is on the developing area of biorefineries, and the fifth section covers feedstocks that are produced and used in the biomass industry. The sources used represent the latest available data. There are also four appendices which include frequently needed conversion factors, a table of selected biomass feedstock characteristics, assumptions for selected tables and figures, and discussions on sustainability. A glossary of terms and a list of acronyms are also included for the reader's convenience.

1. INTRODUCTION TO BIOMASS

BIOMASS OVERVIEW

Biomass is defined as any organic matter that is available on a renewable or recurring basis. It includes all plants and plant derived materials, including agricultural crops and trees, wood and wood residues, grasses, aquatic plants, animal manure, municipal residues, and other residue materials. Plants (on land or in water) use the light energy from the sun to convert water and carbon dioxide to carbohydrates, fats, and proteins along with small amounts minerals. The carbohydrate component includes cellulose and hemi-cellulose fibers which gives strength to plant structures and lignin which binds the fibers together. Some plants store starches and fats (oils) in seeds or roots and simple sugars can be found in plant tissues.

In 2007, biomass production contributed 3.6 quadrillion Btu of energy to the 71.7 quadrillion Btu of energy produced in the United States or about 5% of total energy production. Since a substantial portion of U.S. energy is imported, the more commonly quoted figure is that biomass consumption amounted to 3.6 quadrillion Btu of energy of the 101.6 quadrillion Btu of energy consumed in the United States in 2007 or about 3.5%. At present, wood resources contribute most to the biomass resources consumed in the United States and most of that is used in the generation of electricity and industrial process heat and steam. However, the contribution of biofuels has doubled since 2005 and now amounts to close to one third of all biomass consumed. While most biofuels feedstocks are currently starches, oils and fats derived from the agricultural sector, whole plants and plant residues will soon be an important feedstock for cellulosic biofuels. Algae are being developed as a source of both oil and cellulosic feedstocks. The industrial sector (primarily the wood products industry) used about 1.4 quadrillion Btu in 2007. The residential and commercial sectors consume 0.06 quadrillion Btu of biomass; however, this figure may understate consumption in these sectors due to unreported consumption, such as home heating by wood collected on private property. The use of biomass fuels such as ethanol and biodiesel by the transportation sector is now at about 0.6 quadrillion Btu. This is less than the total amount of biofuels produced because some liquid biofuels are used by other sources.

The Renewable Fuels Association characterized 2007 as a year that ushered in a new energy era for America. The enactment of the Energy Independence and Security Act of 2007 (H.R. 6) coupled increased vehicle efficiency with greater renewable fuel use. The law increased the Renewable Fuel Standard (RFS) to 36 billion gallons of annual renewable fuel use by 2022 and required that 60 percent of the new RFS be met by advanced biofuels, including cellulosic ethanol.

To stimulate progress in this direction, the Department of Energy's (DOE) Biomass Program awarded cost-sharing contracts in 2007 to six companies to develop commercial scale integrated biorefineries using cellulosic biomass. One of the commercial scale projects, Range Fuels, broke ground for construction of the first cellulosic ethanol biorefinery near Soperton, Georgia during 2007. An existing corn to ethanol company, Poet, LLC began construction of a cellulosic to ethanol unit at an existing facility in Scotland, S.D. during 2007. To facilitate innovation in cellulosic biomass conversion technologies, DOE awarded 9 cost-sharing contracts for the development of small-scale cellulosic biorefineries. Recipients ranged from existing pulp and paper companies and existing ethanol companies to new companies working in collaboration with universities and private sector supporters. Many new types of technologies are being developed by the small-scale biorefinery efforts (see Biorefinery Section).

With the passage of the 2008 Farm Bill in May of 2008, USDA extended or instituted several programs that provide incentives for the development of advanced biofuels using cellulosic biomass.

In 2007 biomass accounted for just over half of the renewable energy production in the United States.

Table 1.1
Energy Production by Source, 1973—2007
(Quadrillion Btu)

	Fossil Fuels						Renewable Energy[a]						
Year	Coal	Natural Gas (Dry)	Crude Oil[b]	Natural Gas Plant Liquids	Total	Nuclear Electric Power	Hydro-electric Power[c]	Biomass[d]	Geo-thermal	Solar	Wind	Total	Total
1973	13.99	22.19	19.49	2.57	58.24	0.91	2.86	1.53	0.04	NA	NA	4.43	63.58
1974	14.07	21.21	18.57	2.47	56.33	1.27	3.18	1.54	0.05	NA	NA	4.77	62.37
1975	14.99	19.64	17.73	2.37	54.73	1.90	3.15	1.50	0.07	NA	NA	4.72	61.36
1976	15.65	19.48	17.26	2.33	54.72	2.11	2.98	1.71	0.08	NA	NA	4.77	61.60
1977	15.75	19.57	17.45	2.33	55.10	2.70	2.33	1.84	0.08	NA	NA	4.25	62.05
1978	14.91	19.49	18.43	2.25	55.07	3.02	2.94	2.04	0.06	NA	NA	5.04	63.14
1979	17.54	20.08	18.10	2.29	58.01	2.78	2.93	2.15	0.08	NA	NA	5.17	65.95
1980	18.60	19.91	18.25	2.25	59.01	2.74	2.90	2.48	0.11	NA	NA	5.49	67.23
1981	18.38	19.70	18.15	2.31	58.53	3.01	2.76	2.60	0.12	NA	NA	5.48	67.01
1982	18.64	18.32	18.31	2.19	57.46	3.13	3.27	2.66	0.10	NA	NA	6.03	66.62
1983	17.25	16.59	18.39	2.18	54.42	3.20	3.53	2.90	0.13	NA	0.00	6.56	64.18
1984	19.72	18.01	18.85	2.27	58.85	3.55	3.39	2.97	0.16	0.00	0.00	6.52	68.92
1985	19.33	16.98	18.99	2.24	57.54	4.08	2.97	3.02	0.20	0.00	0.00	6.18	67.80
1986	19.51	16.54	18.38	2.15	56.58	4.38	3.07	2.93	0.22	0.00	0.00	6.22	67.18
1987	20.14	17.14	17.67	2.22	57.17	4.75	2.63	2.87	0.23	0.00	0.00	5.74	67.66
1988	20.74	17.60	17.28	2.26	57.87	5.59	2.33	3.02	0.22	0.00	0.00	5.57	69.03
1989	21.36	17.85	16.12	2.16	57.48	5.60	2.84	3.16	0.32	0.06	0.02	6.39	69.48
1990	22.49	18.33	15.57	2.17	58.56	6.10	3.05	2.74	0.34	0.06	0.03	6.21	70.87
1991	21.64	18.23	15.70	2.31	57.87	6.42	3.02	2.78	0.35	0.06	0.03	6.24	70.53
1992	21.69	18.38	15.22	2.36	57.66	6.48	2.62	2.93	0.35	0.06	0.03	5.99	70.13
1993	20.34	18.58	14.49	2.41	55.82	6.41	2.89	2.91	0.36	0.07	0.03	6.26	68.50
1994	22.20	19.35	14.10	2.39	58.04	6.69	2.68	3.03	0.34	0.07	0.04	6.16	70.89
1995	22.13	19.08	13.89	2.44	57.54	7.08	3.21	3.10	0.29	0.07	0.03	6.70	71.32
1996	22.79	19.34	13.72	2.53	58.39	7.09	3.59	3.16	0.32	0.07	0.03	7.17	72.64
1997	23.31	19.39	13.66	2.50	58.86	6.60	3.64	3.11	0.32	0.07	0.03	7.18	72.63
1998	24.05	19.61	13.24	2.42	59.31	7.07	3.30	2.93	0.33	0.07	0.03	6.66	73.04
1999	23.30	19.34	12.45	2.53	57.61	7.61	3.27	2.97	0.33	0.07	0.05	6.68	71.91
2000	22.74	19.66	12.36	2.61	57.37	7.86	2.81	3.01	0.32	0.07	0.06	6.26	71.49
2001	23.55	20.17	12.28	2.55	58.54	8.03	2.24	2.63	0.31	0.07	0.07	5.32	71.89
2002	22.73	19.44	12.16	2.56	56.89	8.14	2.69	2.71	0.33	0.06	0.11	5.90	70.94
2003	22.09	19.69	12.03	2.35	56.16	7.96	2.82	2.82	0.33	0.06	0.11	6.15	70.26
2004	22.85	19.09	11.50	2.47	55.91	8.22	2.69	3.01	0.34	0.06	0.14	6.25	70.38
2005	23.19	18.57	10.96	2.33	55.06	8.16	2.70	3.14	0.34	0.07	0.18	6.43	69.65
2006	23.79	18.99	10.80	2.36	55.94	8.21	2.87	3.32	0.34	0.07	0.26	6.87	71.02
2007	23.50	19.82	10.80	2.40	56.52	8.41	2.46	3.58	0.35	0.08	0.32	6.80	71.73

Source:
Energy Information Administration. 2008. *Monthly Energy Review*, Table 1.2, July, www.eia.doe.gov/emeu/mer/overview.html.

Note: NA = Not available.

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[a] End-use consumption and electricity net generation.
[b] Includes lease condensate.
[c] Conventional hydroelectric power.
[d] Wood, waste, and alcohol fuels (ethanol blended into motor gasoline).

Table 1.2
Energy Consumption by Source, 1973—2007
(Quadrillion Btu)

	Fossil Fuels					Renewable Energy[a]						
Year	Coal	Natural Gas[b]	Petro-leum[c,d]	Total[e]	Nuclear Electric Power	Hydro-electric Power[f]	Biomass[d,g]	Geo-thermal	Solar	Wind	Total	Total[d,h]
1973	12.97	22.51	34.84	70.32	0.91	2.86	1.53	0.04	NA	NA	4.43	75.71
1974	12.66	21.73	33.45	67.91	1.27	3.18	1.54	0.05	NA	NA	4.77	73.99
1975	12.66	19.95	32.73	65.35	1.90	3.15	1.50	0.07	NA	NA	4.72	72.00
1976	13.58	20.35	35.17	69.10	2.11	2.98	1.71	0.08	NA	NA	4.77	76.01
1977	13.92	19.93	37.12	70.99	2.70	2.33	1.84	0.08	NA	NA	4.25	78.00
1978	13.77	20.00	37.97	71.86	3.02	2.94	2.04	0.06	NA	NA	5.04	79.99
1979	15.04	20.67	37.12	72.89	2.78	2.93	2.15	0.08	NA	NA	5.17	80.90
1980	15.42	20.24	34.20	69.83	2.74	2.90	2.48	0.11	NA	NA	5.49	78.12
1981	15.91	19.75	31.93	67.57	3.01	2.76	2.60	0.12	NA	NA	5.48	76.17
1982	15.32	18.36	30.23	63.89	3.13	3.27	2.66	0.10	NA	NA	6.03	73.15
1983	15.89	17.22	30.05	63.15	3.20	3.53	2.90	0.13	NA	0.00	6.56	73.04
1984	17.07	18.39	31.05	66.50	3.55	3.39	2.97	0.16	0.00	0.00	6.52	76.71
1985	17.48	17.70	30.92	66.09	4.08	2.97	3.02	0.20	0.00	0.00	6.18	76.49
1986	17.26	16.59	32.20	66.03	4.38	3.07	2.93	0.22	0.00	0.00	6.22	76.76
1987	18.01	17.64	32.87	68.52	4.75	2.63	2.87	0.23	0.00	0.00	5.74	79.17
1988	18.85	18.45	34.22	71.56	5.59	2.33	3.02	0.22	0.00	0.00	5.57	82.82
1989	19.07	19.60	34.21	72.91	5.60	2.84	3.16	0.32	0.06	0.02	6.39	84.94
1990	19.17	19.60	33.55	72.33	6.10	3.05	2.74	0.34	0.06	0.03	6.21	84.65
1991	18.99	20.03	32.85	71.88	6.42	3.02	2.78	0.35	0.06	0.03	6.24	84.61
1992	19.12	20.71	33.53	73.40	6.48	2.62	2.93	0.35	0.06	0.03	5.99	85.96
1993	19.84	21.23	33.74	74.84	6.41	2.89	2.91	0.36	0.07	0.03	6.26	87.60
1994	19.91	21.73	34.56	76.26	6.69	2.68	3.03	0.34	0.07	0.04	6.16	89.26
1995	20.09	22.67	34.44	77.26	7.08	3.21	3.10	0.29	0.07	0.03	6.71	91.17
1996	21.00	23.09	35.67	79.78	7.09	3.59	3.16	0.32	0.07	0.03	7.17	94.18
1997	21.45	23.22	36.16	80.87	6.60	3.64	3.11	0.32	0.07	0.03	7.18	94.77
1998	21.66	22.83	36.82	81.37	7.07	3.30	2.93	0.33	0.07	0.03	6.66	95.18
1999	21.62	22.91	37.84	82.43	7.61	3.27	2.97	0.33	0.07	0.05	6.68	96.82
2000	22.58	23.82	38.26	84.73	7.86	2.81	3.01	0.32	0.07	0.06	6.26	98.98
2001	21.91	22.77	38.19	82.90	8.03	2.24	2.63	0.31	0.07	0.07	5.32	96.33
2002	21.90	23.56	38.23	83.75	8.14	2.69	2.71	0.33	0.06	0.11	5.89	97.86
2003	22.32	22.90	38.81	84.08	7.96	2.82	2.82	0.33	0.06	0.11	6.15	98.21
2004	22.47	22.93	40.29	85.83	8.22	2.69	3.02	0.34	0.06	0.14	6.26	100.35
2005	22.80	22.58	40.39	85.82	8.16	2.70	3.15	0.34	0.07	0.18	6.44	100.51
2006	22.45	22.19	39.96	84.66	8.21	2.87	3.37	0.34	0.07	0.26	6.92	99.86
2007	22.77	23.64	39.82	86.25	8.41	2.46	3.61	0.35	0.08	0.32	6.83	101.60

Source:
Energy Information Administration. 2008. *Monthly Energy Review*, Table 1.3, July 2008, www.eia.doe.gov/emeu/mer/overview.html.

Note: NA = Not available.

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[a] End-use consumption and electricity net generation.
[b] Natural gas, plus a small amount of supplemental gaseous fuels that cannot be identified separately.
[c] Petroleum products supplied, including natural gas plant liquids and crude oil burned as fuel. Beginning in 1993, also includes ethanol blended into other gasoline.
[d] Beginning in 1993, ethanol blended into motor gasoline is included in both "Petroleum and "biomass," but is counted only once in total consumption.
[e] Includes coal coke net imports.
[f] Conventional hydroelectric power.
[g] Wood, waste, and alcohol fuels (ethanol blended into motor gasoline).
[h] Includes coal coke net imports and electricity net imports, which are not separately displayed.

Except for corn and soybeans, all biomass resources being used in 2007 for energy are some type of residue or waste. Corn grain is used for ethanol and soybeans are used for biodiesel fuel.

Table 1.3
Renewable Energy Consumption by Source, 1973—2007
(Trillion Btu)

Year	Hydro-electric Power[a]	Biomass				Geo-thermal[e]	Solar[f]	Wind[g]	Total
		Wood[b]	Waste[c]	Biofuels[d]	Total				
1973	2,861.45	1,527.01	2.06	NA	1,529.07	42.61	NA	NA	4,433.12
1974	3,176.58	1,537.76	1.90	NA	1,539.66	53.16	NA	NA	4,769.40
1975	3,154.61	1,496.93	1.81	NA	1,498.73	70.15	NA	NA	4,723.49
1976	2,976.27	1,711.48	1.89	NA	1,713.37	78.15	NA	NA	4,767.79
1977	2,333.25	1,836.52	1.81	NA	1,838.33	77.42	NA	NA	4,249.00
1978	2,936.98	2,036.15	1.46	NA	2,037.61	64.35	NA	NA	5,038.94
1979	2,930.69	2,149.85	2.05	NA	2,151.91	83.79	NA	NA	5,166.38
1980	2,900.14	2,473.86	1.64	NA	2,475.50	109.78	NA	NA	5,485.42
1981	2,757.97	2,495.56	88.00	12.83	2,596.39	123.04	NA	NA	5,477.40
1982	3,265.56	2,510.05	119.00	34.51	2,663.56	104.75	NA	NA	6,033.86
1983	3,527.26	2,684.27	157.00	63.18	2,904.45	129.34	NA	0.03	6,561.07
1984	3,385.81	2,685.82	208.00	77.23	2,971.05	164.90	0.06	0.07	6,521.87
1985	2,970.19	2,686.77	236.32	93.02	3,016.11	198.28	0.11	0.06	6,184.75
1986	3,071.18	2,562.13	262.86	106.98	2,931.98	219.18	0.15	0.04	6,222.52
1987	2,634.51	2,463.16	289.00	122.66	2,874.82	229.12	0.11	0.04	5,738.59
1988	2,334.27	2,576.66	315.33	124.12	3,016.11	217.29	0.09	0.01	5,567.77
1989	2,837.26	2,679.62	354.36	125.59	3,159.57	317.16	55.29	22.03	6,391.32
1990	3,046.39	2,216.17	408.08	111.21	2,735.45	335.80	59.72	29.01	6,206.37
1991	3,015.94	2,214.08	439.72	128.61	2,782.41	346.25	62.69	30.80	6,238.08
1992	2,617.44	2,313.47	473.20	145.97	2,932.64	349.31	63.89	29.86	5,993.14
1993	2,891.61	2,259.77	479.34	170.51	2,909.62	363.72	66.46	30.99	6,262.39
1994	2,683.46	2,323.82	515.32	190.40	3,029.54	338.11	68.55	35.56	6,155.21
1995	3,205.31	2,369.87	531.48	202.39	3,103.73	293.89	69.86	32.63	6,705.42
1996	3,589.66	2,437.03	576.99	144.94	3,158.96	315.53	70.83	33.44	7,168.42
1997	3,640.46	2,370.99	550.60	186.82	3,108.42	324.96	70.24	33.58	7,177.65
1998	3,297.05	2,184.16	542.30	205.00	2,931.46	328.30	69.79	30.85	6,657.46
1999	3,267.58	2,214.17	540.16	213.16	2,967.48	330.92	68.79	45.89	6,680.67
2000	2,811.12	2,261.72	510.80	240.52	3,013.04	316.80	66.39	57.06	6,264.40
2001	2,241.86	2,005.83	363.88	257.60	2,627.31	311.26	65.45	69.62	5,315.51
2002	2,689.02	1,995.28	402.01	308.88	2,706.17	328.31	64.39	105.33	5,893.22
2003	2,824.53	2,002.04	401.34	413.70	2,817.09	330.55	63.62	114.57	6,150.36
2004	2,690.08	2,121.25	388.72	513.36	3,023.33	341.08	64.50	141.75	6,260.74
2005	2,702.94	2,156.35	403.22	594.59	3,154.16	342.58	66.13	178.09	6,443.90
2006	2,869.04	2,171.73	407.23	794.99	3,373.95	342.88	72.22	263.74	6,921.82
2007	2,463.01	2,165.11	431.36	1,018.39	3,614.85	352.96	80.41	318.83	6,830.07

Source:
Energy Information Administration. 2008. *Monthly Energy Review*, Table 10.1, July, www.eia.doe.gov/emeu/mer/renew.html.

Note: NA = Not available.

[a] Conventional hydroelectric power.
[b] Wood, black liquor, and other wood waste.
[c] Municipal solid waste, landfill gas, sludge waste, tires, agricultural byproducts, and other biomass.
[d] Fuel ethanol and biodiesel consumption, plus losses and co-products from the production of fuel ethanol and biodiesel.
[e] Geothermal electricity net generation, heat pump, and direct use energy.
[f] Solar thermal and photovoltaic electricity net generation, and solar thermal direct use energy.
[g] Wind electricity net generation.

Ethanol provided 90% of the renewable transportation fuels consumed in the United States in 2007 while biodiesel accounted for about 10%. In the industrial sector, biomass accounted for nearly all of the renewable energy consumed.

Table 1.4
Renewable Energy Consumption for Industrial and Transportation Sectors, 1973–2007
(Trillion Btu)

	Industrial Sector[a]								Transportation Sector		
		Biomass							Biomass		
Year	Hydro-electric Power[b]	Wood[c]	Waste[d]	Fuel Ethanol[f]	Losses and Co-products[g]	Total	Geo-thermal[e]	Total	Fuel Ethanol[h]	Biodiesel[g]	Total
1973	34.77	1,164.85	NA	NA	NA	1,164.85	NA	1,199.63	NA	NA	NA
1974	33.20	1,159.07	NA	NA	NA	1,159.07	NA	1,192.28	NA	NA	NA
1975	32.32	1,063.27	NA	NA	NA	1,063.27	NA	1,095.59	NA	NA	NA
1976	33.37	1,219.88	NA	NA	NA	1,219.88	NA	1,253.25	NA	NA	NA
1977	32.60	1,281.25	NA	NA	NA	1,281.25	NA	1,313.85	NA	NA	NA
1978	31.56	1,400.42	NA	NA	NA	1,400.42	NA	1,431.99	NA	NA	NA
1979	34.09	1,404.86	NA	NA	NA	1,404.86	NA	1,438.96	NA	NA	NA
1980	32.84	1,600.00	NA	NA	NA	1,600.00	NA	1,632.84	NA	NA	NA
1981	33.04	1,602.00	86.72	0.09	5.83	1,694.64	NA	1,727.68	6.86	NA	6.86
1982	33.05	1,516.00	117.69	0.21	15.51	1,649.41	NA	1,682.46	18.66	NA	18.66
1983	33.26	1,690.00	155.29	0.31	28.18	1,873.77	NA	1,907.03	34.41	NA	34.41
1984	33.00	1,679.00	203.57	0.53	34.23	1,917.33	NA	1,950.33	42.11	NA	42.11
1985	33.02	1,645.00	229.64	0.87	41.02	1,916.52	NA	1,949.55	50.75	NA	50.75
1986	33.02	1,610.00	255.70	0.92	46.98	1,913.60	NA	1,946.62	58.61	NA	58.61
1987	32.94	1,576.00	281.77	1.03	53.66	1,912.45	NA	1,945.39	67.42	NA	67.42
1988	32.64	1,625.00	307.71	0.96	54.12	1,987.78	NA	2,020.42	68.50	NA	68.50
1989	28.40	1,583.56	200.41	1.00	54.59	1,839.56	1.80	1,869.76	69.48	NA	69.48
1990	30.95	1,441.91	192.32	0.84	48.21	1,683.28	1.90	1,716.13	61.65	NA	61.65
1991	29.68	1,409.85	184.67	1.02	55.61	1,651.16	2.10	1,682.93	71.53	NA	71.53
1992	30.51	1,461.22	178.51	1.15	62.97	1,703.86	2.20	1,736.57	81.37	NA	81.37
1993	29.59	1,484.35	181.16	1.21	73.52	1,740.24	2.40	1,772.23	95.57	NA	95.57
1994	62.19	1,579.77	199.25	1.44	81.79	1,862.25	2.80	1,927.23	106.98	NA	106.98
1995	54.70	1,652.08	195.03	1.57	85.89	1,934.56	3.00	1,992.26	114.79	NA	114.79
1996	60.77	1,683.50	223.55	1.11	61.38	1,969.53	2.90	2,033.21	82.31	NA	82.31
1997	58.06	1,730.61	184.02	1.47	81.01	1,997.11	3.10	2,058.27	104.05	NA	104.05
1998	54.54	1,603.44	180.35	1.49	88.08	1,873.35	3.00	1,930.89	115.15	NA	115.15
1999	48.66	1,619.52	171.04	1.15	91.60	1,883.31	4.10	1,936.07	120.20	NA	120.20
2000	42.18	1,635.93	145.11	1.30	101.20	1,883.53	4.40	1,930.12	137.64	NA	137.64
2001	32.50	1,442.64	128.60	2.64	109.83	1,683.72	4.76	1,720.98	143.70	1.09	144.79
2002	38.91	1,396.44	146.35	3.21	132.86	1,678.85	4.79	1,722.55	171.01	1.34	172.35
2003	43.24	1,363.32	142.44	4.54	173.77	1,684.06	3.40	1,730.70	232.74	1.81	234.55
2004	32.56	1,475.73	131.63	6.41	210.48	1,824.25	3.80	1,860.61	292.07	3.57	295.64
2005	31.95	1,451.73	148.25	6.98	241.02	1,847.98	4.30	1,884.23	334.11	11.58	345.69
2006	28.76	1,515.19	140.25	9.43	301.18	1,966.04	4.40	1,999.20	451.22	31.96	483.17
2007	22.50	1,456.63	151.00	11.78	378.88	1,998.29	4.70	2,025.49	563.57	62.65	626.22

Source:
Energy Information Administration. 2008. *Monthly Energy Review*, Table 10.2b, July, www.eia.doe.gov/emeu/mer/renew.html.

Note: NA = Not available.

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[a] Industrial sector fuel use, including that at industrial combined-heat-and-power (CHP) and industrial electricity plants.
[b] Conventional hydroelectric power.
[c] Wood, black liquor, and other wood waste.
[d] Municipal solid waste, landfill gas, sludge waste, tires, agricultural byproducts, and other biomass.
[e] Geothermal heat pump and direct use energy.
[f] Ethanol blended into motor gasoline.
[g] Losses and co-products from the production of fuel ethanol and biodiesel. Does not include natural gas, electricity, and other non-biomass energy used in the production of fuel ethanol and biodiesel—these are included in the industrial sector consumption statistics for the appropriate energy source.
[h] The ethanol portion of motor fuels (such as E10 and E85) consumed by the transportation sector.

In 2007, biomass accounted for about 83% of the renewable energy used in the residential sector and about 87% of the renewable energy used in the commercial sector.

Table 1.5
Renewable Energy Consumption for Residential and Commercial Sectors, 1973–2007
(Trillion Btu)

	Residential Sector				Commercial Sector[a]						
	Biomass					Biomass					
Year	Wood[b]	Geo-thermal[c]	Solar[d]	Total	Hydro-electric	Wood[b]	Waste	Fuel Ethanol	Total	Geo-thermal[c]	Total
1973	354.10	NA	NA	354.10	NA	6.71	NA	NA	6.71	NA	6.71
1974	370.95	NA	NA	370.95	NA	7.02	NA	NA	7.02	NA	7.02
1975	425.41	NA	NA	425.41	NA	8.07	NA	NA	8.07	NA	8.07
1976	481.63	NA	NA	481.63	NA	9.10	NA	NA	9.10	NA	9.10
1977	541.78	NA	NA	541.78	NA	10.29	NA	NA	10.29	NA	10.29
1978	621.85	NA	NA	621.85	NA	11.83	NA	NA	11.83	NA	11.83
1979	728.08	NA	NA	728.08	NA	13.81	NA	NA	13.81	NA	13.81
1980	850.00	NA	NA	850.00	NA	21.00	NA	NA	21.00	NA	21.00
1981	870.00	NA	NA	870.00	NA	21.00	NA	0.05	21.05	NA	21.05
1982	970.00	NA	NA	970.00	NA	22.00	NA	0.13	22.13	NA	22.13
1983	970.00	NA	NA	970.00	NA	22.00	NA	0.28	22.28	NA	22.28
1984	980.00	NA	NA	980.00	NA	22.00	NA	0.36	22.36	NA	22.36
1985	1010.00	NA	NA	1010.00	NA	24.00	NA	0.38	24.38	NA	24.38
1986	920.00	NA	NA	920.00	NA	27.00	NA	0.47	27.47	NA	27.47
1987	850.00	NA	NA	850.00	NA	29.00	NA	0.55	29.55	NA	29.55
1988	910.00	NA	NA	910.00	NA	32.00	NA	0.55	32.55	NA	32.55
1989	920.00	5.00	52.68	977.68	0.69	76.48	22.00	0.52	98.99	2.50	102.18
1990	580.00	5.50	55.90	641.40	1.43	65.74	27.77	0.51	94.01	2.80	98.24
1991	610.00	5.90	57.77	673.67	1.37	68.44	26.49	0.45	95.38	3.00	99.75
1992	640.00	6.40	59.75	706.15	1.27	72.03	32.45	0.47	104.95	3.20	109.42
1993	550.00	6.80	61.69	618.49	1.03	75.60	33.39	0.20	109.19	3.40	113.62
1994	520.00	6.20	63.53	589.73	0.96	71.72	34.52	0.19	106.43	4.20	111.58
1995	520.00	6.60	64.73	591.33	1.22	72.38	40.20	0.14	112.72	4.50	118.44
1996	540.00	7.00	65.44	612.44	1.30	75.67	53.03	0.15	128.84	5.30	135.44
1997	430.00	7.50	65.02	502.52	1.23	73.39	57.61	0.30	131.29	5.70	138.22
1998	380.00	7.70	64.66	452.36	1.23	64.01	54.16	0.29	118.47	7.10	126.80
1999	390.00	8.50	63.73	462.23	1.17	66.62	53.92	0.22	120.75	6.70	128.63
2000	420.00	8.60	61.36	489.96	1.02	71.47	47.26	0.38	119.11	7.60	127.73
2001	370.00	9.45	59.85	439.30	0.69	66.79	24.54	0.34	91.67	8.27	100.63
2002	380.00	10.20	58.75	448.95	0.13	68.66	25.88	0.47	95.00	8.75	103.89
2003	400.00	13.00	58.15	471.15	0.74	71.44	29.03	0.84	101.30	11.00	113.04
2004	410.00	14.00	58.74	482.74	1.05	70.32	34.24	0.84	105.40	12.00	118.45
2005	450.00	15.90	60.63	526.53	0.86	69.65	34.25	0.90	104.80	13.60	119.26
2006	410.00	18.30	67.19	495.49	0.93	64.73	36.31	1.21	102.25	14.00	117.18
2007	460.00	22.00	74.40	556.40	0.70	64.74	37.42	1.51	103.67	14.40	118.77

Source:
Energy Information Administration. 2008. *Monthly Energy Review*, Table 10.2a, July, www.eia.doe.gov/emeu/mer/renew.html.

Note: NA = Not available.

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[a] Commercial sector fuel use, including that at commercial combined-heat-and-power (CHP) and commercial electricity-only plants.
[b] Wood, black liquor, and other wood waste.
[c] Geothermal heat pump and direct use energy.
[d] Solar thermal direct use energy and photovoltaic electricity generation. Small amounts of commercial sector are included in the residential sector.

Total industrial biomass energy consumption was approximately 1,533 trillion Btu in 2003. The bulk of industrial biomass energy consumption is derived from forestlands. More than one-half of this total is black liquor – a pulping mill by-product containing unutilized wood fiber and chemicals. Black liquor is combusted in recovery boilers to recover valuable chemicals and to produce heat and power. Wood and wood wastes generated in primary wood processing mills account for another third of total industrial biomass energy consumption. The data contained in this table are from a survey of manufacturers that is conducted every four years by the EIA.

Table 1.6
Industrial Biomass Energy Consumption and Electricity Net Generation by Industry and Energy Sources, 2003

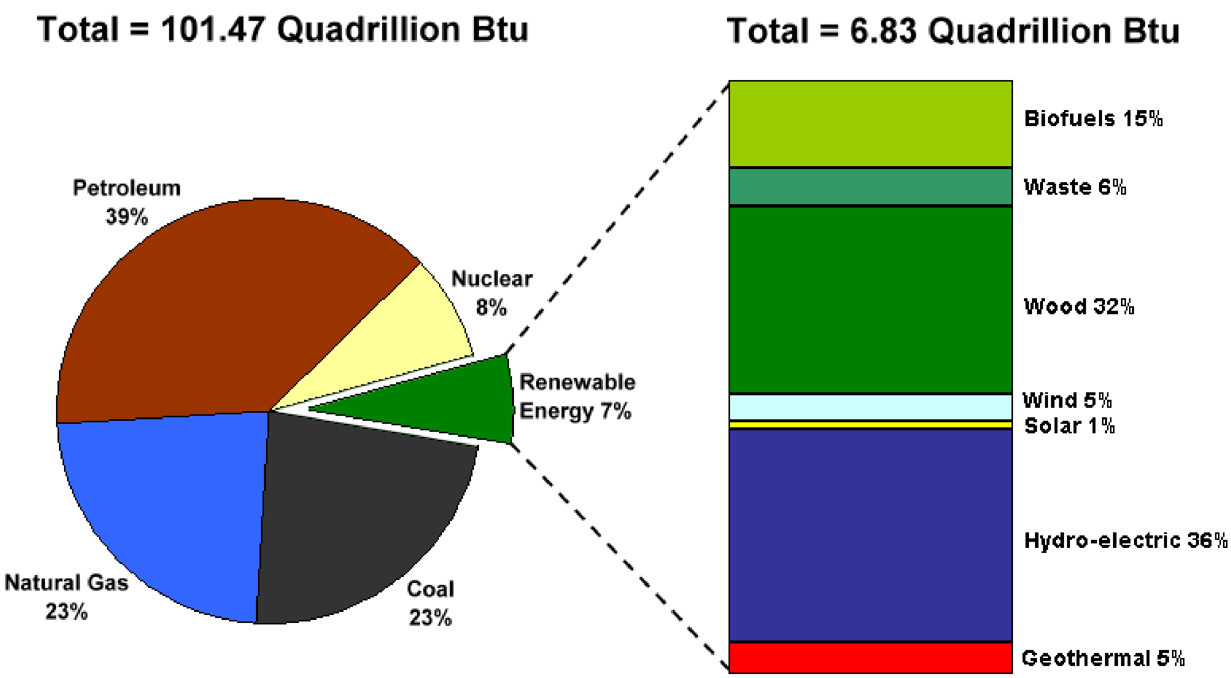
		Biomass Energy Consumption (Trillon Btus)			
Industry	**Energy Source**	**Total**	**For Electricity**	**For Useful Thermal Output**	**Net Generation (Million**
Total	**Total**	**1,532.947**	**378.706**	**1,154.242**	**29,001**
Agriculture, Forestry, and Mining	**Total**	**9.010**	**2.720**	**6.290**	**167**
	Agricultural Byproducts/Crops	9.010	2.720	6.290	167
Manufacturing	**Total**	**1,444.208**	**375.986**	**1,068.222**	**28,834**
Food and Kindred Industry Products	**Total**	**41.318**	**5.176**	**36.142**	**104**
	Agricultural Byproducts/Crops	37.153	4.073	33.079	28
	Other Biomass Gases	0.278	0.217	0.062	8
	Other Biomass Liquids	0.067	0.067	-	5
	Tires	0.379	0.179	0.201	14
	Wood/Wood Waste Solids	3.441	0.641	2.801	49
Lumber	**Total**	**216.442**	**16.364**	**200.078**	**1,499**
	Sludge Waste	0.058	0.019	0.039	3
	Wood/Wood Waste Liquids	0.248	0.080	0.168	12
	Wood/Wood Waste Solids	216.137	16.265	199.872	1,483
Paper and Allied Products	**Total**	**1,150.781**	**352.138**	**798.643**	**27,039**
	Agricultural Byproducts/Crops	1.131	0.092	1.040	7
	Black Liquor	814.120	239.340	574.780	18,311
	Landfill Gas	0.310	0.063	0.247	7
	Municipal Solid Waste	2.274	0.427	1.848	53
	Other Biomass Liquids	0.071	0.034	0.037	2
	Other Biomass Solids	0.741	0.586	0.155	59
	Sludge Waste	10.136	3.536	6.600	251
	Tires	7.540	2.627	4.913	253
	Wood/Wood Waste Liquids	21.019	4.697	16.322	416
	Wood/Wood Waste Solids	293.439	100.738	192.701	7,679
Chemicals and Allied Products	**Total**	**3.870**	**0.745**	**3.125**	**43**
	Landfill Gas	0.214	0.041	0.173	4
	Municipal Solid Waste	1.398	0.122	1.276	12
	Other Biomass Liquids	0.073	0.014	0.059	0
	Other Biomass Solids	0.004	0.001	0.003	0
	Sludge Waste	0.300	0.072	0.228	9
	Wood/Wood Waste Solids	1.881	0.496	1.385	18
Other[a]	**Total**	**31.797**	**1.564**	**30.233**	**149**
Nonspecified[b]	**Total**	**79.730**	**-**	**79.730**	**-**
	Landfill Gas	74.730	-	74.730	-
	Municipal Solid Waste	5.000	-	5.000	-

Sources:
Energy Information Administration, Form EIA-906, "Power Plant Report," Government Advisory Associates, Resource Recovery Yearbook and Methane Recovery Yearbook; and analysis conducted by the Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels.
Notes: Totals may not equal sum of components due to independent rounding.
- = Not Applicable.

[a] Other includes Apparel; Petroleum Refining; Rubber and Misc. Plastic Products; Transportation Equipment; Stone, Clay, Glass, and Concrete Products; Furniture and Fixtures; and related industries.
[b] Primary purpose of business is not specified.

Biomass is the single largest source of renewable energy in the United States. Biomass, which includes biofuels, waste and woody materials, surpassed hydroelectric power in 2005 and by 2007 accounted for 53% of all renewable energy consumption. In 2007, biomass contributed about 3.7% of the total U.S. energy consumption of 101 quadrillion Btu. Wood, wood waste, and black liquor from pulp mills is the single largest source accounting for more than two-thirds of total biomass energy consumption. Wastes (which include municipal solid waste, landfill gas, sludge waste, tires, agricultural by-products, and other secondary and tertiary sources of biomass) accounts for about 20% of total biomass consumption. The remaining share is alcohol fuel derived principally from corn grain.

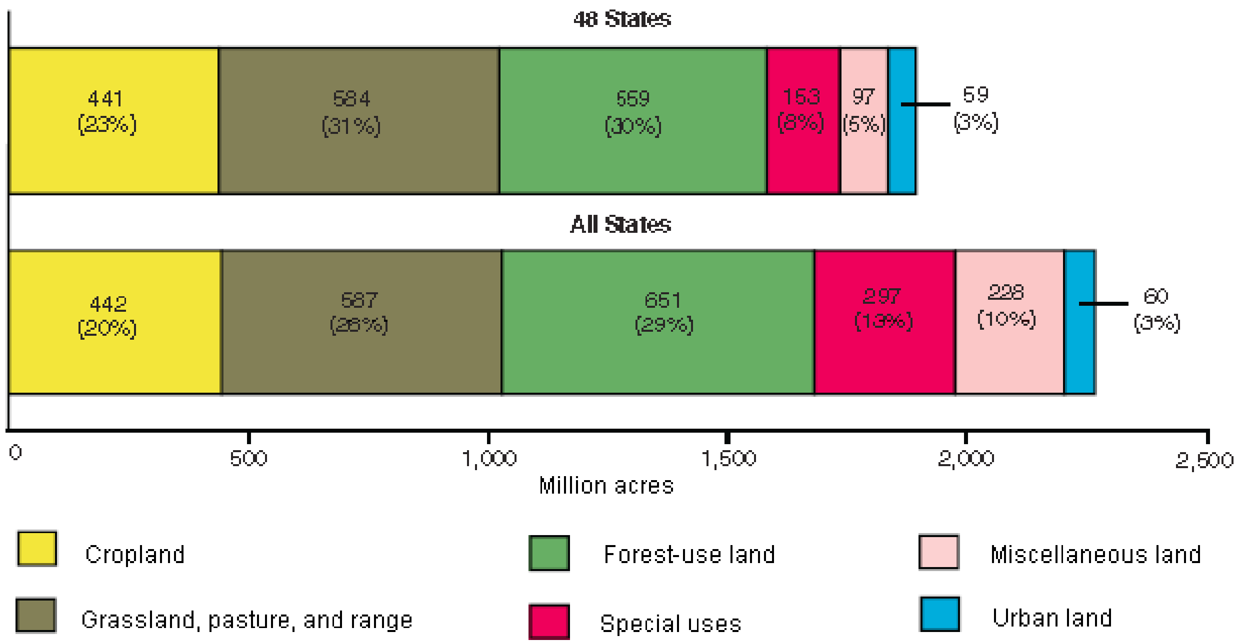
Figure 1.1
Summary of Biomass Energy Consumption, 2007



Source:
Energy Information Administration. 2008. *Monthly Energy Review*, July, http://www.eia.doe.gov/emeu/mer/contents.html.

The United States has a total land area in all 50 states of 2.263 billion acres. Based on the 2002 land use inventory, 20% of that land was categorized as cropland and 29% as forest-use land, thus about 49% of U.S. land is a potential source of biomass residuals or biomass crops for bioenergy. Grassland pasture and range land is, for the most part, too dry to provide much biomass resources. Miscellaneous, special use land and urban land may be a source of post-consumer biomass residuals, but are not areas where biomass crops could be produced on a large scale.

Figure 1.2
Major Uses of Land in the United States, 2002



U.S. land use categories differ slightly depending on who is reporting the results. The numbers below published in 2006, but based on a 2002 land inventory, were generated by the Economic Research Service (ERS) of USDA. They have been producing similar estimates since 1945. Other USDA organizations, the Natural Resources Conservation Service (NRCS) and the Forest Service (FS) place land into somewhat different categories. URL's for NRCS and FS estimates are given below. The NRCS divides the land into additional sub-categories (such as a "Federal land" category), and only gives values for the lower 48 states. The Forest Service documents only deal with forest land, but include a larger area of the U.S. in that category (747 million acres based on 1997 inventory data). However, ERS in a 2002 publication on land use stated that 105 million acres in the special uses category overlaps with forestland. If that area is added to the ERS forestland category then it nearly matches the NRCS forest land use estimate. Definitions of the ERS land use categories follow. NRCS and FS land use references can be found at: www.nrcs.usda.gov/technical/nri02/landuse.pdf and by searching for publications by Alig at: www.treesearch.fs.fed.us/pubs.

Source:

Lubowski, R.N., M. Vesterby, S. Bucholtz, A. Baez, and M.J. Roberts. 2006. "Major Uses of Land in the United States, 2002," *Economic Information Bulletin Number 14*, USDA Economic Research Service, May, www.ers.usda.gov/publications/eib14.

Figure 1.2 (Continued)
Major Uses of Land in the United States, 2002

Notes: Cropland: All land in the crop rotation, including cropland used for crops, land with crop failure, summer fallow, idle cropland (including Conservation Reserve Program land), and cropland used only for pasture. Cropland in Alaska and Hawaii total less than 0.4 million acres.

Grassland pasture and range: Permanent grassland and other nonforested pasture and range.

Forest-use land: Total forest land as classified by the U.S. Forest Service includes grazed forest land (134 million acres) as well as other forest land (517 million acres). It does not include land in the special uses category that is forested. This category includes a small amount of rural residential area within forested areas.

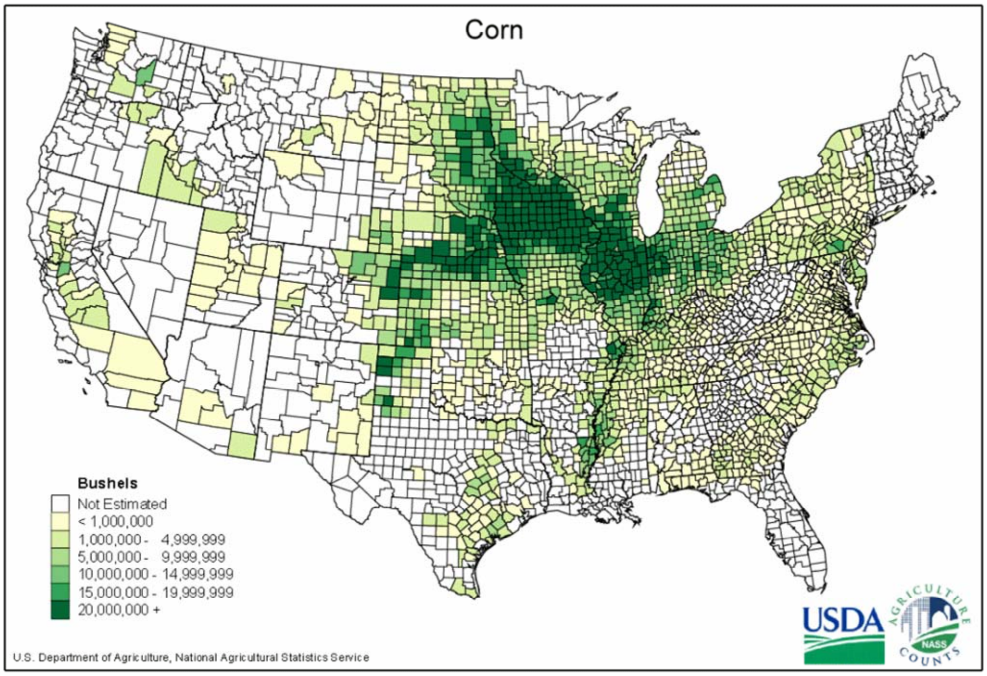
Special Uses: This land includes recreation and wildlife areas, national defense areas, and land used for rural highways, roads and railroad rights-of-way, and rural airports. It also includes 11 million acres for farmsteads and farm roads.

Miscellaneous land: This includes tundra, deserts, bare rock areas, snow and ice fields, swamps, marshes, and other unclassified areas generally of low agricultural value.

Urban land: Urban lands are newly separated from special use lands in the 2006 Major Land Uses report prepared by ERS. Urban areas are based on Census Bureau definitions which identify “urban clusters” based primarily on population density, not political boundaries.

Current commodity crop locations are good indicators of where biomass resources can be cultivated.

Figure 1.3
Geographic Locations of Major Crops, 2007
(Production acreage by county)



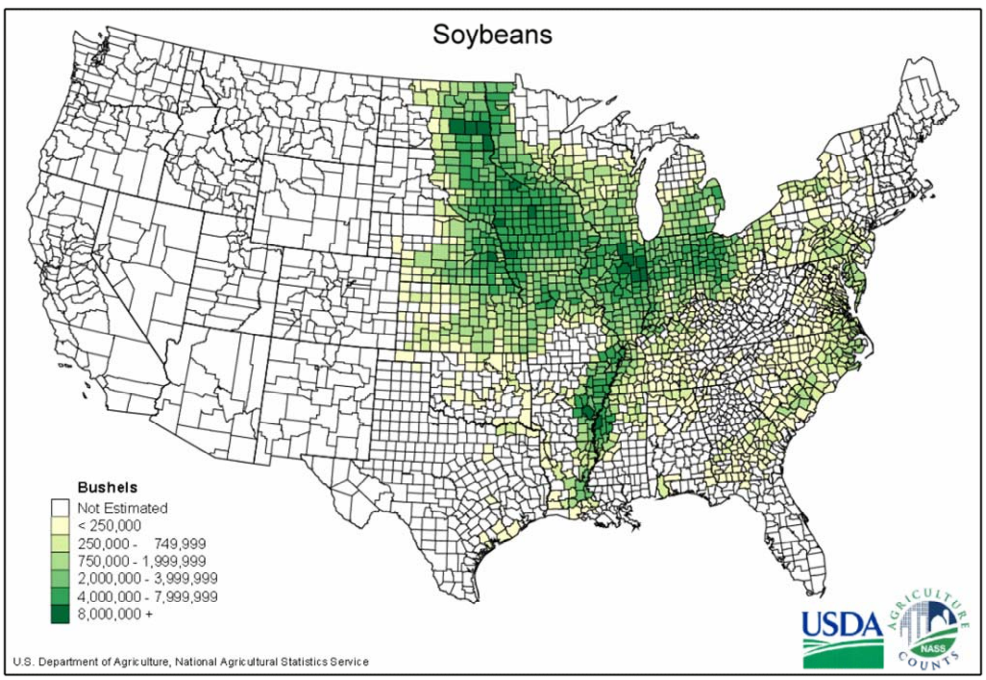
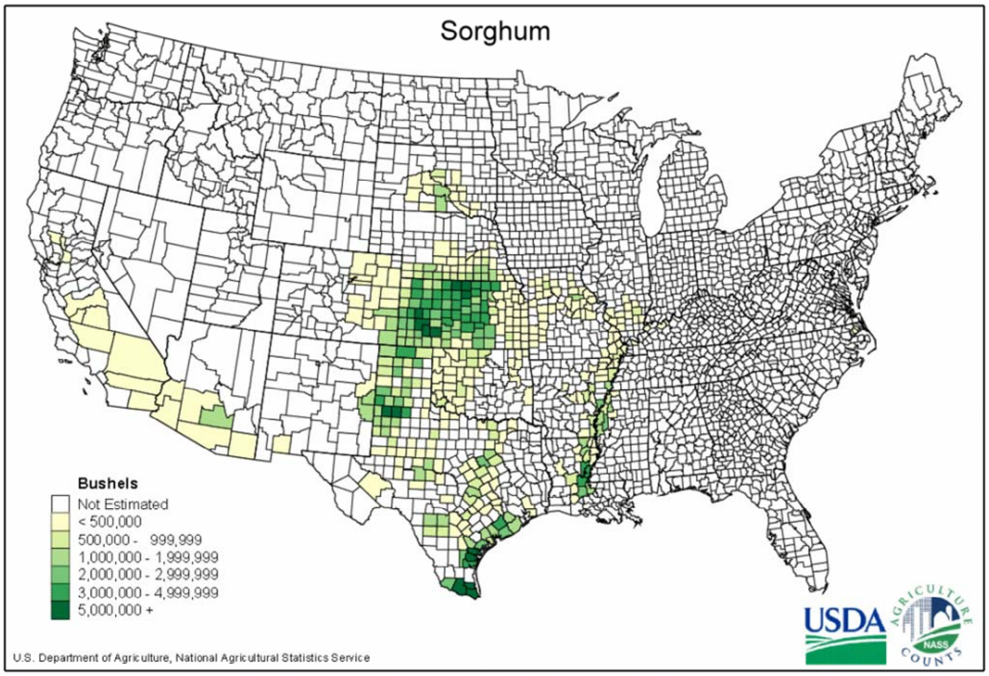


Figure 1.3 (Continued)
Geographic Locations of Major Crops, 2007
(Production acreage by county)



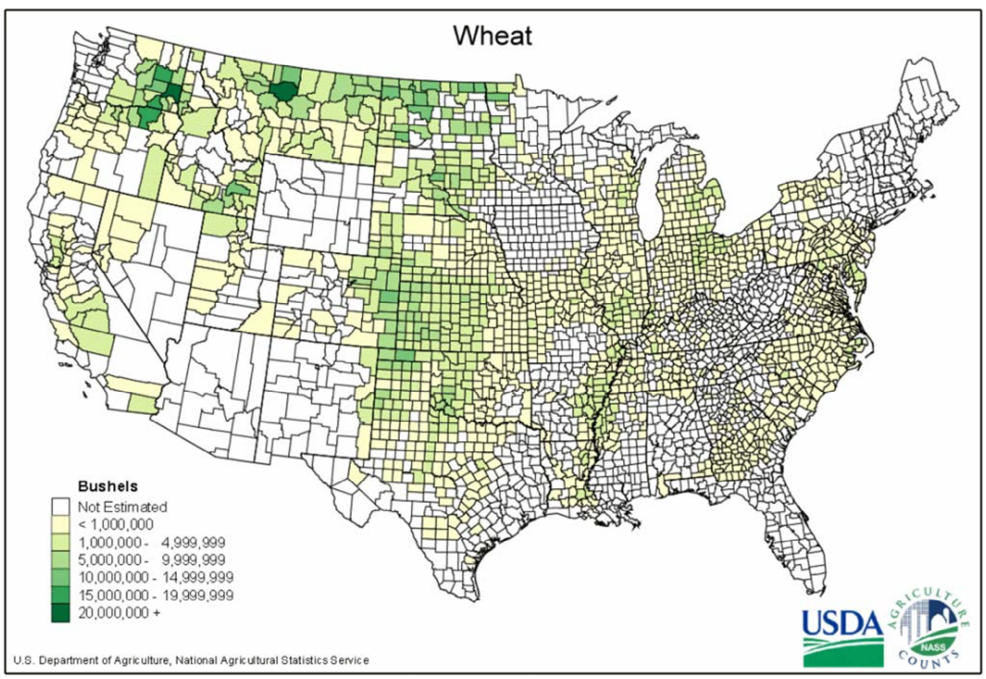
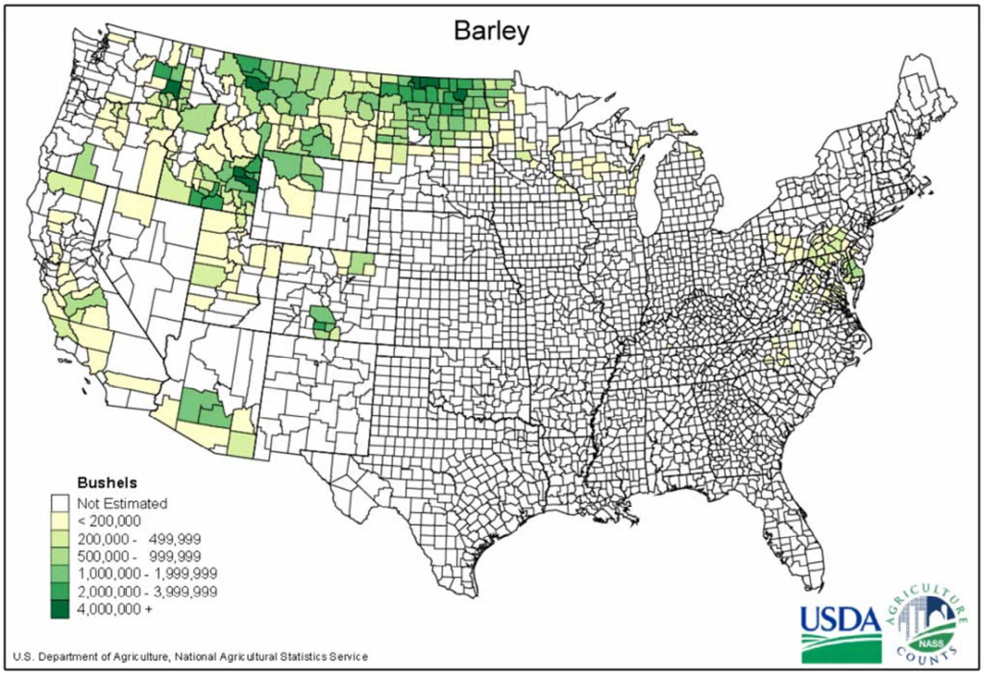


Figure 1.3 (Continued)
Geographic Locations of Major Crops, 2007
(Production acreage by county)



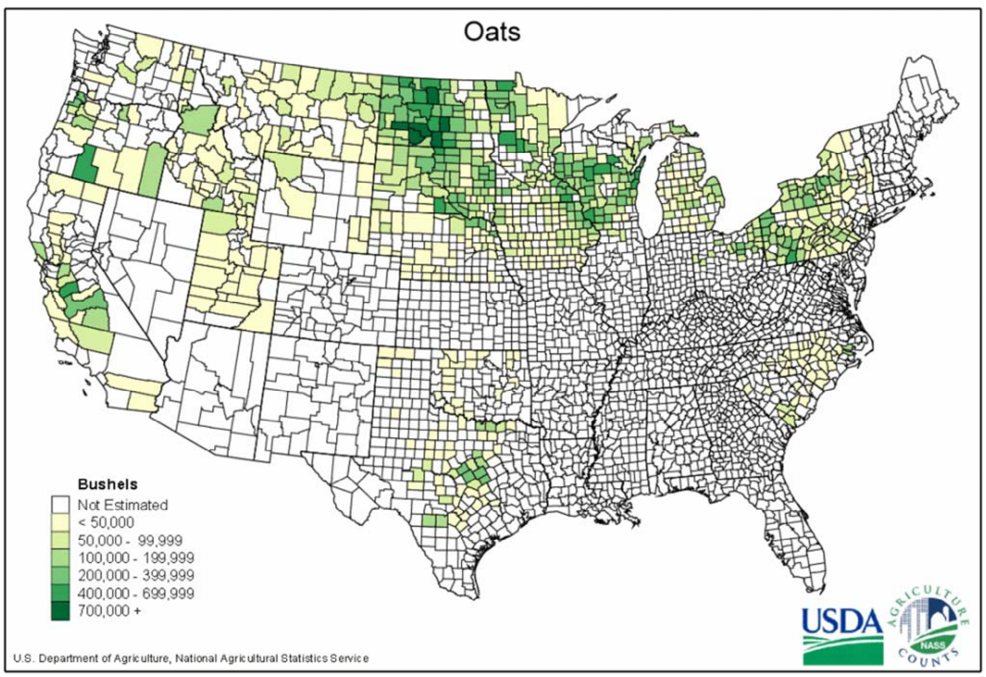
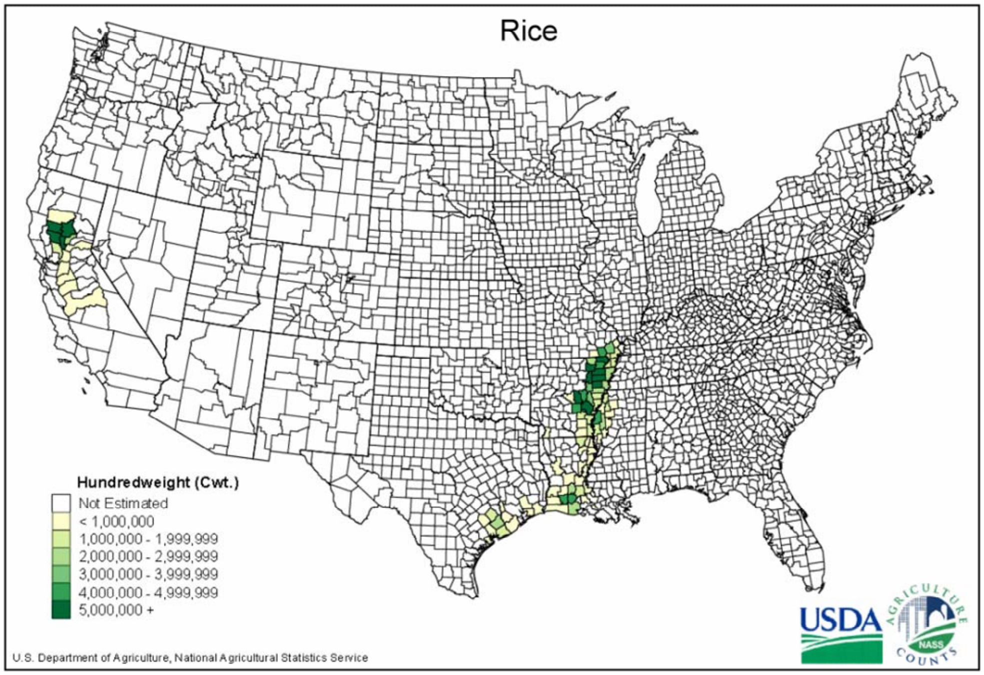
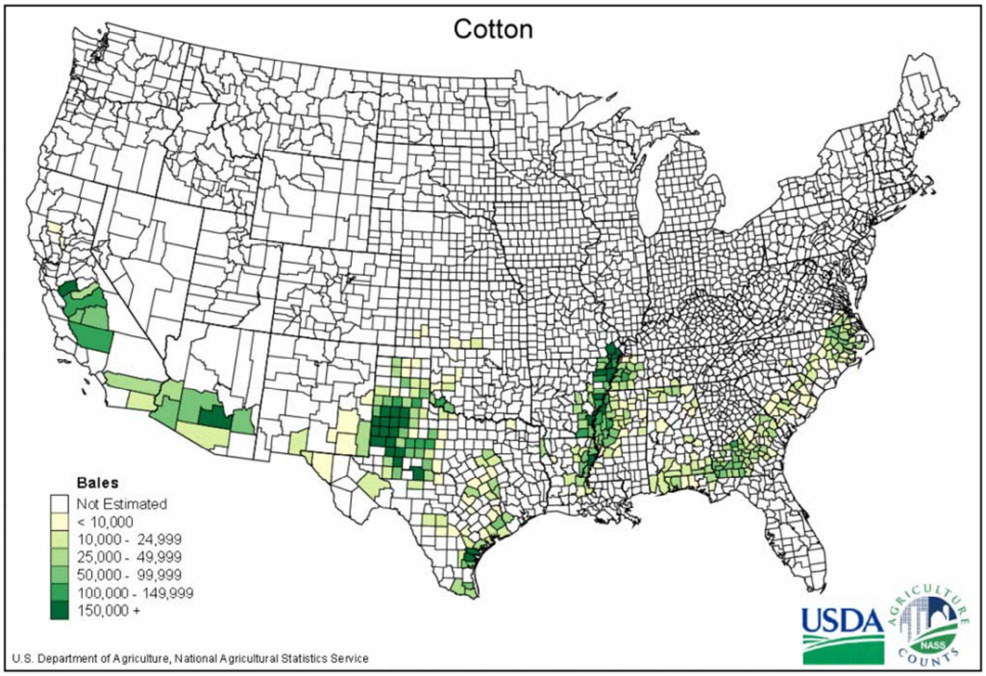


Figure 1.3 (Continued)
Geographic Locations of Major Crops, 2007
(Production acreage by county)



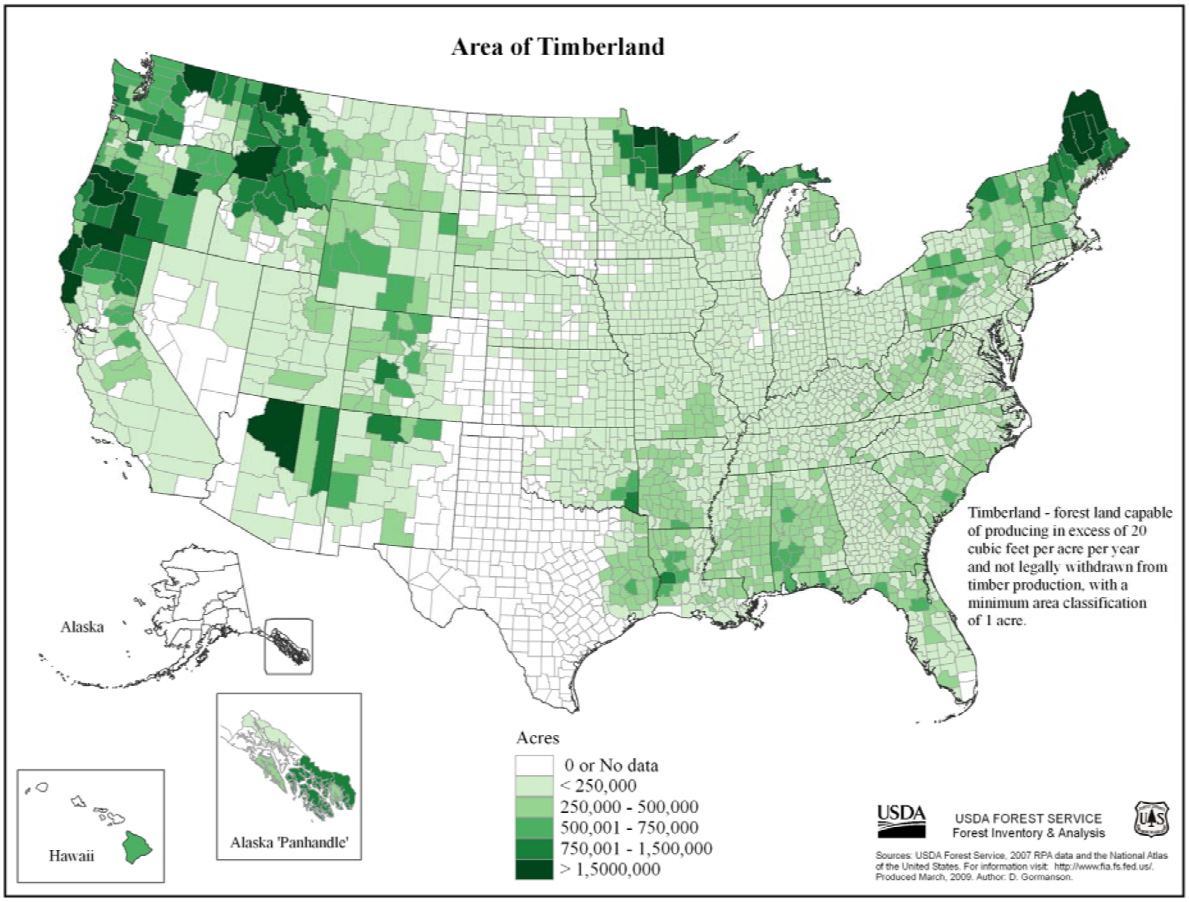


Source:
U.S. Department of Agriculture, National Agricultural Statistics Service.
http://www.nass.usda.gov/Charts_and_Maps/A_to_Z/index.asp#h .

This map shows the spatial distribution of the nation's timberland in 2007 by county. Nationwide, there are 514 million acres forestland classified as timberland. This land is the source of a wide variety of forest products and forest residue feedstocks, such as logging residue and fuel treatment thinnings to reduce the risk of fire.

Timberland is defined as forest land capable of producing in excess of 20 cubic feet per acre per year and not legally withdrawn from timber production, with a minimum area classification of 1 acre.

Figure 1.4
Geographic Distribution of Timberland by County, 2007



Source:

U.S. Department of Agriculture Forest Service, 2007 RPA data, available at: http://fia.fs.fed.us/tools-data/tools/.

U.S. Department of Agriciulture Forest Service, Forest Inventory and Analysis. 2007 RPA data and the National Atlas of the United States.

FUTURE ENERGY CROP SUPPLY POTENTIAL—CELLULOSIC BIOMASS

"Woodchips, Stalks, and Switchgrass" - Cellulosic Biomass:

Cellulosic feedstocks such as switchgrass, first came to the attention of many in America when President Bush spoke in his January 31, 2006, State of the Union address of producing biofuels by 2012 using "woodchips, stalks and switchgrass" as the source of cellulosic biomass for producing ethanol. The President also put forward the advanced energy initiative which supported a 22% increase in clean-energy research and set a goal of replacing 75% of the oil imports from the Middle East by 2025. The 2007 State of the Union address re-enforced the concept of using cellulosic biomass for producing ethanol. The president ramped up the goals for alternative fuel use by proposing that the U.S. reduce gasoline consumption by 20% in ten years.

The legislation that was passed in 2007 to support the President's goals, the Energy Independence and Security Act (EISA) of 2007 (H.R. 6), established Renewable Fuel Standards that will require, by 2022, very large supplies of cellulosic biomass in addition to the grains and oils already being used. The potential exists in the U.S. for large supplies since cellulosic biomass can include everything from primary biomass sources of energy crops and forest thinnings or residuals harvested or collected directly from the land, to secondary biomass sources such as sawmill residuals, to tertiary biomass sources of post-consumer residuals that often end up in landfills. Biomass resources also include the gases that result from anaerobic digestion of animal manures or organic materials in landfills.

The estimated potential future availability of agricultural and forestry biomass in the U.S. was reported in 2005 in a joint DOE and USDA document entitled "Biomass as Feedstock For a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply" ; Perlack et al. (2005). The report indicates a technical availability of about 200 million dry tons from the agriculture sector with yields, collection technology and crop management approaches in place in 2001. However scenarios of possible future changes in crop yield, crop management and harvest technology, and in use of perennial energy crops (such as switchgrass) suggests that about 400 to nearly 1 billion dry tons could be technically derived from the agricultural sector later this century. Details on individual crops are provided in the Feedstocks Section of the *Biomass Energy Data Book*. The ultimate limit for the amount of biomass that can be sustainably produced on agricultural land in the United States depends on land availability. The areas of the country with adequate rainfall and soil quality for production and harvest of energy crops are roughly the same areas where major crops are currently produced in the United States. The major crops (especially corn) are the primary source of lignocellulosic biomass from the agricultural sector. Changes in the way that land is managed will be necessary for increasing biomass resource availability in the U.S. An update of the biomass supply assessment is currently underway including consideration of economic constraints. The current summary tables will be replaced with updated information when they become available.

One of the larger unexploited sources of cellulosic biomass is wood that needs to be removed from forests to reduce the risk of forest fires. Well over 8 billion dry tons of biomass has been identified by the U.S. Forest Service as needing fuel treatment removal (Perlack et al., 2005). The amount of this biomass potentially available for bioenergy uses is estimated to be about 60 million dry tons annually. This estimate takes into consideration factors affecting forest access, residue recovery and the desirability of using some of the recoverable biomass for conventional wood products. The fraction that could be available annually for bioenergy and bioproducts is less than 1% of the total size of the fuel treatment biomass resource. The other large underutilized sources of woodchips are logging residues and urban wood residues. In the case of forest biomass, the relatively high costs of removal, handling, and transportation have not, in the past, compared favorably to their relatively low value as bioenergy resources. Factors affecting the rate at which this source of material will become available for bioenergy includes public opinion toward this type of removal, as well as delivered costs and the extent to which technology is developed for utilizing small diameter wood for products other than bioenergy. The compost market already competes for urban wood resources.

A factor that could greatly affect the amount of wood used for bioenergy, especially of forest fuel treatment removals, is that the definition of "renewable biomass" in EISA 2007 does not include thinnings and residues from federal forests, and some woody feedstocks from private forests except where that biomass is "obtained from the immediate vicinity of buildings, and other areas regularly occupied by people, or of public infrastructure, at risk from wildfire." While the legislation does not prohibit the use of forest thinnings and fuel reduction treatments from federal forests for bioenergy or bioproducts, it does exclude them from qualifying as feedstocks suitable for meeting the Renewable Fuel Standard targets in EISA 2007. Bills were introduced in both the Senate (S. 2558) and House (H.R. 5236) in an attempt to revise the definitions to include sustainably collected fuel reduction treatments from federal forestlands. Those bills have been referred to committees.

The Biomass Research and Development Technical Advisory Committee has provided numerous recommendations to DOE, USDA and other Federal Agencies on the research and development needed to ensure that a broad portfolio of diverse domestic feedstocks is available for our nation's energy and chemical supplies. The Executive Summary of the *Roadmap for Bioenergy and Biobased Products in the U.S.* states that significant research breakthroughs are needed in a number of key area including advances in plant science to improve the cost effectiveness of converting biomass to fuel, power, and products. Additionally, it recommends that R&D in geographical information systems will help the U.S. more accurately identify biomass availability. Finally, it recommends a focus on advancements in harvesting methods for both agricultural and forest resources. Additionally, the report *Increasing Feedstock Production for Biofuels: Economic Drivers, Environmental Implications, and the Role of Research* was released in 2008.

Sources:

The White House. 2007 and 2008. *State of the Union Addresses*. Available online at: http://www.whitehouse.gov/news.

The Energy Independence and Security Act of 2007 (H.R.6). Final version available online at: http://thomas.loc.gov/cgi-bin/query/z?c110:H.R.6.

Perlack, R.D., L.L. Wright, A.F. Turhollow, R.L. Graham, B.H. Stokes, and D.C. Erbach. 2005. *Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply*, DOE/GO-102005-2135 also ORNL/TM-2005/66. A joint U.S. Department of Energy and U.S. Department of Agriculture report available online at: http://www.eere.energy.gov/biomass/publications.html.

Biomass Research and Development Technical Advisory Committee. 2007. *The Roadmap for Bioenergy and Biobased Products in the Unites States*, October. Available online at: http://www1.eere.energy.gov/biomass/pdfs/obp_roadmapv2_web.pdf.

Biomass Research and Development Technical Advisory Committee. 2008. *Increasing Feedstock Production for Biofuels: Economic Drivers, Environmental Implications, and the Role of Research*. Available online at: http://www.brdisolutions.com.

2. BIOFUELS

BRIEF OVERVIEW

A variety of fuels can be produced from biomass resources including liquid fuels, such as, ethanol, methanol, biodiesel, Fischer-Tropsch diesel and gasoline, and gaseous fuels, such as hydrogen and methane. Biofuels are primarily used to fuel vehicles, but can also fuel engines or fuel cells for electricity generation.

FUELS

Ethanol

Ethanol is most commonly made by converting the starch from corn into sugar, which is then converted into ethanol in a fermentation process similar to brewing beer. Ethanol is the most widely used biofuel today with 2008 capacity expected to be 12 billion gallons per year based on starch crops, such as corn. Ethanol produced from cellulosic biomass is currently the subject of extensive research, development and demonstration efforts.

Biodiesel

Biodiesel is produced through a process in which organically derived oils are combined with alcohol (ethanol or methanol) in the presence of a catalyst to form ethyl or methyl ester. The biomass-derived ethyl or methyl esters can be blended with conventional diesel fuel or used as a neat fuel (100% biodiesel). Biodiesel can be made from any vegetable oil, animal fats, waste vegetable oils, or microalgae oils. Soybeans and Canola (rapeseed) oils are the most common vegetable oils used today.

Bio-oil

A totally different process than that used for biodiesel production can be used to convert biomass into a type of fuel similar to diesel which is known as bio-oil. The process, called fast or flash pyrolysis, occurs when heating compact solid fuels at temperatures between 350 and 500 degrees Celsius for a very short period of time (less than 2 seconds). While there are several fast pyrolysis technologies under development, there are only two commercial fast pyrolysis technologies as of 2008. The bio-oils currently produced are suitable for use in boilers for electricity generation. There is currently ongoing research and development to produce bio-oil of sufficient quality for transportation applications.

Other Hydrocarbon Biofuels

Biomass can be gasified to produce a synthesis gas composed primarily of hydrogen and carbon monoxide, also called syngas or biosyngas. Syngas produced today is used directly to generate heat and power but several types of biofuels may be derived from syngas. Hydrogen can be recovered from this syngas, or it can be catalytically converted to methanol or ethanol. The gas can also be run through a biological reactor to produce ethanol or can also be converted using Fischer-Tropsch catalyst into a liquid stream with properties similar to diesel fuel, called Fischer-Tropsch diesel. However, all of these fuels can also be produced from natural gas using a similar process.

A wide range of single molecule biofuels or fuel additives can be made from lignocellulosic biomass. Such production has the advantage of being chemically essentially the same as petroleum-based fuels. Thus modifications to existing engines and fuel distribution infrastructure are not required. Additional information on green hydrocarbon fuels can be found on the Green Hydrocarbon Biofuels page.

Source:
U.S. Department of Energy, Energy Efficiency and Renewable Energy,
http://www.eere.energy.gov/RE/bio_fuels.html.

GREEN HYDROCARBON BIOFUELS

A biofuel is a liquid transportation fuel made from biomass. A wide range of single molecule biofuels or fuel additives can be made from lignocellulosic biomass including:

• Ethanol or ethyl alcohol
• Butanol or butyl alcohol
• Hydroxymethylfurfural (HMF) or furfural
• y-valerolactone (GVL)
• Ethyl levulinate (ELV)

The production of hydrocarbon biofuels from biomass has many advantages:

- "Green" hydrocarbon fuels are chemically essentially the same as petroleum-based fuels. Thus modifications to existing engines and fuel distribution infrastructure are not required.
- "Green" hydrocarbon fuels are energy equivalent to petroleum-based fuels, thus no mileage penalty is encountered from their use.
- "Green" hydrocarbon fuels are immiscible in water. This allows the biofuels to self-separate from water which eliminates the high cost associated with water separation by distillation.
- "Green" hydrocarbon fuels are produced at high temperatures, which translates into faster reactions and smaller reactors. This allows for the fabrication and use of portable processing units that allow the conversion of biomass closer to the biomass source.
- The amount of water required for processing "Green" hydrocarbon fuels from biomass, if any, is minimal.
- The heterogeneous catalysts used for the production of "Green" hydrocarbon biofuels are inherently recyclable, allowing them to be used for months or years.

Additionally, "Green" gasoline or diesel biofuels, which are a mixture of compounds, can be synthesized from lignocellulosic biomass by catalytic deoxygenation. Green diesel can also be made via the catalytic deoxygenation of fatty acids derived from virgin or waste vegetable oils or animal fats.

Biofuels can be produced using either biological (e.g., yeast) or chemical catalysts with each having advantages and disadvantages (see Table 2.1). Chemical catalysts range from solid heterogeneous catalysts to homogeneous acids. As shown in *Figure 2.1* , most biofuel production pathways use chemical catalysts.

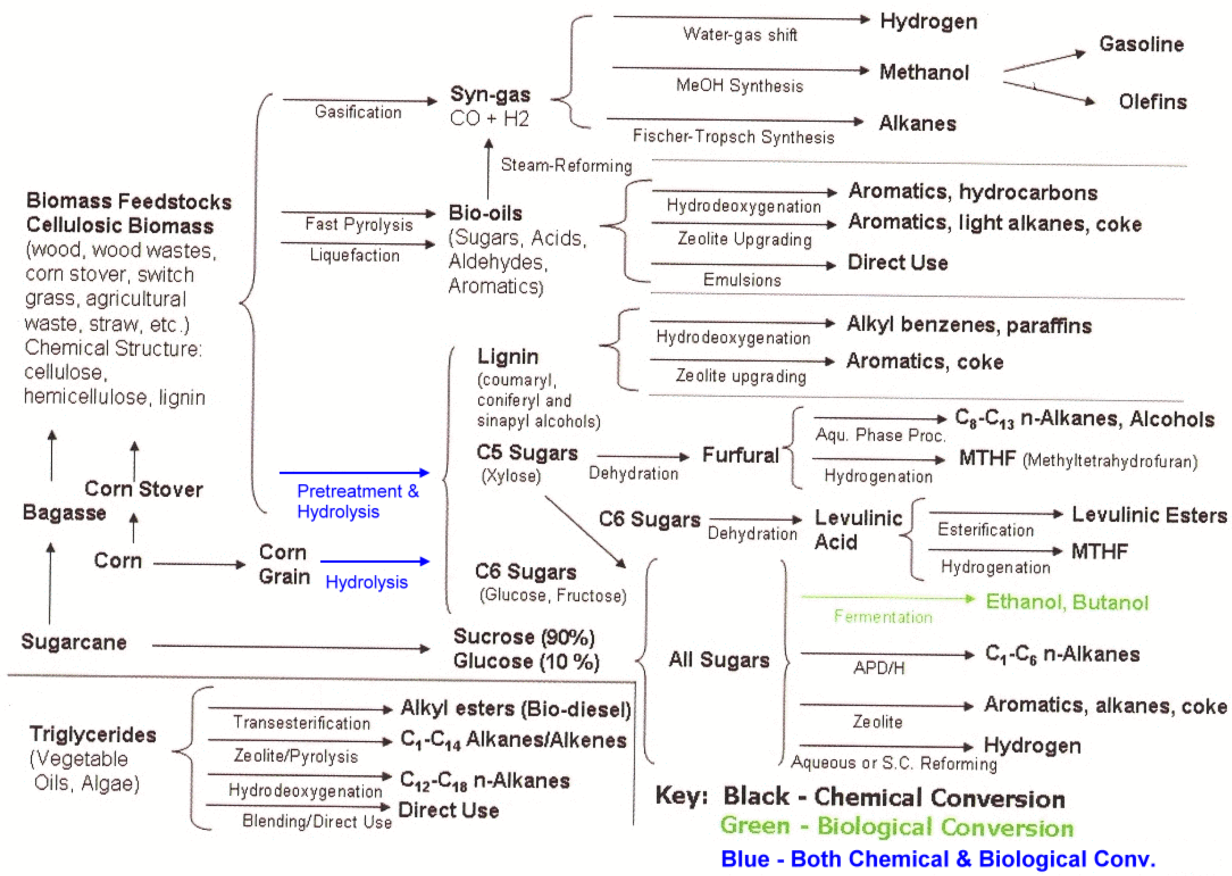
Source:
National Science Foundation. 2008. *Breaking the Chemical and Engineering Barriers to Lignocellulosic Biofuels: Next Generation Hydrocarbon Biorefineries*, Ed. George Huber, University of Massachusetts Amherst, National Science Foundation, Bioengineering, Environmental, and Transport Systems Division, Washington DC.

Table 2.1
Biological and Chemical Catalysts for Biofuels

	Biological Catalysts	Chemical Catalysts
Products	Alcohols	A Wide Range of Hydrocarbon Fuels
Reaction Conditions	Less than 70°C, 1 atm	10-1200°C, 1-250 atm
Residence Time	2-5 days	0.01 second to 1 hour
Selectivity	Can be tuned to be very selective (greater than 95%)	Depends on reaction. New catalysts need to be developed that are greater than 95% selective.
Catalyst Cost	$0.50/gallon ethanol *(cost for cellulase enzymes, and they require sugars to grow) $0.04/gallon of corn ethanol*	$0.01/gallon gasoline *(cost in mature petroleum industry)*
Sterilization	Sterilize all Feeds *(enzymes are being developed that do not require sterilization of feed)*	No sterilizaton needed
Recyclability	*Not possible*	Yes with Solid Catalysts
Size of Cellulosic Plant	2,000-5,000 tons/day	100-2,000 tons/day

Source:
National Science Foundation. 2008. *Breaking the Chemical and Engineering Barriers to Lignocellulosic Biofuels: Next Generation Hydrocarbon Biorefineries*, Ed. George Huber, University of Massachusetts Amherst, National Science Foundation, Bioengineering, Environmental, and Transport Systems Division, Washington DC.

Figure 2.1
Diagram of Routes to Make Biofuels



Source:

National Science Foundation. 2008. *Breaking the Chemical and Engineering Barriers to Lignocellulosic Biofuels: Next Generation Hydrocarbon Biorefineries*, Ed. George Huber, University of Massachusetts Amherst, National Science Foundation, Bioengineering, Environmental, and Transport Systems Division, Washington DC.

ETHANOL OVERVIEW

There are two types of ethanol produced in the United States – fermentation ethanol and synthetic ethanol. Fermentation ethanol (or bioethanol) is produced from corn or other biomass feedstocks and is by far the most common type of ethanol produced, accounting for more than 90% of all ethanol production. Fermentation ethanol is mainly produced for fuel, though a small share is used by the beverage industry and the industrial industry. Synthetic ethanol is produced from ethylene, a petroleum by-product, and is used mainly in industrial applications. A small amount of synthetic ethanol is exported to other countries.

Ethanol is the most widely used biofuel today. In 2006, more than 3.7 billion gallons were added to gasoline in the United States to improve vehicle performance and reduce air pollution. Ethanol is currently produced using a process similar to brewing beer where starch crops are converted into sugars, the sugars are fermented into ethanol, and the ethanol is then distilled into its final form.

Ethanol is used to increase octane and improve the emissions quality of gasoline. In many areas of the United States today, ethanol is blended with gasoline to form an E10 blend (10% ethanol and 90% gasoline), but it can be used in higher concentrations, such as E85, or in its pure form E100. All automobile manufacturers that do business in the United States approve the use of E10 in gasoline engines; however, only flex fuel vehicles (FFVs) are designed to use E85. Pure ethanol or E100 is used in Brazil but is not currently compatible with vehicles manufactured for the U.S. market. Manufacturer approval of ethanol blends is found in vehicle owners' manuals under references to refueling or gasoline.

Bioethanol from cellulosic biomass materials (such as agricultural residues, trees, and grasses) is made by first using pretreatment and hydrolysis processes to extract sugars, followed by fermentation of the sugars. Although producing bioethanol from cellulosic biomass is currently more costly than producing bioethanol from starch crops, the U.S. Government has launched a Biofuels Initiative with the objective of quickly reducing the cost of cellulosic bioethanol. Researchers are working to improve the efficiency and economics of the cellulosic bioethanol production process. When cellulosic bioethanol becomes commercially available, it will be used exactly as the bioethanol currently made from corn grain.

Source:
DOE Energy Efficiency and Renewable Energy,
http://www1.eere.energy.gov/biomass/abcs_biofuels.html.

Below are the primary quality specifications for denatured fuel ethanol for blending with gasoline meeting Federal requirements. The state of California has additional restrictions that apply in addition to the performance requirements in ASTM D 4806.

Table 2.2
Specifications Contained in ASTM D 4806 Standard Specification for Denatured Fuel Ethanol for Blending with Gasoline

Property	Specification	ASTM Test Method
Ethanol volume %, min	92.1	D 5501
Methanol, volume %. max	0.5	
Solvent-washed gum, mg/100 ml max	5	D 381
Water content, volume %, max	1	E 203
Denaturant content, volume %, min	1.96	
volume %, max	4.76	
Inorganic Chloride content, mass ppm (mg/L) max	40	D 512
Copper content, mg/kg, max	0.1	D1688
Acidity (as acetic acid CH3COOH), mass percent (mg/L), max	0.007	D1613
pHe	6.5-9.0	D 6423
Appearance	Visibly free of suspended or precipitated contaminants (clear & bright)	

Source:
Renewable Fuels Association, Industry Guidelines, Specifications, and Procedures, http://www.ethanolrfa.org/industry/resources/guidelines/ .

Note: ASTM = American Society for Testing and Materials

Table 2.3
Fuel Property Comparison for Ethanol, Gasoline and No. 2 Diesel

Property	Ethanol	Gasoline	No. 2 Diesel
Chemical Formula	C2H5OH	C4 to C12	C3 to C25
Molecular Weight	46.07	100–105	≈200
Carbon	52.2	85–88	84–87
Hydrogen	13.1	12–15	33–16
Oxygen	34.7	0	0
Specific gravity, 60° F/60° F	0.796	0.72–0.78	0.81–0.89
Density, lb/gal @ 60° F	6.61	6.0–6.5	6.7–7.4
Boiling temperature, °F	172	80–437	370–650
Reid vapor pressure, psi	2.3	8–15	0.2
Research octane no.	108	90–100	--
Motor octane no.	92	81–90	--
(R + M)/2	100	86–94	N/A
Cetane no.(1)	--	5–20	40–55
Fuel in water, volume %	100	Negligible	Negligible
Water in fuel, volume %	100	Negligible	Negligible
Freezing point, °F	-173.2	-40	-40–30[b]
Centipoise @ 60° F	1.19	0.37–0.44[a]	2.6–4.1
Flash point, closed cup, °F	55	-45	165
Autoignition temperature, °F	793	495	≈600
Lower	4.3	1.4	1
Higher	19	7.6	6
Btu/gal @ 60° F	2,378	≈900	≈700
Btu/lb @ 60° F	396	≈150	≈100
Btu/lb air for stoichiometric mixture @ 60° F	44	≈10	≈8
Higher (liquid fuel-liquid water) Btu/lb	12,800	18,800–20,400	19,200–20000
Lower (liquid fuel-water vapor) Btu/lb	11,500	18,000–19,000	18,000–19,000
Higher (liquid fuel-liquid water) Btu/gal	84,100	124,800	138,700
Lower (liquid fuel-water vapor) Btu/gal @ 60° F	76,000[a]	115,000	128,400
Mixture in vapor state, Btu/cubic foot @ 68° F	92.9	95.2	96.9[c]
Fuel in liquid state, Btu/lb or air	1,280	1,290	–
Specific heat, Btu/lb °F	0.57	0.48	0.43
Stoichiometric air/fuel, weight	9	14.7[a]	14.7
Volume % fuel in vaporized stoichiometric mixture	6.5	2	–

Source:
U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Alternative Fuels Data Center, http://www.eere.energy.gov/afdc/altfuel/fuel_properties.html.

[a] Calculated.
[b] Pour Point, ASTM D 97.
[c] Based on Cetane.

The U.S. and Brazil produced about 88 percent of the world's fuel ethanol in 2007.

Table 2.4
World Fuel Ethanol Production by Country or Region, 2007
(Millions of gallons, all grades)

Country	2007
U.S.	6,498.6
Brazil	5,019.2
European Union	570.3
China	486.0
Canada	211.3
Thailand	79.2
Colombia	74.9
India	52.8
Central America	39.6
Australia	26.4
Turkey	15.8
Pakistan	9.2
Peru	7.9
Argentina	5.2
Paraguay	4.7
Total	**13,101.1**

Source:
Renewable Fuels Association, Industry Statistics,
http://www.ethanolrfa.org/industry/statistics/#E .

Note: Some countries listed in the table titled: "U.S. Fuel Ethanol Imports by Country" do not appear in this table because they process ethanol (dehydration) rather than produce it from feedstock.

The United States imports a small percentage of ethanol from countries that are usually within relatively close geographic proximity.

Table 2.5
U.S. Fuel Ethanol Imports by Country, 2002 – 2007
(Millions of gallons)

Country	2002	2003	2004	2005	2006	2007
Brazil	0	0	90.3	31.2	433.7	188.8
Costa Rica	12	14.7	25.4	33.4	35.9	39.3
El Salvadore	4.5	6.9	5.7	23.7	38.5	73.3
Jamaica	29	39.3	36.6	36.3	66.8	75.2
Trinadad & Tobago	0	0	0	10.0	24.3	42.7
Canada	0	0	0	0.0	0	5.4
China	0	0	0	0.0	0	4.5
Total	**45.5**	**60.9**	**158.0**	**134.6**	**599.2**	**429.2**

Source:
Renewable Fuels Association, http://www.ethanolrfa.org/industry/statistics/ .

Note: Some countries listed in this table do not appear in the table titled: "World Ethanol Production by Country" because they process ethanol (dehydration) rather than produce it from feedstock.

Fuel ethanol production has been on the rise in the U.S. since 1980, though production has increased dramatically in recent years. Fuel ethanol production increased nearly 300% between 2000 and 2007.

Table 2.6
Historic Fuel Ethanol Production, 1980-2007

Year	Millions of Gallons
1980	175
1981	215
1982	350
1983	375
1984	430
1985	610
1986	710
1987	830
1988	845
1989	870
1990	900
1991	950
1992	1,100
1993	1,200
1994	1,350
1995	1,400
1996	1,100
1997	1,300
1998	1,400
1999	1,470
2000	1,630
2001	1,770
2002	2,130
2003	2,800
2004	3,400
2005	3,904
2006	4,855
2007	6,500

Source:
Renewable Fuels Association, Industry Statistics, August 15, 2008, http://www.ethanolrfa.org/industry/statistics/#E .

Between 1999 and 2008, the number of ethanol plants in the U.S. more than tripled, accompanied by a rapid rise in production capacity. Additional information on specific plant locations and up-to-date statistics can be obtained at the Renewable Fuels Association, www.ethanolrfa.org/industry/statistics/.

Table 2.7
Ethanol Production Statistics, 1999-2008
(As of January of each year)

Year	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Total Ethanol Plants	50	54	56	61	68	72	81	95	110	170[a]
Ethanol Production Capacity (million gallons per year)	1,701.7	1,748.7	1,921.9	2,347.3	2,706.8	3,100.8	3,643.7	4,336.4	5,493.4	10569.4[b]
Plants Under Construction/Expanding	5	6	6	13	11	15	16	31	76	24
Capacity Under Construction/Expanding (million gallons per year)	77.0	91.5	64.7	390.7	483.0	598.0	754.0	1,778.0	5,635.5	2,066.0
States with Ethanol Plants	17	17	18	19	20	19	18	20	21	26

Source:
Renewable Fuels Association, Table titled: "Ethanol Industry Overview," www.ethanolrfa.org/industry/statistics/.

[a] Operating plants.
[b] Capacity including idled capacity.

Although ethanol can be made from a wide variety of feedstocks, the vast majority of ethanol is made from corn. Future cellulosic production methods using grasses and woody plant material may eventually account for a sizeable share, but in the near term, corn remains the dominant feedstock.

Table 2.8
Ethanol Production by Feedstock, 2006

Plant Feedstock	Capacity (million galllons/year)	% of Capacity	No. of Plants	% of Plants
Corn[a]	4,516	92.7%	85	83.3%
Corn/Grain Sorghum	162	3.3%	5	4.9%
Corn/Wheat	90	1.8%	2	2.0%
Corn/Barley	40	0.8%	1	1.0%
Milo/Wheat	40	0.8%	1	1.0%
Waste Beverage[b]	16	0.3%	5	4.9%
Cheese Whey	8	0.2%	2	2.0%
Sugars & Starches	2	0.0%	1	1.0%
Total	**4,872**	**100.0%**	**102**	**100.0%**

Source:
Environmental Protection Agency, Office of Transportation and Air Quality. 2006. *Renewable Fuel Standard Program - Draft Regulatory Impact Analysis*, EPA420-D-06-008, September.

[a] Includes seed corn.
[b] Includes brewery waste.

The great majority of ethanol production facilities operating in the United States use natural gas as their energy source.

Table 2.9
Ethanol Production by Plant Energy Source, 2006

Energy Source	Capacity MMGal/year	% of Capacity	No. of Plants	% of Plants
Natural Gas[a]	4,671	95.9%	98	96.1%
Coal	102	2.1%	2	2.0%
Coal & Biomass	50	1.0%	1	1.0%
Syrup	49	1.0%	1	1.0%
Total	**4,872**	**100.0%**	**102**	**100.0%**

Source:
Environmental Protection Agency, Office of Transportation and Air Quality. 2006. *Renewable Fuel Standard Program - Draft Regulatory Impact Analysis*, EPA420-D-06-008, September.

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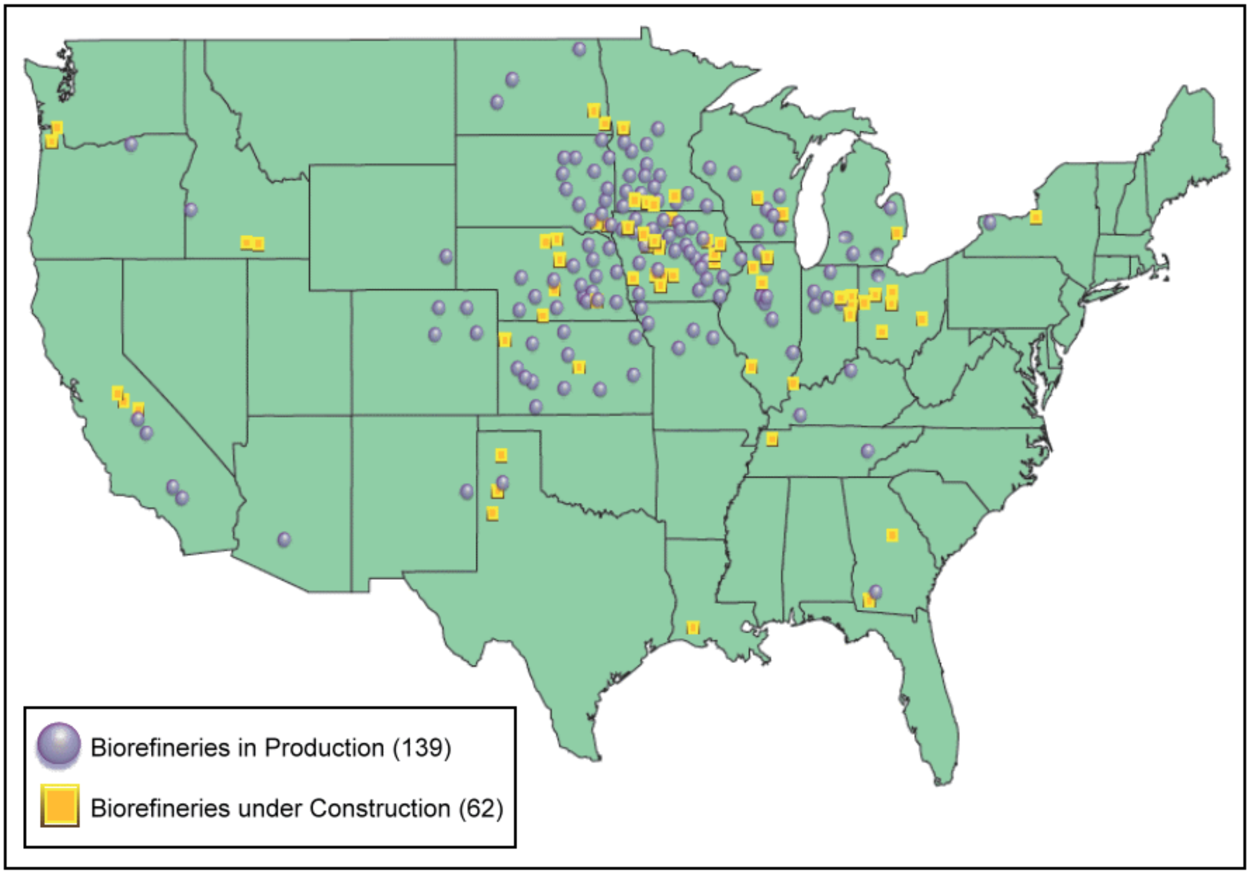
[a] Includes a natural gas facility which is considering transitioning to coal.

The majority of ethanol production facilities are concentrated where corn is grown. However, the geographic distribution of biorefineries is beginning to spread as feedstocks other than corn are increasingly used. For an up-to-date listing of all production facilities, visit the Renewable Fuels Association at: http://www.ethanolrfa.org/

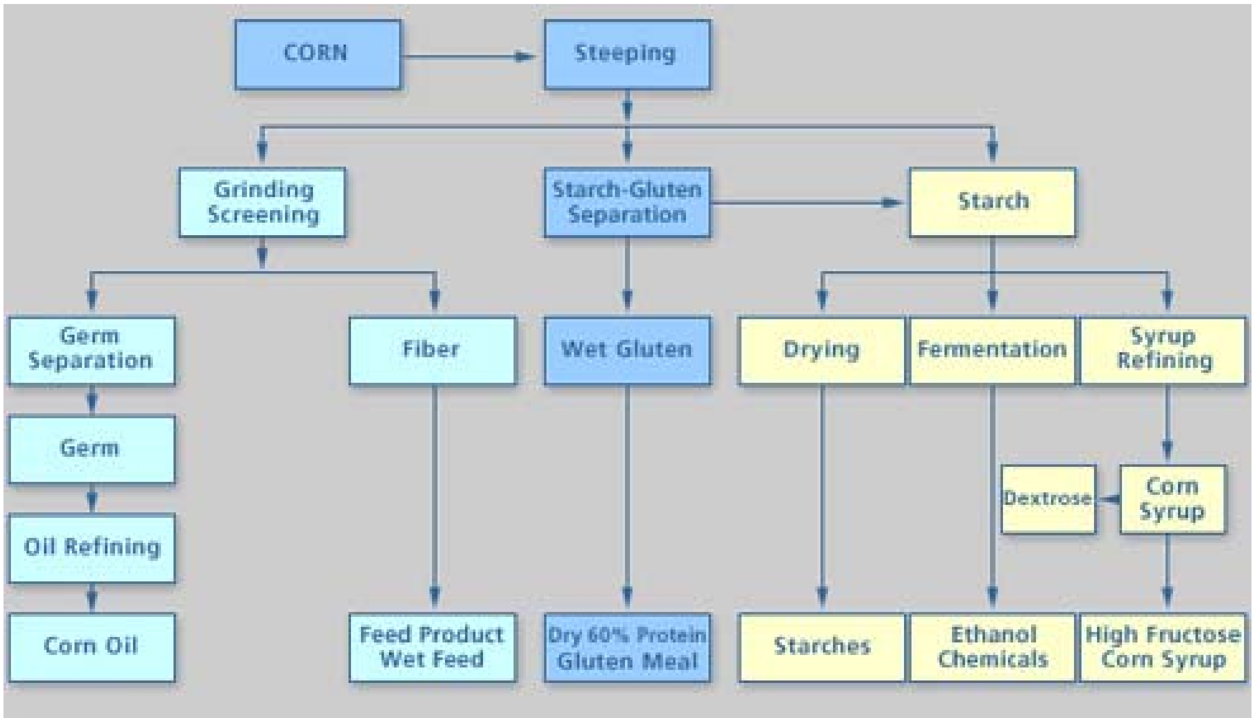
Figure 2.2
Ethanol Production Facilities Current and Under Construction, January 24, 2008



Source:
Renewable Fuels Association, http://www.ethanolrfa.org/.

The production of ethanol or ethyl alcohol from starch or sugar-based feedstocks is among man's earliest ventures into value-added processing. While the basic steps remain the same, the process has been considerably refined in recent years, leading to a very efficient process. There are two production processes: wet milling and dry milling. The main difference between the two is in the initial treatment of the grain.

Figure 2.3
The Ethanol Production Process - Wet Milling



In wet milling, the grain is soaked or "steeped" in water and dilute sulfurous acid for 24 to 48 hours. This steeping facilitates the separation of the grain into its many component parts.

After steeping, the corn slurry is processed through a series of grinders to separate the corn germ. The corn oil from the germ is either extracted on-site or sold to crushers who extract the corn oil. The remaining fiber, gluten and starch components are further segregated using centrifugal, screen and hydroclonic separators.

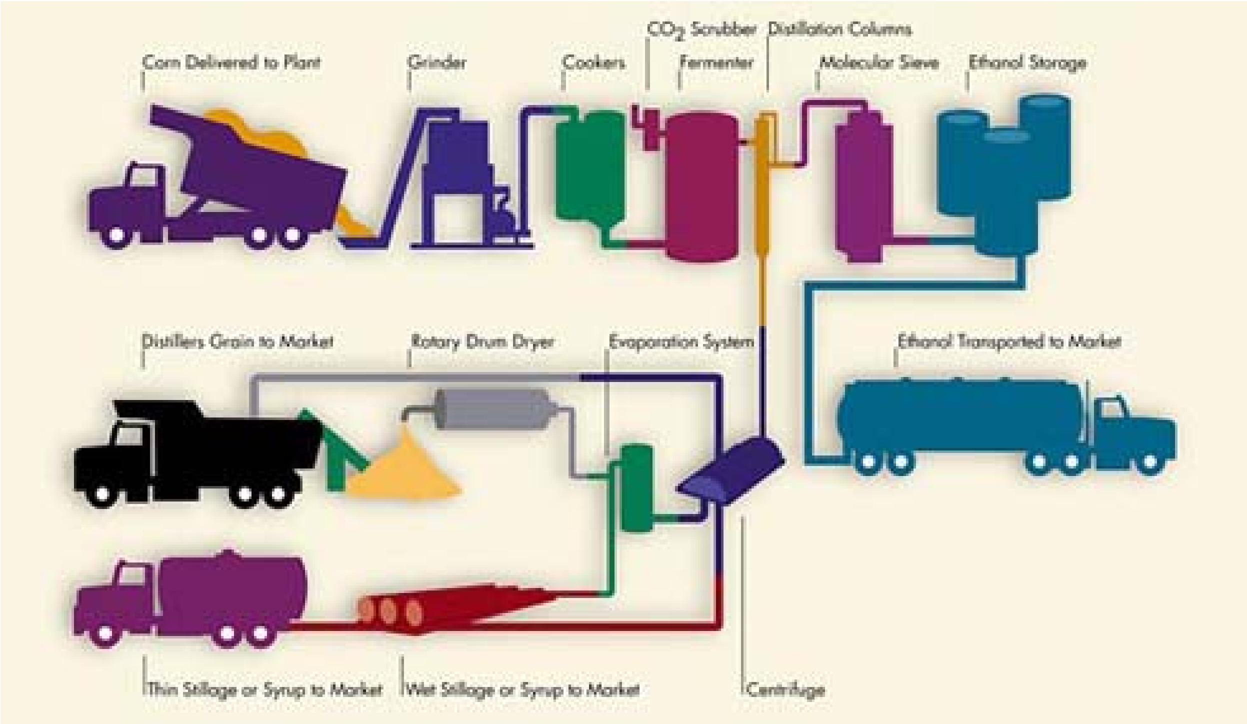
The steeping liquor is concentrated in an evaporator. This concentrated product, heavy steep water, is co-dried with the fiber component and is then sold as corn gluten feed to the livestock industry. Heavy steep water is also sold by itself as a feed ingredient and is used as a component in Ice Ban, an environmentally friendly alternative to salt for removing ice from roads.

The gluten component (protein) is filtered and dried to produce the corn gluten meal co-product. This product is highly sought after as a feed ingredient in poultry broiler operations.

The starch and any remaining water from the mash can then be processed in one of three ways: fermented into ethanol, dried and sold as dried or modified corn starch, or processed into corn syrup. The fermentation process for ethanol is very similar to the dry mill process.

Source:
Renewable Fuels Association, http://www.ethanolrfa.org/resource/made/ .

Figure 2.4
The Ethanol Production Process - Dry Milling



In dry milling, the entire corn kernel or other starchy grain is first ground into flour, which is referred to in the industry as "meal" and processed without separating out the various component parts of the grain. The meal is slurried with water to form a "mash." Enzymes are added to the mash to convert the starch to dextrose, a simple sugar. Ammonia is added for pH control and as a nutrient to the yeast.

The mash is processed in a high-temperature cooker to reduce bacteria levels ahead of fermentation. The mash is cooled and transferred to fermenters where yeast is added and the conversion of sugar to ethanol and carbon dioxide (CO2) begins.

The fermentation process generally takes about 40 to 50 hours. During this part of the process, the mash is agitated and kept cool to facilitate the activity of the yeast. After fermentation, the resulting "beer" is transferred to distillation columns where the ethanol is separated from the remaining "stillage." The ethanol is concentrated to 190 proof using conventional distillation and is then dehydrated to approximately 200 proof in a molecular sieve system.

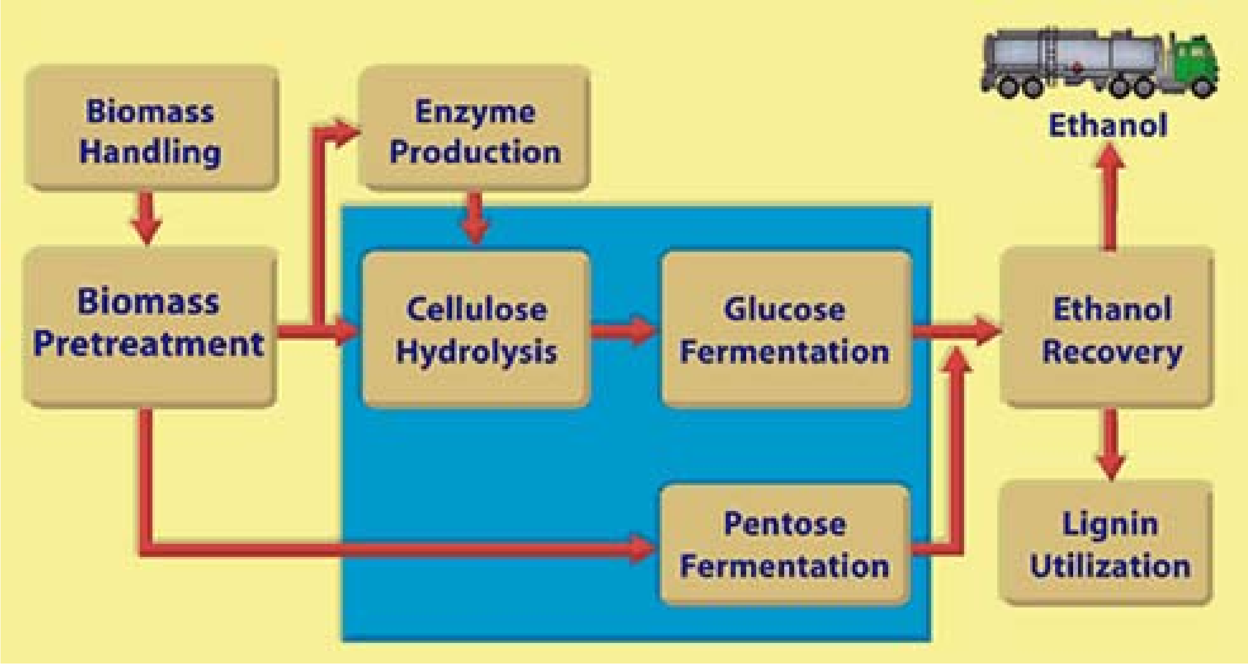
The anhydrous ethanol is blended with about 5% denaturant (such as natural gasoline) to render it undrinkable and thus not subject to beverage alcohol tax. It is then ready for shipment to gasoline terminals or retailers.

The stillage is sent through a centrifuge that separates the coarse grain from the solubles. The solubles are then concentrated to about 30% solids by evaporation, resulting in Condensed Distillers Solubles (CDS) or "syrup." The coarse grain and the syrup are dried together to produce dried distillers grains with solubles (DDGS), a high quality, nutritious livestock feed. The CO2 released during fermentation is captured and sold for use in carbonating soft drinks and the manufacture of dry ice.

Source:
Renewable Fuels Association, http://www.ethanolrfa.org/resource/made/ .

This process flow diagram shows the basic steps in production of ethanol from cellulosic biomass. While cellulosic ethanol is not yet commercial in the U.S., it has been demonstrated by several groups, and commercial facilities are being planned in North America. Note that there are a variety of options for pretreatment and other steps in the process and that some specific technologies combine two or all three of the hydrolysis and fermentation steps within the shaded box. Chart courtesy of the National Renewable Energy Laboratory.

Figure 2.5
The Production of Ethanol from Cellulosic Biomass



Hydrolysis is the chemical reaction that converts the complex polysaccharides in the raw feedstock to simple sugars. In the biomass-to-bioethanol process, acids and enzymes are used to catalyze this reaction.

Fermentation is a series of chemical reactions that convert sugars to ethanol. The fermentation reaction is caused by yeast or bacteria, which feed on the sugars. Ethanol and carbon dioxide are produced as the sugar is consumed.

Process Description. The basic processes for converting sugar and starch crops are well-known and used commercially today. While these types of plants generally have a greater value as food sources than as fuel sources there are some exceptions to this. For example, Brazil uses its huge crops of sugar cane to produce fuel for its transportation needs. The current U.S. fuel ethanol industry is based primarily on the starch in the kernels of feed corn, America's largest agricultural crop.

1. **Biomass Handling.** Biomass goes through a size-reduction step to make it easier to handle and to make the ethanol production process more efficient. For example, agricultural residues go through a grinding process and wood goes through a chipping process to achieve a uniform particle size.

2. **Biomass Pretreatment.** In this step, the hemicellulose fraction of the biomass is broken down into simple sugars. A chemical reaction called hydrolysis occurs when dilute sulfuric acid is mixed with the biomass feedstock. In this hydrolysis reaction, the complex chains of sugars that make up the hemicellulose are broken, releasing simple sugars. The complex

Figure 2.5 (Continued)
The Production of Ethanol from Cellulosic Biomass

hemicellulose sugars are converted to a mix of soluble five-carbon sugars, xylose and arabinose, and soluble six-carbon sugars, mannose and galactose. A small portion of the cellulose is also converted to glucose in this step.

3. **Enzyme Production.** The cellulase enzymes that are used to hydrolyze the cellulose fraction of the biomass are grown in this step. Alternatively the enzymes might be purchased from commercial enzyme companies.

4. **Cellulose Hydrolysis.** In this step, the remaining cellulose is hydrolyzed to glucose. In this enzymatic hydrolysis reaction, cellulase enzymes are used to break the chains of sugars that make up the cellulose, releasing glucose. Cellulose hydrolysis is also called cellulose saccharification because it produces sugars.

5. **Glucose Fermentation.** The glucose is converted to ethanol, through a process called fermentation. Fermentation is a series of chemical reactions that convert sugars to ethanol. The fermentation reaction is caused by yeast or bacteria, which feed on the sugars. As the sugars are consumed, ethanol and carbon dioxide are produced.

6. **Pentose Fermentation.** The hemicellulose fraction of biomass is rich in five-carbon sugars, which are also called pentoses. Xylose is the most prevalent pentose released by the hemicellulose hydrolysis reaction. In this step, xylose is fermented using Zymomonas mobilis or other genetically engineered bacteria.

7. **Ethanol Recovery.** The fermentation product from the glucose and pentose fermentation is called ethanol broth. In this step the ethanol is separated from the other components in the broth. A final dehydration step removes any remaining water from the ethanol.

8. **Lignin Utilization.** Lignin and other byproducts of the biomass-to-ethanol process can be used to produce the electricity required for the ethanol production process. Burning lignin actually creates more energy than needed and selling electricity may help the process economics.

Converting cellulosic biomass to ethanol is currently too expensive to be used on a commercial scale. Researchers are working to improve the efficiency and economics of the ethanol production process by focusing their efforts on the two most challenging steps:

- **Cellulose hydrolysis.** The crystalline structure of cellulose makes it difficult to hydrolyze to simple sugars, ready for fermentation. Researchers are developing enzymes that work together to efficiently break down cellulose.

- **Pentose fermentation.** While there are a variety of yeast and bacteria that will ferment six-carbon sugars, most cannot easily ferment five-carbon sugars, which limits ethanol production from cellulosic biomass. Researchers are using genetic engineering to design microorganisms that can efficiently ferment both five- and six-carbon sugars to ethanol at the same time.

Source:
Renewable Fuels Association, http://www.ethanolrfa.org/resource/made/, and the Department of Energy, Energy Efficiency and Renewable Energy, http://www1.eere.energy.gov/biomass/abcs_biofuels.html.

Note: See Appendix B, Table B1 "Characteristics of Selected Feedstocks and Fuels."

Ethanol is used as an oxygenate, blended with gasoline to be used as gasohol in conventional vehicles. The amount of ethanol used in gasohol dwarfs the amount used in E85.

Table 2.10
Ethanol Consumption in E85 and Gasohol, 1995-2006
(Thousands of gallons)

	E85	Percent of Total	Ethanol in Gasohol	Percent of Total	Total
1995	166	0.02%	934,615	99.98%	934,781
2000	10,530	0.94%	1,114,313	99.06%	1,124,843
2001	12,756	1.08%	1,173,323	98.92%	1,186,079
2002	15,513	1.06%	1,450,721	98.94%	1,466,234
2003	22,420	1.15%	1,919,572	98.85%	1,941,992
2004	26,844	1.10%	2,414,167	98.90%	2,441,011
2005	32,363	1.16%	2,756,663	98.84%	2,789,026
2006	37,435	0.99%	3,729,168	99.01%	3,766,603

Source:
U.S. Department of Energy, Energy Information Administration, *Alternatives to Traditional Transportation Fuels*, 2006, Table C1. Washington DC, October 2008, Web site: http://www.eia.doe.gov/cneaf/alternate/page/atftables/afvtransfuel_II.html#consumption.

Note: Gallons of E85 and gasohol do not include the gasoline portion of the blended fuel.

Twenty-one ethanol dry mill processing plants contributed to the survey results reported here. The costs reported are 2002 dollars.

Table 2.11
Undenatured Ethanol Cash Operating Expenses and Net Feedstock Costs for Dry-milling Process by Plant Size, 2002

Feedstock	Unit	All Dry Mills	Small	Large
Corn	1,000 bu	193,185	103,213	89,972
Sorghum	1,000 bu	10,409	N/A	10,409
Other	1,000 ton	44.9	N/A	44.9
Alcohol production:				
Fuel	1,000 gal	548,684	275,900	272,784
Industrial	1,000 gal	1,000	1,000	
Total	1,000 gal	549,684	276,900	272,784
Ethanol yield	Gal/bu	2.6623	2.6828	2.649
Feedstock costs	Dol./gal	0.8030	0.7965	0.8095
Byproducts credits:				
Distiller's dried grains	Dol./gal	0.2520	0.2433	0.261
Carbon dioxide	Dol./gal	0.0060	0.0038	0.008
Net feedstock costs	Dol./gal	0.5450	0.5494	0.5405
Cash operating expenses:				
Electricity	Dol./gal	0.0374	0.04	0.0349
Fuels	Dol./gal	0.1355	0.1607	0.1099
Waste management	Dol./gal	0.0059	0.0077	0.0041
Water	Dol./gal	0.0030	0.0044	0.0015
Enzymes	Dol./gal	0.0366	0.0377	0.0365
Yeast	Dol./gal	0.0043	0.0039	0.0046
Chemicals	Dol./gal	0.0229	0.0231	0.0228
Denaturant	Dol./gal	0.0348	0.0356	0.0339
Maintenance	Dol./gal	0.0396	0.0319	0.0474
Labor	Dol./gal	0.0544	0.0609	0.0478
Administrative costs	Dol./gal	0.0341	0.0357	0.0325
Other	Dol./gal	0.0039	0.0035	0.0043
Total	**Dol./gal**	**0.4124**	**0.4451**	**0.3802**
Total cash costs and net feedstock costs	**Dol./gal**	**0.9574**	**0.9945**	**0.9207**

Source:
Shapouri, H. and P. Gallagher. 2005. *USDA's Ethanol Cost of Production Survey*, U.S. Department of Agriculture, Agricultural Economic Report Number 841. July.

Note: Dol - dollars, bu - bushels, gal - gallons.

The ethanol industry spent $6.7 billion in 2006 to produce an estimated 4.9 billion gallons of ethanol. Most of this spending was for corn and other grains used as raw material to make ethanol though a significant amount was spent on new construction. All expenditures for operations, transportation and spending for new plants under construction added an estimated $41.9 billion in additional gross output in the U.S. economy, increased household earnings by nearly $6.7 billion, and created over 163,034 jobs.

Table 2.12
Economic Contribution of the Ethanol Industry, 2006

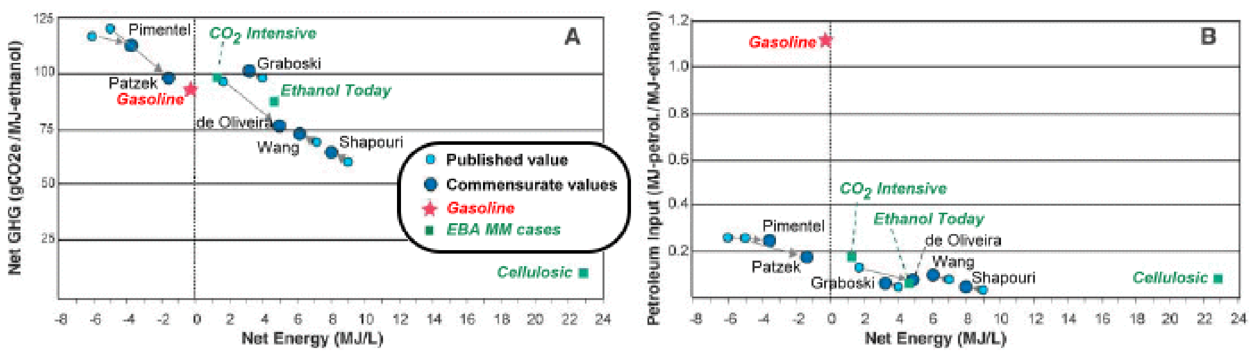
Industry	Spending (Mil 2005$)	Impact: Output (Mil 2005$)	Impact: Earnings (Mil 2005$)	Impact: Employment (Jobs)
Construction	2,100.0	9,337.4	2,223.3	54,861
Plus initial changes		2,100.0		
Total		**9337.4**	**2223.3**	**54861**
Annual Operations				
Farm Products/Agriculture	4,062.5	11,278.4	2,157.2	62,278
Industrial Chemicals	299.8	1,009.6	214.2	4,355
Petroleum Refineries	181.3	497.8	98.2	1,839
Electricity, Natural Gas, Water	1,570.4	4,655.6	1,016.5	19,712
Maintenance and Repair	127.4	340.3	120.8	3,318
Business Services	294.0	840.3	222.1	5,075
Earnings paid to households	156.8	371.4	103.7	2,805
Rail, truck, barge	409.8	1,196.0	328.1	7,100
Subtotal	**7,102.1**	**20,189.5**	**4,334.8**	**108,173**
Plus initial changes:				
Value of ethanol production		10,795.0	156.8	
Value of co-products		1,595.9		
Total Annual Operations		**32,580.0**	**4,491.6**	**108,173**
Total		**41,917.9**	**6,714.8**	**163,034**

Source:
John M. Urbanchuk, Director, LECG, LLC, 1255 Drummers Lane, Suite 320, Wayne, PA 19087, www.lecg.com .

Figure 2.6
Ethanol Net Energy Balances and Greenhouse Gas Emissions

The net energy balance and greenhouse gas emissions associated with ethanol production have been analyzed by multiple groups in the past 5 years. Some analysts have shown negative energy input to output balances while others have shown neutral to positive balances. Greenhouse gas emission estimates have also varied accordingly. Some differences can be explained by use of older versus new data, by inclusion or exclusion of co-products and by use of different system boundaries. Alexander Farrell and others in the Energy and Resources Group at the University of California, Berkeley, recently developed the Biofuel Analysis MetaModel (EBAMM) to investigate these issues. The group first replicated the results of six published studies with EBAMM then adjusted all six analyses to (a) add coproduct credit where needed, (b) apply a consistent system boundary, (c) account for different energy types, and (d) calculate policy relevant metrics.

The results shown below in figures A & B show the original and adjusted values for the six studies, EBAMM generated values for 3 cases including CO2 intensive ethanol, ethanol today, and cellulosic ethanol, and a gasoline comparison. Equalizing system boundaries among studies reduces scatter in the results. All studies show that ethanol made from conventionally grown corn can have greenhouse gas emissions that are slightly more or less than gasoline per unit of energy but that conventional corn ethanol requires much less petroleum inputs. The model suggests that ethanol produced from cellulosic materials reduces both GHG's and petroleum inputs substantially.



Source:
Farrell, A.E., R.J. Plevin, B.T. Turner, A.D. Jones, M. O'Hare, and D.M. Kammen. 2006. "Ethanol Can Contribute to Energy and Environmental Goals," *Science*, Vol 311, January 27.

Note: gCO2e (as shown in Figure A above) is grams of CO2 equivalent.

Additional References:

Patzek, T. 2004. *Crit. Rev. Plant Sci*. 23, 519.

Pimentel, D. and T. Patzek. 2005. *Nat. Resourc. Res*. 14, 65.

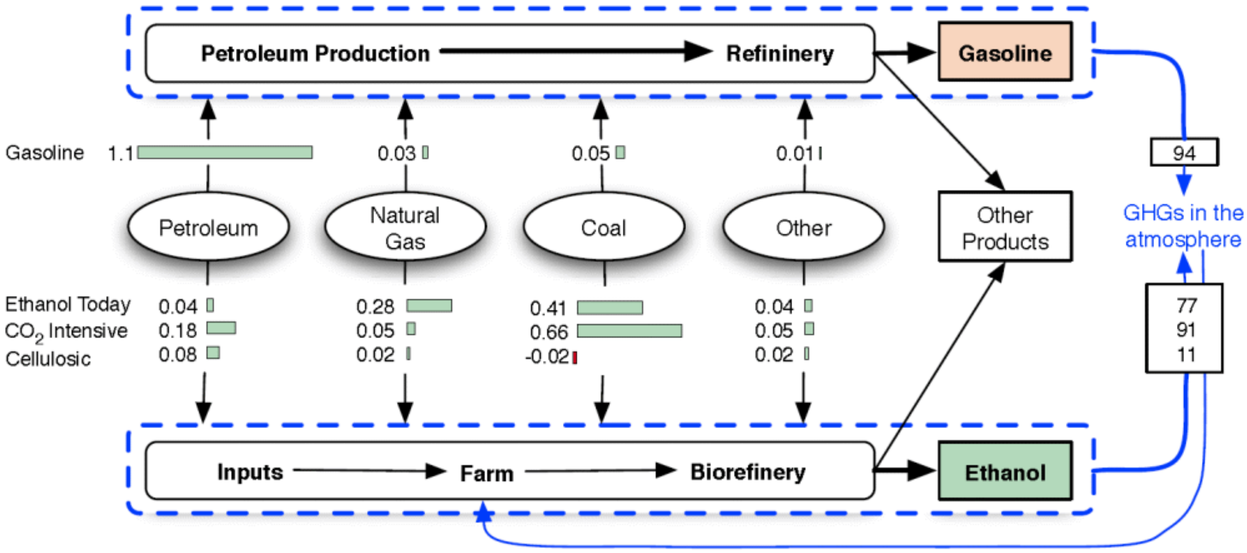
de Oliveira, M.E.D., B.E. Vaughn, and E.J. Rykiel. 2005. *Bioscience*, 55, 593.

Shapouri, H. J. Duffield, A. McAloon and M. Wang. 2004. *The 2001 Net Energy Balance of Corn Ethanol*, U.S. Department of Agriculture, Washington, DC.

Graboski, M. 2002. *Fossil Energy Use in the Manufacture of Corn Ethanol*, National Corn Growers Association, Washington, DC, www.ncga.com/ethanol/main.

Wang, M. 2001. *Development and Use of GREET 1.6 Fuel-Cycle Model for Transportation Fuels and Vehicle Technologies*, Technical Report ANL/ESD/TM-163, Argonne National Laboratory, Argonne, Illinois, http://www.transportation.anl.gov/pdfs/TA/153.pdf.

Figure 2.7
Comparisons of Energy Inputs and GHG Emissions for Three Ethanol Scenarios and Gasoline



The graphic above was developed by the Energy and Resources group at the University of California, Berkeley using their Biofuel Analysis MetaModel. It is comparing the intensity of primary energy inputs (MJ) per MJ of fuel produced (ethanol or gasoline) and of net greenhouse gas emissions (kg CO2 – equivalent) per MJ. For gasoline both petroleum feedstock and petroleum energy inputs are included. "Other" includes nuclear and hydroelectric generation. The Ethanol Today case includes typical values for the current U.S. corn ethanol industry. The CO2 intensive case assumes the ethanol is produced in a lignite-fired biorefinery located far from where the corn is grown. The Cellulosic case assumes ethanol is produced from switchgrass grown locally. Cellulosic ethanol is expected to have an extremely low intensity for all fossil fuels and a very slightly negative coal intensity due to electricity sales that would displace coal.

Source:
Farrell, A.E., R.J. Plevin, B.T. Turner, A.D. Jones, M. O'Hare, and D.M. Kammen. 2006. "Ethanol Can Contribute To Energy and Environmental Goals," *Science*, Vol 311, January 27, www.science.org.

Figure 2.6 includes a data point from M. Wang based on use of the GREET (Greenhouse gases, Regulated Emissions, and Energy Use in Transportation) model. This page provides more information about this public domain model that is available at:
http://www.transportation.anl.gov/software/GREET/index.html

Figure 2.8
Comparative Results between Ethanol and Gasoline Based on an Evaluation by the GREET Model

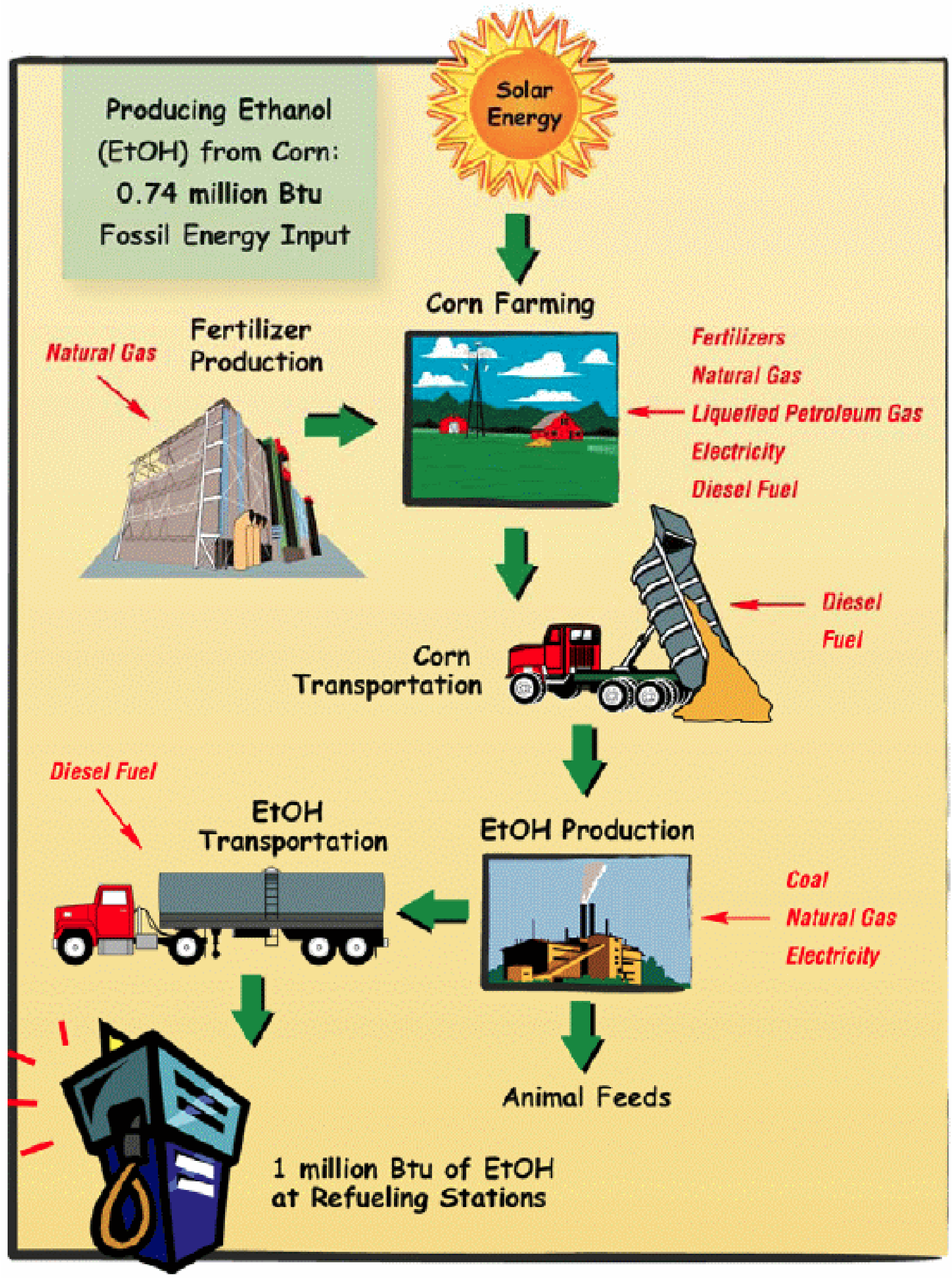
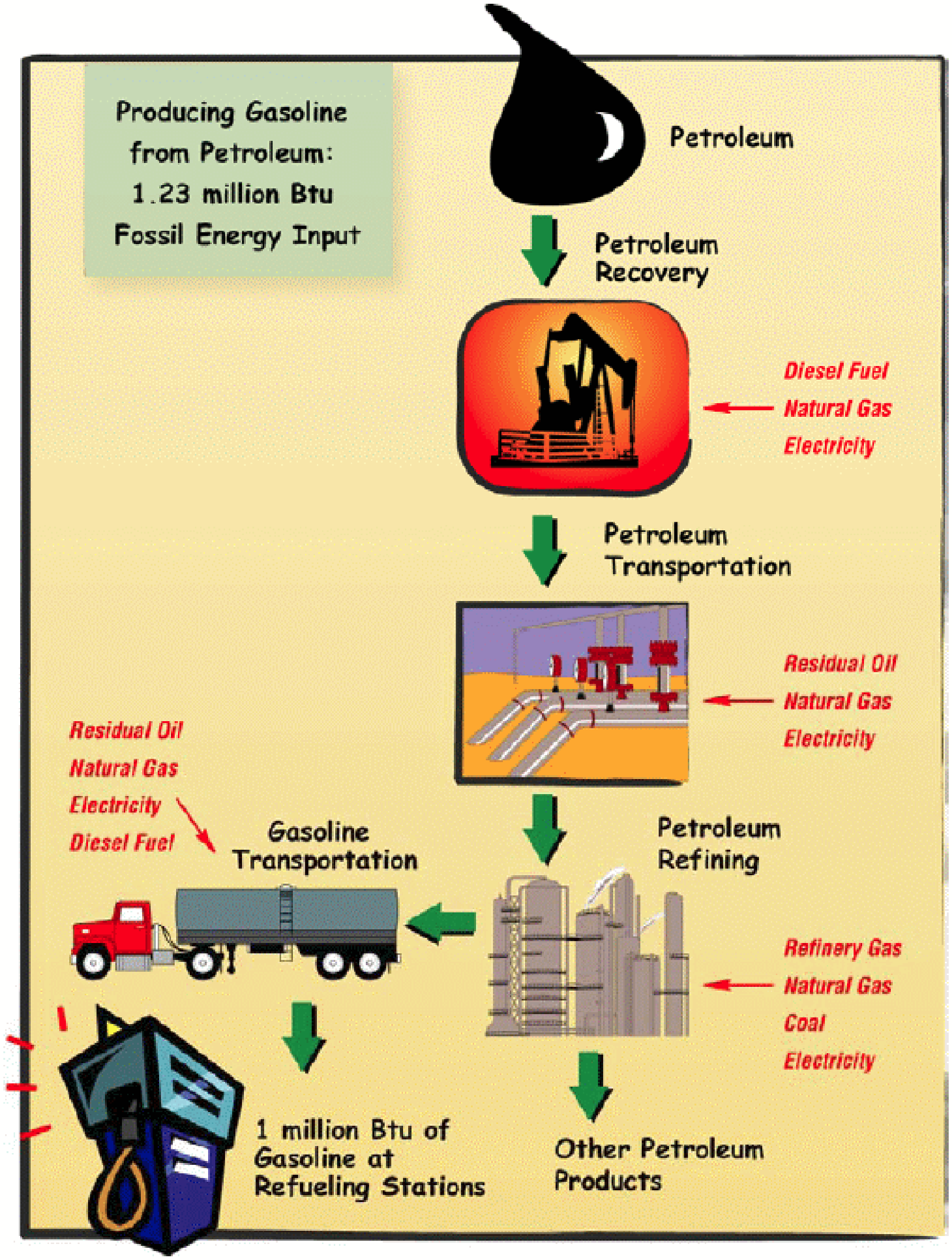


Figure 2.8 (Continued)
Comparative Results between Ethanol and Gasoline Based on an Evaluation by the GREET Model



The GREET model was developed by Argonne National Laboratory under the sponsorship of the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy in order to fully evaluate energy and emission impacts of advanced vehicle technologies and new transportation fuels. The first version of this public domain model was released in 1996. Since then, Argonne has continued to update and expand the model with GREET 1.7 version now available. The model allows researchers and analysts to evaluate various vehicle and fuel combinations on a full fuel-cycle basis that includes wells to wheels and the vehicle cycle through material recovery and vehicle disposal.

For a given vehicle and fuel system, GREET separately calculates the following:

- Consumption of total energy (energy in non-renewable and renewable sources) and fossil fuels (petroleum, natural gas, and coal).

Figure 2.8 (Continued)
Comparative Results between Ethanol and Gasoline Based on an Evaluation by the GREET Model

- Emissions of CO2-equivalent greenhouse gases – primarily carbon dioxide, methane, and nitrous oxide.
- Emissions of five criteria pollutants: volatile organic oxide, particulate matter with size smaller than 10 micron (PM10), and sulfur oxides.

GREET includes more than 30 fuel-cycle pathway groups and the following vehicle technologies:
- Conventional spark-ignition engines
- Direct injection, compression ignition engines
- Grid-connected hybrid electric vehicles
- Grid-independent hybrid electric vehicles
- Battery-powered electric vehicles
- Fuel-cell vehicles.

Sources:
Figures: Wang, Michael. 2005. *The Debate on Energy and Greenhouse Gas Emissions Impacts of Fuel Ethanol*, Energy Systems Division Seminar, Argonne National Laboratory August 3.
Text: Argonne National Laboratory, Transportation Technology R&D Center, http://www.transportation.anl.gov/software/GREET/index.html.

Table 2.13
Comparison of Ethanol Energy Balance With and Without Inclusion of Coproduct Energy Credits

Tables A and B, from a paper by H. Shapouri and A. McAloon, show the effects of partitioning the energy inputs to coproducts as well as to the ethanol produced at wet and dry mills.

Table A summarizes the input energy requirements, by phase of ethanol production on a Btu per gallon basis (LHV) for 2001, without byproduct credits. Energy estimates are provided for both dry- and wet-milling as well as an industry average. In each case, corn ethanol has a positive energy balance, even before subtracting the energy allocated to byproducts.

Table B presents the final net energy balance of corn ethanol adjusted for byproducts. The net energy balance estimate for corn ethanol produced from wet-milling is 27,729 Btu per gallon, the net energy balance estimate for dry-milling is 33,196 Btu per gallon, and the weighted average is 30,528 Btu per gallon. The energy ratio is 1.57 and 1.77 for wet- and dry-milling, respectively, and the weighted average energy ratio is 1.67.

Table A
Energy Use and Net Energy Value Per Gallon Without Coproduct Energy Credits, 2001

Production Process	Milling Process		Weighted
	Dry	**Wet**	**average**
	Btu per gallon		
Corn production	18,875	18,551	18,713
Corn transport	2,138	2,101	2,120
Ethanol conversion	47,116	52,349	49,733
ethanol distribution	1,487	1,487	1,487
Total energy used	69,616	74,488	72,052
Net energy value	6,714	1,842	4,278
Energy ratio	1.10	1.02	1.06

Table B
Energy Use and Net Energy Value Per Gallon with Coproduct Energy Credits, 2001

Production Process	Milling process		Weighted
	Dry	**Wet**	**average**
	Btu per gallon		
Corn production	12,457	12,244	12,350
Corn transport	1,411	1,387	1,399
Ethanol conversion	27,799	33,503	30,586
ethanol distribution	1,467	1,467	1,467
Total energy used	43,134	48,601	45,802
Net energy value	33,196	27,729	30,528
Energy ratio	1.77	1.57	1.67

Source:
Shappouri, H., J. Duffield, A. McAloon and M. Wang. 2004. *The 2001 Net Energy Balance of Corn Ethanol*, U.S. Department of Agriculture, Washington, DC.

BIODIESEL OVERVIEW

Biodiesel is a clean burning alternative fuel produced from domestic, renewable resources. The fuel is a mixture of fatty acid alkyl esters made from vegetable oils, animal fats or recycled greases. Where available, biodiesel can be used in compression-ignition (diesel) engines in its pure form with little or no modifications. Biodiesel is simple to use, biodegradable, nontoxic, and essentially free of sulfur and aromatics. It is usually used as a petroleum diesel additive to reduce levels of particulates, carbon monoxide, hydrocarbons and air toxics from diesel-powered vehicles. When used as an additive, the resulting diesel fuel may be called B5, B10 or B20, representing the percentage of the biodiesel that is blended with petroleum diesel.

In the United States, most biodiesel is made from soybean oil or recycled cooking oils. Animal fats, other vegetable oils, and other recycled oils can also be used to produce biodiesel, depending on their costs and availability. In the future, blends of all kinds of fats and oils may be used to produce biodiesel. Biodiesel is made through a chemical process called transesterification whereby the glycerin is separated from the fat or vegetable oil. The process leaves behind two products -- methyl esters (the chemical name for biodiesel) and glycerin (a valuable byproduct usually sold to be used in soaps and other products).

Fuel-grade biodiesel must be produced to strict industry specifications (ASTM D6751) in order to insure proper performance. Biodiesel is the only alternative fuel to have fully completed the health effects testing requirements of the 1990 Clean Air Act Amendments. Biodiesel that meets ASTM D6751 and is legally registered with the Environmental Protection Agency is a legal motor fuel for sale and distribution. Raw vegetable oil cannot meet biodiesel fuel specifications; therefore, it is not registered with the EPA and it is not a legal motor fuel.

Sources:
U.S. Department of Energy, Energy Efficiency and Renewable Energy, www.eere.energy.gov/RE/bio_fuels.html; National Biodiesel Board, www.biodiesel.org/resources/biodiesel_basics/default.shtm.

During 2002, Europe, in general, and particularly the EU countries of Germany, France and Italy, were the dominant producers of biodiesel worldwide.

Table 2.14
World Biodiesel Capacity, 2002
(Million gallons)

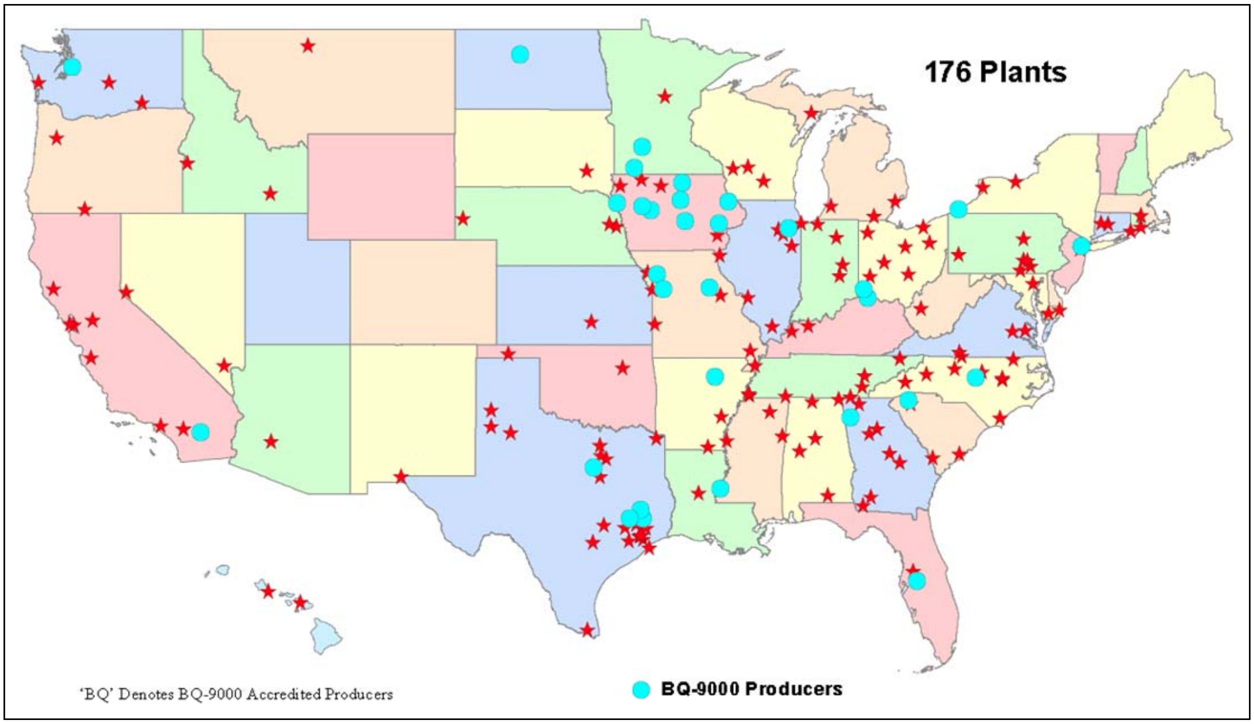
Country	Capacity[a]	Typical use
United States	18.49	blends <25%
IEA North America	**18.49**	
Austria	8.45	blends <25%
Belgium	9.51	
Denmark	0.79	
France	101.97	mainly 5%
Germany	165.11	100% biodiesel; some blends
Italy	63.14	blends <25%
Spain	2.38	
Sweeden	4.49	blends <25%
UK	1.59	
EU	**357.42**	
Poland	21.13	
IEA Europe	**378.56**	
World	**397.05**	

Source:
International Energy Agency. 2004. *Biofuels for Transport: An International Perspective*, page 30, Table 1.1, May.

Note: Production of biodiesel in 2003 is roughly 65% of capacity. Some minor production (e.g. India, Africa) not reported.

[a] Feedstock in the United States is soybeans; in Europe, rapeseed and sunflower.

Figure 2.9
Active Commercial Biodiesel Production Facilities, September 29, 2008

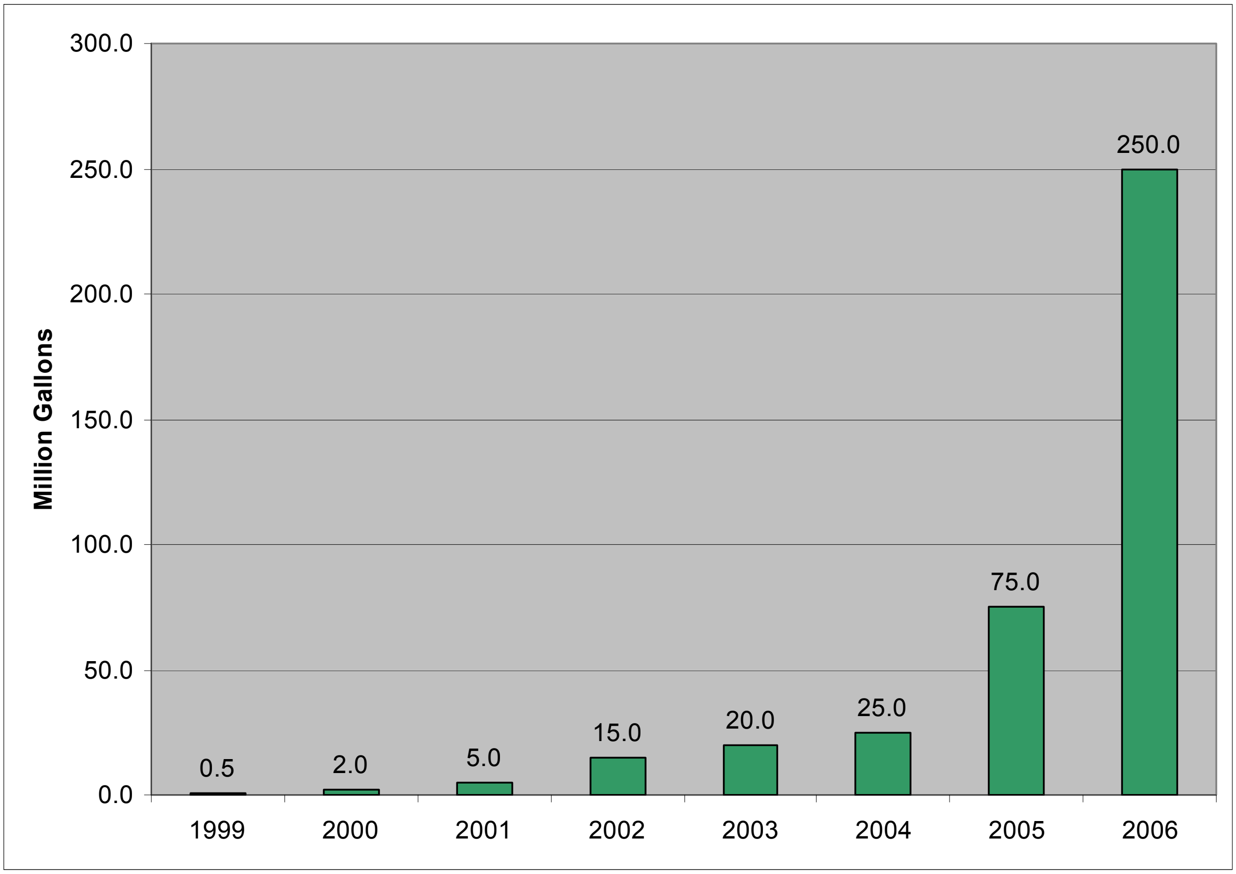


Source:
National Biodiesel Board. *Existing Plants - Production Map & Table*, http://www.nbb.org/resources/fuelfactsheets/default.shtm.

Notes:
1. BQ-9000 is a cooperative and voluntary national program for the accreditation of producers of biodiesel fuel. To learn more about BQ-9000 Accreditation, visit: http://www.bq-9000.org/.
2. For the most current listing of production facilities including company name, state, city, capacity, and primary feedstock used, follow the link listed under source following the map.

The sale of biodiesel has been on the rise since 1999, but the most notable growth was between 2004 and 2006 when sales increased ten-fold to 250 million gallons.

Figure 2.10
Estimated U.S. Biodiesel Sales, 1999-2006



Source:
National Biodiesel Board. *Biodiesel Fact Sheets*, Biodiesel Sales Graph FY99-FY06, http://www.biodiesel.org/resources/fuelfactsheets/default.shtm.

Note: Years refer to fiscal year October 1 through September 30.

It is extremely important to realize that vegetable oils are mixtures of tryglycerides from various fatty acids. The composition of vegetable oils varies with the plant source. The table below indicates the percentages of each type of fatty acid that is in common vegetable oils or animal fats. The two numbers at the top of each column represents the number of carbon atoms and double bonds (e.g. 16:0 refers to the 16 carbon atoms and 0 double bonds found in the long chain of Palmitic acid). See text on Typical Proportions of Chemicals Used to Make Biodiesel (Figure 2.12) for a description of several types of tryglycerides that are found in vegetable oils.

Table 2.15
Composition of Various Oils and Fats Used for Biodiesel
(Percentage of each type of fatty acid common to each type of feedstock)

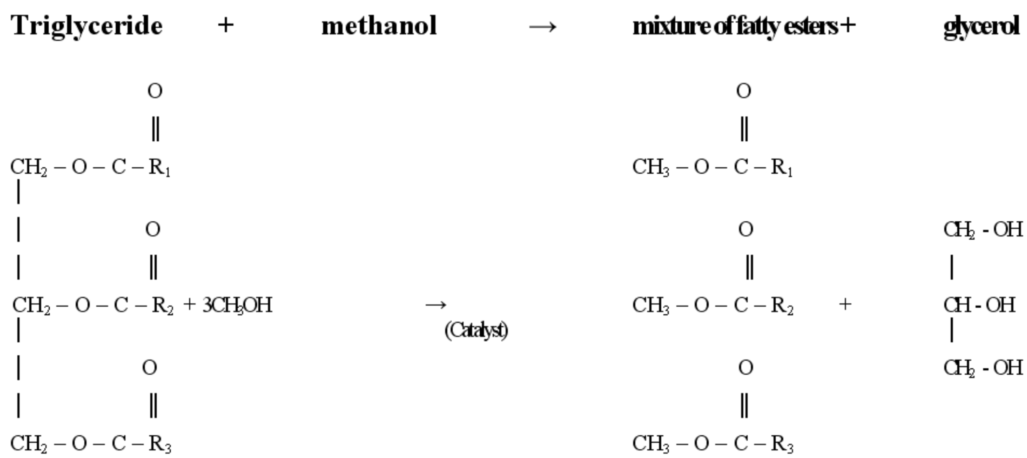
Oil or fat	14:0	16:0	18:0	18:1	18:2	18:3	20.0	22:1
Soybean		6-10	2-5	20-30	50-60	5-11		
Corn	1-2	8-12	2-5	19-49	34-52	trace		
Peanut		8-9	2-3	50-60	20-30			
Olive		9-10	2-3	73-84	10-12	trace		
Cottonseed	0-2	20-25	1-2	23-35	40-50	trace		
Hi Linoleic Safflower		5.9	1.5	8.8	83.8			
Hi Oleic Safflower		4.8	1.4	74.1	19.7			
Hi Oleic Rapeseed		4.3	1.3	59.9	21.1	13.2		
Hi Erucic Rapeseed		3.0	0.8	13.1	14.1	9.7	7.4	50.7
Butter	7-10	24-26	10-13	28-31	1-2.5	.2-.5		
Lard	1-2	28-30	12-18	40-50	7-13	0-1		
Tallow	3-6	24-32	20-25	37-43	2-3			
Linseed Oil		4-7	2-4	25-40	35-40	25-60		
Yellow grease (typical)	2.43	23.24	12.96	44.32	6.97	0.67		
		16:1=3.97						

Source:
Van Gerpen, J., B. Shanks, R. Pruszko, D. Clements, and G. Knothe. 2004. *Biodiesel Production Technology*, National Renewable Energy Laboratory subcontractor report NREL/SR-510-36244, chapter 1, page 1. Please see this document for a full discussion. Available on-line in DOE's biomass document database. Search by author or title. http://www1.eere.energy.gov/biomass/document_database.html.

Figure 2.11
Typical Proportions of Chemicals Used to Make Biodiesel

The most cursory look at the literature relating to biodiesel reveals the following relationship for production of biodiesel from fats and oils:

100 lbs of oil + 10 lbs of methanol → 100 lbs of biodiesel + 10 lbs of glycerol - This equation is a simplified form of the following transesterfication reaction:



R_1, R_2, and R_3 in the above equation are long chains of carbons and hydrogen atoms, sometimes called fatty acid chains. There are five types of chains that are common in soybean oil and animal fats shown below (others are present in small amounts).

Palmitic:	R = $-(CH_2)_{14}-CH_3$	16 carbons, 0 double bonds (16:0)
Stearic:	R = $-(CH_2)_{16}-CH_3$	18 carbons, 0 double bonds (18:0)
Oleic:	R = $-(CH_2)_7\,CH{=}CH(CH_2)_7CH_3$	18 carbons, 1 double bonds (18:1)
Linoleic:	R = $-(CH_2)_7\,CH{=}CH\text{-}CH_2\text{-}CH{=}CH(CH_2)_4CH_3$	18 carbons, 2 double bonds (18:2)
Linolenic:	R = $-(CH_2)_7\,CH{=}CH\text{-}CH_2\text{-}CH{=}CH\text{-}CH_2\text{-}CH{=}CH\text{-}CH_2\text{-}CH_3$	18 carbons, 3 double bonds (18:3)

As indicated, a short-hand designation for these chains is two numbers separated by a colon. The first number designates the number of carbon atoms in the chain and the second number designates the number of double bonds. Note that the number of carbon atoms includes the carbon that is double bonded to the oxygen atom at one end of the fatty acid (called the carboxylic carbon). This is the end that the methanol attaches to when methyl ester is produced.

Source:

Van Gerpen, J., B. Shanks, R. Pruszko, D. Clements, and G. Knothe. 2004. *Biodiesel Production Technology,*National Renewable Energy Laboratory subcontractor report NREL/SR-510-36244, chapter 1, page 1. Available on-line in DOE's biomass document database. Search by author or title. http://www1.eere.energy.gov/biomass/document_database.html.

The parameters for B100 fuel are specified through the biodiesel standard, ASTM D 6751. This standard identifies the parameters that pure biodiesel (B100) must meet before being used as a pure fuel or being blended with petrodiesel. The National Biodiesel Board has adopted ASTM biodiesel specifications.

Table 2.16
Specification for Biodiesel (B100)

Property	ASTM Method	Limits	Units
Flash Point	D93	130 min.	Degrees C
Water & Sediment	D2709	0.050 max.	% vol.
Kinematic Viscosity, 40 C	D445	1.9 - 6.0	mm2/sec.
Sulfated Ash	D874	0.020 max.	% mass
Sulfur	D5453	0.05 max.	% mass
Copper Strip Corrosion	D130	No. 3 max.	
Cetane	D613	47 min.	
Cloud Point	D2500	Report	Degrees C
Carbon Residue 100% sample	D4530[a]	0.050 max.	% mass
Acid Number	D664	0.80 max.	mg KOH/gm
Free Glycerin	D6584	0.020 max.	% mass
Total Glycerin	D6584	0.240 max.	% mass
Phosphorus Content	D 4951	0.001 max.	% mass
Distillation Temp, Atmospheric Equivalent Temperature, 90% Recovered	D 1160	360 max.	Degrees C

Source:
National Biodiesel Board. *Biodiesel Fact Sheets*, Biodiesel Production & Quality Standards, http://www.biodiesel.org/resources/fuelfactsheets/

Alternate source providing explanations for the various specifications can be found at:
Van Gerpen, J., B. Shanks, R. Pruszko, D. Clements, and G. Knothe. 2004. *Biodiesel Production Technology*, National Renewable Energy Laboratory subcontractor report NREL/SR-510-36244; Chapter 1, page 23. Available on-line in DOE's biomass document database. Search by author or title, http://www1.eere.energy.gov/biomass/document_database.html.

Notes: To meet special operating conditions, modifications of individual limiting requirements may be agreed upon between purchaser, seller and manufacturer.

A considerable amount of experience exists in the United States with a 20% blend of biodiesel with 80% diesel fuel (B20). Although biodiesel (B100) can be used, blends of over 20% biodiesel with diesel fuel should be evaluated on a case-by-case basis until further experience is available.

[a] The carbon residue shall be run on the 100% sample.

Figure 2.12
Commercial Biodiesel Production Methods

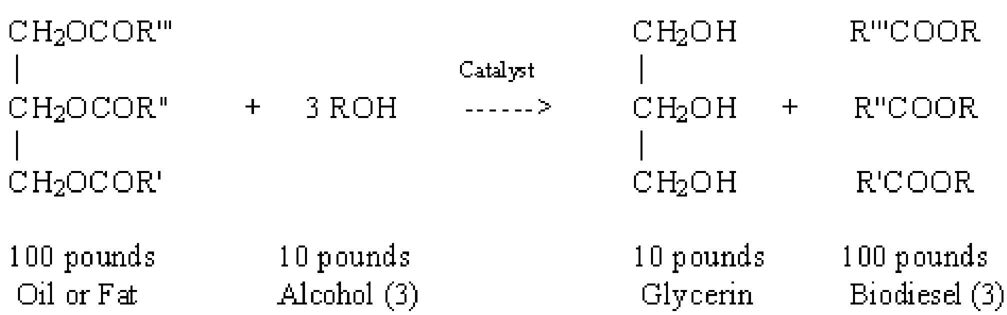
The production processes for biodiesel are well known. There are three basic routes to biodiesel production from oils and fats:

1. Base catalyzed transesterification of the oil.
2. Direct acid catalyzed transesterification of the oil.
3. Conversion of the oil to its fatty acids and then to biodiesel.

Most of the biodiesel produced today uses the base catalyzed reaction for several reasons:

- It is low temperature and pressure.
- It yields high conversion (98%) with minimal side reactions and reaction time.
- It is a direct conversion to biodiesel with no intermediate compounds.
- No exotic materials of construction are needed.

The chemical reaction for base catalyzed biodiesel production is depicted below. One hundred pounds of fat or oil (such as soybean oil) are reacted with 10 pounds of a short chain alcohol in the presence of a catalyst to produce 10 pounds of glycerin and 100 pounds of biodiesel. The short chain alcohol, signified by ROH (usually methanol, but sometimes ethanol) is charged in excess to assist in quick conversion. The catalyst is usually sodium or potassium hydroxide that has already been mixed with the methanol. R', R'', and R''' indicate the fatty acid chains associated with the oil or fat which are largely palmitic, stearic, oleic, and linoleic acids for naturally occurring oils and fats.



Source:
National Biodiesel Board. Fact Sheet, "Biodiesel Production and Quality,"
http://www.biodiesel.org/resources/fuelfactsheets/default.shtm.

Note: The term glycerin may include glycerol and related co-products of the glycerol production process.

The results of a study conducted by the EPA on the emissions produced by biodiesel show that except for nitrogen oxides (NOx), regulated and non regulated emissions from both B100 (100% biodiesel) and B20 (20% biodiesel) are significantly lower than for conventional petroleum based diesel.

Table 2.17
Average Biodiesel (B100 and B20) Emissions Compared to Conventional Diesel

Emission Type	**B100**	**B20**
	Emissions in relation to conventional diesel	
Regulated		
Total Unburned Hydrocarbons	-67%	-20%
Carbon Monoxide	-48%	-12%
Particulate Matter	-47%	-12%
NOx	+10%	+2%
Non-Regulated		
Sulfates	-100%	-20%[a]
PAH (Polycyclic Aromatic Hydrocarbons)[b]	-80%	-13%
nPAH (nitrated PAH's)[b]	-90%	-50%[c]
Ozone potential of speciated HC	-50%	-10%

Source:
National Biodiesel Board. *Biodiesel Fact Sheets*, Emissions, http://www.biodiesel.org/resources/fuelfactsheets/.

Note: Testing was performed by the EPA. The full report titled *A Comprehensive Analysis of Biodiesel Impacts on Exhaust Emissions* can be found at: www.epa.gov/otaq/models/biodsl.htm

B100 is 100% Biodiesel while B20 is a blend of 20% Biodiesel and 80% conventional petroleum based diesel.

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[a] Estimated from B100 result.
[b] Average reduction across all compounds measured.
[c] 2-nitroflourine results were within test method variability.

The market effects of increased biodiesel production and use in the United States would likely drive up the price of soybean oil while driving down the price for soybean meal used in livestock feed. The overall net impact on farm incomes is estimated to be an increase of about 0.3%.

Table 2.18
Estimated Impacts from Increased Use of Biodiesel

	Market scenario (percentage change from baseline)		
	Low	**Medium**	**High**
Soybean oil production	0.3	0.8	1.6
Soybean oil price	2.8	7.2	14.1
Soybean meal price	–0.7	–1.7	–3.3
Soybean price	0.4	1	2
Livestock price (“broilers”)	–0.3	–0.7	–1.4
US net farm income	0.1	0.2	0.3

Source:
International Energy Agency. 2004. *Biofuels for Transport: An International Perspective*, May, Page 96, Table 4.12.

BIO-OIL

BIO-OIL OVERVIEW

A totally different process than that used to produce biodiesel can be used to convert biomass into a renewable diesel fuel known as bio-oil. The process, called fast or flash pyrolysis, occurs by heating compact solid fuels in the absence of air at temperatures between 400 and 500 degrees Celsius for a very short period of time (less than 2 seconds) and then condensing the resulting vapors within 2 seconds. While there are several fast pyrolysis technologies under development, there are only two commercial fast pyrolysis technologies as of 2008. The bio-oils currently produced are suitable for use in boilers or in turbines designed to burn heavy oils for electricity generation. There is currently ongoing research and development to upgrade bio-oil into transportation fuels.

DynaMotive Energy Systems is commercializing a proprietary fast pyrolysis process that converts forest and agricultural residue into liquid bio-oil and char. The company is in the process of launching the first bio-oil cogeneration facility in West Lorne, Ontario, in collaboration with Erie Flooring and Wood Products Company. The flooring company provides the wood residue and DynaMotive's 2.5-megawatt plant uses its fast pyrolysis technology and a gas turbine to supply power to the wood product company's mills and lumber kilns. DynaMotive is now in the process of building a second 200 ton-per-day plant in Guelph, Ontario.

Ensyn Group Inc. has commercialized a fast pyrolysis technology under the name of Rapid Thermal Processing RTP[tm]. This technology is based on the biomass refining concept, where value added chemicals are produced in addition to a consistent quality bio-oil. Ensyn has four RTP[tm] facilities in commercial operation; a new facility and a bio-oil refining plant are currently under construction. Three of the commercial facilities are in Wisconsin and one is near Ottawa, Canada. The largest of these facilities, built in 1996, processes about 75 green tons per day of mixed hardwood wastes. Ensyn currently produces about 30 chemical products from RTP[tm] bio-oil with lower value remnant bio-oil used for boiler fuel. Ensyn is just beginning to enter the energy market.

Sources:
DynaMotive Energy Systems Corporation, http://www.dynamotive.com/ .
Ensyn Group Inc., http://www.ensyn.com/.

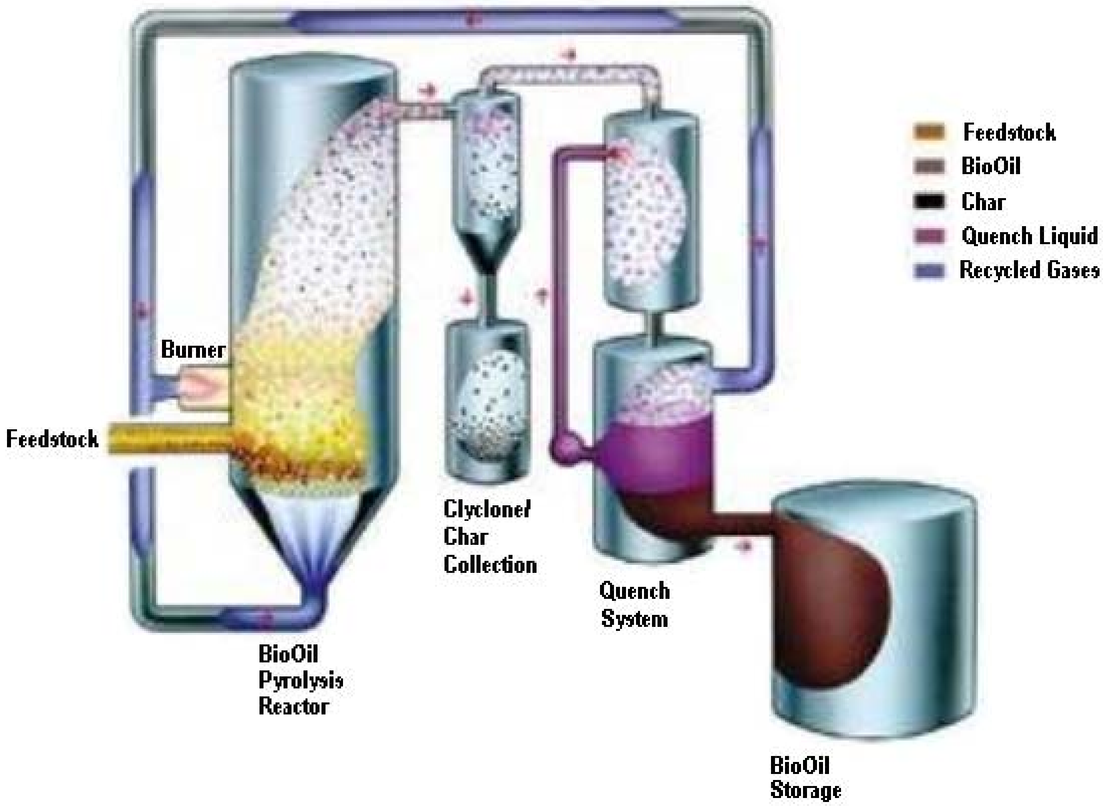
Table 2.19
Output Products by Method of Pyrolysis

Process	Liquid	Char	Gas
Fast Pyrolysis	75%	12%	13%
Carbonization	30%	35%	35%
Gasification	5%	10%	85%

Source: Czernik, Stefan. 2002. *Review of Fast Pyrolysis of Biomass*, National Renewable Energy Laboratory.

Bio-oil has many of the advantages of petroleum fuels since it can be stored, pumped and transported. It is currently being combusted directly in boilers, gas turbines, and slow and medium speed diesels for heat and power applications.

Figure 2.13
A Fast Pyrolysis Process for Making Bio-oil



Source: http://www.dynamotive.com/biooil/technology.html.

"Bio-oil is a dark brown, free flowing liquid comprised of highly oxygenated compounds. As a fuel, bio-oil is considered to be CO_2 neutral, and emits no SO_x and low NOx when combusted. Bio-oil density is high at 1.2 kgs/litre. Heating value on a weight basis is approximately 40 % to that of diesel. On a volume basis the heating value compared to diesel is approximately 55%." -DynaMotive.

Table 2.20
Bio-oil Characteristics

	Feedstock	
Bio-oil Characteristics	**Pine 53% Spruce 47% (including bark)**	**Bagasse**
pH	2.4	2.6
Water Content wt%	23.4	20.8
Methanol Insoluable Solids (Lignin content wt%)	24.9	23.5
Solids Content wt%	<0.10	<0.10
Ash Content wt%	<0.02	<0.02
Density kg/L	1.19	1.2
Low Heating MJ/kg	16.4	15.4
Kinematic Viscosity cSt @ 20^{o}C	40	50
Kinematic Viscosity cSt @ 80^{o}C	6	7

Source:
DynaMotive, http://www.dynamotive.com/biooil/whatisbiooil.html.

Note: wt% =percent by weight. The exact composition of bio-oil may vary depending on feedstock and processing. The table above is based on the fast pyrolysis method using the specific feedstock listed in the table. Other companies also produce bio-oil using other conversion processes and feedstocks and the resulting bio-oil properties can vary widely.

SO_x = Sulfur oxides.
NO_x = Nitrogen oxides.
CO_2 = Carbon dioxide.

"Bio-oil is miscible with alcohols such as ethanol and methanol but is immiscible with hydrocarbons. The following table lists the chemical composition of major bio-oil constituents." -DynaMotive.

Table 2.21
Bio-oil Composition

Concentrations wt%	**Feedstock:** Pine 53% Spruce 47% (including bark)	**Bagasse**
Water	23.4	20.8
Methanol Insoluable Solids & Lignin	24.9	23.5
Cellubiosan	1.9	-
Glyoxal	1.9	2.2
Hydroxyacetaldehyde	10.2	10.2
Levoglucosan	6.3	3.0
Formaldehyde	3.0	3.4
Formic Acid	3.7	5.7
Acetic Acid	4.2	6.6
Acetol	4.8	5.8

Source:
DynaMotive, http://www.dynamotive.com/biooil/whatisbiooil.html.

Note: wt% =percent by weight. The exact composition of bio-oil may vary depending on feedstock and processing. The table above is based on the fast pyrolysis method using the specific feedstock listed in the table. Other companies also produce bio-oil using other conversion processes and feedstocks and the resulting bio-oil properties can vary widely.

"Bio-oil fuels have unique characteristics that distinguish them from petroleum-based (hydro-carbon) products. The table below illustrates the primary differences between bio-oil and other fuels including light and heavy fuel oil." -DynaMotive

Table 2.22
Bio-oil Fuel Comparisons

	BioTherm® Bio-oil	Light Fuel Oil	Heavy Fuel Oil
Heat of combustion Btu/lb	7,100	18,200	17,600
Heat of combustion MJ/liter	19.5	36.9	39.4
Viscosity (centistokes) 50°C	7	4	50
Viscosity (centistokes) 80°C	4	2	41
Ash % by weight	<0.02	<0.01	0.03
Sulphur % by weight	Trace	0.15 to 0.5	0.5 to 3
Nitrogen % by weight	Trace	0	0.3
Pour Point °C	-33	-15	-18
Turbine NOx g/MJ	<0.7	1.4	N/A
Turbine SOx g/MJ	0	0.28	N/A

Source:
DynaMotive, http://www.dynamotive.com/biooil/whatisbiooil.html.

Notes: The exact characteristics of Bio-oil may vary depending on feedstock and processing. The table above is based on the fast pyrolysis method using feedstock composed of 53% pine and 47% spruce including bark. Other companies also produce bio-oil using other conversion processes and feedstocks and the resulting bio-oil properties can vary widely.

N/A = Not Available.

Table 2.23
Annotated Summary of Biofuel and Biomass Electric Incentives as of September 2008: Online Information Resources

Yacobucci B D. Biofuels Incentives: A Summary of Federal Programs - Updated July 29, 2008
http://assets.opencrs.com/rpts/RL33572_20080729.pdf

This 18 page document is easily readable and well-organized. It first describes Federal programs supporting research, development and deployment of biofuels and biomass electric, then has tables showing the legislative incentives that were updated by the Energy Independence and Security Act of 2007 (EISA 2007) and added by the 2008 Farm Bill - The Food, Conservation, and Energy Act of 2008.

U.S. Department of Agriculture. 2008 Farm Bill Side-By-Side. Title IX: Energy
http://www.ers.usda.gov/FarmBill/2008/Titles/TitleIXEnergy.htm

This is an extremely useful document providing brief descriptions of 2008 Farm Bill provisions and authorizations relevant to energy with comparisons to similar provisions in the previous farm bill where they existed. The document also links to energy provisions in other sections of the 2008 Farm Bill.

Energy Efficiency and Renewable Energy State Activities and Partnerships
http://apps1.eere.energy.gov/states/maps/renewable_portfolio_states.cfm
A Department of Energy site that contains a map linking to descriptions of state Renewable Portfolio Standards (RPS) as of June 2007 (created by DSIRE - Database of State Incentives for Renewables & Efficiency). The site also contains a list summarizing state RPS levels with links to the administrative offices.

DSIRE - Database for State Incentives for Renewables & Efficiency
http://www.dsireusa.org/

The DSIRE website , which is kept up-to date claims to be a comprehensive source of information on state, local, utility, and federal incentives that promote renewable energy and energy efficiency. The site contains many summary maps and tables that can be downloaded as PowerPoint files.

American Wind Energy Association
http://www.awea.org/pubs/factsheets/State_RPS_Fact_Sheet.pdf
This website contains a very nicely done 2-page fact sheet with one page containing a table that summarizes RPS requirements of 25 states and includes more detail than similar tables on other websites.

Renewable Fuels Association. Renewable Fuels Standard
http://www.ethanolrfa.org/resource/standard/
The Renewable Fuels Standard webpage on the Renewable Fuels Association site describes amendments to the 2005 Renewable Fuels Standard, and summarizes pertainent sections of EISA 2007.

Cantwell M. Comprehensive Guide to Federal Biofuel Incentives. 2006
http://cantwell.senate.gov/services/Biofuels/Comprehensive_Guide_to_Federal%20Biofuel_In
This 25 page document is a very comprehensive and easily readable guide to federal legislation resulting from EPACT 2005 (of which several incentives are still in effect). It also contains information on Federal agency program authorizations for supporting the research, development and deployment of biofuels, and biomass electric technologies. It is valuable for comparison with them more recent EISA 2007 bill and the 2008 Farm Bill.

These states have laws and incentives for alternative fuels production and/or use.

Table 2.24
Federal and State Alternative Fuel Incentives, 2007

State	Biodiesel	Ethanol	Natural gas	Liquefied petroleum gas (LPG)	Electric vehicles (EV and NEV)	Hydrogen fuel cells	Blends	Alternative fuel-all
Federal US	22	20	17	17	0	21	2	17
Alabama	0	0	2	1	0	0	0	0
Alaska	1	1	1	1	2	1	0	1
Arizona	4	3	9	10	9	7	0	5
Arkansas	6	4	5	5	3	4	3	3
California	18	17	25	19	28	20	1	16
Colorado	6	6	9	7	5	5	1	5
Connecticut	2	3	8	6	6	4	0	2
Delaware	4	2	3	3	2	2	0	2
Dist. of Columbia	3	3	4	3	3	3	0	3
Florida	7	8	3	3	4	7	0	3
Georgia	5	4	5	3	5	4	1	3
Hawaii	5	7	4	5	4	5	2	4
Idaho	4	4	2	2	1	1	4	0
Illinois	9	12	5	4	5	3	2	2
Indiana	9	9	4	2	3	2	13	2
Iowa	11	13	7	6	8	6	5	6
Kansas	5	7	4	4	4	2	1	2
Kentucky	4	3	4	2	1	1	2	1
Louisiana	5	4	5	3	4	2	0	2
Maine	7	8	6	6	6	5	1	5
Maryland	4	3	1	1	2	1	0	1
Massachusetts	1	1	3	1	1	1	0	1
Michigan	8	6	4	4	4	5	4	4
Minnesota	7	9	4	4	6	5	2	4
Mississippi	3	2	5	3	1	1	0	1
Missouri	7	6	5	4	5	4	4	3
Montana	7	8	4	4	3	3	2	2
Nebraska	4	4	4	4	2	2	1	2
Nevada	3	3	4	4	3	3	0	3
New Hampshire	3	1	1	1	2	1	0	1
New Jersey	5	5	7	6	6	5	1	4
New Mexico	11	8	8	6	7	8	2	6
New York	11	12	16	10	12	12	1	9
North Carolina	12	10	6	6	6	5	6	5
North Dakota	6	3	0	0	0	1	5	0
Ohio	2	2	1	1	1	2	0	3
Oklahoma	6	7	7	7	7	4	0	4
Oregon	8	8	6	5	8	5	3	5
Pennsylvania	5	5	5	2	3	2	0	3
Puerto Rico	0	0	0	0	0	0	0	0
Rhode Island	5	4	4	4	6	4	0	4
South Carolina	6	6	3	4	4	4	1	3
South Dakota	6	7	1	2	0	0	8	0
Tennessee	5	4	3	3	2	1	0	1
Texas	8	8	11	11	8	8	1	7
Utah	2	2	8	7	8	5	1	2
Vermont	4	3	3	2	3	2	1	3
Virginia	10	9	9	7	8	7	1	7
Washington	16	14	10	9	12	7	7	6
West Virginia	3	2	3	3	4	3	0	3
Wisconsin	12	9	8	7	8	8	0	7
Wyoming	0	2	1	0	0	0	1	0
Totals	327	311	287	244	245	224	90	188

Source:
U.S. Department of Energy, Energy Efficiency and Renewable Energy, Alternative Fuels Data Center. (Additional resources: www.eere.energy.gov/afdc/laws/incen_laws.html.)

Note: Because an incentive may apply to more than one alternative fuel, adding the totals for each row will result in counting one incentive multiple times.

3. BIOPOWER

BIOMASS POWER OVERVIEW

Biomass power technologies convert renewable biomass fuels to heat and electricity using processes similar to that used with fossil fuels. Next to hydropower, more electricity is generated from biomass than any other renewable energy resource in the United States. A key attribute of biomass is its availability upon demand - the energy is stored within the biomass until it is needed. Other forms of renewable energy are dependent on variable environmental conditions such as wind speed or sunlight intensity.

Today in parts of the developing world, biomass is primarily used to provide heat for cooking and comfort. Technologies have now been developed which can generate electricity from the energy in biomass fuels. Biomass technologies are highly scalable - small enough to be used on a farm or in remote villages, or large enough to provide power for a small city.

There are four primary classes of biopower systems: direct-fired, co-fired, gasification, and modular systems. Most of today's biopower plants are **direct-fired** systems that are similar to most fossil-fuel fired power plants. The biomass fuel is burned in a boiler to produce high-pressure steam. This steam is introduced into a steam turbine, where it flows over a series of aerodynamic turbine blades, causing the turbine to rotate. The turbine is connected to an electric generator, so as the steam flow causes the turbine to rotate, the electric generator turns and electricity is produced. Biomass power boilers are typically in the 20-50 MW range, compared to coal-fired plants in the 100-1500 MW range. The small capacity plants tend to be lower in efficiency because of economic trade-offs; efficiency-enhancing equipment cannot pay for itself in small plants. Although techniques exist to push biomass steam generation efficiency over 40%, actual plant efficiencies are often in the low 20% range.

Co-firing involves substituting biomass for a portion of coal in an existing power plant furnace. It is the most economic near-term option for introducing new biomass power generation. Because much of the existing power plant equipment can be used without major modifications, cofiring is far less expensive than building a new biopower plant. Compared to the coal it replaces, biomass reduces sulphur dioxide (SO_2), nitrogen oxides (NO_x), and other air emissions. After "tuning" the boiler for peak performance, there is little or no loss in efficiency from adding biomass. This allows the energy in biomass to be converted to electricity with the high efficiency (in the 33-37% range) of a modern coal-fired power plant.

Biomass gasifiers operate by heating biomass in an oxygen-limited environment where the solid biomass breaks down to form a flammable gas. The producer gas can be cleaned and filtered to remove problem chemical compounds. The producer gas can be used in more efficient power generation systems called combined-cycles, which combine gas turbines and steam turbines to produce electricity. The efficiency of these systems can reach 40 to 50 percent. Additionally, gasifiers are sometimes located next to existing coal or natural gas boilers and used to fire or supplement the fuels to these boilers.

Modular systems employ some of the same technologies mentioned above, but on a smaller scale that is more applicable to villages, farms, and small industry. These systems are now under development and could be most useful in remote areas where biomass is abundant and electricity is scarce. There are many opportunities for these systems in developing countries.

Source:
U.S. Department of Energy, Energy Efficiency and Renewable Energy,
    http://www1.eere.energy.gov/biomass/abcs_biopower.html.

Table 3.1
Biomass Power Technology in Commercial/Demonstration Phase during 2000-2006

Technology Category	Biomass Conversion Technology	Primary Energy Form Produced	Primary Energy Conversion and RecoveryTechnology	Final Energy Products
Direct combustion	Stove/Furnace	Heat	Heat exchanger	Hot air, hot water
Direct combustion	Pile burners	Heat, steam	Steam turbine	Electricity
Direct combustion	Stoker grate boilers	Heat, steam	Steam turbine	Electricity
Direct combustion	Suspension boilers: Air spreader stoker or cyclonic	Heat, steam	Steam turbine	Electricity
Direct combustion	Fluidized-bed combustor FB – bubbling CFB- circulating	Heat, steam	Steam turbine	Electricity
Direct combustion	Co-firing in coal-fired boilers (several types)	Heat, steam	Steam turbine	Electricity
Gasification (atmospheric)	updraft, counter current fixed bed	Low Btu producer gas	Combustion boiler + steam generator and turbine	Process heat or heat plus electricity
Gasification (atmospheric)	Downdraft, moving bed	Low Btu producer gas	Spark engine (internal combustion)	Power, electricity
Gasification (atmospheric)	Circulating Fluidized Bed (CFB) dual vessel	medium Btu producer gas	Burn gas in boiler w/ Steam Turbine	Electricity
Gasification (atmospheric)	Co-fueling in CFB gasifiers	Low or medium Btu producer gas	Combustion turbine or boiler and steam turbine	Electricity
Slow pyrolysis	Kilns or retorts	Charcoal	Stoves and furnaces	Heat
Fast (flash) pyrolysis	Reactors	Pyrolysis oil (bio-oil), charcoal	Combustion turbines, boilers, diesel engines, furnaces, catalytic reactors	Heat, electricity, synthetic liquid fuels, (BTL)
Anerobic digestion	Digesters, landfills	Biogas (medium Btu gas)	Spark ignition engines, combustion turbines,	Heat, electricity

Source:
Compiled by Lynn Wright, Oak Ridge, TN.

Note: See Glossary for definitions of terms found under the "Technology Category" column.

The following references are suggested for further reading:

Overend, Ralph. 2003. “Heat, Power and Combined Heat and Power,” Chapter 3 in: Sims, R. *Bioenergy Options for a Cleaner Environment: In Developed and Developing Countries*, Elsevier, ISBN: 0-08-044351-6, 193 pages.

Broek, R. van den, A. Faaij and van Wijk, J. 1995. *Biomass Combustion Power Generation Technologies*, Study performed within the framework of the extended JOULE-IIA programme of CECDGXII, project “Energy from Biomass: An Assessment of Two Promising Systems for Energy Production,” Department of Science, Technology and Society, Utrech University, Utrecht (Report no. 95029). Available at Web site: http://www.chem.uu.nl/nws/www/publica/95029.htm

Many biomass fuels cause slagging and other forms of deposit formation during combustion. These deposits can reduce heat transfer, reduce combustion efficiency, and damage combustion chambers when large particles break off. Research has focused on two alkali metals, potassium and sodium, and silica, all elements commonly found in living plants. In general, it appears that faster growing plants (or faster growing plant components such as seeds) tend to have higher concentrations of alkali metal and silica. Thus materials such as straw, nut hulls, fruit pits, weeds, and grasses tend to create more problems when burned than wood from a slow growing tree.

Potassium and sodium metals, whether in the form of oxides, hydroxides, or metallo-organic compounds tend to lower the melting point of ash mixtures containing various other minerals such as silica (SiO2). The high alkali content (up to 35%) in the ash from burning annual crop residues lowers the fusion or 'sticky temperature' of these ashes from 2200' F for wood ash to as low as 1300' F. This results in serious slagging on the boiler grate or in the bed and fouling of convection heat transfer surfaces. Even small percentages (10%) of some of these high alkali residues burned with wood in conventional boilers will cause serious slagging and fouling in a day or two, necessitating combustion system shutdown.

A method to predict slagging and fouling from combustion of biomass fuels has been adapted from the coal industry. The method involves calculating the weight in pounds of alkali (K20 + Na20) per million Btu in the fuel as follows:

$$\frac{1 \times 106}{Btu/lb} \quad X \quad \%\ Ash\ X\ \%\ Alkali\ of\ the\ Ash = \frac{lb\ Alkali}{MM\ Btu}$$

This method combines all the pertinent data into one Index Number. A value below 0.4lb/MM Btu is considered a fairly low slagging risk. Values between 0.4 and 0.8 lb/MM Btu will probably slag with increasing certainty of slagging as 0.8 lb/MM Btu is approached. Above 0.8 lb/MM Btu, the fuel is virtually certain to slag and foul.

Table 3.2
Alkali Content and Slagging Potential of Various Biofuels

			Total Alkali			
Fuel	**Btu/lb (dry)**	**Ash %**	**% in Ash**	**lb/ton**	**lb/MMBtu**	
WOOD						**Minimal Slagging**
Pine Chips	8,550	0.70%	3.00%	0.4	0.07	**.4 lb/MMBtu**
White Oak	8,165	0.40%	31.80%	2.3	0.14	
Hybrid Poplar	8,178	1.90%	19.80%	7.5	0.46	
Urban Wood Waste "Clean"	8,174	6.00%	6.20%	7.4	0.46	**Probable Slagging**
Tree Trimmings	8,144	3.60%	16.50%	11.9	0.73	
PITS, NUTS, SHELLS						
Almond Shells	7,580	3.50%	21.10%	14.8	0.97	**Certain Slagging**
Refuse Derived Fuel	5,473	9.50%	9.20%	17.5	1.60	
GRASSES						
Switch Grass	7,741	10.10%	15.10%	30.5	1.97	
Wheat Straw-average	7,978	5.10%	31.50%	32.1	2.00	
Wheat Straw-hi alkali	7,167	11.00%	36.40%	80.0	5.59	
Rice Straw	6,486	18.70%	13.30%	49.7	3.80	
Bagasse - washed	8,229	1.70%	12.30%	4.2	0.25	

Source:

Miles, Thomas R., Thomas R. Miles Jr., Larry L. Baxter, Bryan M. Jenkins and Laurance L. Oden. 1993. “Alkali Slagging Problems with Biomass Fuels,” *First Biomass Conference of the Americas: Energy, Environment, Agriculture, and Industry, Volume 1*.

REBURNING WITH WOOD FUELS FOR NO_X MITIGATION

Reburning is a combustion modification technology based on the principle that hydrocarbon fragments (CH) can react with Nitrogen Oxides (NO_x). Reburning is accomplished by secondary fuel injection downstream of the fuel-lean primary combustion zone or a furnace. The second stage or reburning zone is usually operated at an overall fuel-rich condition, allowing a significant fraction of the primary NO_x to be reduced to N2 and other nitrogenous species. In the third zone, additional air is introduced to establish overall fuel-lean conditions and allow for the burnout of remaining fuel fragments.

Reburning studies with coal and natural gas have shown NO_x emission reductions of 50-60% with about 15% of the heat input coming from the reburn fuel. In contrast, experimental results have shown NO_x reductions as high as 70% using approximately 10-15% wood heat input.

The stoichiometric ratio in the reburn zone was the single most important variable affecting NO_x reduction. The highest reductions were found at a reburn stoichiometric ratio of 0.85.

One additional benefit of using wood instead of natural gas for reburning—it is difficult to mix natural gas into the products of the primary combustion zone since the gas must be injected from the wall, at relatively low flows. Wood particles, which must be transported to the furnace by a carrier medium (likely candidates are air or flue gas), would have a ballistic effect upon entering the furnace that would enhance cross-stream mixing compared to natural gas.

Source:

Brouwer, J., N.S. Harding, M.P. Heap, J.S. Lighty and D.W. Pershing. 1997. *An Evaluation of Wood Reburning for NO_x Reduction from Stationary Sources*, final report to the DOE/TVA Southeastern Regional Biomass Energy Program, Muscle Shoals, Alabama, Contract No. TV-92271 (available at www.bioenergyupdate.com).

The following table shows EPA data for uncontrolled emissions from the combustion of different fuels. Note that wood compares favorably with the other fuels except for particulate emissions (PM). However, particulates are relatively easy to control and can be captured with cyclones and baghouses.

Table 3.3
Typical Uncontrolled Emission Factors for Steam Generator Fuels
(Nanograms/Joule and Pounds/Million Btu) Heat Input

	PM		NO_2		SO_2		CO		HC		Trace Metals[e]	
Fuel Type	NG/J	LB/MMbtu	NG/J	LB/MMbtu	NG/J	LB/MMbtu	NG/J	LB/MMbtu	NG/J	LB/MMbtu	NG/J	LB/MMbtu
Coal[a]	1,093	2.540	387	0.90	2450	5.700	13	0.030	2	0.005	4	0.009
Oil (residual)[b]	96	0.230	[d] 170	[d] 0.39	1,400	3.220	14	0.030	3	0.010	0.07	0.0002
Oil (distillate)[c]	6	0.010	[d] 100	[d] 0.23	220	0.510	16	0.040	3	0.010	-	-
Natural Gas	4	0.010	[d] 100	[d] 0.23	0.3	0.001	7	0.020	1	0.003	0	0
Wood	2,100	4.880	110	0.25	9	0.020	-	-	-	-	-	-
Solid Waste	1,400	3.220	130	0.31	210	0.490	-	-	-	-	-	-

Source:
Federal Register, Tuesday, June 19, 1984, p.25106, Vol. 49, No. 119.

[a] Based on high-sulfur (3.5 percent by weight), high-ash (10.6 percent by weight) coal burned in a spreader stoker coal-fired steam generating unit.
[b] Based on high-sulfur oil (3.0 percent by weight).
[c] Based on low-sulfur oil (0.5 percent by weight.
[d] Assumes no combustion air preheat.
[e] Based on lead to illustrate general level of trace metal emissions.

For the purpose of agricultural soil amendment, wood ash application is similar to lime application. Both materials can benefit crop productivity but wood ash has an added advantage of supplying additional nutrients. Both materials are also alkaline and could cause crop damage if over applied or misused.

Table 3.4
Range in Elemental Composition of Industrial Wood Ash Samples and Ground Limestone

Element	**Wood Ash**[a]	**Limestone**
Macroelements	**Concentration in %**	
Calcium	15 (2.5-33)	31
Potassium	2.6 (0.1-13)	0.13
Aluminum	1.6 (0.5-3.2)	0.25
Magnesium	1.0 (0.1-2.5)	5.1
Iron	0.84 (0.2-2.1)	0.29
Phosphorus	0.53 (0.1-1.4)	0.06
Manganese	0.41 (0-1.3)	0.05
Sodium	0.19 (0-0.54)	0.07
Nitrogen	0.15 (0.02-0.77)	0.01
Microelements	**Concentration in mg/kg**	
Arsenic	6 (3-10)	.
Boron	123 (14-290)	.
Cadmium	3 (0.2-26)	0.7
Chromium	57 (7-368)	6
Copper	70 (37-207)	10
Lead	65 (16-137)	55
Mercury	1.9 (0-5)	.
Molybdenum	19 (0-123)	.
Nickel	20 (0-63)	20
Selenium	0.9 (0-11)	.
Zinc	233 (35-1250)	113
Other Chemical Properties		
$CaCO_3$ Equivalent	43% (22-92%)	100%
pH	10.4 (9-13.5)	9.9
% Total solids	75 (31-100)	100

Source:
Risse, Mark and Glen Harris. “Soil Acidity and Liming Internet Inservice Training,” *Best Management Practices for Wood Ash Used as an Agricultural Soil Amendment*, http://hubcap.clemson.edu/~blpprt/bestwoodash.html.

[a] Mean and (Range) taken from analysis of 37 ash samples.

Table 3.5
Biomass Power Technology Fuel Specifications and Capacity Range

Biomass Conversion Technology	Commonly used fuel types[a]	Particle Size Requirements	Moisture Content Requirements (wet basis)[b]	Average capacity range / link to examples
Stove/Furnace	Solid wood, pressed logs, wood chips and pellets	Limited by stove size and opening	10 – 30%	15 kWt to ?
Pile burners	Virtually any kind of wood residues[c] or agricultural residues[d] except wood flour	Limited by grate size and feed opening	< 65%	4 to 110 MWe
Pile burner fed with underfire stoker (biomass fed by auger below bed)	Sawdust, non-stringy bark, shavings, chips, hog fuel	0.25-2 in (6-38 mm)	10-30%	4 to 110 MWe
Stoker grate boilers	Sawdust, non-stringy bark, shavings, end cuts, chips, chip rejects, hog fuel	0.25 – 2 in (6 -50 mm)	10-50% (keep within 10% of design rate)	20 to 300 MWe many in 20 to 50 MWe range
Suspension boilers Cyclonic	Sawdust. Non-stringy bark, shavings, flour, sander dust	0.25 in (6 mm) max	< 15%	many < 30 MWe
Suspension boilers, Air spreader-stoker	Wood flour, sander dust, and processed sawdust, shavings	0.04 in -0.06 in (1-1.6 mm)	< 20%	1.5 MWe to 30 MWe
Fluidized-bed combustor (FB- bubbling or CFB-circulating)	Low alkali content fuels, mostly wood residues or peat no flour or stringy materials	< 2 in (<50 mm)	< 60%	Many at 20 to 25 MWe, up to 300 Example 1 Example 2
Co-firing: pulverized coal boiler	Sawdust, non-stringy bark, shavings, flour, sander dust	<0.25 in (<6 mm)	< 25%	Up to 1500 MWe[e] Example
Co-firing: cyclones	Sawdust, non-stringy bark, shavings, flour, sander dust	<0.5 in (<12 mm)	10 – 50%	40 to 1150 MWe[e] Example
Co-firing: stokers, fluidized bed	Sawdust, non-stringy bark, shavings, flour, hog fuel	< 3 in (<72 mm)	10 – 50%	MWe[e] Example
Counter current, fixed bed (updraft) atmospheric	Chipped wood or hog fuel, rice hulls, dried sewage sludge	0.25 – 4 in (6 – 100 mm)	< 20%	5 to 90 MWt, + up to 12 MWe Example
Downdraft, moving bed atmospheric gasifier	Wood chips, pellets, wood scrapes, nut shells	< 2 in (<50 mm)	<15%	~ 25-100 kWe Example
Circulating fluidized bed (CFB), dual vessel, gasifier	Most wood and chipped agricultural residues but no flour or stringy materials	0.25 – 2 in (6 -50 mm)	15-50%	~ 5 to 10 MWe Example
Fast pyrolysis	Variety of wood and agricultural resources	0.04-0.25 in (1-6 mm)	< 10%	~ 2.5 MWe Example 1 Example 2
Anerobic digesters	Animal manures & bedding, food processing residues, brewery by-products, other industry organic residues	NA	65 to 99.9% liquid depending on type, i.e., 0.1 to 35% solids	145 to 1700 x 103 kWhr/yr Example 1 Example 2

Source:
Compiled by Lynn Wright, Oak Ridge, TN.

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[a] Primary source for fuel types is: Badger, Phillip C. 2002, *Processing Cost Analysis for Biomass Feedstocks*, ORNL/TM-2002/199. Available at http://bioenergy.ornl.gov/main.aspx (search by title or author)

[b] Most primary biomass, as harvested, has a moisture content (MC) of 50 to 60% (by wet weight) while secondary or tertiary sources of biomass may be delivered at between 10 and 30%. A lower MC always improves efficiency and some technologies require low MC biomass to operate properly while others can handle a range of MC.

[c] Wood residues may include forest logging residues and storm damaged trees (hog fuel), primary mill residues (e.g., chipped bark and chip rejects), secondary mill residues (e.g., dry sawdust), urban wood residues such as construction and demolition debris, pallets and packaging materials, tree trimmings, urban land clearing debris, and other wood residue components of municipal solid waste (as wood chips).

[d] Agricultural residues may include straws and dried grasses, nut hulls, orchard trimmings, fruit pits, etc. Slagging may be more of a problem in some types of combustion units with high alkali straws and grasses, unless the boilers have been specially designed to handle these type fuels.

[e] The biomass component of a co-firing facility will usually be less than the equivalent of 50MWe.

There are three distinct markets for green power in the United States. In regulated markets, a single utility may provide a green power option to its customers through "green pricing," which is an optional service or tariff offered to customers. These utilities include investor-owned utilities, rural electric cooperatives, and other publicly-owned utilities. More than 500 utilities in 34 states offer green pricing or are in the process of preparing programs.

In restructured (or competitive) electricity markets, retail electricity customers can choose from among multiple electricity suppliers, some of which may offer green power. Electricity markets are now open to full competition in a number of states, while others are phasing in competition.

Finally, consumers can purchase green power through "renewable energy certificates." These certificates represent the environmental attributes of renewable energy generation and can be sold to customers in either type of market, whether or not they already have access to a green power product from their existing retail power provider.

Utility market research shows that a majority of customer respondents is likely to state that they would pay at least $5 more per month for renewable energy. And business and other nonresidential customers, including colleges and universities, and government entities, are increasingly interested in green power.

Table 3.6
New Renewable Capacity Supplying Green Power Markets, 2004

Source	MW in Place	Percent	MW Planned	Percent
Wind	2,045.6	91.6	364.5	80.1
Biomass	**135.6**	**6.1**	**58.8**	**12.9**
Solar	8.1	0.4	0.4	0.1
Geothermal	35.5	1.6	0.0	0.0
Small Hydro	8.5	0.4	31.3	6.9
Total	**2,233.3**	**100.0**	**455.0**	**100.0**

Source:
National Renewable Energy Laboratory. *Power Technologies Energy Data Book*, Chapter 3, Table 3.6.5, http://www.nrel.gov/analysis/power_databook/chapter3.html.

Note: MW=megawatt.

Green pricing is an optional utility service that allows customers an opportunity to support a greater level of utility company investment in renewable energy technologies. Participating customers pay a premium on their electric bill to cover the extra cost of the renewable energy. Many utilities are offering green pricing to build customer loyalty and expand business lines and expertise prior to electric market competition. As of 2003, 36 utilities in 19 states had implemented green pricing options that used or included biomass feedstocks.

Table 3.7
New Renewable Capacity Supported through Utility Green Pricing Programs, 2004

Source	MW in Place	Percent	MW Planned	Percent
Wind	584.0	82.8	139.7	61.1
Biomass	76.3	10.8	57.5	25.1
Solar	6.1	0.9	0.2	0.1
Geothermal	30.5	4.3	0.0	0.0
Small Hydro	8.5	1.2	31.3	13.7
Total	**705.5**	**100.0**	**228.7**	**100.0**

Source:
National Renewable Energy Laboratory, *Power Technology Energy Data Book*, Table 3.7.1, http://www.nrel.gov/analysis/power_databook/chapter3.html.

Note: MW=megawatt.

There are a growing number of utilities offering green pricing programs that utilize biomass resources.

Table 3.8
Utility Green Pricing Programs Using Biomass and Biomass Based Resources
(Updated September 2007)

State	Utility Name	Program Name	Type	Start Date	Premium
AL	Alabama Electric Cooperative: City of Andalusia, Baldwin Electric Membership Cooperative, City of Brundidge, Central Alabama Electric Cooperative, Clarke-Washington Electric Membership Cooperative, Coosa Valley Electric Cooperative, Covington Electric Cooperative, Dixie Electric Cooperative, City of Elba, City of Opp, Pea River Electric Cooperative, Pioneer Electric Cooperative, South Alabama Electric Cooperative, Southern Pine Electric Cooperative, Tallapoosa River Electric Cooperative, Wiregrass	Green Power Choice	landfill gas	2006	2.0¢/kWh
AL	Alabama Power Company	Renewable Energy Rate	biomass co-firing (wood)	2003/2000	4.5¢/kWh
AL	TVA: Cherokee Electric Coop, City of Athens Electric Department, Cullman Electric Coop, Cullman Power Board, Decatur Utilities, Florence Utilities, Guntersville Electric Board, Hartselle Utilities, Huntsville Utilities, Joe Wheeler EMC, Marshall-DeKalb Electric Coop, Muscle Shoals Electric Board, North Alabama Electric Coop, Sand Mountain Electric Coop, Scottsboro Electric Power Board, Sheffield Utilities, Tuscumbia Electric Department	Green Power Switch	landfill gas, PV, wind	2000	2.67¢/kWh
AZ	Salt River Project	EarthWise Energy	central PV, wind, landfill gas, small hydro, geothermal	1998/2001	3.0¢/kWh
AZ	Tucson Electric	GreenWatts	landfill gas, PV	2000	10¢/kWh
CA	Anaheim Public Utilities	Green Power for the Grid	wind, landfill gas	2002	1.5¢/kWh
CA	Los Angeles Department of Water and Power	Green Power for a Green LA	wind, landfill gas	1999	3.0¢/kWh
CA	Sacramento Municipal Utility District	Greenergy	wind, landfill gas, hydro, PV	1997	1.0¢/kWh or $6/month
DE	Delaware Electric Cooperative	Renewable Energy Rider	landfill gas	2006	0.2¢/kWh
FL	Alabama Electric Cooperative: CHELCO, Escambia River Electric Cooperative, Gulf Coast Electric Cooperative, West Florida Electric Cooperative	Green Power Choice	landfill gas	2006	2.0¢/kWh
FL	City of Tallahassee/Sterling Planet	Green for You	biomass, PV	2002	1.6¢/kWh
FL	Florida Power & Light / Green Mountain Energy	Sunshine Energy	biomass, wind, PV	2004	0.975¢/kWh
FL	Gainesville Regional Utilities	GRUgreen Energy	landfill gas, wind, PV	2003	2.0¢/kWh
FL	Keys Energy Services / Sterling Planet	GO GREEN: USA Green	wind, biomass,PV	2004	1.60¢/kWh
FL	Keys Energy Services / Sterling Planet	GO GREEN: Florida Ever Green	solar hot water, PV, biomass	2004	2.75¢/kWh
FL	Tampa Electric Company (TECO)	Renewable Energy Program	PV, landfill, biomass co-firing (wood)	2000	2.5¢/kWh

Continued on next page

Table 3.8 (Continued)
Utility Green Pricing Programs Using Biomass and Biomass Based Resources
(Updated September 2007)

State	Utility Name	Program Name	Type	Start Date	Premium
GA	Georgia Electric Membership Corporation (35 of 42 coops offer program): Altamaha EMC, Amicalola EMC, Canoochee EMC, Carroll EMC, Central Georgia EMC, Cobb EMC, Coastal Electric, Colquitt EMC, Coweta-Fayette EMC, Diverse Power, Flint Energies, Grady EMC, GreyStone Power, Habersham EMC, Hart EMC, Irwin EMC, Jackson EMC, Jefferson Energy, Little Ocmulgee EMC, Middle Georgia EMC, Mitchell EMC, Ocmulgee EMC, Oconee EMC, Planters EMC, Rayle EMC, Sawnee EMC, Slash Pine EMC, Snapping Shoals EMC, Southern Rivers Energy, Sumter EMC, Three Notch EMC, Tri-County EMC, Upson EMC, Walton EMC, Washington EMC	Green Power EMC	landfill gas, PV in schools	2001	2.0¢/kWh-3.3¢/kWh
GA	Georgia Power	Green Energy	landfill gas, solar	2006	4.5¢/kWh
GA	TVA: Blue Ridge Mountain EMC, North Georgia EMC, Tri-State EMC	Green Power Switch	landfill gas, PV, wind	2000	2.67¢/kWh
IL	City of St. Charles/ComEd and Community Energy, Inc.	TBD	wind, landfill gas	2003	Contribution
IL	Dairyland Power Cooperative: Jo-Carroll Energy/Elizabeth	Evergreen Renewable Energy Program	landfill gas, biogas, hydro, wind	1997	1.5¢/kWh
IN	Duke Energy	GoGreen Power	wind, PV, landfill gas, digester gas	2001	2.5¢/kWh
IN	Hoosier Energy (5 of 17 coops offer program): Southeastern Indiana REMC, South Central Indiana REMC, Utilities District of Western Indiana REMC, Decatur County REMC, Daviess-Martin County REMC	EnviroWatts	landfill gas	2001	2.0¢/kWh-4.0¢/kWh
IN	Wabash Valley Power Association (7 of 27 coops offer program): Boone REMC, Hendricks Power Cooperative, Kankakee Valley REMC, Miami-Cass REMC, Tipmont	EnviroWatts	landfill gas	2000	0.9¢/kWh-1.0¢/kWh
IA	Alliant Energy	Second Nature	landfill gas, wind	2001	2.0¢/kWh
IA	Associated Electric Cooperative, Inc.: Access Energy Cooperative, Chariton Valley Electric Cooperative, Southern Iowa Electric Cooperative	varies by utility	biomass, wind	2003	2.0¢/kWh-3.5¢/kWh
IA	Dairyland Power Cooperative: Allamakee-Clayton/Postville, Hawkeye Tri-County/Cresco, Heartland Power/Thompson & St. Ansgar	Evergreen Renewable Energy Program	hydro, wind, landfill gas, biogas	1998	3.0¢/kWh
IA	Farmers Electric Cooperative	Green Power Project	biodiesel, wind	2004	Contribution
IA	Iowa Association of Municipal Utilities (84 of 137 munis offer program) Afton, Algona, Alta Vista, Aplington, Auburn, Bancroft, Bellevue, Bloomfield, Breda, Brooklyn, Buffalo, Burt, Callender, Carlisle, Cascade, Coggon, Coon Rapids, Corning, Corwith, Danville, Dayton, Durant, Dysart, Earlville, Eldridge, Ellsworth, Estherville, Fairbank, Farnhamville, Fontanelle, Forest City, Gowrie, Grafton, Grand Junction, Greenfield, Grundy Center, Guttenberg, Hopkinton, Hudson, Independence, Keosauqua, La Porte City, Lake Mills, Lake View, Laurens, Lenox, Livermore, Maquoketa, Marathon, McGregor, Milford, Montezuma, Mount Pleasant, Neola, New Hampton, Ogden, Orient, Osage, Panora, Pella, Pocahontas, Preston, Readlyn, Rockford, Sabula, Sergeant Bluff, Sibley, Spencer, Stanhope, State Center, Stratford, Strawberry Point, Stuart, Tipton, Villisca, Vinton, Webster City, West Bend, West Liberty, West Point, Westfield, Whittemore, Wilton, Winterset	Green City Energy	wind, biomass, PV	2003	Varies by uti lity

Continued on next page

Table 3.8 (Continued)
Utility Green Pricing Programs Using Biomass and Biomass Based Resources
(Updated September 2007)

State	Utility Name	Program Name	Type	Start Date	Premium
KY	East Kentucky Power Cooperative: Blue Grass Energy, Clark, Cumberland, Fleming-Mason, Grayson, Inter-County Energy, Jackson, Licking Valley, Nolin, Owen Electric, Salt River, Shelby, South Kentucky	EnviroWatts	landfill gas	2002	2.75¢/kWh
KY	TVA: Bowling Green Municipal Utilities, Franklin Electric Plant Board, Hopkinsville Electric System, Murray Electric System, Pennyrile Rural Electric Coop, Tri-County Electric, Warren Rural Electric Coop	Green Power Switch	landfill gas, PV, wind	2000	2.67¢/kWh
LA	Entergy Gulf States	Green Pricing	biomass	2007	2.5¢/kWh
MI	Consumers Energy	Green Generation	68% wind, 32% landfill gas	2005	1.67¢/kWh
MI	DTE Energy	GreenCurrents	wind, biomass	2007	2.0¢/kWh-2.5¢/kWh
MI	Lansing Board of Water and Light	GreenWise Electric Power	landfill gas, small hydro	2001	3.0¢/kWh
MI	Upper Peninsula Power Company	NatureWise	wind, landfill gas and animal waste methane	2004	4.0¢/kWh
MI	We Energies	Energy for Tomorrow	wind, landfill gas, hydro	2000	2.04¢/kWh
MN	Alliant Energy	Second Nature	landfill gas, wind	2002	2.0¢/kWh
MN	Central Minnesota Municipal Power Agency: Blue Earth, Delano, Glencoe, Granite Falls, Janesville, Kenyon,	Green Energy Program	wind, landfill gas	2000	1.5¢/kWh-2.5¢/kWh
MN	Dairyland Power Cooperative: Freeborn-Mower Cooperative / Albert Lea, People's / Rochester, Tri-	Evergreen Renewable Energy	hydro, wind, landfill gas, biogas	1998	1.5¢/kWh
MS	TVA: 4-County Electric Power Association, Alcorn Electric Power Association, Central Electric Power	Green Power Switch	landfill gas, PV, wind	2000	2.67¢/kWh
MO	Associated Electric Cooperative, Inc.: Black River Electric Cooperative, Boone Electric Cooperative,	varies by utility	biomass, wind	2003	2.0¢/kWh-3.5¢/kWh
NE	Omaha Public Power District	Green Power Program	landfill gas, wind	2002	3.0¢/kWh
NC	Dominion North Carolina Power	NC GreenPower	biomass, hydro, landfill gas, PV, wind	2003	2.5¢/kWh-4.0¢/kWh
NC	Duke Energy	NC GreenPower	biomass, hydro, landfill gas, PV, wind	2003	2.5¢/kWh-4.0¢/kWh
NC	ElectriCities: Town of Apex, Town of Cornelius, Fayetteville PWC, Town of Granite Falls, Greenville Utilities, City of High Point, City of Kinston, City of Laurinburg, City of Lexington, City of Monroe, City of New Bern, City of Newton, City of Shelby, City of	NC GreenPower	biomass, hydro, landfill gas, PV, wind	2003	2.5¢/kWh-4.0¢/kWh
NC	NC Electric Cooperatives (21 of 27 coops offer program): Albemarle Electric Membership Corp., Blue Ridge Electric Membership Corp., Brunswick Electric Membership Corp., Carteret Craven Electric Coop., Central Electric Membership Corp., Edgecombe-Martin County Electric Membership Corp., EnergyUnited, Four County Electric Membership Corp., French Broad Electric Membership Corp., Haywood Electric Membership Corp., Jones-Onslow Electric Membership Corp., Lumbee River Electric Membership Corp., Pee Dee Electric Membership Corp., Piedmont Electric Membership Corp., Randolph Electric Membership Corp., Roanoke Electric Membership Corp., Rutherford	NC GreenPower	biomass, hydro, landfill gas, PV, wind	2003	2.5¢/kWh-4.0¢/kWh
NC	Progress Energy / CP&L	NC GreenPower	biomass, hydro, landfill gas, PV, wind	2003	2.5¢/kWh-4.0¢/kWh
NC	TVA: Mountain Electric Cooperative	Green Power Switch	landfill gas, PV, wind	2000	2.67¢/kWh

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Table 3.8 (Continued)
Utility Green Pricing Programs Using Biomass and Biomass Based Resources
(Updated September 2007)

State	Utility Name	Program Name	Type	Start Date	Premium
OH	AEP Ohio	Green Pricing Option	landfill gas	2007	0.7¢/kWh
OH	American Municipal Power-Ohio / Green Mountain Energy: City of Bowling Green, Cuyahoga Falls, Westerville, Wyandotte, Yellow Springs	Nature's Energy	small hydro, landfill gas, wind	2003	1.3¢/kWh-1.5¢/kWh
OH	Buckeye Power	EnviroWatts	landfill gas	2006	2.0¢/kWh
OH	Duke Energy	GoGreen Power	wind, PV, landfill gas, digester gas	2001	2.5¢/kWh
OK	Associated Electric Cooperative, Inc.: Central Rural Electric Cooperative	varies by utility	biomass, wind	2003	2.0¢/kWh-3.5¢/kWh
OR	Pacific Northwest Generating Cooperative: Blachly-Lane Electric Cooperative, Central Electric Cooperative, Clearwater Power, Consumers Power, Coos-Curry Electric Cooperative, Douglas Electric Cooperative, Fall River Rural Electric Cooperative, Lost River Electric Cooperative, Raft River Rural Electric Cooperative, Umatilla Electric Cooperative, West Oregon Electric Cooperative, (11 of 15 coops offer program)	Green Power	landfill gas	1998	1.8¢/kWh-2.0¢/kWh
OR	PacifiCorp: Pacific Power / 3Degrees	Blue Sky Habitat	wind, biomass, PV	2002	0.78¢/kWh + $2.50/mo.
OR	PacifiCorp: Pacific Power / 3Degrees	Blue Sky Usage	wind, biomass, PV	2002	0.78¢/kWh
SC	Duke Energy Carolinas	Palmetto Clean Energy (PaCE)	wind, solar, landfill gas	2008	4.0¢s;/kWh
SC	Progress Energy Carolinas	Palmetto Clean Energy (PaCE)	wind, solar, landfill gas	2008	4.0¢/kWh
SC	Santee Cooper: Aiken Electric Cooperative, Berkeley Electric Cooperative, Blue Ridge Electric, Coastal Electric Cooperative, Edisto Electric Cooperative, Fairfield Electric Cooperative, Horry Electric Cooperative, Laurens Electric Cooperative, Lynches River Electric Cooperative, Marlboro Electric Cooperative, Mid-Carolina Electric Cooperative, Palmetto Electric Cooperative, Pee Dee Electric Cooperative, Santee Electric Cooperative, Tri-County Electric Cooperative, York Electric Cooperative	Green Power Program	landfill gas	2001	3.0¢/kWh
SC	SCE&G	Palmetto Clean Ener gy (PaCE)	wind, solar, landfill gas	2008	4.0¢/kWh
TN	TVA: Alcoa Electric Department, Appalachian Electric Cooperative, Athens Utility Board, Bristol Tennessee Electric System, Brownsville Utility Department, Caney Fork Electric Cooperative, Chickasaw Electric Cooperative, Clarksville Department of Electricity, Cleveland Utilities, Clinton Utilities Board, Cookeville Electric Department, Covington Electric System, Cumberland Electric Membership Corporation, Dickson Electric Department, Duck River Electric Membership Corporation, Dyersberg Electric System, City of Elizabethton Electric System, EPB (Chattanooga), Erwin Utilities, Etowah Utilities, Fayetteville Public Utilities, Fort Loudon Electric Cooperative, Gallatin Department of Electricity, Gibson Electric Membership Corporation, Greeneville Light and Power System, Harriman Utility Board, Holston Electric Cooperative, Johnson City Power Board, Jackson Energy Authority, Knoxville Utilities Board, Lafollette Utilities Board, Lawrenceburg Power System, Lenoir City Utilities Board, Lexington Electric System, Loudon Utilities, City of Maryville Electric Department, McMinnville Electric System, Memph	Green Power Switch	landfill gas, PV, wind	2000	2.67¢/kWh

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Table 3.8 (Continued)
Utility Green Pricing Programs Using Biomass and Biomass Based Resources
(Updated September 2007)

State	Utility Name	Program Name	Type	Start Date	Premium
TX	Austin Energy (City of Austin)	GreenChoice	wind, landfill gas	2000/1997	1.85¢/kWh
VT	Central Vermont Public Service	CVPS Cow Power	biogas	2004	4.0¢/kWh
VT	Green Mountain Power	CoolHome / CoolBusiness	wind, biomass	2002	Contribution
WA	Benton County Public Utility District	Green Power Program	landfill gas, wind, hydro	1999	Contribution
WA	Clallam County PUD	Clallam County PUD Green Power Program	landfill gas	2001	0.69¢/kWh
WA	Pacific County PUD	Green Power	landfill gas	2002	1.05¢/kWh
WA	Peninsula Light	Green by Choice	wind, hydro, biogas	2002	2.0¢/kWh
WA	Puget Sound Energy	Green Power Program	wind, PV, biogas	2002	1.25¢/kWh
WA	Seattle City Light	Seattle Green Power	PV, biogas	2002	Contribution
WV	AEP Ohio	Green Pricing Option	landfill gas	2007	0.7¢/kWh
WI	Alliant Energy	Second Nature	wind, landfill gas	2000	2.0¢/kWh
WI	Dairyland Power Cooperative: Barron Electric, Bayfield/ Iron River, Chippewa / Cornell Valley, Clark / Greenwood, Dunn / Menomonie, Eau Claire / Fall Creek, Jackson / Black River Falls, Jump River / Ladysmith, Oakdale, Pierce-Pepin / Ellsworth, Polk-Burnett / Centuria, Price / Phillips, Richland, Riverland / Arcadia, St. Croix / Baldwin, Scenic Rivers / Lancaster, Taylor / Medford, Vernon / Westby	Evergreen Renewable Energy Program	hydro, wind, landfill gas, biogas	1998	1.5¢/kWh
WI	We Energies	Energy for Tomorrow	landfill gas, PV, hydro, wind	1996	1.37¢/kWh
WI	Wisconsin Public Power Inc. (34 of 37 munis offer program): Algoma, Cedarburg, Florence, Kaukauna, Muscoda, Stoughton, Reedsburg, Oconomowoc, Waterloo, Whitehall, Columbus, Hartford, Lake Mills, New Holstein, Richland Center, Boscobel, Cuba City, Hustisford, Sturgeon Bay, Waunakee, Lodi, New London, Plymouth, River Falls, Sun Prairie, Waupun, Eagle River, Jefferson, Menasha, New Richmond, Prairie du Sac, Slinger, Two Rivers, Westby	Renewable Energy Program	small hydro, wind, biogas	2001	1.0¢/kWh
WI	Wisconsin Public Service	NatureWise	wind, landfill gas, biogas	2002	1.86¢/kWh

Source:
National Renewable Energy Laboratory, Golden, Colorado,
http://apps3.eere.energy.gov/greenpower/markets/pricing.shtml?page=1 .

Notes: Utility green pricing programs may only be available to customers located in the utility's service territory.

A growing number of states have companies that offer a range of green power products that allow consumers to purchase electricity generated in part or entirely from biomass resources.

Table 3.9
Competitive Electricity Markets Retail Green Power Product Offerings, October 2005

State	Company	Product Name	Residential Price Premium[a]	Fee	Resource Mix[b]	Certification
Connecticut	Community Energy (CT Clean Energy Options Program)	CT Clean Energy Options 50% or 100% of usage	1.1¢/kWh	—	50% new wind, 50% landfill gas	—
	Levco	100% Renewable Electricity Program	0.0¢/kWh	—	98% waste-to-energy and hydro (Class II), 2% new solar, wind, fuel cells, and landfill gas	—
	Sterling Planet (CT Clean Energy Options Program)	Sterling Select 50% or 100% of usage	1.15¢/kWh	—	33% new wind, 33% existing small low impact hydro, 34% new landfill gas	—
District of Columbia	PEPCO Energy Services[c]	Green Electricity 10%, 51% or 100% of usage	1.35¢/kWh (for 100% usage)	—	landfill gas	—
Maryland	PEPCO Energy Services[d]	Green Electricity 10%, 51% or 100% of usage	2.75¢/kWh (for 100% usage)	—	landfill gas	—
	PEPCO Energy Services[d]	Non-residential product	NA	—	50% to 100% eligible renewables	Green-e
Massachusetts	Cape Light Compact[e]	Cape Light Compact Green 50% or 100%	1.768¢/kWh (for 100% usage)	—	75% small hydro, 24% new wind or landfill gas, 1% new solar	—
	Massachusetts Electric/Nantucket Electric/Mass Energy Consumers Alliance	New England GreenStart 50% or 100% of usage	2.4¢/kWh (for 100% usage)	—	75% small hydro, 19% biomass, 5% wind, 1% solar (≥25% of total is new)	—
	Massachusetts Electric/Nantucket Electric/Sterling Planet	Sterling Premium 50% or 100% of usage	1.35¢/kWh	—	50% small hydro, 30% bioenergy, 15% wind, 5% new solar	Environmental Resources Trust
New Jersey	Green Mountain Energy Company[f]	Enviro Blend	1.0¢/kWh	$3.95/mo.	5% new wind, 0.4% solar, 44.6% captured methane, 50% large hydro	—
	PSE&G/JCP&L/ Sterling Planet	Clean Power Choice Program	1.2¢/kWh	—	33% wind, 33% small hydro, 34% bioenergy	Environmental Resources Trust
New York	Energy Cooperative of New York[g]	Renewable Electricity	0.5¢/kWh to 0.75¢/kWh	—	25% new wind, 75% existing landfill gas	—
	Long Island Power Authority / EnviroGen	Green Power Program	1.0¢/kWh	—	75% landfill gas, 25% small hydro	—
	Long Island Power Authority / Sterling Planet	New York Clean	1.0¢/kWh	—	55% small hydro, 35% bioenergy, 10% wind	—
	Long Island Power Authority / Sterling Planet	Sterling Green	1.5¢/kWh	—	40% wind, 30% small hydro, 30% bioenergy	—
	Niagara Mohawk / EnviroGen	Think Green!	1.0¢/kWh	—	75% landfill gas, 25% hydro	—
	Niagara Mohawk / Sterling Planet	Sterling Green	1.5¢/kWh	—	40% wind, 30% small hydro, 30% bioenergy	Environmental Resources Trust
	Suburban Energy Services /Sterling Planet	Sterling Green Renewable Electricity	1.5¢/kWh	—	40% new wind, 30% small hydro, 30% bioenergy	—

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Table 3.9 (Continued)
Competitive Electricity Markets Retail Green Power Product Offerings, October 2005

Pennsylvania						
	Energy Cooperative of Pennsylvania[h]	EcoChoice 100	2.78¢/kWh	—	89% landfill gas, 10% wind, 1% solar	Green-e
	PEPCO Energy Services[h]	Green Electricity 10%, 51% or 100% of usage	3.7¢/kWh (for 100% usage)	—	100% renewable	—
Rhode Island						
	Narragansett Electric / Sterling Planet	Sterling Supreme 100%	1.98¢/kWh	—	40% small hydro, 25% biomass, 25% new solar, 10% wind	Environmental Resources Trust
TX						
	Gexa Energy[i]	Gexa Green	-1.1¢/kWh	—	100% renewable	—
VA						
	PEPCO Energy Services[j]	Green Electricity 10%, 51% or 100% of usage	4.53¢/kWh (for 100% usage)	—	landfill gas	—

Source:
National Renewable Energy Laboratory. *Power Technologies Energy Data Book*, Table 3.8.8, http://www.nrel.gov/analysis/power_databook/chapter3.html.

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[a] Prices updated as of July 2005 and may also apply to small commercial customers. Prices may differ for large commercial/industrial customers and may vary by service territory.

[b] New is defined as operating or repowered after January 1, 1999 based on the Green-e TRC certification standards.

[c] Offered in PEPCO service territory. Product prices are for renewal customers based on annual average costs for customers in PEPCO's service territory (6.8¢/kWh).

[d] Product offered in Baltimore Gas and Electric and PEPCO service territories. Price is for PEPCO service territory based on price to compare of 6.55¢/kWh.

[e] Price premium is based on a comparison to the Cape Light Compact's standard electricity product.

[f] Green Mountain Energy offers products in Conectiv, JCPL, and PSE&G service territories. Product prices are for PSE&G (price to compare of 6.503¢/kWh).

[g] Price premium is for Niagara Mohawk service territory. Program only available in Niagara Mohawk service territory. Premium varies depending on energy taxes and usage.

[h] Product prices are for PECO service territory (price to compare of 6.21¢/kWh).

[i] Product prices are based on price to beat of 12.1¢/kWh for TXU service territory (specifically Dallas, Texas) (Except where noted). Except for Gexa Green, which is listed in price per kWh, prices based on 1000 kwh of usage monthly, and include monthly fees.

[j] Products are available in Dominion Virginia Power service territory.

Renewable energy certificates (RECs)—also known as green tags, renewable energy credits, or tradable renewable certificates—represent the environmental attributes of power generated from renewable electric plants. A number of organizations offer green energy certificates separate from electricity service (i.e., customers do not need to switch from their current electricity supplier to purchase these certificates). Organizations that offer green certificate products using biomass resources are listed below.

Table 3.10
Renewable Energy Certificate Product Offerings, October 2005

Certificate Marketer	Product Name	Renewable Resources	Location of Renewable Resources	Residential Price Premium	Certification
Blue Sky Energy Corp	Greener Choice™ Green Tags	Landfill Gas	Utah	1.95¢/kWh	—
Bonneville Environmental Foundation	Green Tags	≥98% new wind, ≤ 1% new solar, ≤ 1% new biomass	Washington, Oregon, Wyoming, Montana, Alberta	2.0¢/kWh	Green-e
Clean Energy Partnership/Sterling Planet	National New Clean Energy MIx	24% wind, 25% biomass, 50% landfill gas, 1% solar	National	0.6¢/kWh	Environmental Resources Trust
Maine Interfaith Power & Light/BEF	Green Tags (supplied by BEF)	≥98% new wind, ≤ 1% new solar, ≤ 1% new biomass	Washington, Oregon, Wyoming, Montana, Alberta	2.0¢/kWh	—
NativeEnergy	CoolHome	New biogas and new wind	Vermont and Pennsylvania (biomass), South Dakota (wind)	0.8¢/kWh - 1.0¢/kWh	[a]
Sterling Planet	Green America	45% new wind 50% new biomass 5% new solar	Nationwide	1.6¢/kWh	Green-e
TerraPass Inc.	TerraPass	Various (including efficiency and CO2 offsets)	Nationwide	~$11/ton CO2	—

Source:
National Renewable Energy Laboratory. *Power Technologies Energy Data Book*, Table 3.8.9, http://www.nrel.gov/analysis/power_databook/chapter3.html.

Note: — Information not available.

New is defined as operating or repowered after January 1, 1999 based on the Green-e TRC certification standards.

Most product prices are as of July 2005.

[a] The Climate Neutral Network certifies the methodology used to calculate the CO2 emissions offset.

Figure 3.1
New Biomass Power Plants by Year

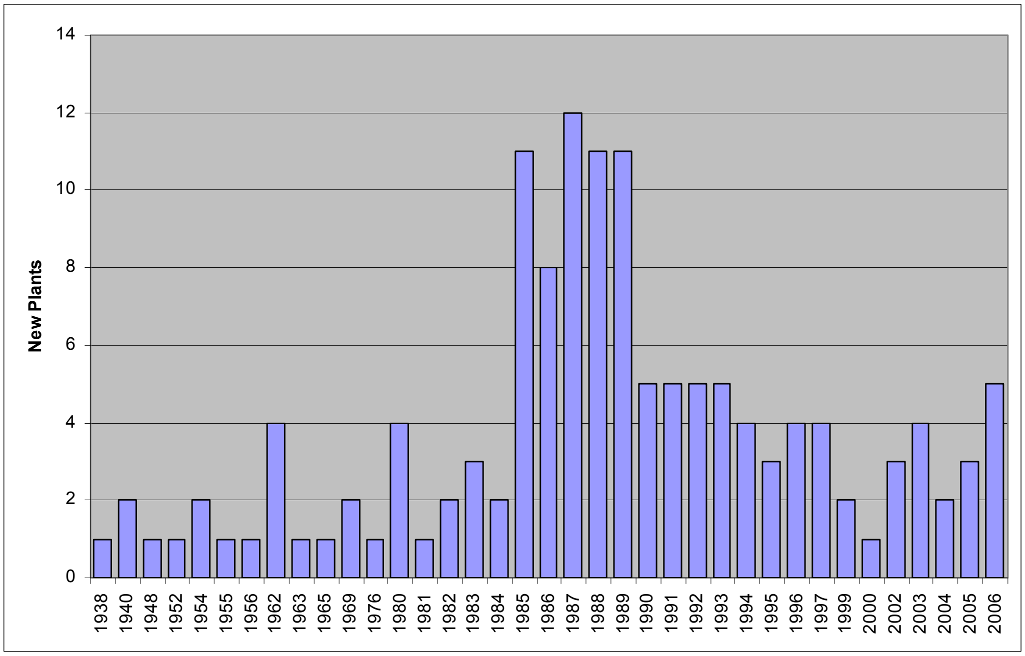
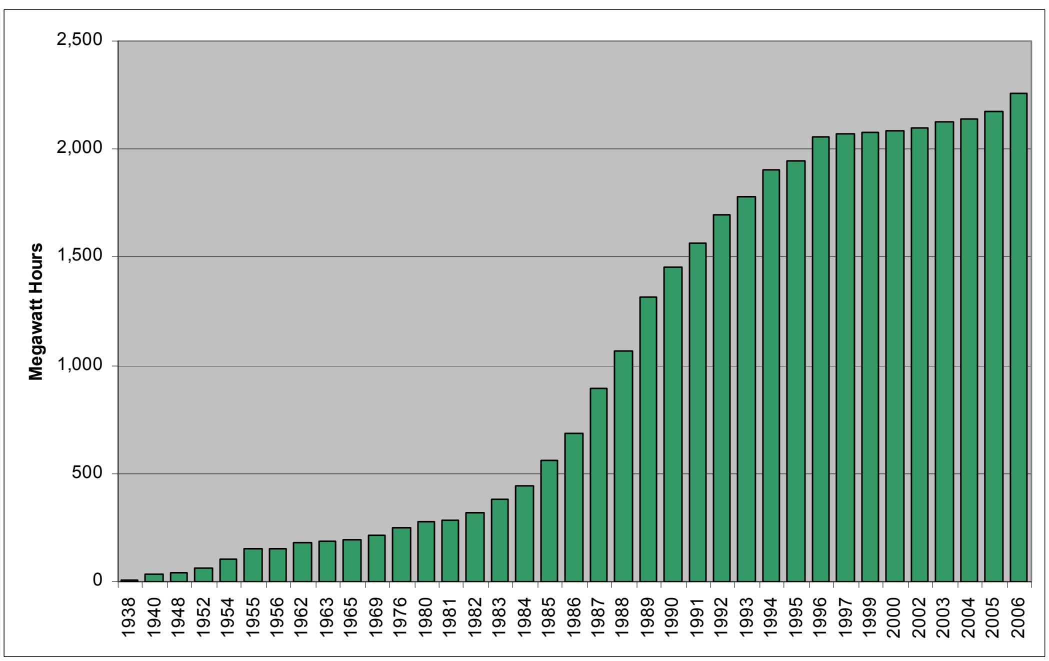


Figure 3.2
Biomass Power Plant Capacity by Year
(Megawatt hours)



Source:
National Electric Energy System (NEEDS) Database for IPM 2006, http://epa.gov/airmarkets/progsregs/epa-ipm/index.html.

Notes:
1. Only years in which new plants were brought online are shown.
2. Power plant capacity based on NEEDS 2006 Data.

Table 3.11
Current Biomass Power Plants

Plant Name	Boiler/Generator/ Committed Unit	State Name	County	Capacity MW	Heat Rate	Cogeneration	On-line Year
Pacific Lumber	G	California	Humboldt	7.50	15826	Yes	1938
French Island	B	Wisconsin	La Crosse	14.00	10400	No	1940
French Island	B	Wisconsin	La Crosse	14.00	10400	No	1940
Berlin Gorham	B	New Hampshire	Coos	5.00	15826	No	1948
Bay Front	B	Wisconsin	Ashland	22.00	16190	No	1952
East Millinocket Mill	B	Maine	Penobscot	19.04	15826	Yes	1954
Bay Front	B	Wisconsin	Ashland	22.00	18720	No	1954
Schiller	B	New Hampshire	Rockingham	47.20	12788	No	1955
Medford Operation	G	Oregon	Jackson	3.10	15826	Yes	1956
Bryant Sugar House	B	Florida	Palm Beach	6.63	15826	Yes	1962
Bryant Sugar House	B	Florida	Palm Beach	6.63	15826	Yes	1962
Bryant Sugar House	B	Florida	Palm Beach	6.63	15826	Yes	1962
Bryant Sugar House	B	Florida	Palm Beach	6.63	15826	Yes	1962
Stone Container Florence Mill	B	South Carolina	Florence	7.63	15826	Yes	1963
Medford Operation	G	Oregon	Jackson	4.40	15826	Yes	1965
Rapids Energy Center	B	Minnesota	Itasca	11.02	10079	Yes	1969
Rapids Energy Center	B	Minnesota	Itasca	11.02	10079	Yes	1969
Somerset Plant	B	Maine	Somerset	34.23	15826	Yes	1976
Century Flooring Co	G	Arkansas	Izard	1.70	15826	Yes	1980
Forster Strong Mill	G	Maine	Franklin	0.35	15826	Yes	1980
American Ref-Fuel of Niagara	B	New York	Niagara	9.00	15826	Yes	1980
Stone Container Hopewell Mill	B	Virginia	Hopewell	20.35	15826	Yes	1980
Diamond Walnut	G	California	San Joaquin	4.20	15826	Yes	1981
Plummer Forest Products	G	Idaho	Benewah	5.77	15000	Yes	1982
S D Warren Somerset	B	Maine	Cumberland	26.88	15826	No	1982
Tamarack Energy Partnership	G	Idaho	Adams	5.80	9650	Yes	1983
Snider Industries	G	Texas	Harrison	5.00	15826	Yes	1983
Kettle Falls Generating Station	G	Washington	Stevens	50.00	11860	No	1983
Agrilectric Power Partners Ltd	B	Louisiana	Calcasieu	10.90	17327	No	1984
J C McNeil	B	Vermont	Chittenden	52.00	21020	No	1984
Wheelabrator Martell	G	California	Amador	15.00	15826	Yes	1985
Pacific Oroville Power	B	California	Butte	8.25	20081	No	1985
Pacific Oroville Power	B	California	Butte	8.25	20081	No	1985
Mt Lassen Power	B	California	Lassen	10.50	19607	No	1985
Sierra Pacific Susanville	B	California	Lassen	12.60	15826	Yes	1985
Collins Pine Project	B	California	Plumas	9.80	15826	Yes	1985
Burney Mountain Power	B	California	Shasta	9.75	18938	No	1985
Sierra Power	G	California	Tulare	7.00	15826	Yes	1985
Ultrapower Chinese Station	B	California	Tuolumne	19.80	20111	No	1985
Biomass One LP	B	Oregon	Jackson	8.50	19236	Yes	1985
Biomass One LP	B	Oregon	Jackson	14.00	14427	Yes	1985
Fairhaven Power	B	California	Humboldt	17.30	21020	No	1986
Sierra Pacific Quincy Facility	B	California	Plumas	14.50	15826	Yes	1986
Sierra Pacific Quincy Facility	B	California	Plumas	14.50	15826	Yes	1986
Sierra Pacific Burney Facility	B	California	Shasta	18.00	15826	Yes	1986
DG Telogia Power	B	Florida	Liberty	12.50	21020	No	1986
Wheelabrator Sherman Energy Facility	B	Maine	Penobscot	21.00	11987	Yes	1986
Pinetree Power	B	New Hampshire	Grafton	15.00	15033	No	1986
Co-Gen LLC	G	Oregon	Grant	6.98	11987	Yes	1986
Wheelabrator Shasta	B	California	Shasta	17.30	19254	No	1987
Wheelabrator Shasta	B	California	Shasta	17.30	19254	No	1987
Wheelabrator Shasta	B	California	Shasta	17.30	19254	No	1987
Boralex Fort Fairfield	B	Maine	Aroostook	31.00	21020	No	1987
Indeck West Enfield Energy Center	B	Maine	Penobscot	25.60	21020	No	1987
Indeck Jonesboro Energy Center	G	Maine	Washington	26.80	9650	No	1987
Central Michigan University	G	Michigan	Isabella	0.95	15826	Yes	1987
Hillman Power LLC	B	Michigan	Montmorency	17.80	15655	No	1987
Pinetree Power Tamworth	B	New Hampshire	Carroll	20.00	14972	No	1987
Bridgewater Power LP	B	New Hampshire	Grafton	16.00	14232	No	1987
Hemphill Power & Light	B	New Hampshire	Sullivan	14.13	14605	No	1987
Co-Gen II LLC	G	Oregon	Douglas	6.98	11987	Yes	1987
Rio Bravo Fresno	B	California	Fresno	24.30	18456	No	1988
Pacific Lumber	B	California	Humboldt	8.67	15826	Yes	1988
Pacific Lumber	B	California	Humboldt	8.67	15826	Yes	1988
Pacific Lumber	B	California	Humboldt	8.67	15826	Yes	1988
Greenville Steam	B	Maine	Piscataquis	16.10	13337	No	1988
Viking Energy of McBain	B	Michigan	Missaukee	16.00	15982	No	1988
M L Hibbard	B	Minnesota	St. Louis	15.30	14500	Yes	1988
M L Hibbard	B	Minnesota	St. Louis	33.30	14500	Yes	1988

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Table 3.11 (Continued)
Current Biomass Power Plants

Plant Name	Boiler/Generator/ Committed Unit	State Name	County	Capacity MW	Heat Rate	Cogeneration	On-line Year
Whitefield Power & Light	B	New Hampshire	Coos	14.50	13025	No	1988
Koopers Susquehanna Plant	B	Pennsylvania	Lycoming	11.50	9650	Yes	1988
Viking Energy of Northumberland	B	Pennsylvania	Northumberland	16.00	13500	Yes	1988
Wadham Energy LP	B	California	Colusa	25.50	12637	No	1989
AES Mendota	B	California	Fresno	25.00	17874	No	1989
HL Power	B	California	Lassen	30.00	14944	No	1989
Rio Bravo Rocklin	B	California	Placer	24.40	16645	No	1989
Burney Forest Products	B	California	Shasta	15.50	16350	Yes	1989
Burney Forest Products	B	California	Shasta	15.50	16350	Yes	1989
Sierra Pacific Loyalton Facility	B	California	Sierra	14.00	15826	Yes	1989
Woodland Biomass Power Ltd	B	California	Yolo	25.00	15302	No	1989
Boralex Stratton Energy	B	Maine	Franklin	45.70	19601	No	1989
Worcester Energy	G	Maine	Washington	13.00	14500	No	1989
Viking Energy of Lincoln	B	Michigan	Alcona	16.00	13646	No	1989
Delano Energy	B	California	Kern	27.00	17237	No	1990
Tracy Biomass	B	California	San Joaquin	16.46	17342	No	1990
Jefferson Power LLC	G	Florida	Jefferson	7.50	16258	No	1990
Somerset Plant	B	Maine	Somerset	42.63	15826	Yes	1990
Craven County Wood Energy LP	B	North Carolina	Craven	45.00	12622	No	1990
Alabama Pine Pulp	B	Alabama	Monroe	32.09	15826	Yes	1991
Potlatch Southern Wood Products	B	Arkansas	Bradley	10.00	15826	Yes	1991
Mecca Plant	B	California	Riverside	23.50	14158	No	1991
Mecca Plant	B	California	Riverside	23.50	14158	No	1991
Port Wentworth	B	Georgia	Chatham	21.60	15826	Yes	1991
Boralex Beaver Livermore Falls	B	Maine	Androscoggin	34.70	14309	No	1992
Pinetree Power Fitchburg	B	Massachusetts	Worcester	17.00	15673	No	1992
Grayling Generating Station	B	Michigan	Crawford	36.20	14597	No	1992
Lyonsdale Biomass LLC	B	New York	Lewis	19.00	13230	Yes	1992
Ryegate Power Station	B	Vermont	Caledonia	20.00	21020	No	1992
Delano Energy	B	California	Kern	22.00	17237	No	1993
Cadillac Renewable Energy	B	Michigan	Wexford	36.80	15470	No	1993
Boralex Chateaugay Power Station	B	New York	Franklin	18.00	15094	No	1993
Sauder Power Plant	G	Ohio	Fulton	3.60	14900	Yes	1993
Sauder Power Plant	G	Ohio	Fulton	3.60	14900	Yes	1993
Ridge Generating Station	B	Florida	Polk	47.10	21020	No	1994
Multitrade of Pittsylvania LP	B	Virginia	Pittsylvania	26.55	13541	No	1994
Multitrade of Pittsylvania LP	B	Virginia	Pittsylvania	26.55	13541	No	1994
Multitrade of Pittsylvania LP	B	Virginia	Pittsylvania	26.55	13541	No	1994
Cox Waste to Energy	G	Kentucky	Taylor	3.00	15826	Yes	1995
Agrilectric Power Partners Ltd	B	Louisiana	Calcasieu	1.30	17327	No	1995
Genesee Power Station LP	B	Michigan	Genesee	35.00	21020	No	1995
Okeelanta Cogeneration	B	Florida	Palm Beach	24.97	13600	Yes	1996
Okeelanta Cogeneration	B	Florida	Palm Beach	24.97	13600	Yes	1996
Okeelanta Cogeneration	B	Florida	Palm Beach	24.97	13600	Yes	1996
Everett Cogen	B	Washington	Snohomish	36.00	19000	Yes	1996
STEC-S LLC	B	Arkansas	Arkansas	2.00	10265	Yes	1997
STEC-S LLC	B	Arkansas	Arkansas	2.00	10265	Yes	1997
Sierra Pacific Lincoln Facility	B	California	Placer	5.60	15826	Yes	1997
Sierra Pacific Lincoln Facility	B	California	Placer	5.60	15826	Yes	1997
Sierra Pacific Anderson Facility	G	California	Shasta	4.00	15826	Yes	1999
Minergy Neenah	G	Wisconsin	Winnebago	6.50	15826	Yes	1999
Wheelabrator Shasta	G	California	Shasta	3.50	19254	No	2000
Cox Waste to Energy	G	Kentucky	Taylor	0.30	15826	Yes	2002
Colville Indian Power & Veneer	G	Washington	Okanogan	5.00	15826	No	2002
Colville Indian Power & Veneer	G	Washington	Okanogan	7.50	15826	No	2002
Ware Biomass Cogen	C	Massachusetts	a	7.79	15826	Yes	2003
Scott Wood	C	Virginia	Amelia	0.80	15826	No	2003
Scott Wood	C	Virginia	Amelia	2.60	15826	No	2003
Sierra Pacific Aberdeen	B	Washington	Grays Harbor	16.00	15826	Yes	2003
Sierra Pacific Lincoln Facility	G	California	Placer	18.00	15826	Yes	2004
Forster Strong Mill	G	Maine	Franklin	0.50	15826	Yes	2004
Puente Hills Energy Recovery	C	California	Los Angeles	8.00	8911	No	2005
Worcester Energy	C	Maine	a	24.56	8911	No	2005
Blue Spruce Farm Ana	C	Vermont	a	0.26	8911	No	2005
APS Biomass I	C	Arizona	a	2.85	8911	No	2006
Buckeye Florida	C	Florida	Taylor	25.00	8911	No	2006
Ware Cogeneration	C	Massachusetts	a	4.09	8911	Yes	2006
Central Minn. Ethano	C	Minnesota	a	0.95	8911	No	2006
Schiller Biomass Con	C	New Hampshire	a	47.50	8911	No	2006
Fibrominn Biomass Power Plant	C	Minnesota	Swift	55.00	8911	No	2007

Source:
National Electric Energy System (NEEDS) Database for IPM 2006, http://epa.gov/airmarkets/progsregs/epa-ipm/index.html.

[a] Data are not available

Figure 3.3
New Landfill Gas Power Plants by Year

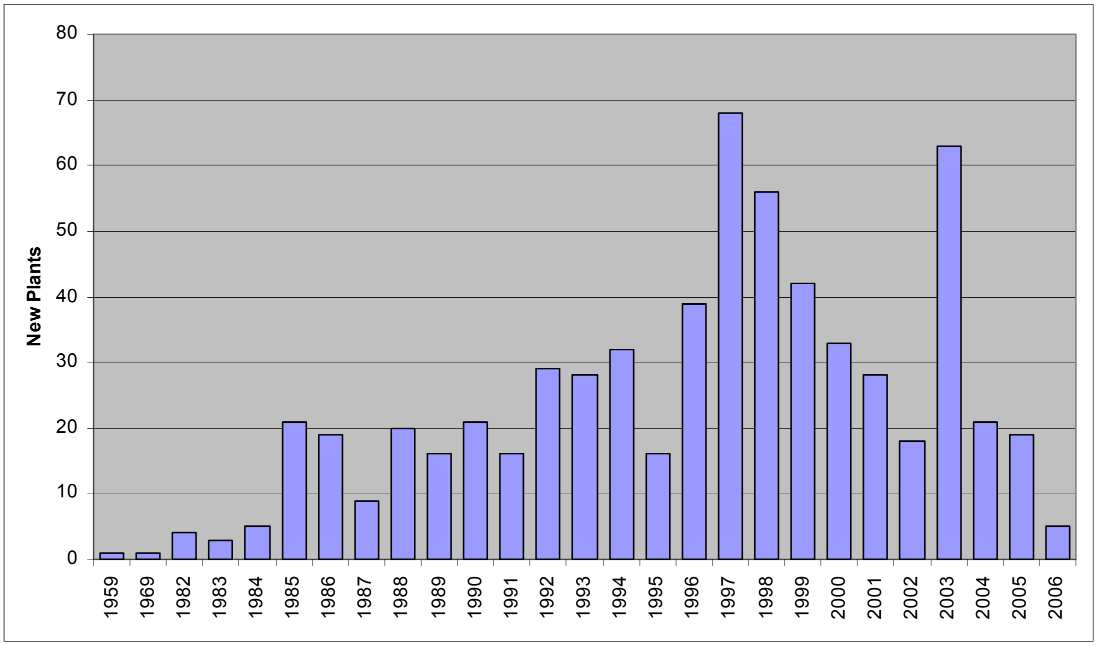
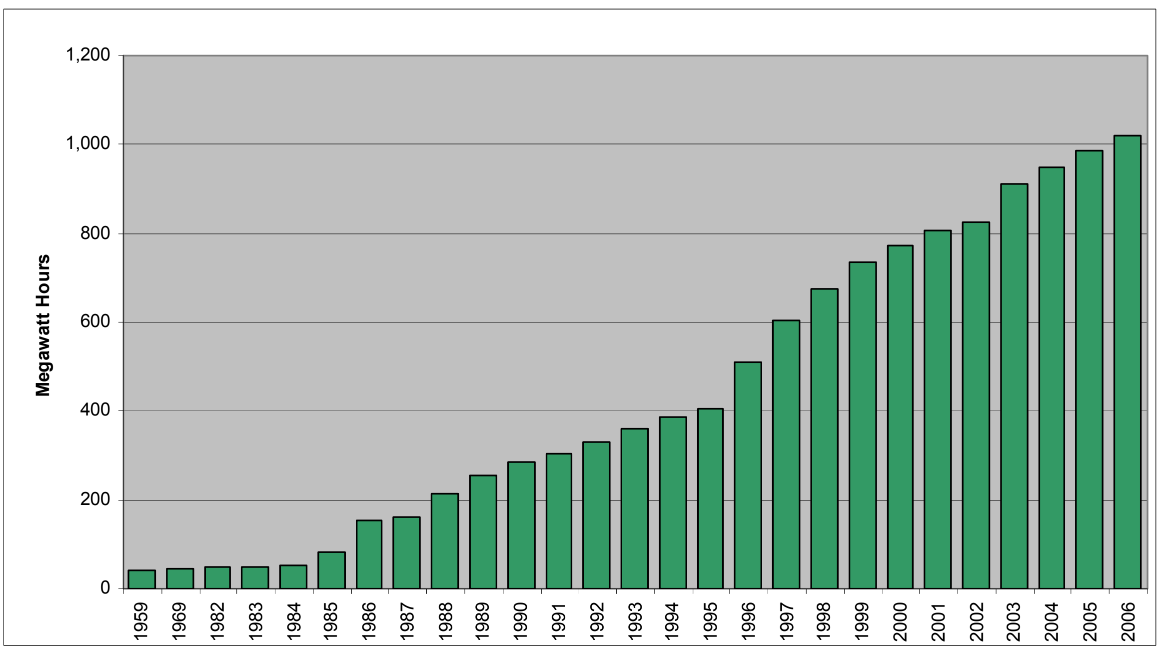


Figure 3.4
Landfill Gas Power Plant Capacity by Year
(Megawatt hours)



Source:
National Electric Energy System (NEEDS) Database for IPM 2006,
http://epa.gov/airmarkets/progsregs/epa-ipm/index.html.

Notes:
1. Only years in which new plants were brought online are shown.
2. Power plant capacity based on NEEDS 2006 Data.

Table 3.12
Current Landfill Gas Power Plants

Plant Name	Boiler/Generator/Committed Unit	State Name	County	Capacity MW	Heat Rate	Cogeneration	On-line Year
Grayson	B	California	Los Angeles	42.00	14348	No	1959
Altamont Gas Recovery	G	California	Alameda	2.90	18748	No	1969
Marsh Road Power Plant	G	California	San Mateo	0.50	18412	No	1982
Marsh Road Power Plant	G	California	San Mateo	0.50	18412	No	1982
Marsh Road Power Plant	G	California	San Mateo	0.50	18412	No	1982
Marsh Road Power Plant	G	California	San Mateo	0.50	18412	No	1982
Guadalupe Power Plant	G	California	Santa Clara	0.50	13763	No	1983
Guadalupe Power Plant	G	California	Santa Clara	0.50	13763	No	1983
Guadalupe Power Plant	G	California	Santa Clara	0.50	13763	No	1983
Newby Island I	G	California	Santa Clara	0.50	12991	No	1984
Newby Island I	G	California	Santa Clara	0.50	12991	No	1984
Newby Island I	G	California	Santa Clara	0.50	12991	No	1984
Newby Island I	G	California	Santa Clara	0.50	12991	No	1984
Puente Hills Energy Recovery	G	California	Los Angeles	1.10	36790	No	1984
American Canyon Power Plant	G	California	Napa	0.70	10887	No	1985
American Canyon Power Plant	G	California	Napa	0.70	10887	No	1985
Olinda Landfill Gas Recovery Plant	G	California	Orange	1.70	12348	No	1985
Olinda Landfill Gas Recovery Plant	G	California	Orange	1.70	12348	No	1985
Olinda Landfill Gas Recovery Plant	G	California	Orange	1.70	12348	No	1985
Nove Power Plant	G	California	Contra Costa	2.50	10205	No	1985
Nove Power Plant	G	California	Contra Costa	2.50	10205	No	1985
Oxnard	G	California	Ventura	1.70	13533	No	1985
Oxnard	G	California	Ventura	1.70	13533	No	1985
Gude	G	Maryland	Montgomery	1.30	14768	No	1985
Gude	G	Maryland	Montgomery	1.30	14768	No	1985
Kinsleys Landfill	G	New Jersey	Gloucester	0.50	10400	No	1985
Kinsleys Landfill	G	New Jersey	Gloucester	0.50	10400	No	1985
Kinsleys Landfill	G	New Jersey	Gloucester	0.50	10400	No	1985
Kinsleys Landfill	G	New Jersey	Gloucester	0.50	10400	No	1985
Lebanon Methane Recovery	G	Pennsylvania	Lebanon	0.60	14707	No	1985
Lebanon Methane Recovery	G	Pennsylvania	Lebanon	0.60	14707	No	1985
Metro Gas Recovery	G	Wisconsin	Milwaukee	2.90	17718	No	1985
Metro Gas Recovery	G	Wisconsin	Milwaukee	2.90	17718	No	1985
Omega Hills Gas Recovery	G	Wisconsin	Washington	2.90	18070	No	1985
Omega Hills Gas Recovery	G	Wisconsin	Washington	2.90	18070	No	1985
Total Energy Facilities	G	California	Los Angeles	4.73	12917	Yes	1986
Puente Hills Energy Recovery	B	California	Los Angeles	22.50	11487	No	1986
Puente Hills Energy Recovery	B	California	Los Angeles	22.50	11487	No	1986
Otay	G	California	San Diego	1.70	12265	No	1986
Salinas	G	California	Monterey	1.30	18136	No	1986
Santa Clara	G	California	Santa Clara	1.30	11259	No	1986
Penrose Power Station	G	California	Los Angeles	1.70	13169	No	1986
Penrose Power Station	G	California	Los Angeles	1.70	13169	No	1986
Penrose Power Station	G	California	Los Angeles	1.70	13169	No	1986
Penrose Power Station	G	California	Los Angeles	1.70	13169	No	1986
Penrose Power Station	G	California	Los Angeles	1.70	13169	No	1986
Toyon Power Station	G	California	Los Angeles	1.70	13200	No	1986
Toyon Power Station	G	California	Los Angeles	1.70	13200	No	1986
Toyon Power Station	G	California	Los Angeles	1.70	13200	No	1986
Toyon Power Station	G	California	Los Angeles	1.70	13200	No	1986
EQ Waste Energy Services	G	Michigan	Wayne	0.50	11123	Yes	1986
EQ Waste Energy Services	G	Michigan	Wayne	0.30	11123	Yes	1986
EQ Waste Energy Services	G	Michigan	Wayne	0.30	11123	Yes	1986
EQ Waste Energy Services	G	Michigan	Wayne	0.30	11123	Yes	1986
Guadalupe Power Plant	G	California	Santa Clara	1.00	13763	No	1987
Nove Power Plant	G	California	Contra Costa	2.50	10205	No	1987
Prince Georges County Brown Station Road	G	Maryland	Prince Georges	0.74	12917	Yes	1987
Prince Georges County Brown Station Road	G	Maryland	Prince Georges	0.74	12917	Yes	1987
Prince Georges County Brown Station Road	G	Maryland	Prince Georges	0.74	12917	Yes	1987
Taylor Energy Partners LP	G	Pennsylvania	Lackawanna	0.50	14512	No	1987
Taylor Energy Partners LP	G	Pennsylvania	Lackawanna	0.40	14512	No	1987
Taylor Energy Partners LP	G	Pennsylvania	Lackawanna	0.40	14512	No	1987
Taylor Energy Partners LP	G	Pennsylvania	Lackawanna	0.40	14512	No	1987
Palos Verdes Gas to Energy	B	California	Los Angeles	3.00	21020	No	1988
Palos Verdes Gas to Energy	B	California	Los Angeles	3.00	21020	No	1988
Settlers Hill Gas Recovery	G	Illinois	Kane	2.90	18340	No	1988
Lake Gas Recovery	G	Illinois	Cook	2.90	17932	No	1988
Riverview Energy Systems	G	Michigan	Wayne	2.81	17800	No	1988
Riverview Energy Systems	G	Michigan	Wayne	2.81	17800	No	1988
Dunbarton Energy Partners LP	G	New Hampshire	Hillsborough	0.59	10640	No	1988
Dunbarton Energy Partners LP	G	New Hampshire	Hillsborough	0.59	10640	No	1988
Al Turi	G	New York	Orange	0.70	15600	No	1988
Al Turi	G	New York	Orange	0.70	15600	No	1988
Smithtown Energy Partners LP	G	New York	Suffolk	0.60	21971	No	1988
Smithtown Energy Partners LP	G	New York	Suffolk	0.60	21971	No	1988
Onondaga Energy Partners LP	G	New York	Onondaga	0.60	12543	No	1988
Onondaga Energy Partners LP	G	New York	Onondaga	0.60	12543	No	1988
Monroe Livingston Gas Recovery	G	New York	Monroe	0.80	13146	No	1988
Monroe Livingston Gas Recovery	G	New York	Monroe	0.80	13146	No	1988
Monroe Livingston Gas Recovery	G	New York	Monroe	0.80	13146	No	1988
Archbald Power Station	B	Pennsylvania	Lackawanna	20.00	21020	Yes	1988
DFW Gas Recovery	G	Texas	Denton	2.90	18736	No	1988
DFW Gas Recovery	G	Texas	Denton	2.90	18736	No	1988
Sycamore San Diego	G	California	San Diego	0.70	10000	No	1989
Sycamore San Diego	G	California	San Diego	0.70	10000	No	1989
Newby Island II	G	California	Santa Clara	1.00	10998	No	1989
Newby Island II	G	California	Santa Clara	1.00	10998	No	1989
Newby Island II	G	California	Santa Clara	1.00	10998	No	1989
Coyote Canyon Steam Plant	B	California	Orange	17.00	16797	No	1989
Altamont Gas Recovery	G	California	Alameda	2.90	18748	No	1989

Continued on next page

Table 3.12 (Continued)
Current Landfill Gas Power Plants

Plant Name	Boiler/Generator/Committed Unit	State Name	County	Capacity MW	Heat Rate	Cogeneration	On-line Year
CSL Gas Recovery	G	Florida	Broward	2.90	11860	No	1989
CSL Gas Recovery	G	Florida	Broward	2.90	11860	No	1989
CSL Gas Recovery	G	Florida	Broward	2.90	11860	No	1989
CID Gas Recovery	G	Illinois	Cook	2.90	19051	No	1989
CID Gas Recovery	G	Illinois	Cook	2.90	19051	No	1989
Tazewell Gas Recovery	G	Illinois	Tazewell	0.80	11786	No	1989
Tazewell Gas Recovery	G	Illinois	Tazewell	0.80	11786	No	1989
Al Turi	G	New York	Orange	0.70	15600	No	1989
Stowe Power Production Plant	G	Pennsylvania	Montgomery	2.90	19515	No	1989
San Marcos	G	California	San Diego	0.70	17340	No	1990
San Marcos	G	California	San Diego	0.70	17340	No	1990
Spadra Landfill Gas to Energy	B	California	Los Angeles	8.50	14888	No	1990
Byxbee Park Sanitary Landfill	G	California	Santa Clara	1.00	10339	No	1990
Byxbee Park Sanitary Landfill	G	California	Santa Clara	1.00	10339	No	1990
MM Yolo Power LLC Facility	G	California	Yolo	0.45	23737	No	1990
MM Yolo Power LLC Facility	G	California	Yolo	0.45	23737	No	1990
MM Yolo Power LLC Facility	G	California	Yolo	0.45	23737	No	1990
Lafayette Energy Partners LP	G	New Jersey	Sussex	0.50	17767	No	1990
Lafayette Energy Partners LP	G	New Jersey	Sussex	0.50	17767	No	1990
Oceanside Energy	G	New York	Nassau	0.60	12392	No	1990
Oceanside Energy	G	New York	Nassau	0.60	12392	No	1990
Oceanside Energy	G	New York	Nassau	0.60	12392	No	1990
Ridgewood Providence Power	G	Rhode Island	Providence	1.70	11832	No	1990
Ridgewood Providence Power	G	Rhode Island	Providence	1.70	11832	No	1990
Ridgewood Providence Power	G	Rhode Island	Providence	1.70	11832	No	1990
Ridgewood Providence Power	G	Rhode Island	Providence	1.70	11832	No	1990
Ridgewood Providence Power	G	Rhode Island	Providence	1.70	11832	No	1990
Ridgewood Providence Power	G	Rhode Island	Providence	1.70	11832	No	1990
Ridgewood Providence Power	G	Rhode Island	Providence	1.70	11832	No	1990
Ridgewood Providence Power	G	Rhode Island	Providence	1.70	11832	No	1990
Otay	G	California	San Diego	1.70	12245	No	1991
Oxnard	G	California	Ventura	1.70	13533	No	1991
New Milford Gas Recovery	G	Connecticut	Litchfield	3.00	17053	No	1991
Milam Gas Recovery	G	Illinois	St. Clair	0.80	12888	No	1991
Milam Gas Recovery	G	Illinois	St. Clair	0.80	12888	No	1991
Granger Electric Generating Station #2	G	Michigan	Clinton	0.80	12740	No	1991
Granger Electric Generating Station #2	G	Michigan	Clinton	0.80	12740	No	1991
Granger Electric Generating Station #2	G	Michigan	Clinton	0.80	12740	No	1991
High Acres Gas Recovery	G	New York	Monroe	0.80	11852	No	1991
High Acres Gas Recovery	G	New York	Monroe	0.80	11852	No	1991
High Acres Gas Recovery	G	New York	Monroe	0.80	11852	No	1991
High Acres Gas Recovery	G	New York	Monroe	0.80	11852	No	1991
Stowe Power Production Plant	G	Pennsylvania	Montgomery	2.90	19515	No	1991
Outagamie County Co-Generation Facility	G	Wisconsin	Outagamie	0.80	12917	Yes	1991
Outagamie County Co-Generation Facility	G	Wisconsin	Outagamie	0.80	12917	No	1991
Outagamie County Co-Generation Facility	G	Wisconsin	Outagamie	0.80	12917	No	1991
Kankakee Gas Recovery	G	Illinois	Kankakee	0.80	11892	No	1992
Kankakee Gas Recovery	G	Illinois	Kankakee	0.80	11892	No	1992
Woodland Landfill Gas Recovery	G	Illinois	Kane	0.80	13196	No	1992
Woodland Landfill Gas Recovery	G	Illinois	Kane	0.80	13196	No	1992
Sumpter Energy Associates	G	Michigan	Wayne	0.80	13388	No	1992
Sumpter Energy Associates	G	Michigan	Wayne	0.80	13388	No	1992
Sumpter Energy Associates	G	Michigan	Wayne	0.80	13388	No	1992
Sumpter Energy Associates	G	Michigan	Wayne	0.80	13388	No	1992
Sumpter Energy Associates	G	Michigan	Wayne	0.80	13388	No	1992
Sumpter Energy Associates	G	Michigan	Wayne	0.80	13388	No	1992
Sumpter Energy Associates	G	Michigan	Wayne	0.80	13388	No	1992
Sumpter Energy Associates	G	Michigan	Wayne	0.80	13388	No	1992
Sumpter Energy Associates	G	Michigan	Wayne	0.80	13388	No	1992
Sumpter Energy Associates	G	Michigan	Wayne	0.80	13388	No	1992
Venice Resources Gas Recovery	G	Michigan	Shiawassee	0.80	16218	No	1992
Venice Resources Gas Recovery	G	Michigan	Shiawassee	0.80	16218	No	1992
Turnkey Landfill Gas Recovery	G	New Hampshire	Strafford	0.80	12840	No	1992
Turnkey Landfill Gas Recovery	G	New Hampshire	Strafford	0.80	12840	No	1992
Turnkey Landfill Gas Recovery	G	New Hampshire	Strafford	0.80	12840	No	1992
Chestnut Ridge Gas Recovery	G	Tennessee	Anderson	0.80	14268	No	1992
Chestnut Ridge Gas Recovery	G	Tennessee	Anderson	0.80	14268	No	1992
Chestnut Ridge Gas Recovery	G	Tennessee	Anderson	0.80	14268	No	1992
Chestnut Ridge Gas Recovery	G	Tennessee	Anderson	0.80	14268	No	1992
I 95 Municipal Landfill Phase I	G	Virginia	Fairfax	0.80	11031	No	1992
I 95 Municipal Landfill Phase I	G	Virginia	Fairfax	0.80	11031	No	1992
I 95 Municipal Landfill Phase I	G	Virginia	Fairfax	0.80	11031	No	1992
I 95 Municipal Landfill Phase I	G	Virginia	Fairfax	0.80	11031	No	1992
Pheasant Run Landfill Gas Recovery	G	Wisconsin	Kenosha	0.80	12475	No	1992
Pheasant Run Landfill Gas Recovery	G	Wisconsin	Kenosha	0.80	12475	No	1992
BKK Landfill	G	California	Los Angeles	4.40	21020	No	1993
MM Yolo Power LLC Facility	G	California	Yolo	0.60	23737	No	1993
Sonoma Central Landfill Phase I	G	California	Sonoma	0.70	13634	No	1993
Sonoma Central Landfill Phase I	G	California	Sonoma	0.70	13634	No	1993
Sonoma Central Landfill Phase I	G	California	Sonoma	0.70	13634	No	1993
Sonoma Central Landfill Phase I	G	California	Sonoma	0.70	13634	No	1993
BJ Gas Recovery	G	Georgia	Gwinnett	0.80	12460	No	1993
BJ Gas Recovery	G	Georgia	Gwinnett	0.80	12460	No	1993
BJ Gas Recovery	G	Georgia	Gwinnett	0.80	12460	No	1993
Milam Gas Recovery	G	Illinois	St. Clair	0.80	12888	No	1993
Lake Gas Recovery	G	Illinois	Cook	2.90	17932	No	1993
Lake Gas Recovery	G	Illinois	Cook	2.90	17932	No	1993
Chicopee Electric	G	Massachusetts	Hampden	0.90	14170	No	1993
Chicopee Electric	G	Massachusetts	Hampden	0.90	14170	No	1993
Granger Electric Generating Station #1	G	Michigan	Clinton	0.80	14015	No	1993
Granger Electric Generating Station #1	G	Michigan	Clinton	0.80	14015	No	1993

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Table 3.12 (Continued)
Current Landfill Gas Power Plants

Plant Name	Boiler/Generator/Committed Unit	State Name	County	Capacity MW	Heat Rate	Cogeneration	On-line Year
Lyon Development	G	Michigan	Oakland	0.90	17641	No	1993
Lyon Development	G	Michigan	Oakland	0.90	17641	No	1993
Lyon Development	G	Michigan	Oakland	0.90	17641	No	1993
Lyon Development	G	Michigan	Oakland	0.90	17641	No	1993
Lyon Development	G	Michigan	Oakland	0.90	17641	No	1993
Turnkey Landfill Gas Recovery	G	New Hampshire	Strafford	0.80	12840	No	1993
I 95 Landfill Phase II	G	Virginia	Fairfax	0.80	10773	No	1993
I 95 Landfill Phase II	G	Virginia	Fairfax	0.80	10773	No	1993
I 95 Landfill Phase II	G	Virginia	Fairfax	0.80	10773	No	1993
I 95 Landfill Phase II	G	Virginia	Fairfax	0.80	10773	No	1993
Richmond Electric	G	Virginia	Henrico	0.90	14012	No	1993
Richmond Electric	G	Virginia	Henrico	0.90	14012	No	1993
Marina Landfill Gas	G	California	Monterey	0.70	12917	No	1994
Twin Bridges Gas Recovery	G	Indiana	Hendricks	0.80	11895	No	1994
Twin Bridges Gas Recovery	G	Indiana	Hendricks	0.80	11895	No	1994
Twin Bridges Gas Recovery	G	Indiana	Hendricks	0.80	11895	No	1994
Twin Bridges Gas Recovery	G	Indiana	Hendricks	0.80	11895	No	1994
Prairie View Gas Recovery	G	Indiana	St. Joseph	0.80	10991	No	1994
Prairie View Gas Recovery	G	Indiana	St. Joseph	0.80	10991	No	1994
Prairie View Gas Recovery	G	Indiana	St. Joseph	0.80	10991	No	1994
Prairie View Gas Recovery	G	Indiana	St. Joseph	0.80	10991	No	1994
Granger Electric Generating Station #1	G	Michigan	Clinton	0.80	14015	No	1994
Ottawa Generating Station	G	Michigan	Ottawa	0.80	11797	No	1994
Ottawa Generating Station	G	Michigan	Ottawa	0.80	11797	No	1994
Ottawa Generating Station	G	Michigan	Ottawa	0.80	11797	No	1994
Ottawa Generating Station	G	Michigan	Ottawa	0.80	11797	No	1994
Ottawa Generating Station	G	Michigan	Ottawa	0.80	11797	No	1994
Ottawa Generating Station	G	Michigan	Ottawa	0.80	11797	No	1994
Grand Blanc Generating Station	G	Michigan	Genesee	0.80	11080	No	1994
Grand Blanc Generating Station	G	Michigan	Genesee	0.80	11080	No	1994
Grand Blanc Generating Station	G	Michigan	Genesee	0.80	11080	No	1994
Adrian Energy Associates LLC	G	Michigan	Lenawee	0.80	13171	No	1994
Adrian Energy Associates LLC	G	Michigan	Lenawee	0.80	13171	No	1994
Adrian Energy Associates LLC	G	Michigan	Lenawee	0.80	13171	No	1994
Woodlake Sanitary Services	G	Minnesota	Hennepin	1.50	11749	No	1994
Woodlake Sanitary Services	G	Minnesota	Hennepin	1.50	11749	No	1994
Woodlake Sanitary Services	G	Minnesota	Hennepin	1.50	11749	No	1994
EKS Landfill	G	Minnesota	Dakota	1.50	12381	No	1994
EKS Landfill	G	Minnesota	Dakota	1.50	12381	No	1994
EKS Landfill	G	Minnesota	Dakota	0.80	12381	No	1994
Suffolk Energy Partners LP	G	Virginia	Fairfax	0.70	12500	No	1994
Suffolk Energy Partners LP	G	Virginia	Fairfax	0.70	12500	No	1994
Suffolk Energy Partners LP	G	Virginia	Fairfax	0.70	12500	No	1994
Suffolk Energy Partners LP	G	Virginia	Fairfax	0.70	12500	No	1994
Peoples Generating Station	G	Michigan	Genesee	2.20	9350	No	1995
C & C Electric	G	Michigan	Calhoun	0.90	13697	No	1995
C & C Electric	G	Michigan	Calhoun	0.90	13697	No	1995
C & C Electric	G	Michigan	Calhoun	0.90	13697	No	1995
Al Turi	G	New York	Orange	0.70	15600	No	1995
Brookhaven Facility	G	New York	Suffolk	1.20	13158	No	1995
Brookhaven Facility	G	New York	Suffolk	1.20	13158	No	1995
Brookhaven Facility	G	New York	Suffolk	1.20	13158	No	1995
Brookhaven Facility	G	New York	Suffolk	1.20	13158	No	1995
Coffin Butte	G	Oregon	Benton	2.30	13151	No	1995
Coffin Butte	G	Oregon	Benton	0.74	13151	No	1995
Coffin Butte	G	Oregon	Benton	0.74	13151	No	1995
Keystone Landfill	G	Pennsylvania	Lackawanna	0.70	12125	No	1995
Keystone Landfill	G	Pennsylvania	Lackawanna	0.70	12125	No	1995
Keystone Landfill	G	Pennsylvania	Lackawanna	0.70	12125	No	1995
Keystone Landfill	G	Pennsylvania	Lackawanna	0.70	12125	No	1995
Sonoma Central Landfill Phase II	G	California	Sonoma	0.70	13643	No	1996
Sonoma Central Landfill Phase II	G	California	Sonoma	0.70	13643	No	1996
Sonoma Central Landfill Phase II	G	California	Sonoma	0.70	13643	No	1996
Sonoma Central Landfill Phase II	G	California	Sonoma	0.70	13643	No	1996
Greene Valley Gas Recovery	G	Illinois	Du Page	2.90	17551	No	1996
Greene Valley Gas Recovery	G	Illinois	Du Page	2.90	17551	No	1996
Rockford Electric	G	Illinois	Ogle	0.90	12317	No	1996
Rockford Electric	G	Illinois	Ogle	0.90	12317	No	1996
Barre	G	Massachusetts	Worcester	0.40	11941	No	1996
Barre	G	Massachusetts	Worcester	0.40	11941	No	1996
Granger Electric Generating Station #2	G	Michigan	Clinton	0.80	12740	No	1996
Arbor Hills	G	Michigan	Washtenaw	3.80	11860	No	1996
Arbor Hills	G	Michigan	Washtenaw	3.80	11860	No	1996
Arbor Hills	G	Michigan	Washtenaw	3.80	11860	No	1996
Arbor Hills	G	Michigan	Washtenaw	7.60	11860	No	1996
Pine Bend	G	Minnesota	Dakota	3.80	11860	No	1996
Pine Bend	G	Minnesota	Dakota	3.80	11860	No	1996
Pine Bend	G	Minnesota	Dakota	6.00	11860	No	1996
Four Hills Nashua Landfill	G	New Hampshire	Hillsborough	0.46	13152	No	1996
Four Hills Nashua Landfill	G	New Hampshire	Hillsborough	0.46	13152	No	1996
Seneca Energy	G	New York	Seneca	0.77	11012	No	1996
Seneca Energy	G	New York	Seneca	0.77	11012	No	1996
Seneca Energy	G	New York	Seneca	0.77	11012	No	1996
Seneca Energy	G	New York	Seneca	0.77	11012	No	1996
Seneca Energy	G	New York	Seneca	0.77	11012	No	1996
Salem Energy Systems LLC	G	North Carolina	Forsyth	3.30	16895	No	1996
Keystone Landfill	G	Pennsylvania	Lackawanna	0.70	12125	No	1996
Keystone Landfill	G	Pennsylvania	Lackawanna	0.70	12125	No	1996
Keystone Landfill	G	Pennsylvania	Lackawanna	0.70	12125	No	1996
Pennsbury	G	Pennsylvania	Bucks	2.67	9960	No	1996
Pennsbury	G	Pennsylvania	Bucks	2.67	9960	No	1996

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Table 3.12 (Continued)
Current Landfill Gas Power Plants

Plant Name	Boiler/Generator/Committed Unit	State Name	County	Capacity MW	Heat Rate	Cogeneration	On-line Year
Fairless Hills	B	Pennsylvania	Bucks	20.00	10265	Yes	1996
Fairless Hills	B	Pennsylvania	Bucks	20.00	10265	Yes	1996
Sunset Farms	G	Texas	Travis	0.90	12845	No	1996
Sunset Farms	G	Texas	Travis	0.90	12845	No	1996
Sunset Farms	G	Texas	Travis	0.90	12845	No	1996
Pheasant Run Landfill Gas Recovery	G	Wisconsin	Kenosha	0.80	12475	No	1996
Mallard Ridge Gas Recovery	G	Wisconsin	Walworth	0.80	11500	No	1996
Mallard Ridge Gas Recovery	G	Wisconsin	Walworth	0.80	11500	No	1996
Marina Landfill Gas	G	California	Monterey	0.90	12917	No	1997
Miramar Landfill Metro Biosolids Center	G	California	San Diego	1.56	10123	Yes	1997
Miramar Landfill Metro Biosolids Center	G	California	San Diego	1.56	10123	Yes	1997
Miramar Landfill Metro Biosolids Center	G	California	San Diego	1.56	10123	Yes	1997
Miramar Landfill Metro Biosolids Center	G	California	San Diego	1.56	10123	Yes	1997
Girvin Landfill	G	Florida	Duval	3.00	13806	No	1997
Biodyne Peoria	G	Illinois	Peoria	0.80	15860	No	1997
Biodyne Peoria	G	Illinois	Peoria	0.80	15860	No	1997
Biodyne Peoria	G	Illinois	Peoria	0.80	15860	No	1997
Biodyne Peoria	G	Illinois	Peoria	0.80	15860	No	1997
Biodyne Peoria	G	Illinois	Peoria	0.80	15860	No	1997
Biodyne Springfield	G	Illinois	Sangamon	0.60	23000	No	1997
Biodyne Springfield	G	Illinois	Sangamon	0.60	23000	No	1997
Biodyne Springfield	G	Illinois	Sangamon	0.60	23000	No	1997
Biodyne Springfield	G	Illinois	Sangamon	0.60	23000	No	1997
Biodyne Lyons	G	Illinois	Cook	0.90	15000	No	1997
Biodyne Lyons	G	Illinois	Cook	0.90	15000	No	1997
Biodyne Lyons	G	Illinois	Cook	0.90	15000	No	1997
Mallard Lake Electric	G	Illinois	Du Page	3.80	9800	No	1997
Mallard Lake Electric	G	Illinois	Du Page	3.80	9800	No	1997
Mallard Lake Electric	G	Illinois	Du Page	3.80	9800	No	1997
Mallard Lake Electric	G	Illinois	Du Page	7.60	9800	No	1997
South Barrington Electric	G	Illinois	Du Page	0.80	12744	No	1997
South Barrington Electric	G	Illinois	Du Page	0.80	12744	No	1997
Devonshire Power Partners LLC	G	Illinois	Cook	1.00	11883	No	1997
Devonshire Power Partners LLC	G	Illinois	Cook	1.00	11883	No	1997
Devonshire Power Partners LLC	G	Illinois	Cook	1.00	11883	No	1997
Devonshire Power Partners LLC	G	Illinois	Cook	1.00	11883	No	1997
Devonshire Power Partners LLC	G	Illinois	Cook	1.00	11883	No	1997
Riveside Resource Recovery LLC	G	Illinois	Will	0.90	12739	No	1997
Avon Energy Partners LLC	G	Illinois	Cook	0.90	10367	No	1997
Avon Energy Partners LLC	G	Illinois	Cook	0.90	10367	No	1997
Avon Energy Partners LLC	G	Illinois	Cook	0.90	10367	No	1997
KMS Joliet Power Partners LP	G	Illinois	Will	0.43	10000	No	1997
KMS Joliet Power Partners LP	G	Illinois	Will	0.43	10000	No	1997
Wheeler Landfill Gas Recovery	G	Indiana	La Porte	0.80	12270	No	1997
Taunton Landfill	G	Massachusetts	Bristol	0.88	11754	No	1997
Taunton Landfill	G	Massachusetts	Bristol	0.88	11754	No	1997
Lowell Landfill	G	Massachusetts	Middlesex	0.78	9350	No	1997
Lowell Landfill	G	Massachusetts	Middlesex	0.78	9350	No	1997
East Bridgewater	G	Massachusetts	Plymouth	0.90	13410	No	1997
East Bridgewater	G	Massachusetts	Plymouth	0.90	13410	No	1997
East Bridgewater	G	Massachusetts	Plymouth	0.90	13410	No	1997
East Bridgewater	G	Massachusetts	Plymouth	0.90	13410	No	1997
East Bridgewater	G	Massachusetts	Plymouth	0.90	13410	No	1997
East Bridgewater	G	Massachusetts	Plymouth	0.90	13410	No	1997
Halifax Electric	G	Massachusetts	Plymouth	0.90	13629	No	1997
Halifax Electric	G	Massachusetts	Plymouth	0.90	13629	No	1997
Halifax Electric	G	Massachusetts	Plymouth	0.90	13629	No	1997
Granger Electric Generating Station #2	G	Michigan	Clinton	0.80	12740	No	1997
Granger Electric Generating Station #1	G	Michigan	Clinton	0.80	14015	No	1997
Turnkey Landfill Gas Recovery	G	New Hampshire	Strafford	2.90	17620	No	1997
Turnkey Landfill Gas Recovery	G	New Hampshire	Strafford	2.90	17620	No	1997
Ocean County Landfill	G	New Jersey	Ocean	0.80	9350	No	1997
Ocean County Landfill	G	New Jersey	Ocean	0.80	9350	No	1997
Ocean County Landfill	G	New Jersey	Ocean	0.80	9350	No	1997
Ocean County Landfill	G	New Jersey	Ocean	0.80	9350	No	1997
Ocean County Landfill	G	New Jersey	Ocean	0.80	9350	No	1997
Ocean County Landfill	G	New Jersey	Ocean	0.80	9350	No	1997
O'Brien Biogas IV LLC	G	New Jersey	Middlesex	9.50	19943	No	1997
Seneca Energy	G	New York	Seneca	0.77	11012	No	1997
Seneca Energy	G	New York	Seneca	0.77	11012	No	1997
Lakeview Gas Recovery	G	Pennsylvania	Erie	3.00	12517	No	1997
Lakeview Gas Recovery	G	Pennsylvania	Erie	3.00	12517	No	1997
Ridgewood Providence Power	G	Rhode Island	Providence	1.70	11832	No	1997
Mallard Ridge Gas Recovery	G	Wisconsin	Walworth	0.80	11500	No	1997
Dane County Landfill #2 Rodefeld	G	Wisconsin	Dane	0.70	12596	No	1997
Dane County Landfill #2 Rodefeld	G	Wisconsin	Dane	0.70	12596	No	1997
Marina Landfill Gas	G	California	Monterey	0.90	12917	No	1998
Visalia Landfill Gas Utilization Project	G	California	Tulare	0.78	15410	No	1998
Visalia Landfill Gas Utilization Project	G	California	Tulare	0.78	15410	No	1998
Lopez Landfill Gas Utilization Project	G	California	Los Angeles	2.73	12698	No	1998
Lopez Landfill Gas Utilization Project	G	California	Los Angeles	2.73	12698	No	1998
Hartford Landfill Gas Utilization Project	G	Connecticut	Hartford	0.83	12503	No	1998
Hartford Landfill Gas Utilization Project	G	Connecticut	Hartford	0.83	12503	No	1998
Hartford Landfill Gas Utilization Project	G	Connecticut	Hartford	0.83	12503	No	1998
Volusia Landfill Gas Utilization Project	G	Florida	Volusia	1.85	10333	No	1998
Volusia Landfill Gas Utilization Project	G	Florida	Volusia	1.85	10333	No	1998
Settlers Hill Gas Recovery	G	Illinois	Kane	2.90	18340	No	1998
Greene Valley Gas Recovery	G	Illinois	Du Page	2.90	17551	No	1998
Quad Cities	G	Illinois	Rock Island	0.90	16840	No	1998

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Table 3.12 (Continued)
Current Landfill Gas Power Plants

Plant Name	Boiler/Generator/Committed Unit	State Name	County	Capacity MW	Heat Rate	Cogeneration	On-line Year
KMS Macon Power	G	Illinois	Macon	0.80	12917	No	1998
KMS Macon Power	G	Illinois	Macon	0.80	12917	No	1998
Metro Methane Recovery Facility	G	Iowa	Polk	0.80	12265	No	1998
Metro Methane Recovery Facility	G	Iowa	Polk	0.80	12265	No	1998
Metro Methane Recovery Facility	G	Iowa	Polk	0.80	12265	No	1998
Metro Methane Recovery Facility	G	Iowa	Polk	0.80	12265	No	1998
Metro Methane Recovery Facility	G	Iowa	Polk	0.80	12265	No	1998
Metro Methane Recovery Facility	G	Iowa	Polk	0.80	12265	No	1998
Metro Methane Recovery Facility	G	Iowa	Polk	0.80	12265	No	1998
Metro Methane Recovery Facility	G	Iowa	Polk	0.80	12265	No	1998
Sumpter Energy Associates	G	Michigan	Wayne	0.80	13388	No	1998
Sumpter Energy Associates	G	Michigan	Wayne	0.80	13388	No	1998
Sumpter Energy Associates	G	Michigan	Wayne	0.80	13388	No	1998
Sumpter Energy Associates	G	Michigan	Wayne	0.80	13388	No	1998
Sumpter Energy Associates	G	Michigan	Wayne	0.80	13388	No	1998
Brent Run Generating Station	G	Michigan	Genesee	0.80	11472	No	1998
Brent Run Generating Station	G	Michigan	Genesee	0.80	11472	No	1998
Pine Tree Acres	G	Michigan	Macomb	0.80	10976	No	1998
Pine Tree Acres	G	Michigan	Macomb	0.80	10976	No	1998
Pine Tree Acres	G	Michigan	Macomb	0.80	10976	No	1998
Pine Tree Acres	G	Michigan	Macomb	0.80	10976	No	1998
Pine Tree Acres	G	Michigan	Macomb	0.80	10976	No	1998
Balefill Landfill Gas Utilization Project	G	New Jersey	Bergen	1.80	12611	No	1998
Balefill Landfill Gas Utilization Project	G	New Jersey	Bergen	1.80	12611	No	1998
Monmouth Landfill Gas to Energy	G	New Jersey	Monmouth	7.37	9960	No	1998
Al Turi	G	New York	Orange	0.80	15600	No	1998
Al Turi	G	New York	Orange	0.80	15600	No	1998
Seneca Energy	G	New York	Seneca	0.77	11012	No	1998
Seneca Energy	G	New York	Seneca	0.77	11012	No	1998
Seneca Energy	G	New York	Seneca	0.77	11012	No	1998
Seneca Energy	G	New York	Seneca	0.77	11012	No	1998
Seneca Energy	G	New York	Seneca	0.77	11012	No	1998
Seneca Energy	G	New York	Seneca	0.77	11012	No	1998
Seneca Energy	G	New York	Seneca	0.77	11012	No	1998
Albany Landfill Gas Utilization Project	G	New York	Albany	0.90	11914	No	1998
Albany Landfill Gas Utilization Project	G	New York	Albany	0.90	11914	No	1998
Modern Landfill Production Plant	G	Pennsylvania	York	3.00	10820	No	1998
Modern Landfill Production Plant	G	Pennsylvania	York	3.00	10820	No	1998
Modern Landfill Production Plant	G	Pennsylvania	York	3.00	10820	No	1998
Prince William County Landfill	G	Virginia	Prince William	0.89	10206	No	1998
Prince William County Landfill	G	Virginia	Prince William	0.89	10206	No	1998
Tacoma Landfill Gas Utilization Project	G	Washington	Pierce	0.75	12917	No	1998
Tacoma Landfill Gas Utilization Project	G	Washington	Pierce	0.75	12917	No	1998
BKK Landfill	G	California	Los Angeles	4.40	12597	No	1999
Prima Desheha Landfill	G	California	Orange	2.70	13752	No	1999
Prima Desheha Landfill	G	California	Orange	2.70	13752	No	1999
North City Cogen Facility	G	California	San Diego	0.88	12325	No	1999
North City Cogen Facility	G	California	San Diego	0.88	12325	No	1999
North City Cogen Facility	G	California	San Diego	0.88	12325	No	1999
North City Cogen Facility	G	California	San Diego	0.88	12325	No	1999
Kiefer Landfill	G	California	Sacramento	2.80	12917	No	1999
Kiefer Landfill	G	California	Sacramento	2.80	12917	No	1999
Kiefer Landfill	G	California	Sacramento	2.80	12917	No	1999
Tazewell Gas Recovery	G	Illinois	Tazewell	0.80	11786	No	1999
Roxana Resource Recovery	G	Illinois	Madison	0.90	10600	No	1999
Roxana Resource Recovery	G	Illinois	Madison	0.90	10600	No	1999
Roxana Resource Recovery	G	Illinois	Madison	0.90	10600	No	1999
Roxana Resource Recovery	G	Illinois	Madison	0.90	10600	No	1999
Streator Energy Partners LLC	G	Illinois	La Salle	0.90	10919	No	1999
Brickyard Energy Partners LLC	G	Illinois	Vermilion	0.90	10793	No	1999
Brickyard Energy Partners LLC	G	Illinois	Vermilion	0.90	10793	No	1999
Brickyard Energy Partners LLC	G	Illinois	Vermilion	0.90	10793	No	1999
Dixon/Lee Energy Partners LLC	G	Illinois	Lee	0.90	12101	No	1999
Dixon/Lee Energy Partners LLC	G	Illinois	Lee	0.90	12101	No	1999
Dixon/Lee Energy Partners LLC	G	Illinois	Lee	0.90	12101	No	1999
Dixon/Lee Energy Partners LLC	G	Illinois	Lee	0.90	12101	No	1999
KMS Joliet Power Partners LP	G	Illinois	Will	0.43	10000	No	1999
Deercroft Gas Recovery	G	Indiana	La Porte	0.80	12030	No	1999
Deercroft Gas Recovery	G	Indiana	La Porte	0.80	12030	No	1999
Deercroft Gas Recovery	G	Indiana	La Porte	0.80	12030	No	1999
Deercroft Gas Recovery	G	Indiana	La Porte	0.80	12030	No	1999
HMDC Kingsland Landfill	G	New Jersey	Bergen	0.90	13406	No	1999
HMDC Kingsland Landfill	G	New Jersey	Bergen	0.90	13406	No	1999
Blackburn Landfill Co-Generation	G	North Carolina	Catawba	1.00	10433	Yes	1999
Blackburn Landfill Co-Generation	G	North Carolina	Catawba	1.00	10433	Yes	1999
Charlotte Motor Speedway	G	North Carolina	Cabarrus	4.30	14303	No	1999
Cuyahoga Regional Landfill	G	Ohio	Cuyahoga	1.80	10374	No	1999
Cuyahoga Regional Landfill	G	Ohio	Cuyahoga	1.80	10374	No	1999
P.E.R.C.	G	Washington	Pierce	0.75	17782	No	1999
P.E.R.C.	G	Washington	Pierce	0.75	17782	No	1999
P.E.R.C.	G	Washington	Pierce	0.75	17782	No	1999
Roosevelt Biogas 1	G	Washington	Klickitat	2.10	10000	No	1999
Roosevelt Biogas 1	G	Washington	Klickitat	2.10	10000	No	1999
Roosevelt Biogas 1	G	Washington	Klickitat	2.10	10000	No	1999
Roosevelt Biogas 1	G	Washington	Klickitat	2.10	10000	No	1999
Tajiguas Landfill	G	California	Santa Barbara	2.70	11332	No	2000
CSL Gas Recovery	G	Florida	Broward	2.20	11860	No	2000
Upper Rock Energy Partners LLC	G	Illinois	Rock Island	0.90	10828	No	2000
Upper Rock Energy Partners LLC	G	Illinois	Rock Island	0.90	10828	No	2000
Upper Rock Energy Partners LLC	G	Illinois	Rock Island	0.90	10828	No	2000

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Table 3.12 (Continued)
Current Landfill Gas Power Plants

Plant Name	Boiler/Generator/Committed Unit	State Name	County	Capacity MW	Heat Rate	Cogeneration	On-line Year
Countyside Genco LLC	G	Illinois	Lake	1.30	12917	No	2000
Countyside Genco LLC	G	Illinois	Lake	1.30	12917	No	2000
Countyside Genco LLC	G	Illinois	Lake	1.30	12917	No	2000
Countyside Genco LLC	G	Illinois	Lake	1.30	12917	No	2000
Countyside Genco LLC	G	Illinois	Lake	1.30	12917	No	2000
Countyside Genco LLC	G	Illinois	Lake	1.30	12917	No	2000
KMS Joliet Power Partners LP	G	Illinois	Will	0.43	10000	No	2000
Randolph Electric	G	Massachusetts	Norfolk	0.90	14779	No	2000
Randolph Electric	G	Massachusetts	Norfolk	0.90	14779	No	2000
Randolph Electric	G	Massachusetts	Norfolk	0.90	14779	No	2000
Fall River Electric	G	Massachusetts	Bristol	0.90	18550	No	2000
Fall River Electric	G	Massachusetts	Bristol	0.90	18550	No	2000
Fall River Electric	G	Massachusetts	Bristol	4.40	13219	No	2000
Grand Blanc Generating Station	G	Michigan	Genesee	0.80	11080	No	2000
MM Nashville	G	Tennessee	Davidson	0.80	11399	No	2000
MM Nashville	G	Tennessee	Davidson	0.80	11399	No	2000
Roosevelt Biogas 1	G	Washington	Klickitat	2.10	10000	No	2000
Metro Gas Recovery	G	Wisconsin	Milwaukee	0.80	13749	No	2000
Metro Gas Recovery	G	Wisconsin	Milwaukee	0.80	13749	No	2000
Metro Gas Recovery	G	Wisconsin	Milwaukee	0.80	13749	No	2000
Metro Gas Recovery	G	Wisconsin	Milwaukee	0.80	13749	No	2000
Winnebago County Landfill Gas	G	Wisconsin	Winnebago	0.90	9350	No	2000
Winnebago County Landfill Gas	G	Wisconsin	Winnebago	0.90	9350	No	2000
Winnebago County Landfill Gas	G	Wisconsin	Winnebago	0.90	9350	No	2000
Pheasant Run Landfill Gas Recovery	G	Wisconsin	Kenosha	0.80	12475	No	2000
Pheasant Run Landfill Gas Recovery	G	Wisconsin	Kenosha	0.80	12475	No	2000
Pheasant Run Landfill Gas Recovery	G	Wisconsin	Kenosha	0.80	12475	No	2000
Pheasant Run Landfill Gas Recovery	G	Wisconsin	Kenosha	0.80	12475	No	2000
Tri Cities	G	Arizona	Maricopa	0.80	11992	No	2001
Tri Cities	G	Arizona	Maricopa	0.80	11992	No	2001
Tri Cities	G	Arizona	Maricopa	0.80	11992	No	2001
Tri Cities	G	Arizona	Maricopa	0.80	11992	No	2001
Tri Cities	G	Arizona	Maricopa	0.80	11992	No	2001
RCWMD Badlands Landfill Gas Project	G	California	Riverside	1.00	12917	No	2001
Biodyne Beecher	G	Illinois	Will	4.20	12536	No	2001
Morris Genco LLC	G	Illinois	Grundy	1.30	12917	No	2001
Morris Genco LLC	G	Illinois	Grundy	1.30	12917	No	2001
Morris Genco LLC	G	Illinois	Grundy	1.30	12917	No	2001
Model City Energy Facility	G	New York	Niagara	0.77	11220	No	2001
Model City Energy Facility	G	New York	Niagara	0.77	11220	No	2001
Model City Energy Facility	G	New York	Niagara	0.77	11220	No	2001
Model City Energy Facility	G	New York	Niagara	0.77	11220	No	2001
Model City Energy Facility	G	New York	Niagara	0.77	11220	No	2001
Model City Energy Facility	G	New York	Niagara	0.77	11220	No	2001
Model City Energy Facility	G	New York	Niagara	0.77	11220	No	2001
Green Knight Energy Center	G	Pennsylvania	Northampton	2.40	18426	No	2001
Green Knight Energy Center	G	Pennsylvania	Northampton	2.40	18426	No	2001
Green Knight Energy Center	G	Pennsylvania	Northampton	2.40	18426	No	2001
Horry Land Fill Gas Site	G	South Carolina	Horry	1.10	10523	No	2001
Horry Land Fill Gas Site	G	South Carolina	Horry	1.10	10523	No	2001
Omega Hills Gas Recovery	G	Wisconsin	Washington	3.00	18070	No	2001
Superior Glacier Ridge Landfill	G	Wisconsin	Dodge	0.90	12917	No	2001
Superior Glacier Ridge Landfill	G	Wisconsin	Dodge	0.90	12917	No	2001
Berlin	G	Wisconsin	Green Lake	0.79	10583	No	2001
Berlin	G	Wisconsin	Green Lake	0.80	10583	No	2001
Berlin	G	Wisconsin	Green Lake	0.79	10583	No	2001
Marina Landfill Gas	G	California	Monterey	0.90	12917	No	2002
Altamont Gas Recovery	G	California	Alameda	1.30	10500	No	2002
Altamont Gas Recovery	G	California	Alameda	1.30	10500	No	2002
Quad Cities	G	Illinois	Rock Island	1.00	16840	No	2002
Brent Run Generating Station	G	Michigan	Genesee	0.80	12917	No	2002
Elk City Station	G	Nebraska	Douglas	0.80	12064	No	2002
Elk City Station	G	Nebraska	Douglas	0.80	12064	No	2002
Elk City Station	G	Nebraska	Douglas	0.80	12064	No	2002
Elk City Station	G	Nebraska	Douglas	0.80	12064	No	2002
HMDC Kingsland Landfill	G	New Jersey	Bergen	0.90	13406	No	2002
Blackburn Landfill Co-Generation	G	North Carolina	Catawba	0.90	10433	Yes	2002
Pheasant Run Landfill Gas Recovery	G	Wisconsin	Kenosha	0.80	12475	No	2002
Pheasant Run Landfill Gas Recovery	G	Wisconsin	Kenosha	0.80	12475	No	2002
Pheasant Run Landfill Gas Recovery	G	Wisconsin	Kenosha	0.80	12475	No	2002
Pheasant Run Landfill Gas Recovery	G	Wisconsin	Kenosha	0.80	12475	No	2002
Ridgeview	G	Wisconsin	Manitowoc	0.80	11054	No	2002
Ridgeview	G	Wisconsin	Manitowoc	0.80	11054	No	2002
Ridgeview	G	Wisconsin	Manitowoc	0.80	11054	No	2002
Colton Landfill	G	California	San Bernardino	1.27	12173	No	2003
Mid Valley Landfill	G	California	San Bernardino	1.27	12168	No	2003
Mid Valley Landfill	G	California	San Bernardino	1.27	12168	No	2003
Milliken Landfill	G	California	San Bernardino	1.07	12166	No	2003
Milliken Landfill	G	California	San Bernardino	1.07	12166	No	2003
Bradley	C	California	Los Angeles	6.18	12917	No	2003
Acme Landfill	C	California	Contra Costa	0.27	12917	No	2003
California Street	C	California	San Bernardino	0.95	12917	No	2003
South West Landfill	G	Florida	Alachua	0.80	9413	No	2003
South West Landfill	G	Florida	Alachua	0.80	9413	No	2003
South West Landfill	G	Florida	Alachua	0.80	9413	No	2003
Taylor County Landfill	C	Georgia	Taylor	3.80	12917	No	2003
Bavarian LFGTE	G	Kentucky	Boone	0.80	11489	No	2003
Bavarian LFGTE	G	Kentucky	Boone	0.80	11489	No	2003
Bavarian LFGTE	G	Kentucky	Boone	0.80	11489	No	2003
Bavarian LFGTE	G	Kentucky	Boone	0.80	11489	No	2003
Green Valley LFGTE	G	Kentucky	Greenup	0.80	11826	No	2003
Green Valley LFGTE	G	Kentucky	Greenup	0.80	11826	No	2003
Green Valley LFGTE	G	Kentucky	Greenup	0.80	11826	No	2003
Laurel Ridge LFGTE	G	Kentucky	Laurel	0.80	11021	No	2003
Laurel Ridge LFGTE	G	Kentucky	Laurel	0.80	11021	No	2003
Laurel Ridge LFGTE	G	Kentucky	Laurel	0.80	11021	No	2003
Laurel Ridge LFGTE	G	Kentucky	Laurel	0.80	11021	No	2003

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Table 3.12 (Continued)
Current Landfill Gas Power Plants

Plant Name	Boiler/Generator/Committed Unit	State Name	County	Capacity MW	Heat Rate	Cogeneration	On-line Year
PG Cnty Brown Station Road II	G	Maryland	Prince Georges	0.98	12917	No	2003
PG Cnty Brown Station Road II	G	Maryland	Prince Georges	0.98	12917	No	2003
PG Cnty Brown Station Road II	G	Maryland	Prince Georges	0.98	12917	No	2003
PG Cnty Brown Station Road II	G	Maryland	Prince Georges	0.98	12917	No	2003
Chicopee II LFG	C	Massachusetts	a	5.42	12917	No	2003
Plainville LFG	C	Massachusetts	a	5.32	12917	No	2003
Grand Blanc Generating Station	G	Michigan	Genesee	0.80	11080	No	2003
Pine Tree Acres	G	Michigan	Macomb	0.80	10976	No	2003
Pine Tree Acres	G	Michigan	Macomb	0.80	10976	No	2003
Ontario LFGTE	G	New York	Ontario	0.80	10500	No	2003
Ontario LFGTE	G	New York	Ontario	0.80	10500	No	2003
Ontario LFGTE	G	New York	Ontario	0.80	10500	No	2003
Ontario LFGTE	G	New York	Ontario	0.80	10500	No	2003
Horry Land Fill Gas Site	G	South Carolina	Horry	1.10	10523	No	2003
Reliant Energy Renewables Atascosita	G	Texas	Harris	1.70	10518	No	2003
Reliant Energy Renewables Atascosita	G	Texas	Harris	1.70	10518	No	2003
Reliant Energy Renewables Atascosita	G	Texas	Harris	1.70	10518	No	2003
Reliant Energy Renewables Atascosita	G	Texas	Harris	1.70	10518	No	2003
Reliant Energy Renewables Atascosita	G	Texas	Harris	1.70	10518	No	2003
Reliant Baytown	G	Texas	Chambers	1.00	10535	No	2003
Reliant Baytown	G	Texas	Chambers	1.00	10535	No	2003
Reliant Baytown	G	Texas	Chambers	1.00	10535	No	2003
Reliant Baytown	G	Texas	Chambers	1.00	10535	No	2003
Reliant Bluebonnet	G	Texas	Harris	1.00	11043	No	2003
Reliant Bluebonnet	G	Texas	Harris	1.00	11043	No	2003
Reliant Bluebonnet	G	Texas	Harris	1.00	11043	No	2003
Reliant Bluebonnet	G	Texas	Harris	1.00	11043	No	2003
Reliant Coastal Plains	G	Texas	Galveston	1.70	10353	No	2003
Reliant Coastal Plains	G	Texas	Galveston	1.70	10353	No	2003
Reliant Coastal Plains	G	Texas	Galveston	1.70	10353	No	2003
Reliant Coastal Plains	G	Texas	Galveston	1.70	10353	No	2003
Reliant Conroe	G	Texas	Montgomery	1.00	11168	No	2003
Reliant Conroe	G	Texas	Montgomery	1.00	11168	No	2003
Reliant Conroe	G	Texas	Montgomery	1.00	11168	No	2003
Reliant Security	G	Texas	Liberty	1.70	9910	No	2003
Reliant Security	G	Texas	Liberty	1.70	9910	No	2003
Reliant Security	G	Texas	Liberty	1.70	9910	No	2003
Tessman Road LFG - A	C	Texas	Bexar	2.47	12917	No	2003
Hutchins LFG	C	Texas	Dallas	2.47	12917	No	2003
Ridgeview	G	Wisconsin	Manitowoc	0.80	11054	No	2003
Sonoma Central Landfill Phase III	G	California	Sonoma	0.70	12917	No	2004
Sonoma Central Landfill Phase III	G	California	Sonoma	0.70	12917	No	2004
Simi Valley	C	California	Ventura	2.57	12917	No	2004
Brickyard Recycling	C	Illinois	Vermilion	0.19	12917	No	2004
Des Plaines Landfill	C	Illinois	Cook	3.80	12917	No	2004
Westchester Landfill	C	Illinois	Cook	3.33	12917	No	2004
Twiss Street (Westfi	C	Massachusetts	a	0.46	12917	No	2004
Dairyland PPA Landfi	C	Minnesota	a	2.85	12917	No	2004
Atlantic City Landfi	C	New Jersey	a	1.44	12917	No	2004
Troy	C	New York	Rensselaer	0.76	12917	No	2004
Broome County	C	New York	Broome	0.67	12917	No	2004
Ontario County SLF	C	New York	Ontario	3.04	12917	No	2004
Johnston LFG (MA RPS	C	Rhode Island	a	2.50	12917	No	2004
Central LF	C	Rhode Island	a	2.38	12917	No	2004
Charles County Landf	C	Virginia	Charles City	4.56	12917	No	2004
Fauquier County Land	C	Virginia	Fauquier	1.80	12917	No	2004
Shoosmith Landfill	C	Virginia	Chesterfield	4.56	12917	No	2004
Dane County Landfill #2 Rodefeld	G	Wisconsin	Dane	0.80	11000	No	2004
Seven Mile Creek LFG	G	Wisconsin	Eau Claire	0.98	10123	No	2004
Seven Mile Creek LFG	G	Wisconsin	Eau Claire	0.98	10123	No	2004
Seven Mile Creek LFG	G	Wisconsin	Eau Claire	0.98	10123	No	2004
Owl Creek-Richmond C	C	Georgia	Richmond	3.80	13648	No	2005
New Paris Pike LF	C	Indiana	Pike	1.52	13648	No	2005
Pearl Hollow Landfil	C	Kentucky	Hardin	2.28	13648	No	2005
Crapo Hill Landfill	C	Massachusetts	a	3.04	13648	No	2005
Glendale	C	Massachusetts	a	1.14	13648	No	2005
Atlantic County Util	C	New Jersey	Atlantic	1.52	13648	No	2005
IGENCO (Upton)	C	Pennsylvania	Franklin	5.80	13648	No	2005
Lanchester	C	Pennsylvania	Lancaster	0.88	13648	No	2005
Pine Hurst Acres	C	Pennsylvania	Northumberland	0.05	13648	No	2005
Brookside Dairy	C	Pennsylvania	Indiana	0.13	13648	No	2005
Wanner's Pride	C	Pennsylvania	Lancaster	0.15	13648	No	2005
Rolling Hills	C	Pennsylvania	Berks	2.00	13648	No	2005
Lee County Landfill	C	South Carolina	Lee	1.90	13648	No	2005
Lee County Landfill	C	South Carolina	Lee	1.90	13648	No	2005
Lee County Landfill	C	South Carolina	Lee	1.90	13648	No	2005
Davis County	C	Utah	Davis	0.95	13648	No	2005
Coventry LFG	C	Vermont	a	4.56	13648	No	2005
Rodefeld Landfill Ga	C	Wisconsin	Dane	3.80	13648	No	2005
Double S Dairy Diges	C	Wisconsin	Green Lake	0.38	13648	No	2005
Los Reales LFG Expan	C	Arizona	a	1.90	13648	No	2006
Dekalb County Landfi	C	Georgia	De Kalb	3.04	13648	No	2006
Harrisburg Facility	C	Pennsylvania	Dauphin	20.82	13648	No	2006
Lee County Landfill	C	South Carolina	Lee	1.90	13648	No	2006
Texas Mandate Landfill Gas	C	Texas	a	5.00	13648	No	2006
Lee County Solid Waste Energy	C	Florida	Lee	18.60	13648	No	2007

Source:
National Electric Energy System (NEEDS) Database for IPM 2006, http://epa.gov/airmarkets/progsregs/epa-ipm/index.html.

[a] Data are not available

Figure 3.5
New Municipal Solid Waste Power Plants by Year

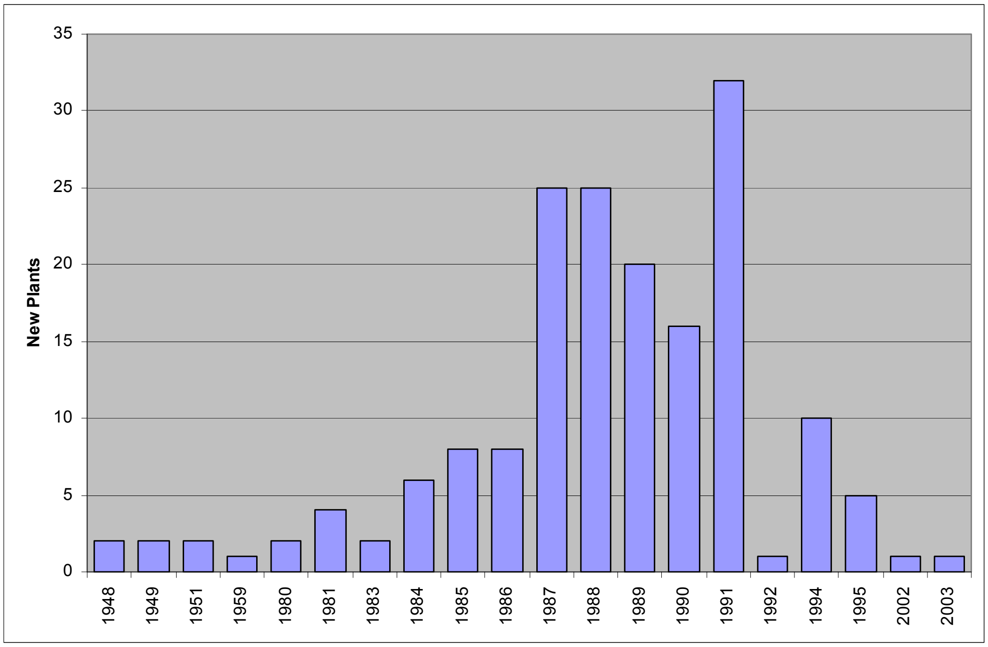
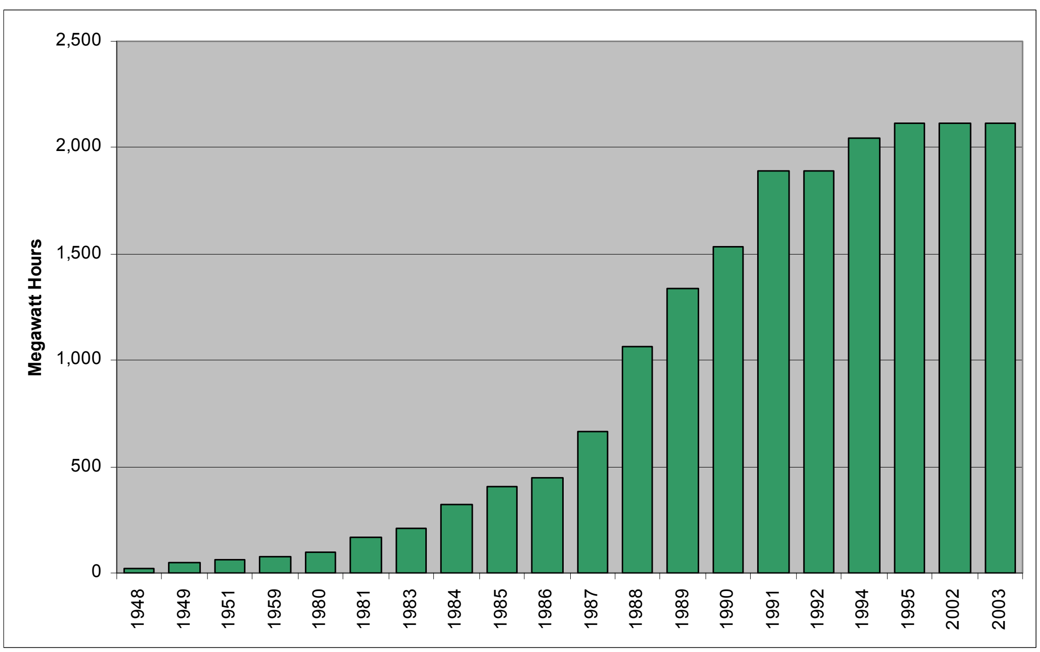


Figure 3.6
Municipal Solid Waste Power Plant Capacity by Year
(Megawatt Hours)



Source:
National Electric Energy System (NEEDS) Database for IPM 2006,
http://epa.gov/airmarkets/progsregs/epa-ipm/index.html.

Notes:
1. Only years in which new plants were brought online are shown.
2. Power plant capacity based on NEEDS 2006 Data.

Table 3.13
Current Municipal Solid Waste Power Plants

Plant Name	Boiler/Generator/Committed Unit	State Name	County	Capacity MW	Heat Rate	Cogeneration	On-line Year
Wilmarth	B	Minnesota	Blue Earth	12.00	18268	No	1948
Wilmarth	B	Minnesota	Blue Earth	12.00	18268	No	1948
Red Wing	B	Minnesota	Goodhue	12.00	16876	No	1949
Red Wing	B	Minnesota	Goodhue	12.00	16876	No	1949
Elk River	B	Minnesota	Sherburne	7.80	14800	No	1951
Elk River	B	Minnesota	Sherburne	7.50	14800	No	1951
Elk River	B	Minnesota	Sherburne	14.50	14800	No	1959
American Ref-Fuel of Niagara	B	New York	Niagara	9.00	11987	Yes	1980
American Ref-Fuel of Niagara	B	New York	Niagara	9.00	11987	Yes	1980
Miami Dade County Resource Recovery	B	Florida	Miami-Dade	17.91	21020	No	1981
Miami Dade County Resource Recovery	B	Florida	Miami-Dade	17.91	21020	No	1981
Miami Dade County Resource Recovery	B	Florida	Miami-Dade	17.91	21020	No	1981
Miami Dade County Resource Recovery	B	Florida	Miami-Dade	17.91	21020	No	1981
Pinellas County Resource Recovery	B	Florida	Pinellas	20.55	16170	Yes	1983
Pinellas County Resource Recovery	B	Florida	Pinellas	20.55	16170	Yes	1983
Wheelabrator Baltimore Refuse	B	Maryland	Baltimore City	20.43	9650	Yes	1984
Wheelabrator Baltimore Refuse	B	Maryland	Baltimore City	20.43	9650	Yes	1984
Wheelabrator Baltimore Refuse	B	Maryland	Baltimore City	20.43	9650	Yes	1984
Wheelabrator Westchester	B	New York	Westchester	17.00	17567	No	1984
Wheelabrator Westchester	B	New York	Westchester	17.00	17567	No	1984
Wheelabrator Westchester	B	New York	Westchester	17.00	17567	No	1984
McKay Bay Facility	B	Florida	Hillsborough	4.50	21020	No	1985
McKay Bay Facility	B	Florida	Hillsborough	4.50	21020	No	1985
McKay Bay Facility	B	Florida	Hillsborough	4.50	21020	No	1985
McKay Bay Facility	B	Florida	Hillsborough	4.50	21020	No	1985
Wheelabrator North Andover	B	Massachusetts	Essex	16.50	19214	No	1985
Wheelabrator North Andover	B	Massachusetts	Essex	16.50	19214	No	1985
Wheelabrator Saugus	B	Massachusetts	Essex	16.00	18019	No	1985
Wheelabrator Saugus	B	Massachusetts	Essex	16.00	18019	No	1985
Commerce Refuse To Energy	B	California	Los Angeles	7.00	16788	No	1986
Pinellas County Resource Recovery	B	Florida	Pinellas	17.00	16170	Yes	1986
Southernmost Waste To Energy	G	Florida	Monroe	2.30	17330	No	1986
Oswego County Energy Recovery	G	New York	Oswego	1.67	17330	Yes	1986
Oswego County Energy Recovery	G	New York	Oswego	1.67	17330	Yes	1986
Covanta Marion Inc.	B	Oregon	Marion	5.75	11987	Yes	1986
Covanta Marion Inc.	B	Oregon	Marion	5.75	11987	Yes	1986
Wasatch Energy Systems Energy	G	Utah	Davis	1.40	11987	Yes	1986
Covanta Bristol Energy	B	Connecticut	Hartford	6.60	16715	No	1987
Covanta Bristol Energy	B	Connecticut	Hartford	6.60	16715	No	1987
Bay Resource Management Center	B	Florida	Bay	5.00	19140	No	1987
Bay Resource Management Center	B	Florida	Bay	5.00	19140	No	1987
Hillsborough County Resource Recovery	B	Florida	Hillsborough	8.67	20245	No	1987
Hillsborough County Resource Recovery	B	Florida	Hillsborough	8.67	20245	No	1987
Hillsborough County Resource Recovery	B	Florida	Hillsborough	8.67	20245	No	1987
Maine Energy Recovery	B	Maine	York	9.00	15226	No	1987
Maine Energy Recovery	B	Maine	York	9.00	15226	No	1987
Penobscot Energy Recovery	B	Maine	Penobscot	10.60	17330	No	1987
Penobscot Energy Recovery	B	Maine	Penobscot	10.60	17330	No	1987
Wheelabrator Millbury Facility	B	Massachusetts	Worcester	20.00	15079	No	1987
Wheelabrator Millbury Facility	B	Massachusetts	Worcester	20.00	15079	No	1987
Olmsted Waste Energy	G	Minnesota	Olmsted	1.30	17330	Yes	1987
Olmsted Waste Energy	G	Minnesota	Olmsted	1.40	17330	Yes	1987
Wheelabrator Claremont Facility	G	New Hampshire	Sullivan	4.50	21020	No	1987
Dutchess County Resource Recovery	B	New York	Dutchess	3.60	13117	Yes	1987
Dutchess County Resource Recovery	B	New York	Dutchess	3.60	13117	Yes	1987
Covanta Alexandria/Arlington Energy	B	Virginia	Alexandria	9.67	17330	No	1987
Covanta Alexandria/Arlington Energy	B	Virginia	Alexandria	9.67	17330	No	1987
Covanta Alexandria/Arlington Energy	B	Virginia	Alexandria	9.67	17330	No	1987
SPSA Waste To Energy Power Plant	B	Virginia	Portsmouth	11.63	17330	Yes	1987
SPSA Waste To Energy Power Plant	B	Virginia	Portsmouth	11.63	17330	Yes	1987
SPSA Waste To Energy Power Plant	B	Virginia	Portsmouth	11.63	17330	Yes	1987
SPSA Waste To Energy Power Plant	B	Virginia	Portsmouth	11.63	17330	Yes	1987
Covanta Stanislaus Energy	B	California	Stanislaus	9.00	18297	No	1988
Covanta Stanislaus Energy	B	California	Stanislaus	9.00	18297	No	1988
Southeast Resource Recovery	B	California	Los Angeles	9.32	18340	Yes	1988
Southeast Resource Recovery	B	California	Los Angeles	9.32	18340	Yes	1988
Southeast Resource Recovery	B	California	Los Angeles	9.32	18340	Yes	1988
Covanta Wallingford Energy	B	Connecticut	New Haven	2.80	21020	No	1988
Covanta Wallingford Energy	B	Connecticut	New Haven	2.80	21020	No	1988
Covanta Wallingford Energy	B	Connecticut	New Haven	2.80	21020	No	1988
Wheelabrator Bridgeport	B	Connecticut	Fairfield	20.42	15666	No	1988
Wheelabrator Bridgeport	B	Connecticut	Fairfield	20.42	15666	No	1988
Wheelabrator Bridgeport	B	Connecticut	Fairfield	20.42	15666	No	1988
Covanta Mid-Connecticut Energy	B	Connecticut	Hartford	37.60	19402	No	1988
Covanta Mid-Connecticut Energy	B	Connecticut	Hartford	37.60	19402	No	1988
Covanta Mid-Connecticut Energy	B	Connecticut	Hartford	37.60	17330	No	1988
Regional Waste Systems	B	Maine	Cumberland	5.75	19483	No	1988
Regional Waste Systems	B	Maine	Cumberland	5.75	19483	No	1988
Pioneer Valley Resource Recovery	G	Massachusetts	Hampden	7.50	21020	No	1988
SEMASS Resource Recovery	B	Massachusetts	Plymouth	26.67	17961	No	1988
SEMASS Resource Recovery	B	Massachusetts	Plymouth	26.67	17961	No	1988
SEMASS Resource Recovery	B	Massachusetts	Plymouth	26.67	17961	No	1988
Greater Detroit Resource Recovery	B	Michigan	Wayne	21.20	17330	Yes	1988
Greater Detroit Resource Recovery	B	Michigan	Wayne	21.20	17330	Yes	1988
Greater Detroit Resource Recovery	B	Michigan	Wayne	21.20	17330	Yes	1988
Covanta Warren Energy	B	New Jersey	Warren	5.00	18843	No	1988
Covanta Warren Energy	B	New Jersey	Warren	5.00	18843	No	1988

Continued on next page

Table 3.13 (Continued)
Current Municipal Solid Waste Power Plants

Plant Name	Boiler/Generator/Committed Unit	State Name	County	Capacity MW	Heat Rate	Cogeneration	On-line Year
North County Regional Resource	B	Florida	Palm Beach	21.75	17862	No	1989
North County Regional Resource	B	Florida	Palm Beach	21.75	17862	No	1989
Covanta Haverhill	B	Massachusetts	Essex	21.39	15734	No	1989
Covanta Haverhill	B	Massachusetts	Essex	21.39	15734	No	1989
Kent County Waste to Energy Facility	B	Michigan	Kent	7.85	9650	Yes	1989
Kent County Waste to Energy Facility	B	Michigan	Kent	7.85	9650	Yes	1989
Covanta Hennepin Energy	B	Minnesota	Hennepin	16.85	15894	No	1989
Covanta Hennepin Energy	B	Minnesota	Hennepin	16.85	15894	No	1989
Wheelabrator Concord Facility	B	New Hampshire	Merrimack	7.00	18592	No	1989
Wheelabrator Concord Facility	B	New Hampshire	Merrimack	7.00	18592	No	1989
American Ref-Fuel of Hempstead	B	New York	Nassau	22.57	16566	No	1989
American Ref-Fuel of Hempstead	B	New York	Nassau	22.57	17330	No	1989
American Ref-Fuel of Hempstead	B	New York	Nassau	22.57	17330	No	1989
Covanta Babylon Energy	B	New York	Suffolk	7.18	21020	No	1989
Covanta Babylon Energy	B	New York	Suffolk	7.18	21020	No	1989
York County Resource Recovery	B	Pennsylvania	York	9.33	20113	No	1989
York County Resource Recovery	B	Pennsylvania	York	9.33	20113	No	1989
York County Resource Recovery	B	Pennsylvania	York	9.33	20113	No	1989
Charleston Resource Recovery Facility	B	South Carolina	Charleston	4.75	17330	Yes	1989
Charleston Resource Recovery Facility	B	South Carolina	Charleston	4.75	17330	Yes	1989
Covanta Lake County Energy	B	Florida	Lake	6.25	20026	No	1990
Covanta Lake County Energy	B	Florida	Lake	6.25	20026	No	1990
American Ref-Fuel of Essex	B	New Jersey	Essex	10.00	11500	No	1990
American Ref-Fuel of Essex	B	New Jersey	Essex	10.00	11500	No	1990
American Ref-Fuel of Essex	B	New Jersey	Essex	40.00	11500	No	1990
Wheelabrator Gloucester LP	B	New Jersey	Gloucester	6.00	19829	No	1990
Wheelabrator Gloucester LP	B	New Jersey	Gloucester	6.00	19829	No	1990
MacArthur Waste to Energy Facility	B	New York	Suffolk	2.30	21020	No	1990
MacArthur Waste to Energy Facility	B	New York	Suffolk	2.30	17330	No	1990
Lancaster County Resource Recovery	B	Pennsylvania	Lancaster	10.80	17820	No	1990
Lancaster County Resource Recovery	B	Pennsylvania	Lancaster	10.80	17820	No	1990
Lancaster County Resource Recovery	B	Pennsylvania	Lancaster	10.80	17820	No	1990
Covanta Fairfax Energy	B	Virginia	Fairfax	19.75	17055	No	1990
Covanta Fairfax Energy	B	Virginia	Fairfax	19.75	17055	No	1990
Covanta Fairfax Energy	B	Virginia	Fairfax	19.75	17055	No	1990
Covanta Fairfax Energy	B	Virginia	Fairfax	19.75	17055	No	1990
American Ref-Fuel of SE CT	B	Connecticut	New London	6.00	18528	No	1991
American Ref-Fuel of SE CT	B	Connecticut	New London	6.00	18528	No	1991
Pasco Cnty Solid Waste Resource	B	Florida	Pasco	8.67	21020	No	1991
Pasco Cnty Solid Waste Resource	B	Florida	Pasco	8.67	21020	No	1991
Pasco Cnty Solid Waste Resource	B	Florida	Pasco	8.67	21020	No	1991
Wheelabrator South Broward	B	Florida	Broward	19.30	17997	No	1991
Wheelabrator South Broward	B	Florida	Broward	19.30	17997	No	1991
Wheelabrator South Broward	B	Florida	Broward	19.30	17997	No	1991
Wheelabrator North Broward	B	Florida	Broward	18.67	18534	No	1991
Wheelabrator North Broward	B	Florida	Broward	18.67	18534	No	1991
Wheelabrator North Broward	B	Florida	Broward	18.67	18534	No	1991
Camden Resource Recovery Facility	B	New Jersey	Camden	10.00	20835	No	1991
Camden Resource Recovery Facility	B	New Jersey	Camden	10.00	20835	No	1991
Camden Resource Recovery Facility	B	New Jersey	Camden	10.00	20835	No	1991
Wheelabrator Hudson Falls, LLC	B	New York	Washington	5.75	9650	No	1991
Wheelabrator Hudson Falls, LLC	B	New York	Washington	5.75	9650	No	1991
Huntington Resource Recovery Facility	B	New York	Suffolk	8.33	18674	No	1991
Huntington Resource Recovery Facility	B	New York	Suffolk	8.33	18674	No	1991
Huntington Resource Recovery Facility	B	New York	Suffolk	8.33	18674	No	1991
New Hanover County WASTEC	B	North Carolina	New Hanover	0.57	9650	Yes	1991
New Hanover County WASTEC	B	North Carolina	New Hanover	0.57	9650	Yes	1991
New Hanover County WASTEC	B	North Carolina	New Hanover	0.57	9650	Yes	1991
American Ref-Fuel of Delaware Valley	B	Pennsylvania	Delaware	13.33	18675	No	1991
American Ref-Fuel of Delaware Valley	B	Pennsylvania	Delaware	13.33	18675	No	1991
American Ref-Fuel of Delaware Valley	B	Pennsylvania	Delaware	13.33	18675	No	1991
American Ref-Fuel of Delaware Valley	B	Pennsylvania	Delaware	13.33	18675	No	1991
American Ref-Fuel of Delaware Valley	B	Pennsylvania	Delaware	13.33	18675	No	1991
American Ref-Fuel of Delaware Valley	B	Pennsylvania	Delaware	13.33	18675	No	1991
Montenay Montgomery LP	B	Pennsylvania	Montgomery	14.00	17330	No	1991
Montenay Montgomery LP	B	Pennsylvania	Montgomery	14.00	17330	No	1991
Wheelabrator Spokane	B	Washington	Spokane	13.00	18657	No	1991
Wheelabrator Spokane	B	Washington	Spokane	13.00	18657	No	1991
MMWAC Resource Recovery Facility	G	Maine	Androscoggin	2.10	17330	No	1992
Lee County Solid Waste Energy	B	Florida	Lee	19.50	15175	No	1994
Lee County Solid Waste Energy	B	Florida	Lee	19.50	15175	No	1994
Union County Resource Recovery	B	New Jersey	Union	12.50	17339	No	1994
Union County Resource Recovery	B	New Jersey	Union	12.50	17339	No	1994
Union County Resource Recovery	B	New Jersey	Union	12.50	17339	No	1994
Onondaga County Resource Recovery	B	New York	Onondaga	10.00	17330	No	1994
Onondaga County Resource Recovery	B	New York	Onondaga	10.00	17330	No	1994
Onondaga County Resource Recovery	B	New York	Onondaga	10.00	17330	No	1994
Wheelabrator Falls	B	Pennsylvania	Bucks	24.05	15195	No	1994
Wheelabrator Falls	B	Pennsylvania	Bucks	24.05	15195	No	1994
Wheelabrator Lisbon	B	Connecticut	New London	6.50	16839	No	1995
Wheelabrator Lisbon	B	Connecticut	New London	6.50	16839	No	1995
Montgomery County Resource Recovery	B	Maryland	Montgomery	18.00	17172	No	1995
Montgomery County Resource Recovery	B	Maryland	Montgomery	18.00	17172	No	1995
Montgomery County Resource Recovery	B	Maryland	Montgomery	18.00	17172	No	1995
New Hanover County WASTEC	G	North Carolina	New Hanover	1.90	9650	Yes	2002
Perham Incinerator	G	Minnesota	Otter Tail	1.20	17330	No	2003

Source:
National Electric Energy System (NEEDS) Database for IPM 2006,
http://epa.gov/airmarkets/progsregs/epa-ipm/index.html.

Table 3.14
Total Net Generation of Electricity by State from Wood and Wood Waste, 2005
(Thousand Kilowatt hours)

State	Wood/Wood Waste[a]	Percent of all Renewables	Total from all Renewables
Alabama	3,738,421	26.89%	13,903,838
Arizona	12058	0.19%	6,484,059
Arkansas	1,706,996	35.44%	4,817,205
California	3,610,097	5.70%	63,280,278
Connecticut	7314	0.59%	1,231,534
Florida	2,005,937	43.32%	4,630,013
Georgia	3,148,749	43.38%	7,258,184
Idaho	577,040	6.33%	9,119,161
Kentucky	359,065	10.61%	3,383,578
Louisiana	2,643,987	74.79%	3,535,442
Maine	3,786,633	46.37%	8,165,916
Maryland	195,466	8.44%	2,316,510
Massachusetts	120,027	5.22%	2,300,240
Michigan	1,801,330	45.24%	3,981,975
Minnesota	649,415	18.98%	3,422,350
Mississippi	1,519,941	99.65%	1,525,285
Montana	65,245	0.68%	9,652,594
New Hampshire	785733	28.67%	2,740,802
New York	537,510	1.93%	27,780,976
North Carolina	1,739,583	24.04%	7,234,871
Ohio	359,014	39.24%	914,831
Oklahoma	289,217	7.68%	3,767,351
Oregon	809,306	2.48%	32,589,968
Pennsylvania	687,496	15.07%	4,561,646
South Carolina	1,697,465	35.94%	4,723,363
Tennessee	528,281	5.35%	9,868,426
Texas	843,789	12.66%	6,666,969
Vermont	410,491	25.14%	1,632,789
Virginia	1,799,862	45.20%	3,981,778
Washington	1,419,394	1.91%	74,190,549
Wisconsin	824,996	27.18%	3,034,797
Total	**38,679,858**	**11.63%**	**332,697,278**

Source:
Energy Information Administration. 2008. *Renewable Energy Annual 2006*, Table 1.17, http://www.eia.doe.gov/cneaf/solar.renewables/page/rea_data/rea_sum.html.

Note: States not listed contained no data for wood/wood waste.

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[a] Black liquor, and wood/woodwaste solids and liquids.

Table 3.15
Net Generation and Fuel Consumption at Power Plants Consuming Coal and Biomass by State and Plant Name, 2003

State	County	Plant Name	Net Electricity Generation (Thousand Kilowatthours)	Total Energy Consumed (MMBtu)	Energy Consumed from Biomass (MMBtu)	Percent of Energy Consumed from		
						Biomass	Coal	Other
New York	Yates	AES Greenidge LLC	1,040,354	11,705,155	99,328	0.85	98.90	0.25
	Jefferson	Black River Power LLC	355,861	4,539,007	9,635	0.21	74.06	25.73
	Niagara	WPS Power Niagara	251,890	3,353,781	28,760	0.86	98.21	0.94
North Carolina	Haywood	Canton North Carolina	344,245	20,265,972	9,641,230	47.57	52.12	0.30
	Forsyth	Corn Products Winston Salem	56,591	3,948,209	3,441,379	87.16	11.73	1.11
	Halifax	International Paper Roanoke Ra	174,563	12,732,892	8,624,055	67.73	23.23	9.04
	Columbus	International Paper Riegelwood	503,301	25,783,234	18,114,256	70.26	5.22	24.52
	Bladen	Elizabethtown Power LLC	117,590	1,659,872	383,987	23.13	76.87	
	Robeson	Lumberton	83,280	1,075,248	201,011	18.69	81.31	
	Martin	Weyerhaeuser Plymouth NC	806,280	39,957,341	32,330,211	80.91	17.27	1.81
	Pickaway	Picway	402,519	4,674,846	29,550	0.63	98.86	0.51
Ohio	Ross	Mead Custom Paper	532,453	15,151,763	8,077,827	53.31	45.29	1.40
Pennsylvania	Delaware	Chester Operations	389,779	6,591,803	23,657	0.36	54.54	45.10
	Northampton	Northhampton Generating LP	820,274	8,762,273	205,553	2.35	56.42	41.24
	Schuylkill	Kline Township Cogen Facility	393,564	5,978,255	423,384	7.08	92.01	0.91
	York	P H Glatfelter	680,328	17,422,344	8,766,181	50.32	48.75	0.94
	Elk	Johnsonburg Mill	279,550	8,572,138	4,801,100	56.01	38.92	5.07
South Carolina	Richland	International Paper Eastover F	529,454	21,208,564	16,189,319	76.33	16.94	6.72
	Georgetown	International Paper Georgetown	527,894	21,735,489	17,702,311	81.44	10.33	8.23
	Florence	Stone Container Florence Mill	710,340	20,402,914	12,541,662	61.47	27.28	11.25
Tennessee	McMinn	Bowater Newsprint Calhoun Oper	525,280	21,325,300	15,574,553	73.03	25.16	1.81
	Sullivan	Tennessee Eastman Operations	1,239,569	40,812,321	300,054	0.74	98.39	0.88
	Hardin	Packaging Corp of America	373,340	22,112,700	18,034,060	81.56	9.63	8.82
	Sullivan	Weyerhaeuser Kingsport Mill	101,154	6,722,666	5,825,213	86.65	13.35	
Virginia	Bedford	Georgia Pacific Big Island	52,032	3,357,369	1,720,872	51.26	46.83	1.91
	Isle of Wight	International Paper Franklin M	776,727	25,587,752	14,481,554	56.60	22.09	21.32
	King William	St Laurent Paper West Point	525,859	17,126,189	12,851,000	75.04	17.05	7.92
	Portsmouth City	SPSA Waste To Energy Power Pla	173,116	5,415,699	5,388,534	99.50	0.00	0.50
	Hopewell City	Stone Container Hopewell Mill	319,104	8,636,244	6,255,293	72.43	25.30	2.27
	Covington	Covington Facility	671,771	29,004,636	13,064,973	45.04	42.23	12.72
Washington	Cowlitz	Weyerhaeuser Longview WA	327,661	18,235,976	14,422,210	79.09	7.72	13.19
West Virginia	Preston	Albright	1,669,380	18,709,260	1,806	0.01	99.79	0.20
	Pleasants	Willow Island	1,095,678	12,279,409	196,900	1.60	98.02	0.37
	Kanawha	Union Carbide South Charleston	21,488	3,309,914	73,163	2.21	64.49	33.30
Wisconsin	Wood	Georgia Pacific Nekoosa Mill	203,635	5,584,402	3,224,101	57.73	36.09	6.17
	Price	Fraser Paper	36,422	334,360	113,361	33.90	66.10	
	Outagamie	International Paper Kaukauna M	211,943	7,634,467	3,344,608	43.81	39.06	17.13
	Dane	Blount Street	451,308	6,299,195	180,864	2.87	80.63	16.50
	Manitowoc	Manitowoc	315,087	4,761,246	23,264	0.49	66.17	33.34
	Ashland	Bay Front	296,711	4,529,448	1,795,854	39.65	58.60	1.75
	Lincoln	Packaging of America Tomahawk	133,041	10,575,641	7,959,582	75.26	23.01	1.72
	Dane	Univ of Wisc Madison Charter S	42,282	3,947,769	323,026	8.18	82.18	9.64
	Dodge	Waupun Correctional Central He	4,130	288,951	20,665	7.15	88.90	3.95
	Wood	Biron Mill	246,244	4,614,572	326,216	7.07	91.64	1.29
	Marinette	Niagara Mill	114,749	3,000,275	196,181	6.54	71.80	21.66
	Portage	Whiting Mill	25,362	1,572,137	208,755	13.28	78.43	8.29
	Wood	Wisconsin Rapids Pulp Mill	374,930	12,125,962	8,338,658	68.77	26.14	5.10
	Marathon	Wausau Mosinee Paper Pulp	122,059	12,335,121	10,406,885	84.37	13.37	2.26
	Sheboygan	Edgewater	4,893,820	47,746,013	665,280	1.39	98.48	0.12
Total			**95,304,634**	**1,709,675,399**	**630,926,946**	**36.90**	**53.78**	**9.32**

Source:
Energy Information Administration. 2003. *Net Generation and Fuel Consumption at Power Plants Consuming Coal and Biomass by State and Plant Name*, derived from Table 9, http://www.eia.doe.gov/cneaf/solar.renewables/page/trends/table1.html.

Notes: Blank cell indicates the plant had no consumption or other energy to report.
MMBtu = One million British thermal units.

Table 3.16
Coal Displacement Calculation, 2006

Conversion Formula:

Step 1 *Capacity (A) x Capacity Factor (B) x Annual Hours (C) = Annual Electricity Generation (D)*
Step 2 *Annual Electricity Generation (D) x Conversion Efficiency (E) = Total Output (F)*
Step 3 *Total Output (F) / Fuel Heat Rate (G) = Quantity Fuel (H)*

Technology	Wind	Geothermal	Biomass	Hydropower	PV	Solar Thermal
(A) Capacity (kW)	11,558,205	2,232,495	6,594,096	78,312,583	280,355	388,893
(B) Capacity Factor (%)	36.0%	90.0%	80.0%	44.2%	22.5%	24.4%
(C) Annual Hours	8,760	8,760	8,760	8,760	8,760	8,760
(D) Annual Electricity Generation (kWh)	36,449,954,187	17,600,991,128	46,211,427,727	303,176,455,525	552,579,314	831,235,472
(E) Conversion Efficiency (Btu/kWh)	10,107	10,107	10,107	10,107	10,107	10,107
(F) Total Output (Million Btu)	368,399,686	177,893,217	467,058,900	3,064,204,435	5,584,919	8,401,296
(G) Coal Heat Rate (Btu per short ton)	20,411,000	20,411,000	20,411,000	20,411,000	20,411,000	20,411,000
(H) Coal (short tons)	18,049,076	8,715,556	22,882,705	150,125,150	273,623	411,606

Source:
National Renewable Energy Laboratory. *Power Technologies Energy Data Book*, Table 12.3, http://www.nrel.gov/analysis/power_databook/chapter12.html.
Original Sources: Capacity: Energy Information Administration. 2006. *Annual Energy Outlook 2006*, DOE/EIA-0383, Washington, DC, February, Table A16.
Capacity Factors: Hydropower calculated from Energy Information Administration. 2006. *Annual Energy Outlook 2006*, DOE/EIA-0383, Washington, DC, February, Table A16. All others based on U.S. Department of Energy. 1997. *Renewable Energy Technology Characterizations*, EPRI TR-109496, 1997 and Program data.
Conversion Efficiency: Energy Information Administration. 2005. *Annual Energy Review 2004*, DOE/EIA-0384, Washington, DC, August, Table A6.
Heat Rate: Energy Information Administration. 2006. *Annual Energy Outlook 2006*, DOE/EIA-0383, Washington, DC, February, Table F1.

Note: Capacity values exclude combined-heat-and-power (CHP) data but include end-use sector (industrial and commercial) non-CHP data.

Table 3.17
Renewable Energy Impacts Calculation, 2006

Conversion Formula: *Step 1* *Capacity (A) x Capacity Factor (B) x Annual Hours (C) = Annual Electricity Generation (D)*
Step 2 *Annual Electricity Generation (D) x Competing Heat Rate (E) = Annual Output (F)*
Step 3 *Annual Output (F) x Emissions Coefficient (G) = Annual Emissions Displaced (H)*

Technology	Wind	Geothermal	Biomass	Hydropower	PV	Solar Thermal
(A) Capacity (kW)	11,558,205	2,232,495	6,594,096	78,312,583	280,355	388,893
(B) Capacity Factor (%)	36.0%	90.0%	80.0%	44.2%	22.5%	24.4%
(C) Annual Hours	8,760	8,760	8,760	8,760	8,760	8,760
(D) Annual Electricity Generation (kWh)	36,449,954,187	17,600,991,128	46,211,427,727	303,176,455,525	552,579,314	831,235,472
(E) Competing Heat Rate (Btu/kWh)	10,107	10,107	10,107	10,107	10,107	10,107
(F) Annual Output (Trillion Btu)	368.4	177.9	467.1	3,064.2	5.6	8.4
(G) Carbon Coefficient (MMTCB/Trillion Btu)	0.01783	0.01783	0.01783	0.01783	0.01783	0.01783
(H) Annual Carbon Displaced (MMTC)	6.569	3.172	8.328	54.635	0.100	0.128

Source:
National Renewable Energy Laboratory. *Power Technologies Energy Data Book*, Table 12.1, http://www.nrel.gov/analysis/power_databook/chapter12.html.
Original sources: Capacity: Projected values for the year 2006 from Energy Information Administration. 2006. *Annual Energy Outlook 2006*, DOE/EIA-0383, Washington, DC, February, Table A16, 2006.
Capacity Factors: Hydropower calculated from Energy Information Administration. 2005. *Annual Energy Outlook 2005*, DOE/EIA-0383, Washington, DC, February, Table A16. All others based on U.S. Department of Energy. 1997. *Renewable Energy Technology Characterizations*, EPRI TR-109496, Program data.
Heat Rate: Energy Information Administration. 2005. *Annual Energy Review 2004*, DOE/EIA-0384, Washington, DC, August, Table A6.
Carbon Coefficient: U.S. Department of Energy. 2003. *GPRA2003 Data Call*, Appendix B, page B-16.

Notes: Capacity values exclude combined-heat-and-power (CHP) data but include end-use sector (industrial and commercial) non-CHP data. Competing heat rate from Fossil-Fueled Steam-Electric Plants heat rate.

Table 3.18
Number of Home Electricity Needs Met Calculation, 2006

Conversion Formula: *Step 1* *Capacity (A) x Capacity Factor (B) x Annual Hours (C) = Annual Electricity Generation (D)*
Step 2 *Annual Electricity Generation (D) / Average Consumption (E) = Number of Households (F)*

Technology	Wind	Geothermal	Biomass	Hydropower	PV	Solar Thermal
(A) Capacity (kW)	11,558,205	2,232,495	6,594,096	78,312,583	280,355	388,893
(B) Capacity Factor (%)	36.0%	90.0%	80.0%	44.2%	22.5%	24.4%
(C) Annual Hours	8,760	8,760	8,760	8,760	8,760	8,760
(D) Annual Electricity Generation (kWh)	36,449,954,187	17,600,991,128	46,211,427,727	303,176,455,525	552,579,314	831,235,472
(E) Average Annual Household Electricity Consumption (kWh)	11,576	11,576	11,576	11,576	11,576	11,576
(F) Number of Households	3,148,804	1,520,497	3,992,068	26,190,515	47,736	71,808

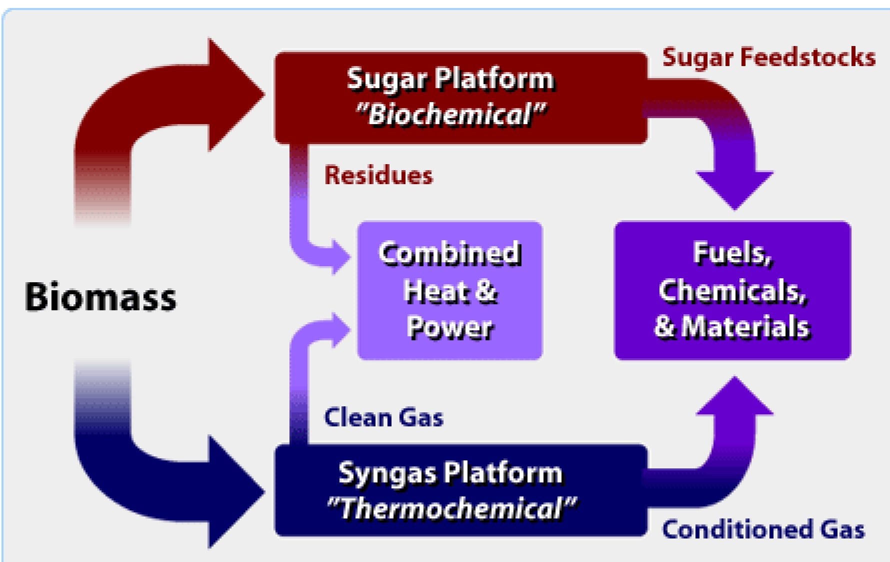
Source:
National Renewable Energy Laboratory. *Power Technologies Data Book*, Table 12.2, http://www.nrel.gov/analysis/power_databook/chapter12.html.
Original sources: Capacity: Energy Information Administration. 2006. *Annual Energy Outlook 2006*, DOE/EIA-0383, Washington, DC, February, Table A16.
Capacity Factors: Hydropower calculated from Energy Information Administration. 2005. *Annual Energy Outlook 2005*, DOE/EIA-0383, Washington, DC, February, Table A16. All others based on U.S. Department of Energy. 1997. *Renewable Energy Technology Characterizations*, EPRI TR-109496, and Program data.
Household electricity Consumption: Calculated from Energy Information Administration. 2006. *Annual Energy Outlook 2006*, DOE/EIA-0383, Washington, DC, February, Tables A4 and A8.

Note: Capacity values exclude combined-heat-and-power (CHP) data but include end-use sector (industrial and commercial) non-CHP data.

4. BIOREFINERIES

BIOREFINERIES OVERVIEW

As a petroleum refinery uses petroleum as the major input and processes it into many different products, a biorefinery uses biomass as the major input and processes it into many different products. Wet-mill and dry-mill corn processing plants and pulp and paper mills can be categorized as biorefineries since they produce multiple products from biomass. Ethanol production facilities produce ethanol and other products from the sugar and starch components of biomass. As of September 2008, the Renewable Fuels Association listed 168 operating ethanol biorefineries with a total production capacity of 9,961 million gallon per year (MGY). New construction and expansion would add another 3,790 MGY. Distillers grains, a high-value, protein rich product being used for livestock feed is the major co-product of the existing dry-mill ethanol biorefineries. Wet-mill ethanol biorefineries have the capacity to produce high fructose corn syrup, and a wide variety of chemical feedstocks such as citric acid, lactic acid, lysine and other products as well as ethanol. Research over the past several years has developed several technologies that have the capability of converting many types of lignocellulosic biomass resources into a wide range of products. The goal is for biorefineries to produce both high-volume liquid fuels and high-value chemicals or products in order to address national energy needs while enhancing operation economics. History was made in 2007 with the ground breaking for construction of the first commercial-scale lignocellulosic ethanol biorefinery in the U.S. The Range Fuels facility near Soperton, Georgia will use initially use wood residues from timber harvesting to produce ethanol and other products. Pulp and Papers mills are existing biorefineries that produce heat, and electricity as well as pulp or paper and some chemicals, but they also have the potential of producing very large amounts of biofuels and biomass power from processing residuals such as bark and black liquor. Three pulp production facilities were included among the 9 awarded funding in 2008 for building small-scale prototype biorefineries to test new ideas.



Two of the emerging biorefinery platforms are the sugar platform and the thermochemical platform (also known as the syngas platform) illustrated below. Sugar platform biorefineries would break biomass down into different types of component sugars for fermentation or other biological processing into various fuels and chemicals. Thermochemical biorefineries would convert biomass to synthesis gas (hydrogen and carbon monoxide) or pyrolysis oil, the various components of which could be directly used as fuel. Several other biorefinery platforms are included among the medium and small-scale projects being cost-shared by the U.S. Department of Energy, state funding, and private investment.

Source:
National Renewable Energy Laboratory, Biomass Program, July 2008, http://www.nrel.gov/biomass/biorefinery.html.

As of July 2008, there were 55 cellulosic biorefineries either completed, under construction or in the planning stage in a total of 31 states across the country. Altogether they create an expected capacity of 629 million gallons per year (MGY) and a potential expansion to 995 MGY. Most of the demonstration and commercial scale facilities are scheduled to start operation on 2009 or 2010.

Table 4.1
Lignocellulosic Biorefineries by Scale and Stage of Development

	Commercial Scale[a]	Demonstration Scale[b]	Pilot Scale[c]
Completed	-	2	3
Under Construction	1	3	5
Planning Status	21	14	6
Total	**22**	**19**	**14**

Table 4.2
Lignocellulosic Biorefineries by State

Alabama (2)	Indiana (2)	Minnesota (1)	Pennsylvania (3)
Arkansas (1)	Iowa (1)	Missouri (1)	South Carolina (1)
California (2)	Kansas (1)	Montana (1)	South Dakota (1)
Colorado (3)	Kentucky (1)	Nebraska (1)	Tennessee (2)
Connecticut (1)	Louisiana (2)	Nevada (1)	Washington (1)
Florida (6)	Maine (1)	New York (3)	Wisconsin (3)
Georgia (1)	Maryland (1)	North Carolina (2)	Wyoming (1)
Hawaii (1)	Michigan (1)	Oregon (2)	

Source:
The information for these two tables is wholly derived from the fact sheet on cellulosic biofuels developed in July 2008 by Justin Mattingly, Fahran Robb, and Jetta Wong of the Environmental and Energy Study Institute (www.eesi.org). The EESI Fact Sheet provides many references for information summarized above.

Note: Four facilities have not disclosed their location.

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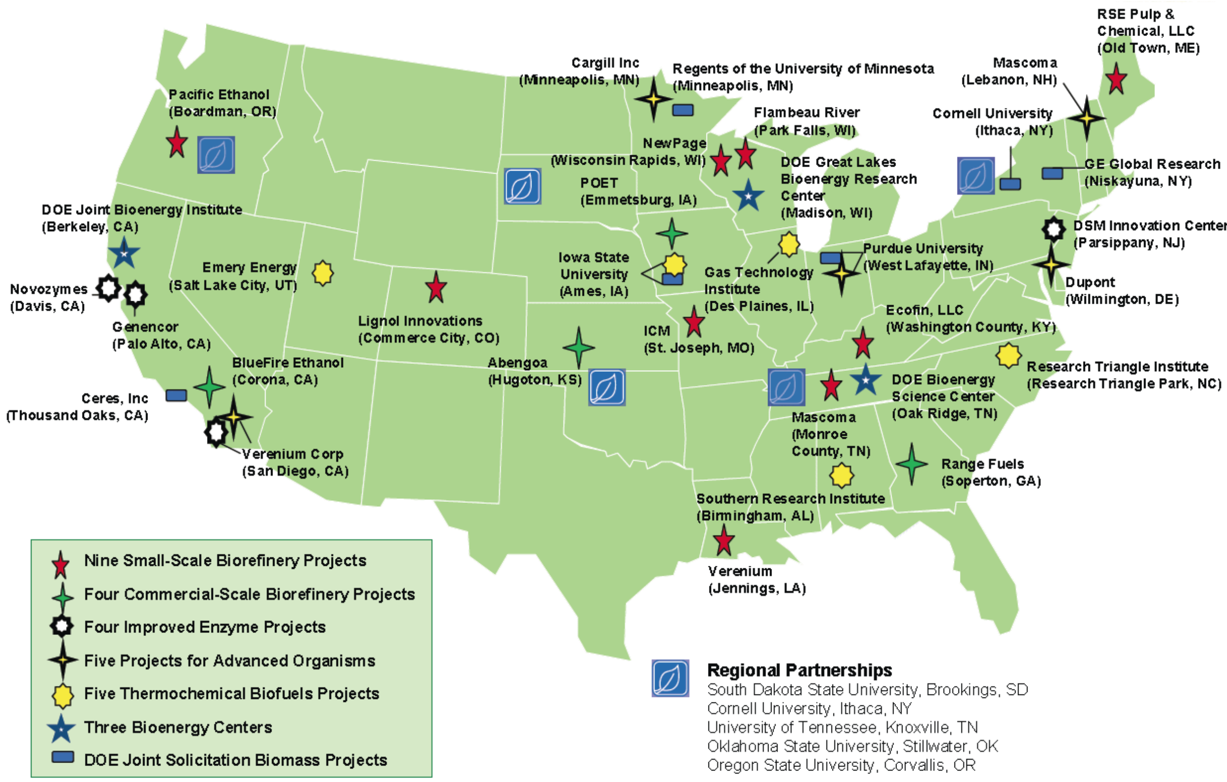
[a] Commercial scale: uses at least 700 tons of feedstock per day to produce 10-20 MGY of biofuel.
[b] Demonstration scale: uses approximately 70 tons of feedstock per day, yielding at least 1 MGY.
[c] Pilot scale facilities are generally smaller and are used to develop new methods and technologies.

Table 4.2
Lignocellulosic Biorefineries by State

Figure 4.1
Major DOE Biorefinery Project Locations



Source:
U.S. Department of Energy, Energy Efficiency and Renewable Energy, Biomass Program, http://www1.eere.energy.gov/biomass/pdfs/biofuels_project_locations.pdf.

Table 4.3
Fuels, Technologies and Feedstocks in Planned Biorefineries as of 2008

Liquid Fuel Types Planned		
Ethanol	Propanol	Biogasoline
Methanol	Fischer-Tropsch diesel fuel	Lignocellulosic biodiesel
Bio-butanol	Renewable Crude Oil	Jet Fuel

Technologies Involved in Producton of Biofuels and Bioproducts	
Weak Acid Hydrolysis	Component of ethanol production, see databook fig. 2.4
Enzymatic hydrolysis	Component of ethanol production, see databook fig. 2.4
Engineered microbes	Component of ethanol production, see databook fig. 2.4
Specialty enzymes	Component of ethanol production, see databook fig. 2.4
Steam explosion hydrolysis	Alternative to weak acid hydrolysis for feedstock pretreatment
Strong acid hydrolysis	Alternative to weak acid hydrolysis for feedstock pretreatment
Hydrogenolysis process	One of several patent descriptions found at http://www.patentstorm.us/patents/4661643
Organosolv process	One of several patent descriptions found at http://www.patentgenius.com/patent/4470851
Fischer-Tropsch process	See http://wikipedia.org/wiki/Fischer-Tropsch for explanation
Gasification*	A thermochemical process creating a synthesis gas that can be transformed by catalysts or microbes to biofuels/bioproducts
Biomass Fractionation*	Separation of biomass components prior to pretreatment for a wide variety of possible end-products
Proprietary technologies*	Several proprietary technologies have been proposed

Feedstocks Planned for Production of New Biofuels and Bioproducts	
Agricultural Residues	**Industry and Municipal Residuals**
Citrus Waste	Municipal solid waste
Corn cobs, fiber and stover	Yellow/trap grease
Grain, rice and wheat straw	Construction waste
Leafy material	Urban wood waste
Energy Crops	**Other Woody Biomass**
Miscanthus	Hazardous forest fuels (thinning & slash)
Specially bred energy cane	Material from habitat restoration
Switchgrass	Logging and mill residues
Poplar, willow, and pine trees	

Source:
The information presented above is largely derived from the fact sheet on cellulosic biofuels developed in July 2008 by Justin Mattingly, Fahran Robb, and Jetta Wong of the Environmental and Energy Study Institute (www.eesi.org). Oak Ridge National Laboratory staff added links for additional information.

Note: More information can be found at: http://www1.eere.energy.gov/biomass/project_factsheets.html.

Table 4.4
Federal and State Investments in Lignocellulosic Biorefineries as of 2008

The following companies were awarded DOE contracts in February 2007 totaling $385 million in federal investment over four years. All projects are cost-shared by the private industry partner and other investors and some projects also receive state support.

Company Name	Location	Size MGY*	Products	Feedstocks
Range Fuels[a]	Soperton, GA	40.0	Ethanol, methanol	Wood residues and crops
BlueFire Ethanol, Inc	Corona, CA	19.0	Ethanol	green & wood wastes diverted from landfills
Abengoa Bioenergy	Hugoton, KS	11.4	Ethanol & power	Ag residues & switchgrass
Poet, LLC[a]	Emmitsburg, IA	125.0	Ethanol; 25% cellulosic	Corn fiber, cobs, stalks

The following companies were awarded DOE contracts in January, April, and July 2008 for small scale biorefinery projects totaling $240 in Federal investment over four years.

Company Name	Location	Size MGY*	Products	Feedstocks
ICM Incorporated	St. Joseph, MO	1.5	Ethanol & other	Corn fiber & stover switchgrass, sorghum
Ecofin, LLC	Nicholasville, KY	1.0	Ethanol & other	Corn cobs
Mascoma Corp.[c]	Vonore, TN	2.0	Ethanol & other	Corn cobs & switchgrass
Pacific Ethanol	Boardman, OR	2.7	Ethanol & other	Wood & crop residues
Verenium Corp[b]	Jennings, LA	1.5	Ethanol & other	Ag & wood residues & energy crops
Lignol Innovations, Inc	Commerce City, CO	2.0	Ethanol, lignin, furfural	Wood residues
New Page (formerly Stora Enso, N America)	Wisconsin Rapids, WI	5.5	Fischer-Tropsch liquids	Mill and forest residues
RSE Pulp & Chemical, LLC	Old Town, ME	2.2	Ethanol & other	Hemicelluloses extract from wood
Flambeau River Biofuels, LLC	Park Falls, WI	6.0	Fischer-Tropsch liquids, heat	Mill and forest residues

Source:
The information presented above is largely derived from the fact sheet on cellulosic biofuels developed in July 2008 by Justin Mattingly, Fahran Robb, and Jetta Wong of the Environmental and Energy Study Institute (www.eesi.org). Oak Ridge National Laboratory staff added more detail from the DOE Biomass Program Web site.

Notes: MGY = Million gallons per year.

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[a] Listed on www.ethanolrfa.org Web site as under construction.
[b] Listed on www.ethanolrfa.org Web site as operational.
[c] Dupont Danisco Cellulosic Ethanol, LLC has replaced Mascoma Corporation as the technology partner on the Vonore, TN project.

Table 4.5
State and Private Investment in Biorefineries for Biofuels and Bioproducts

The following companies are currently planning demonstration or commercial facilities and have received significant state grants or other substantial private financial investments.

Company Name	Location & status	Size	Products	Feedstocks
AE Biofuels[a]	Butte, MT (operating)	Very small	Ethanol	Grasses , Ag residues, s ugar sources
Citrus Energy, LLC (2007 grant)	Clewiston, FL (planning)	4 million gallons per year	Ethanol	Citrus peels
Mascoma Corp	Vonore, TN	2 million gallons per year	Ethanol & other	Corn cobs & switchgrass
Liberty Industries (2008 grant)	Hosford, FL (planning)	7 million gallons per year + 5.4 Mega Watts	Ethanol, electricity	Forest residues, mill wastes, ag residues & other
KL Process Design Group	Upton, WY (operating)	1.5 million gallons per year	Ethanol , protein, syrup, lignin	Forest residues (mostly pine)
SunOpta, Inc	Little Fall, MN (planning)	10 million gallons per year + 50 Mega Watts (in future)	Ethanol, electricity	Wood chips
Coskata	Madison, PA (testing)	Lab demonstration	Ethanol	Municipal Waste
Catalyst Renewables Corp	Lyonsdale, NY (operating)	19 Mega Watts	Electricity	Forest Resources
Gulf Coast Energy (2008 grant)	Mossy Head, FL (planning)	Not Available	Ethanol , methanol, Biodiesel	Wood residues, chicken fat & soybean oil
Southeast Biofuels, LLC (2008 – grant)	Auburndale, FL (planning)	Small demo 8 (future goal)	Ethanol	Citrus peels
Florida Crystals Corp/U. of Florida (2007 grant)	Okeelanta, FL (planning)	1 to 2 million gallons per year	Ethanol	Sugarcane bagasse
ZeaChem, Inc	Boardman, OR (planning)	1.5 million gallons per year	Ethanol & chemicals	Tree crop residues
Poet, LLC	Scotland, SD	9 million gallons per year	Ethanol	Corn cobs

Source:
The list of state and private supported biorefinery projects was largely derived from the fact sheet on cellulosic biofuels developed in July 2008 by Justin Mattingly, Fahran Robb, and Jetta Wong of the Environmental and Energy Study Institute (www.eesi.org). Oak Ridge National Laboratory staff added more detail derived from examining state and company Web sites.

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[a] AE Biofuels demonstration facility opened Aug 11, 2008.
[b] Dupont Danisco Cellulosic Ethanol, LLC has replaced Mascoma Corporation as the technology partner on the Vonore, TN project. This project received both substantial and state and Federal support.
[c] The KL Process Design Group began operaton using wood waste in January 2008.

Below are seven projects relevant to the development of biorefinery technologies that were initiated during the 2000 to 2003 time frame by the U.S. Department of Energy. All projects have ended, some of the project partners are now involved in new biorefinery projects, while others have abandoned their efforts in this area.

Table 4.6
Recently Completed U.S. Department of Energy Biorefinery Projects

Project name	Lead Partner/ Project Period	Project cost	Project Description and Status
Advanced Biorefining of Distillers' Grain and Corn Stover Blends: Pre-Commercialization of a Biomass-Derived Process Technology	Abengoa Bioenergy Corporation FY 2003-2007	$17.7 million	Develop a process for pretreating a blend of distillers' grain (animal feed co-product from corn ethanol production) and stover to allow ethanol production from both, while leaving a high-protein animal feed. A large-scale pilot facility will be built for integration with High Plains' ethanol plant in York, Nebraska.
Big Island Demonstration project - Black Liquor	Georgia Pacific FY 2000 - 2007	NA	The project involved the design and operation of a black liquor gasifier that was to be integrated into Georgia-Pacific's Big Island facility in Virginia. This project anticipated helping pulp and paper mills with the replacement of recovery boilers that are reaching retirement. Current Status: The gasifier was built but the design did not function as anticipated and no current information can be located regarding any further work on the gasifier.
Making Industrial Biorefining Happen	Cargill-Dow LLC FY 2003-2007	$26 million	Develop and build a pilot-scale biorefinery that produces sugars and chemicals such as lactic acid and ethanol from grain. Current Status: Cargill Dow LLC is now known as NatureWorks LLC following Cargill's acquisition of The Dow Chemical Companies interest in the venture. The NatureWorks LLC website suggests that all products are currently made from corn starch.
Collection, Commercial Processing, and Utilization of Corn Stover/Making Industrial Biorefining	Cargill-Dow LLC FY 2003-2007	NA	Develop new technologies that assist in the harvesting, transport, storage, and separation of corn residues. Engineer a fermentation system that will meet the performance targets for the commercial manufacture of lactic acid and ethanol from corn stover. Current Status: See description above.
Enhancement of Co-Products from Bioconversion of Muncipal Solid Waste	Masada OxyNol, LLC FY 2001 - 2004	NA	The unit operations of the Masada OxyNol™ process were to be examined and research focused on improving conversion efficiencies, mitigating scale-up risks, and improving the co-product quality and marketability. Current Status: The company now called Pencor-Masada Oxynol signed an agreement in 2004 with the city of Middletown, New York to build a waste-to-ethanol plant with a projected completion date in 2008. As of December 2007 the company was still trying to attract investors. The companies website still indicates that the project is proceeding, though the city has taken the company to court for failing to meet deadlines.
A New Biorefinery Platform Intermediate	Cargill, Inc. FY 2003 - 2007	$6 million	Develop fermentative organisms and processes to ferment carbohydrates to 3-hydroxypropionic acid (3-HP) and then make a slate of products from the 3-HP. Current Status: Cargill does make ethanol from corn starch at multiple locations. Their website suggests that the only current involvement in cellulosic ethanol is the funding provided to Iowa State University that includes money for an economic analysis of corn stover production, harvest, handling and storage.
A Second Generation Dry Mill Biorefinery	Broin and Associates FY 2003 - 2007	$5.4 million	Separate bran, germ, and endosperm from corn kernels prior to making ethanol from the remaining starch. Investigate making high-value products, as well as ethanol and animal feed from the separated fractions. Current Status: Broin and Associates, now called POET, is pursuing "Project Liberty", a project that is constructing a cellulosic ethanol production stream at their Scotland N.D. corn to ethanol facility. This project was awarded DOE funding in February 2007 and corn cobs were harvested in 2007 as feedstock for the facility.
Separation of Corn Fiber and Conversion to Fuels and Chemicals Phase II: Pilot-Scale Operation	National Corn Growers Association FY 2003 - 2007	$2.4 million	Under a previous DOE-funded project, a process was developed for separation of hemicellulose, protein, and oil from corn fiber. This project will pilot-scale test and validate this process for commercial use. Current Status: ADM a partner in the NCGA project announced in August 2008 that it was partnering with John Deere to harvest,
Integrated Corn-Based Biorefinery	E.I. du Pont de Nemours & Co., Inc. FY 2003-2007	$18.2 million	Development of a biorefinery concept that converts both starch (such as corn) and lignocellulose (such as corn stover) to fermentable sugars for production of value added chemicals (like 1,3 propanediol) and fuel ethanol. Current status. Du Pont is making major investments in bioenergy technologies. The chemical 1,3 propanediol is now being commercial produced at DuPont Tate & Lyle Bio Products, LLC. in Loudon, Tennessee. DuPont and Genencor formed a joint venture company, DuPont Danisco Cellulosic Ethanol LLC, in May 2008 and this company is now the lead partner on the biorefinery project in Vonore, TN.

Source:
U. S. Department of Energy, Energy Efficiency and Renewable Energy, Biomass Program. 2008. http://www1.eere.energy.gov/biomass/project_factsheets.html, July. Web sites of all companies serving as project leaders or key partners on the DOE funded projects.

5. FEEDSTOCKS

PRIMARY BIOMASS FEEDSTOCKS

Primary biomass is produced directly by photosynthesis and includes all terrestrial plants now used for food, feed, fiber and fuelwood. All plants in natural and conservation areas (as well as algae and other aquatic plants growing in ponds, lakes, oceans, or artificial ponds and bioreactors) are also considered primary biomass. However, only a small portion of the primary biomass produced will ever be harvested as feedstock material for the production of bioenergy and bioproducts.

Primary biomass feedstocks are thus primary biomass that is harvested or collected from the field or forest where it is grown. Examples of primary biomass feedstocks currently being used for bioenergy include grains and oilseed crops used for transportation fuel production, plus some crop residues (such as orchard trimmings and nut hulls) and some residues from logging and forest operations that are currently used for heat and power production. In the future it is anticipated that a larger proportion of the residues inherently generated from food crop harvesting, as well as a larger proportion of the residues generated from ongoing logging and forest operations, will be used for bioenergy. Additionally, as the bioenergy industry develops, both woody and herbaceous perennial crops will be planted and harvested specifically for bioenergy and bioproducts end-uses.

Because this version of the Data Book is focusing primarily on the bioenergy industry as it exists today, including the biomass feedstocks actually used, only information on the grain and oilseeds crops are included. It would be desirable to include information on the amount and types of crop residues and forest logging, or pulp fiber residues currently being used for energy on a state by state basis, but that information is not readily available. Clearly there is also no nationwide source of information on woody or herbaceous crops being used for energy since this is occurring only on a very small scale in a few isolated experimental situations.

This Data Book covers only current usage of biomass and does not attempt to address the potential for biomass feedstock. Nonetheless, other sources of information do exist concerning the future potential of biomass. Tables, maps and explanations for assumptions behind the potential biomass resource calculations that have been performed by Oak Ridge National Laboratory biomass economists can be found on the Bioenergy Feedstock Information Network (BFIN) Web site at www.bioenergy.ornl.gov.

Source:
Lynn Wright, Oak Ridge, TN.

Table 5.1
Barley: Area, Yield, Production, and Value, 1996-2007

Year	Area		Yield per harvested acre	Production	Marketing year average price per bushel received by farmers	Value of production
	Planted[a]	Harvested				
	1,000 Acres	1,000 Acres	Bushels	1,000 Bushels	Dollars	1,000 Dollars
1996	7,094	6,707	58.5	392,433	2.74	1,080,940
1997	6,706	6,198	58.1	359,878	2.38	861,620
1998	6,325	5,854	60.1	351,569	1.98	685,734
1999	4,983	4,573	59.5	271,996	2.13	578,425
2000	5,801	5,200	61.1	317,804	2.11	647,966
2001	4,951	4,273	58.1	248,329	2.22	535,110
2002	5,008	4,123	55	226,906	2.72	605,635
2003	5,348	4,727	58.9	278,283	2.83	755,140
2004	4,527	4,021	69.6	279,743	2.48	698,184
2005	3,875	3,269	64.8	211,896	2.53	527,633
2006	3,452	2,951	61.1	180,165	2.85	498,691
2007	4,020	3,508	60.4	211,825	4.10	851,682

Source:
U.S. Department of Agriculture. 2008. *2008 Agricultural Statistics*, Table 1-53 and previous annual editions, http://www.nass.usda.gov/Publications/Ag_Statistics/index.asp.

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[a] Barley sown for all purposes, including barley sown in the preceding fall.
[b] Preliminary.

Table 5.2
Barley: Area, Yield, and Production, by State, 2005-2007

	Area planted[a]			Area harvested			Yield per harvested acre			Production		
	2005	2006	2007	2005	2006	2007	2005	2006	2007	2005	2006	2007
	1,000 Acres	1,000 Acres	1,000 Acres	1,000 Acres	1,000 Acres	1,000 Acres	Bushels	Bushels	Bushels	1,000 Bushels	1,000 Bushels	1,000 Bushels
Arizona	34	25	35	30	22	33	100	115	115	3,000	2,530	3,795
California	100	90	85	60	65	40	63	55	60	3,780	3,575	2,400
Colorado	60	47	60	59	42	58	130	115	125	7,670	4,830	7,250
Delaware	29	27	21	27	24	19	81	80	78	2,187	1,920	1,482
Idaho	630	530	570	600	510	550	87	84	80	52,200	42,840	44,000
Kansas	19	24	20	14	18	13	42	27	48	588	486	624
Kentucky	10	15	10	9	14	3	83	88	35	747	1,232	105
Maine	23	18	18	22	17	17	60	50	70	1320	850	1190
Maryland	46	50	45	41	32	34	86	87	84	3,526	2,784	2,856
Michigan	15	15	14	11	14	13	47	49	56	517	686	728
Minnesota	125	105	130	90	90	110	43	60	56	3,870	5,400	6,160
Montana	900	770	900	700	620	720	56	50	44	39,200	31,000	31,680
Nevada	4	4	3	2	2	1	85	100	90	170	200	90
New Jersey	3	3	3	2	2	2	71	57	68	142	114	136
New York	17	17	13	15	12	11	49	55	46	735	660	506
North Carolina	24	24	22	19	17	14	78	80	53	1,482	1,360	742
North Dakota	1,200	1,100	1,470	1,060	995	1,390	54	49	56	57,240	48,755	77,840
Ohio	6	5	4	5	4	3	60	68	50	300	272	150
Oregon	65	55	63	45	42	53	45	58	47	2,025	2,436	2,491
Pennsylvania	55	55	55	47	46	42	72	81	73	3,384	3,726	3,066
South Dakota	65	55	56	47	14	29	49	40	40	2,303	560	1,160
Utah	40	40	38	24	30	22	80	76	78	1,920	2,280	1,716
Virginia	60	58	48	45	42	30	87	77	71	3,915	3,234	2,130
Washington	215	200	235	205	190	225	61	63	60	12,505	11,970	13,500
Wisconsin	55	50	40	30	30	23	53	54	57	1,590	1,620	1,311
Wyoming	75	70	62	60	57	53	93	85	89	5,580	4,845	4,717
US	**3,875**	**3,452**	**4,020**	**3,269**	**2,951**	**3,508**	**64.8**	**61.1**	**60.4**	**211,896**	**180,165**	**211,825**

Source:
U.S. Department of Agriculture. 2008. *2008 Agricultural Statistics*, Table 1-56, http://www.nass.usda.gov/Publications/Ag_Statistics/index.asp.

[a] Includes area planted in the preceding fall.

Table 5.3
Barley Production Costs and Returns per Planted Acre by Region, Excluding Government Payments, 2006-2007[a]
(Dollars per planted acre)

Item	United States 2006	United States 2007	Northern Great Plains 2006	Northern Great Plains 2007	Basin and Range 2006	Basin and Range 2007	Fruitful Rim 2006	Fruitful Rim 2007	Northern Crescent 2006	Northern Crescent 2007	Heartland 2006	Heartland 2007
Gross value of production												
Primary product: Barley grain	134.64	178.19	101.864	162.624	124.576	148.512	215.784	246.33	133.874	161.76	95.55	133.62
Secondary product: Barley silage, straw, grazir	9.27	10.53	4.79	5.44	9.92	11.26	14.17	16.10	64.83	73.64	15.92	18.09
Total, gross value of production	**143.91**	**188.72**	**106.65**	**168.06**	**134.50**	**159.77**	**229.95**	**262.43**	**198.70**	**235.40**	**111.47**	**151.71**
Operating costs:												
Seed	9.20	10.04	7.83	8.54	10.31	11.25	12.37	13.50	12.43	13.56	10.30	11.24
Fertilizer [b]	28.10	35.16	23.19	29.02	34.86	43.62	38.67	48.39	31.18	39.01	27.89	34.90
Chemicals	13.14	13.34	12.86	13.06	12.93	13.13	16.48	16.74	3.04	3.08	5.31	5.39
Custom operations[c]	7.58	7.70	6.03	6.13	7.06	7.17	11.70	11.89	15.69	15.95	12.84	13.05
Fuel, lube, and electricity	19.39	21.42	13.25	14.63	19.70	21.76	41.09	45.39	17.45	19.27	13.11	14.48
Repairs	16.58	17.13	15.60	16.12	16.94	17.51	21.01	21.72	10.66	11.02	10.56	10.92
Purchased irrigation water	2.38	2.48	0.78	0.81	4.00	4.17	6.60	6.89	2.34	2.44	0.64	0.67
Interest on operating inputs	2.32	2.58	1.91	2.12	2.54	2.85	3.56	3.96	2.23	2.51	1.94	2.18
Total, operating costs	**98.69**	**109.85**	**81.45**	**90.43**	**108.34**	**121.46**	**151.48**	**168.48**	**95.02**	**106.84**	**82.59**	**92.83**
Allocated overhead:												
Hired labor	3.46	3.59	2.15	2.22	3.03	3.13	8.67	8.97	2.36	2.45	2.35	2.44
Opportunity cost of unpaid labor	23.38	24.21	19.41	20.09	30.33	31.40	29.37	30.41	32.64	33.79	24.34	25.20
Capital recovery of machinery and equipment	78.43	82.31	76.61	80.40	78.69	82.59	90.66	95.15	51.62	54.18	50.96	53.48
Opportunity cost of land (rental rate)	46.32	57.91	31.75	39.69	62.22	77.78	82.63	103.29	47.17	58.96	51.48	64.35
Taxes and insurance	8.29	9.62	8.50	9.87	8.20	9.52	8.43	9.78	4.70	5.45	5.45	6.32
General farm overhead	9.58	9.91	9.03	9.35	9.55	9.88	11.69	12.09	8.99	9.30	8.16	8.45
Total, allocated overhead	**169.46**	**187.55**	**147.45**	**161.62**	**192.02**	**214.30**	**231.45**	**259.69**	**147.48**	**164.13**	**142.74**	**160.24**
Total, costs listed	**268.15**	**297.40**	**228.90**	**252.05**	**300.36**	**335.76**	**382.93**	**428.17**	**242.50**	**270.97**	**225.33**	**253.07**
Value of production less total costs listed	-124.24	-108.68	-122.25	-83.99	-165.86	-175.99	-152.98	-165.74	-43.80	-35.57	-113.86	-101.36
Value of production less operating costs	45.22	78.87	25.20	77.63	26.16	38.31	78.47	93.95	103.68	128.56	28.88	58.88
Supporting information:												
Yield (bushels per planted acre)	51	51.5	43	48	46	41	73	69	54	48	39	39
Price (dollars per bushel at harvest)	2.64	3.46	2.38	3.36	2.72	3.64	2.96	3.57	2.47	3.37	2.45	3.40
Enterprise size (planted acres) [a]	219	219	342	342	194	194	266	266	33	33	87	87
Production practices: [a]												
Feed barley (percent of acres)	23	23	8	8	49	49	41	41	96	96	34	34
Malt barley (percent of acres)	77	77	92	92	51	51	59	59	[c]	[c]	66	66
Spring barley (percent of acres)	97	97	100	100	99	99	91	91	52	52	100	100
Winter barley (percent of acres)	[c]	[c]	0	0	[c]	[c]	9	9	47	47	0	0
Dryland (percent of acres)	80	80	94	94	70	70	38	38	98	98	100	100
Irrigated (percent of acres)	20	20	6	6	30	30	62	62	2	2	0	0
Straw harvested (percent of acres)	23	23	12	12	29	29	45	45	87	87	28	28

Source:
Economic Research Service, U.S. Department of Agriculture, http://www.ers.usda.gov/data/costsandreturns/testpick.htm.

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[a] Developed from survey base year, 2003.
[b] Cost of commercial fertilizers, soil conditioners, and manure.
[c] 0.1 to less than 5 percent.

USDA's corn baseline projections show a continuing rise in bushels of corn allocated to fuel alcohol use, a continuing increase in corn yields, a slight increase in corn acreage, and an increase in net returns (over variable costs). This analysis is updated annually.

Table 5.4
Corn Baseline Projections, 2006 – 2018

Item	2006/07	2007/08	2008/09	2009/10	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18
Area (million acres):												
Planted acres	78.3	93.6	88.0	91.0	93.0	92.0	91.0	91.0	91.5	91.5	91.5	92.0
Harvested acres	70.6	86.1	80.6	83.6	85.6	84.6	83.6	83.6	84.1	84.1	84.1	84.6
Yields (bushels per acre):												
Yield/harvested acre	149.1	153.0	155.3	157.3	159.3	161.3	163.3	165.3	167.3	169.3	171.3	173.3
Supply and use (million bushels):												
Beginning stocks	1,967	1,304	1,897	1,327	1,202	1,402	1,502	1,447	1,377	1,372	1,327	1,262
Production	10,535	13,168	12,515	13,150	13,635	13,645	13,650	13,820	14,070	14,240	14,405	14,660
Imports	12	15	15	15	15	15	15	15	15	15	15	15
Supply	12,514	14,487	14,427	14,492	14,852	15,062	15,167	15,282	15,462	15,627	15,747	15,937
Feed & residual	5,598	5,650	5,450	5,425	5,525	5,550	5,600	5,650	5,700	5,750	5,775	5,825
Food, seed, & industrial	3,488	4,590	5,500	5,715	5,800	5,885	5,970	6,055	6,140	6,225	6,310	6,400
Fuel alcohol use[a]	2,117	3,200	4,100	4,300	4,375	4,450	4,525	4,600	4,675	4,750	4,825	4,900
Domestic	9,086	10,240	10,950	11,140	11,325	11,435	11,570	11,705	11,840	11,975	12,085	12,225
Exports	2,125	2,350	2,150	2,150	2,125	2,125	2,150	2,200	2,250	2,325	2,400	2,475
Total use	11,210	12,590	13,100	13,290	13,450	13,560	13,720	13,905	14,090	14,300	14,485	14,700
Ending stocks	1,304	1,897	1,327	1,202	1,402	1,502	1,447	1,377	1,372	1,327	1,262	1,237
Stocks/use ratio, percent	11.6	15.1	10.1	9.0	10.4	11.1	10.5	9.9	9.7	9.3	8.7	8.4
Prices (dollars per bushel):												
Farm price	3.04	3.50	3.75	3.80	3.60	3.50	3.50	3.55	3.55	3.55	3.60	3.60
Loan rate	1.95	1.95	1.95	1.95	1.95	1.95	1.95	1.95	1.95	1.95	1.95	1.95
Variable costs of production (dollars):												
Per acre	203.41	226.68	237.48	244.16	247.88	251.42	254.57	257.32	260.84	264.45	268.06	271.43
Per bushel	1.36	1.48	1.53	1.55	1.56	1.56	1.56	1.56	1.56	1.56	1.56	1.57
Returns over variable costs (dollars per acre):												
Net returns[a]	249.85	308.82	344.90	353.58	325.60	313.13	316.98	329.49	333.08	336.56	348.62	352.45

Source:
United States Department of Agriculture. 2008. *Long-Term Agricultural, Projection Tables to 2018*, Table 8, February; U.S. Corn Projections, http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1192.

Note: Marketing year beginning September 1 for corn.

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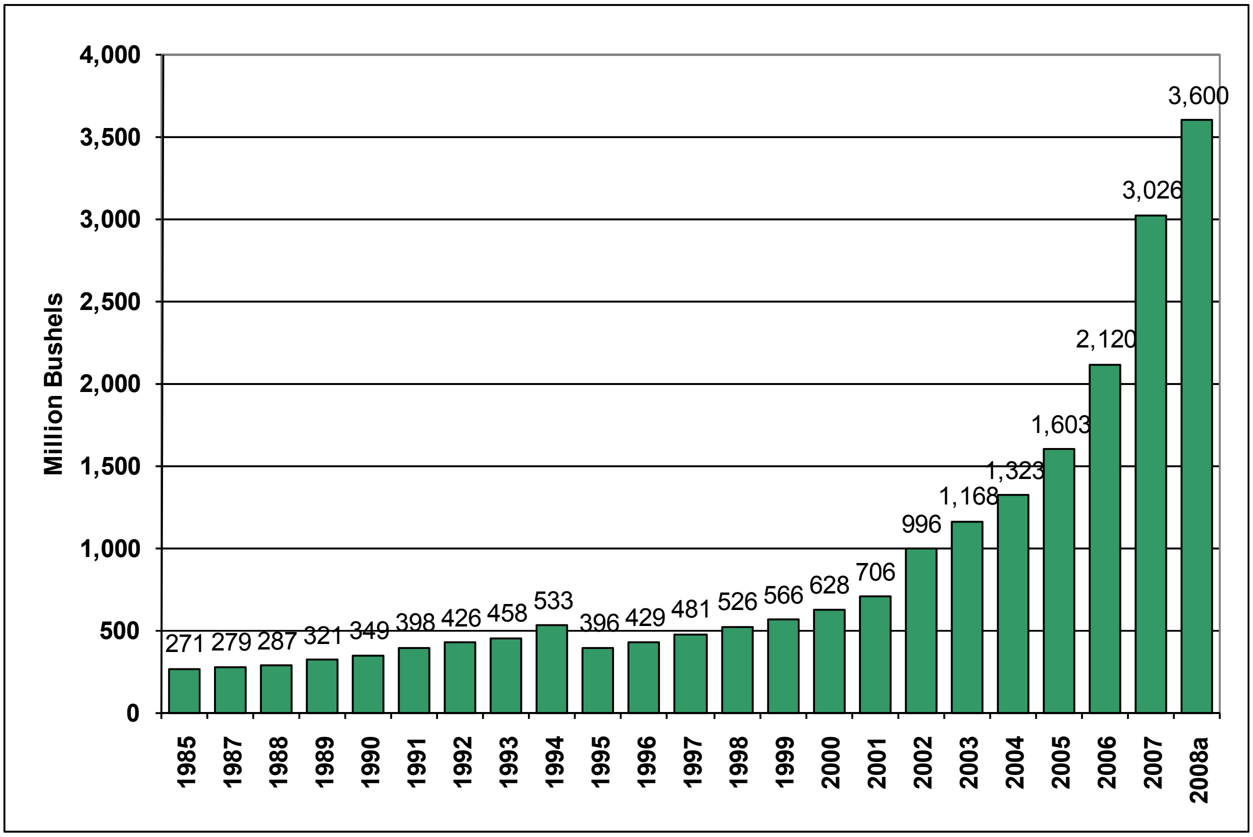
[a] Corn used in ethanol production is accounted for in fuel alcohol use. Distiller's grains, a coproduct of ethanol production, is not accounted for in the balance sheet for corn.

The figure below shows that corn use for ethanol production has increased by nearly five- fold from 2000 to 2008.

Figure 5.1
Corn Used for Ethanol Production, 1985-2008



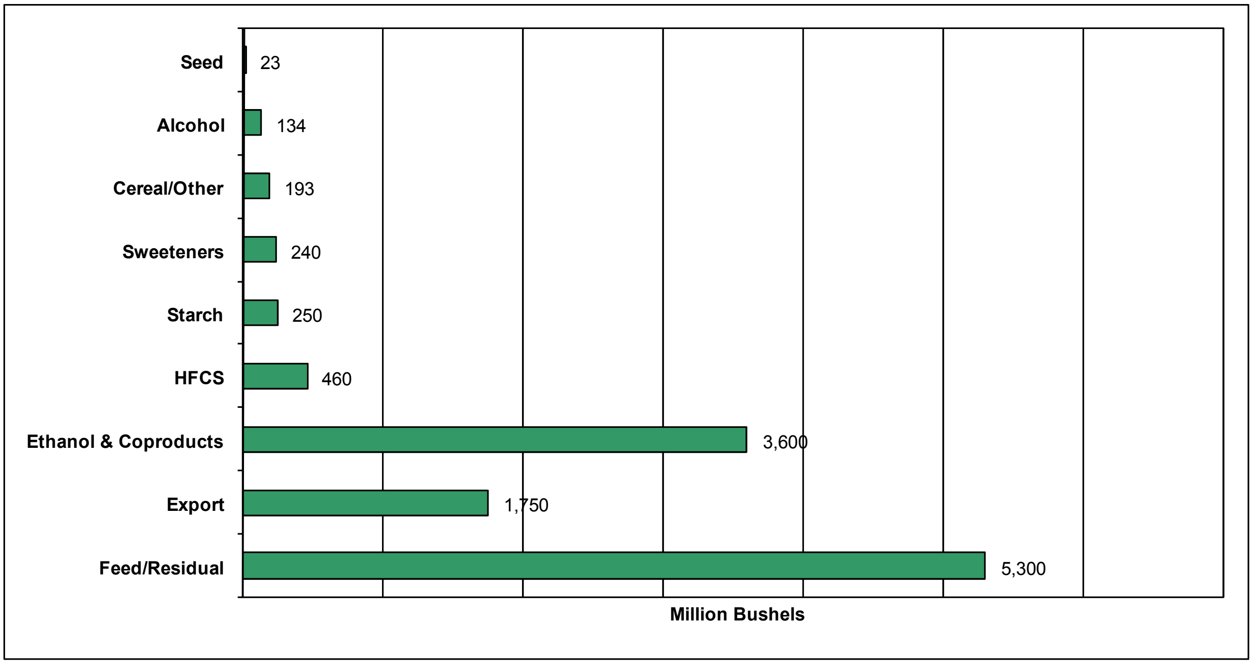
Source:
National Corn Growers Association. 2009. *The World of Corn,* and previous annual editions, http://www.ncga.com.

Note: Marketing year ending August 31, 2009

[a] Preliminary.

In 2008, ethanol production accounted for about 30 percent of the overall corn consumption and more than double the amount used for export.

Figure 5.2
Corn Usage by Segment, 2008

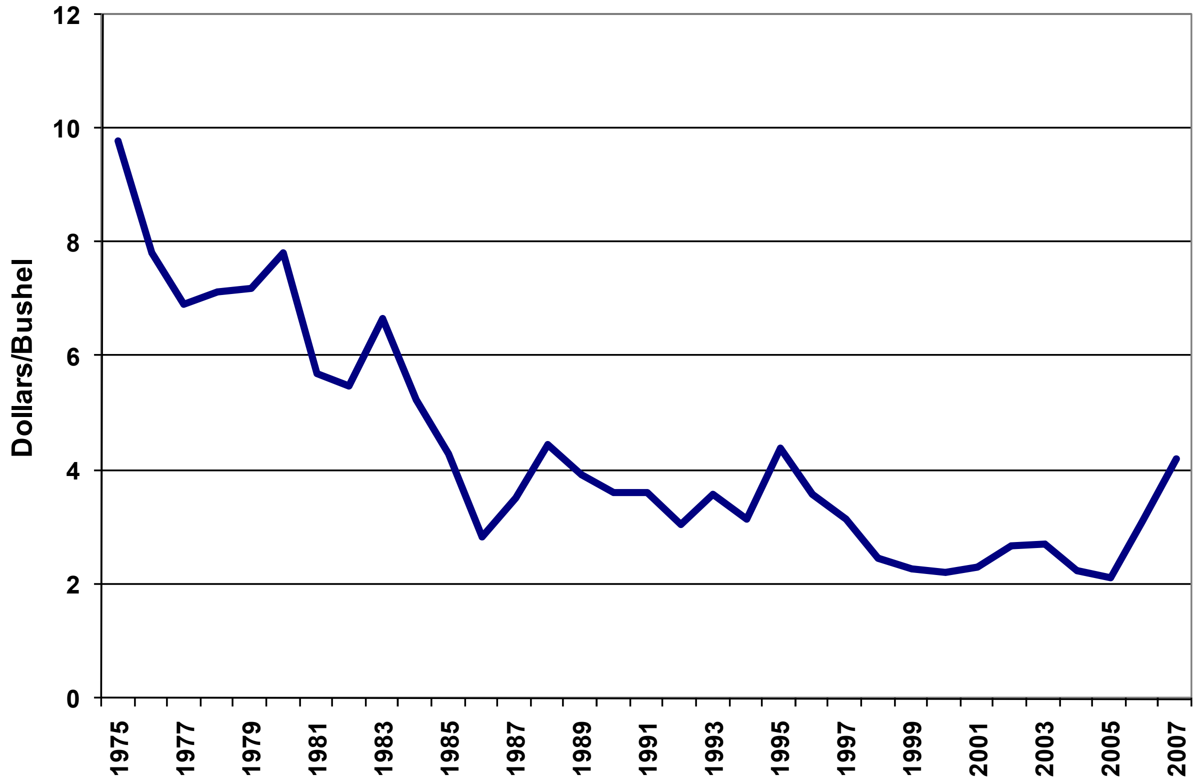


Source:
National Corn Growers Association. 2009. *The World of Corn*, http://www.ncga.com/.

Note: Marketing year ending August 31, 2009.

Overall, the price for corn has been declining due to improvements in farming techniques. Though there has always been variation in corn price from year to year due to factors such as weather, affecting yield, much of the increase beginning in 2005 is likely attributable to increased demand for corn by ethanol producers.

Figure 5.3
Corn: Price per Bushel, 1975-2007
(Constant 2007 dollars)



Source:
U.S. Department of Agriculture, National Agricultural Statistics Service, http://www.nass.usda.gov/.

In the baseline year of 2001, 7.5% of all corn grain produced was used for ethanol production and by 2007 it rose to about 25%. Largely due to this increased demand for ethanol, the acres of corn planted rose sharply in 2007 to 93 million acres over an average of about 80 million acres in previous years; acreage variation is related to feed and export demands, crop subsidy programs, previous year grain prices and animal demand for silage. Yield variation relates to climate variation and improved varieties. The year 2004 provided an unusually favorable climate for high corn yields over much of the corn belt.

Table 5.5
Corn: Area, Yield, Production, and Value, 1996-2007

		Corn for grain					Corn for silage		
Year	Area Planted for all purposes	Area harvested	Yield per harvested acre	Production	Marketing year average price per bushel	Value of production	Area Harvested	Yield per harvested acre	Production
	1,000 Acres	1,000 Acres	Bushels	1,000 Bushels	Dollars	1,000 Dollars	1,000 Acres	Tons	1,000 Tons
1996	79,229	72,644	127.1	9,232,557	2.71	25,149,013	5,607	15.4	86,581
1997	79,537	72,671	126.7	9,206,832	2.43	22,351,507	6,054	16.1	97,192
1998	80,165	72,589	134.4	9,758,685	1.94	18,922,084	5,913	16.1	95,479
1999	77,386	70,487	133.8	9,430,612	1.82	17,103,991	6,037	15.8	95,633
2000	79,551	72,440	136.9	9,915,051	1.85	18,499,002	6,082	16.8	102,156
2001	75,702	68,768	138.2	9,502,580	1.97	18,878,819	6,142	16.6	101,992
2002	78,894	69,330	129.3	8,966,787	2.32	20,882,448	7,122	14.4	102,293
2003	78,603	70,944	142.2	10,089,222	2.42	24,476,803	6,583	16.3	107,378
2004	80,929	73,631	160.4	11,807,086	2.06	24,381,294	6,101	17.6	107,293
2005	81,779	75,117	148	11,114,082	2.00	22,198,472	5,930	18	106,486
2006	78,327	70,648	149.1	10,534,868	3.04	32,094,586	6,477	16.2	105,129
2007	93,600	86,542	151.1	13,073,893	4.20	52,090,108	6,071	17.5	106,328

Source:
U.S. Department of Agriculture. *2008 Agricultural Statistics*, Table 1-35 and previous annual editions, http://www.nass.usda.gov/Publications/Ag_Statistics/index.asp.

Production of sufficient quantities of corn to support ethanol production facilities occurs primarily in the mid-western states. Yields vary considerably across the states. High yields in the western states occur under irrigation.

Table 5.6
Corn: Area, Yield, and Production, by State, 2005-2007

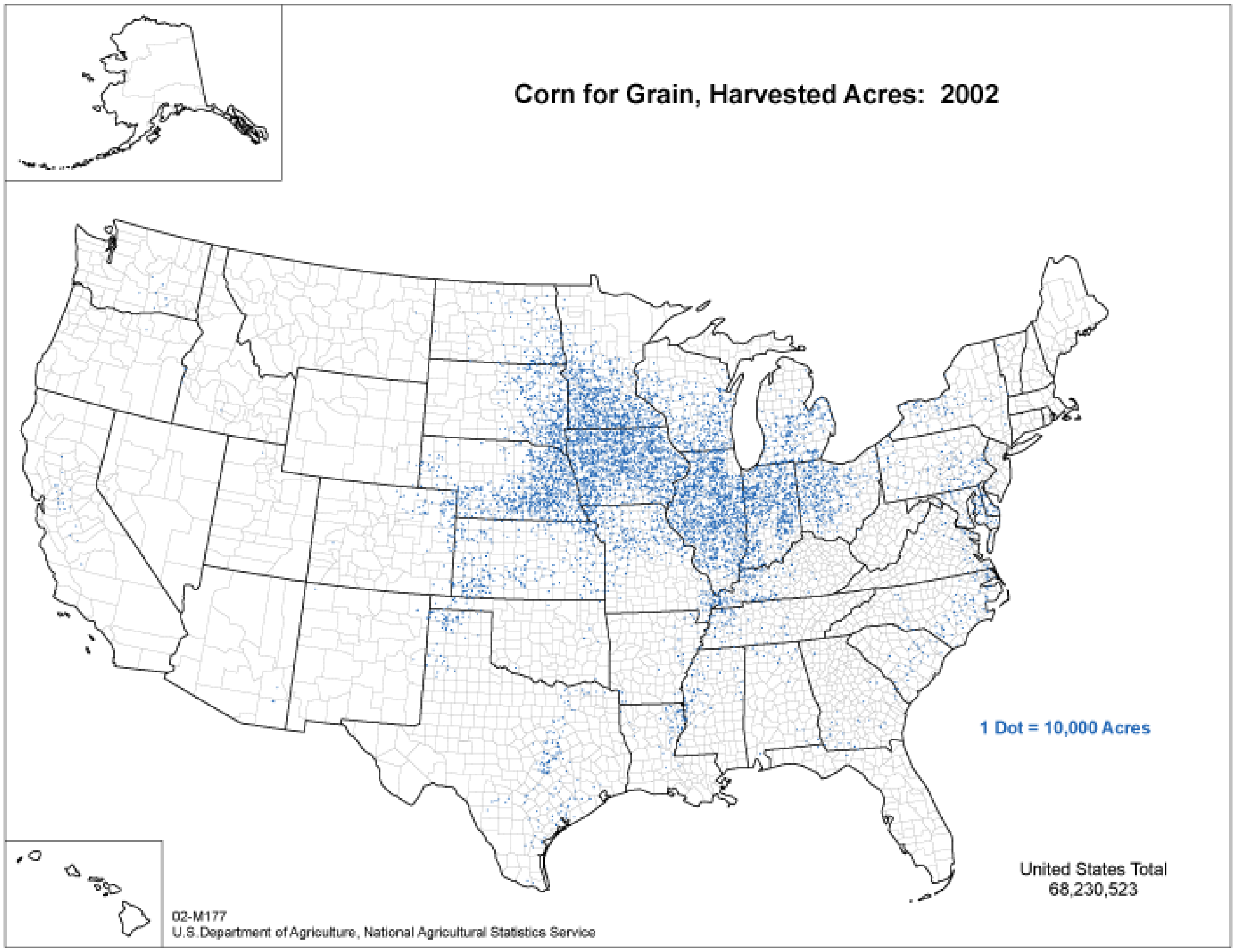
State	Area planted for all purposes			Corn for grain								
				Area harvested			Yield per harvested acre			Production		
	2005	2006	2007[a]	2005	2006	2007[a]	2005	2006	2007[a]	2005	2006	2007[a]
	1,000 Acres	1,000 Acres	1,000 Acres	1,000 Acres	1,000 Acres	1,000 Acres	Bushels	Bushels	Bushels	1,000 Bushels	1,000 Bushels	1,000 Bushels
Alabama	220	200	340	200	165	280	119	72	79	23,800	11,880	22,120
Arizona	50	50	55	22	18	23	195	170	185	4,290	3,060	4,255
Arkansas	240	190	610	230	180	590	131	146	168	30,130	26,280	99,120
California	560	520	650	130	110	200	172	165	180	22,360	18,150	36,000
Colorado	1,100	1,000	1,200	950	860	1060	148	156	142	140,600	134,160	150,520
Connecticut	28	27	26	b	b	b	b	b	b	b	b	b
Delaware	160	170	195	154	161	185	143	145	97	22,022	23,345	17,945
Florida	65	60	75	28	30	35	94	82	95	2,632	2,460	3,325
Georgia	270	280	510	230	225	450	129	112	130	29,670	25,200	58,500
Idaho	235	270	310	60	65	105	170	170	165	10,200	11,050	17,325
Illinois	12,100	11,300	13,200	11,950	11,150	13,050	143	163	175	1,708,850	1,817,450	2,283,750
Indiana	5,900	5,500	6,500	5,770	5,380	6,370	154	157	155	888,580	844,660	987,350
Iowa	12,800	12,600	14,200	12,500	12,350	13,850	173	166	171	2,162,500	2,050,100	2,368,350
Kansas	3,650	3,350	3,900	3,450	3,000	3,700	135	115	140	465,750	345,000	518,000
Kentucky	1,250	1,120	1,450	1,180	1,040	1,360	132	146	129	155,760	151,840	175,440
Louisiana	340	300	740	330	290	730	136	140	165	44,880	40,600	120,450
Maine	26	26	28	b	b	b	b	b	b	b	b	b
Maryland	470	490	540	400	425	455	135	142	103	54,000	60,350	46,865
Massachusetts	20	18	18	b	b	b	b	b	b	b	b	b
Michigan	2,250	2,200	2,650	2,010	1,960	2,350	143	147	124	287,430	288,120	291,400
Minnesota	7,300	7,300	8,400	6,850	6,850	7,800	174	161	146	1,191,900	1,102,850	1,138,800
Mississippi	380	340	960	365	325	940	129	110	150	47,085	35,750	141,000
Missouri	3,100	2,700	3,450	2,970	2,630	3,250	111	138	142	329,670	362,940	461,500
Montana	65	65	84	17	18	38	148	146	145	2,516	2,628	5,510
Nebraska	8,500	8,100	9,400	8,250	7,750	9,200	154	152	160	1,270,500	1,178,000	1,472,000
Nevada	5	4	5	b	b	b	b	b	b	b	b	b
New Hampshire	15	14	14	b	b	b	b	b	b	b	b	b
New Jersey	80	80	95	62	64	82	122	129	125	7,564	8,256	10,250
New Mexico	140	130	135	55	45	55	175	185	175	9,625	8,325	9,625
New York	990	950	1050	460	480	550	124	129	127	57,040	61,920	69,850
North Carolina	750	790	1100	700	740	1020	120	132	100	84,000	97,680	102,000
North Dakota	1,410	1,690	2,550	1,200	1,400	2,350	129	111	116	154,800	155,400	272,600
Ohio	3,450	3,150	3,850	3,250	2,960	3,610	143	159	150	464,750	470,640	541,500
Oklahoma	290	270	320	250	220	270	115	105	145	28,750	23,100	39,150
Oregon	53	51	60	25	29	35	160	180	195	4,000	5,220	6,825
Pennsylvania	1,350	1,350	1,410	960	960	980	122	122	128	117,120	117,120	125,440
Rhode Island	2	2	2	b	b	b	b	b	b	b	b	b
South Carolina	300	310	400	285	290	370	116	110	100	33,060	31,900	37,000
South Dakota	4,450	4,500	5,000	3,950	3,220	4,500	119	97	121	470,050	312,340	544,500
Tennessee	650	550	870	595	500	785	130	125	106	77,350	62,500	83,210
Texas	2,050	1,760	2,150	1,850	1,450	2,000	114	121	148	210,900	175,450	296,000
Utah	55	65	70	12	17	22	163	157	148	1,956	2,669	3,256
Vermont	95	85	92	b	b	b	b	b	b	b	b	b
Virginia	490	480	550	360	345	405	118	120	85	42,480	41,400	34,425
Washington	150	140	195	80	75	120	205	210	210	16,400	15,750	25,200
West Virginia	45	45	46	28	26	27	109	120	111	3,052	3,120	2,997
Wisconsin	3,800	3,650	4,050	2,900	2,800	3,280	148	143	135	429,200	400,400	442,800
Wyoming	80	85	95	49	45	60	140	129	129	6,860	5,805	7,740
US	**81,779**	**78,327**	**93,600**	**75,117**	**70,648**	**86,542**	**148**	**149.1**	**151.1**	**11,114,082**	**10,534,868**	**13,073,893**

Source:
U.S. Department of Agriculture. 2008. *2008 Agricultural Statistics*, Table 1-37, http://www.nass.usda.gov/Publications/Ag_Statistics/index.asp.

[a] Preliminary.
[b] Not estimated.

The large majority of U.S. corn grain is produced in just a few mid-western states. The highest concentration of corn production is found in central Illinois, northern Iowa/southern Minnesota, and eastern Nebraska.

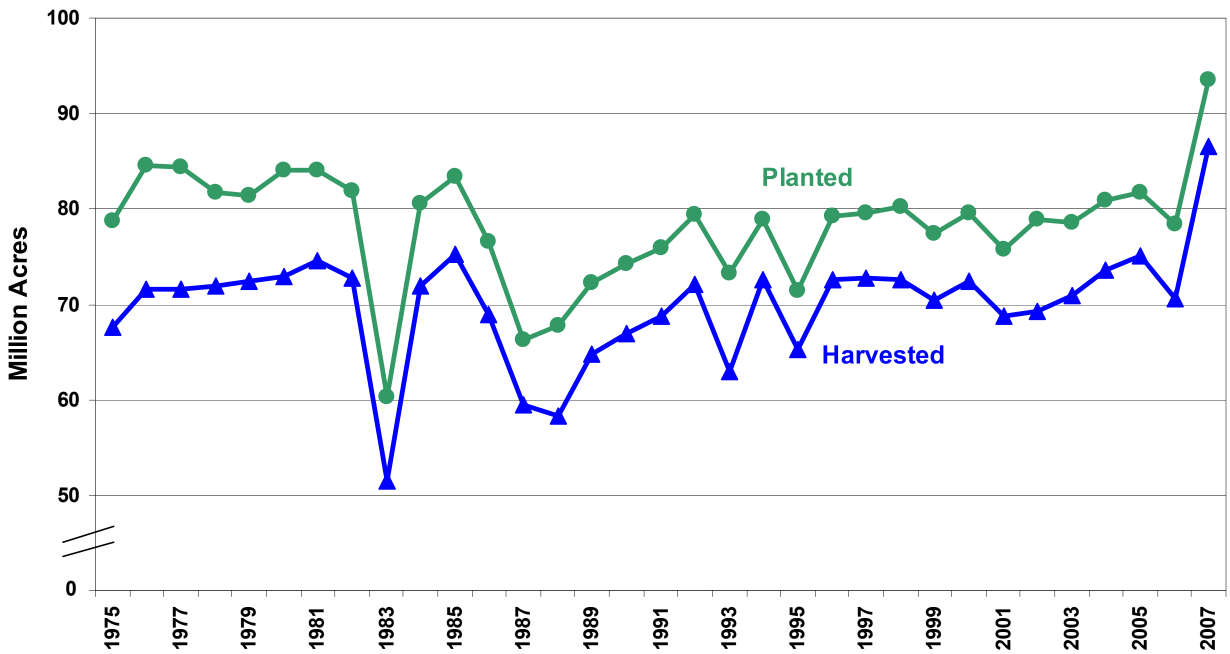
Figure 5.4
Corn for Grain, Harvested Acres, 2002



Source:
U.S. Department of Agriculture, National Agricultural Statistics Service, www.nass.usda.gov/research/atlas02/atlas-crops.html.

Due largely to increased ethanol demand, there was a remarkable increase in the number of corn acres planted in 2007. Acres harvested for grain are always less than planted acres due to silage and crop failure.

Figure 5.5
Corn Acres Planted and Harvested, 1975-2007



Source:
U.S. Department of Agriculture, National Agricultural Statistics Service, http://www.nass.usda.gov/.

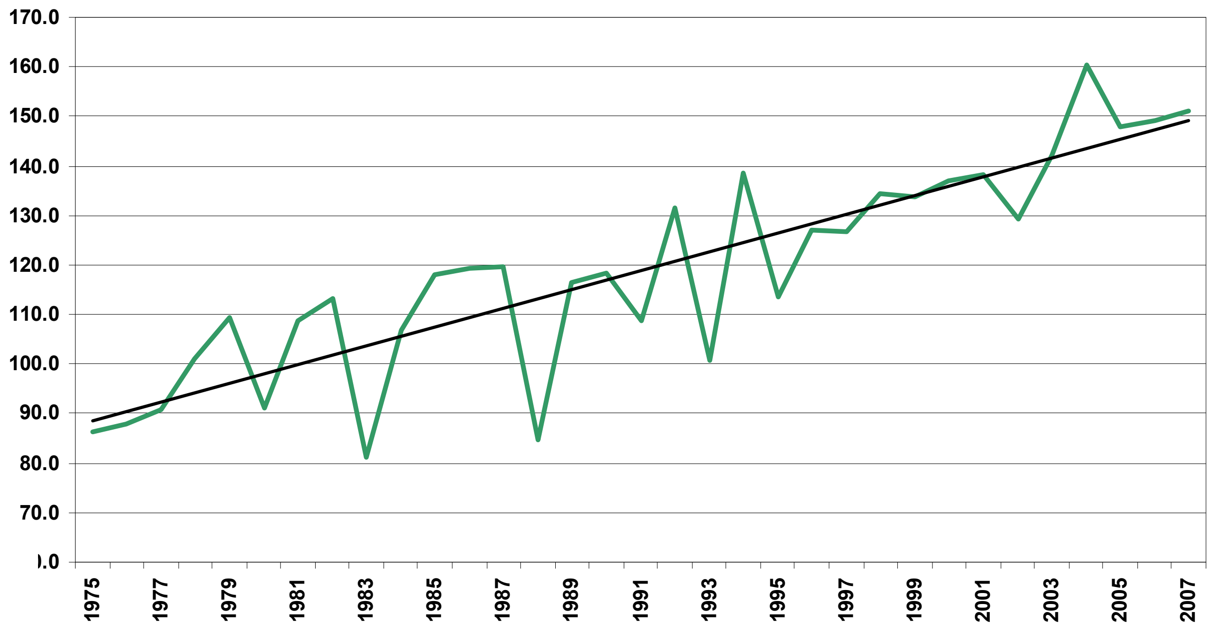
Doberman et. al., noted in 2002 that average corn yields have increased linearly at a rate of 1.7 bushels per acre (bu/ac) per year. At present that translates to a rate of 1.1% per year, but if the same average linear rate continues, the percentage rate will decline. Corn yields must continue to increase at a rate of at least 1% per year to meet the demands created by expected population growth.

In 2002 average corn yields approached 140 bu/ac with progressive farmers routinely harvesting 160 to 220 bu/ac. Yields rose in the 60's and 70's largely due to increasing application of fertilizer to responsive corn hybrids; however, after 1980 yield increases were maintained without continued fertilizer increases due to significant increases in nutrient use efficiency. In the past 15 years, yields have continued to increase due to improved hybrids with greater stress resistance together with improved crop management techniques such as conservation tillage, higher plant densities and improved seed qualities.

Yields at a given site fluctuate as much as 10-15% from year to year due to normal variations in solar radiation and temperature regimes assuming suitable moisture levels. Lack of sufficient moisture is the most important factor reducing yields in most of the U.S. corn belt where most corn is not irrigated. The yield potential of corn continues to be much greater than the average yields currently being obtained in most locations in the U.S.

Genetic improvements (particularly in drought resistance) are expected to continue to contribute to yield increases, but continued improvements in crop management will be ever more important. Key references on yield potential follow.

Figure 5.6
Corn Yield, 1975-2007



Source:
U.S. Department of Agriculture, National Agricultural Statistics Service, http://www.nass.usda.gov/.

Additional References:

Dobermann, A., T. Arkebauer, K. Cassman, J. Lindquist, J. Specht, D. Walters, and H. Yang. 2002. "Understanding and Managing Corn Yield Potential," *Proceedings of the Fertilizer Industry Round Table*, Charleston, South Carolina, The Fertilizer Industry Round Table, Forest Hill, Maryland, October.

Figure 5.6 (Continued)
Corn Yield, 1975-2007

Dobermann, A., T. Arkebauer, K.G. Cassman, R.A. Drijber, J.L. Lindquist, J.E. Specht, D.T. Walters, H. Yang, D. Miller, D.L. Binder, G. Teichmeier, R.B. Ferguson, and C.S. Wortmann. 2003. "Understanding Corn Yield Potential in Different Environments," p. 67-82, in L.S. Murphy (ed.) *Fluid Focus: The Third Decade*. Proceedings of the 2003 Fluid Forum, Vol. 20. Fluid Fertilizer Foundation, Manhattan, KS.

Both Doberman, et al. references can be obtained at the following url: http://soilfertility.unl.edu/Materials%20to%20include/Research%20Pubs/Ecological%20Intensification.htm

Tollenaar, M. and E. A. Lee. 2002. "Yield Potential, Yield Stability, and Stress Tolerance in Maize," *Field Crops Research*, 75:161-169.

Duvick, D.N. and K.G. Cassman. 1999. "Post-Green Revolution Trends in Yield Potential of Temperature Maize in the North-Central United States," *Crop Science* 39:1622-1630.

Production of food for domestic livestock is the largest single use of corn grain, accounting for nearly half of all corn grain produced. Ethanol production is included in the food, seed and industrial category.

Table 5.7
Corn: Supply and Disappearance, 1996-2007
(Million bushels)

Year (beginning September 1)	Supply				Disappearance					Ending stocks August 31		
					Domestic use							
	Beginning stocks	Production	Imports	Total	Feed and residual	Food, seed, and industrial	Total	Exports	Total disappear-ance	Privately held [a]	Govern - ment	Total
1996	426	9,233	13	9,672	5,277	1,714	6,991	1,797	8,789	881	2	883
1997	883	9,207	9	10,099	5,482	1,805	7,287	1,504	8,791	1,304	4	1,308
1998	1,308	9,759	19	11,085	5,471	1,846	7,318	1,984	9,298	1,775	12	1,787
1999	1,787	9,431	15	11,232	5,664	1,913	7,578	1,937	9,515	1,704	14	1,718
2000	1,718	9,915	7	11,639	5,842	1,957	7,799	1,941	9,740	1,891	8	1,899
2001	1,899	9,503	10	11,412	5,864	2,046	7,911	1,905	9,815	1,590	6	1,596
2002	1,596	8,967	14	10,578	5,563	2,340	7,903	1,588	9,491	1,083	4	1,087
2003	1,087	10,089	14	11,190	5,795	2,537	8,332	1,900	10,232	958	0	958
2004	958	11,807	11	12,776	6,157	2,687	8,844	1,818	10,662	2,113	1	2,114
2005	2,114	11,114	9	13,237	6,155	2,981	9,136	2,134	11,270	1,967	0	1,967
2006 [b]	1,967	10,535	12	12,514	5,598	3,488	9,086	2,125	11,210	1,304	0	1,304
2007 [c]	1,304	13,168	15	14,487	5,650	4,590	10,240	2,350	12,590	1,897	0	1,897

Source:
U.S. Department of Agriculture. *2006 Agricultural Statistics*, Table 1-37, http://www.nass.usda.gov/Publications/Ag_Statistics/index.asp.

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[a] Includes quantity under loan and farmer-owned reserve.
[b] Preliminary.
[c] Projected as of January 11, 2008, World Agricultural Supply and Demand Estimates. Totals may not add due to rounding.

Prices of corn used for ethanol production may vary for each mill depending on whether the mills are owned by farmers' cooperatives or whether the corn is purchased on the open market. Prices vary across states considerably.

Table 5.8
Corn for Grain: Marketing Year Average Price and Value, by State, Crops of 2005, 2006, and 2007

State[a]	Marketing year average price per bushel 2005	2006	2007	Value of production 2005	2006	2007
	Dollars	Dollars	Dollars	1,000 Dollars	1,000 Dollars	1,000 Dollars
Alabama	2.50	2.91	3.90	59,500	34,571	86,268
Arizona	3.18	4.37	4.75	13,642	13,372	20,211
Arkansas	2.15	2.73	3.75	64,780	71,744	371,700
California	2.70	3.35	4.40	60,372	60,803	158,400
Colorado	2.23	3.02	4.00	313,538	405,163	602,080
Delaware	2.25	3.61	4.45	49,550	84,275	79,855
Florida	2.00	2.80	3.80	5,264	6,888	12,635
Georgia	2.20	3.00	3.85	65,274	75,600	225,225
Idaho	2.68	3.89	4.75	27,336	42,985	82,294
Illinois	2.08	3.07	4.05	3,554,408	5,579,572	9,249,188
Indiana	2.00	3.17	4.05	1,777,160	2,677,572	3,998,768
Iowa	1.94	3.03	4.00	4,195,250	6,211,803	9,473,400
Kansas	2.07	3.08	4.00	964,103	1,062,600	2,072,000
Kentucky	2.21	3.18	4.10	344,230	482,851	719,304
Louisiana	2.25	2.80	3.80	100,980	113,680	457,710
Maryland	2.19	3.41	4.35	118,260	205,794	203,863
Michigan	1.88	3.10	3.95	540,368	893,172	1,151,030
Minnesota	1.86	2.89	3.85	2,216,934	3,187,237	4,384,380
Mississippi	2.22	2.84	3.70	104,529	101,530	521,700
Missouri	2.03	3.06	3.95	669,230	1,110,596	1,822,925
Montana	2.54	3.93	4.75	6,391	10,328	26,173
Nebraska	1.92	3.00	4.00	2,439,360	3,534,000	5,888,000
New Jersey	2.12	3.37	4.25	16,036	27,823	43,563
New Mexico	2.60	3.70	4.45	25,025	30,803	42,831
New York	2.29	3.42	4.30	130,622	211,766	300,355
North Carolina	2.33	3.03	3.85	195,720	295,970	392,700
North Dakota	1.80	2.77	3.75	278,640	430,458	1,022,250
Ohio	1.98	3.08	3.95	920,205	1,449,571	2,138,925
Oklahoma	2.39	3.17	4.05	68,713	73,227	158,558
Oregon	2.59	3.24	4.45	10,360	16,913	30,371
Pennsylvania	2.30	3.54	4.35	269,376	414,605	545,664
South Carolina	2.19	2.98	3.75	72,401	95,062	138,750
South Dakota	1.79	2.88	3.85	841,390	899,539	2,096,325
Tennessee	2.07	2.93	3.70	160,115	183,125	307,877
Texas	2.47	3.20	4.15	520,923	561,440	1,228,400
Utah	2.77	3.29	4.60	5,418	8,781	14,978
Virginia	2.14	3.07	4.05	90,907	127,098	139,421
Washington	2.81	3.72	4.55	46,084	58,590	114,660
West Virginia	2.17	3.57	4.20	6,623	11,138	12,587
Wisconsin	1.94	3.04	3.90	832,648	1,217,216	1,726,920
Wyoming	2.45	2.64	3.60	16,807	15,325	27,864
US	**2.00**	**3.04**	**4.20**	**22,198,472**	**32,094,586**	**52,090,108**

Source:
U.S. Department of Agriculture. *2008 Agricultural Statistics*, Table 1-40, http://www.nass.usda.gov/Publications/Ag_Statistics/index.asp.

[a] States with no data are not listed.

These data show that government subsidies are vital to ensuring a profit to farmers, when land and labor opportunity costs are considered. However, many farmers only factor operating costs into the calculation, making corn the most profitable commodity crop in most regions of the country. If the residue from corn production also had a market as a bioenergy feedstock, then farmers in areas of high corn yield may come closer to making a profit without subsidies.

Table 5.9
Corn Production Costs and Returns per Planted Acre by Region, Excluding Government Payments, 2006-2007[a]
(Dollars per planted acre)

Item	United States		Heartland		Northern Crescent		Northern Great Planes		Prairie Gateway		Eastern Uplands		Southern Seaboard	
	2006	2007	2006	2007	2006	2007	2006	2007	2006	2007	2006	2007	2006	2007
Gross value of production														
Primary product: Corn grain	350.52	467.61	377.5	500.65	265	348.84	302.56	401.32	324.87	474.6	357.68	406.56	319.7	358
Secondary product: Corn silage	1.35	1.33	0.67	0.62	3.23	3.06	2.34	3.67	3.10	3.27	6.68	4.27	0.00	0.00
Total, gross value of production	**351.87**	**468.94**	**378.17**	**501.27**	**268.23**	**351.90**	**304.90**	**404.99**	**327.97**	**477.87**	**364.36**	**410.83**	**319.70**	**358.00**
Operating costs:														
Seed	43.55	49.04	43.83	49.40	43.83	49.40	41.82	47.14	43.54	49.07	39.98	45.06	38.84	43.78
Fertilizer	80.17	93.13	82.79	96.13	89.27	103.65	52.69	61.18	63.36	73.57	100.21	116.35	83.79	97.29
Chemicals	23.62	24.38	25.73	26.55	20.77	21.43	16.47	16.99	20.02	20.66	23.18	23.92	22.37	23.08
Custom operations[c]	10.58	10.93	9.40	9.80	13.03	13.59	9.58	9.99	14.74	15.37	9.27	9.67	6.76	7.05
Fuel, lube, and electricity	28.73	31.58	22.48	25.00	27.98	31.05	28.60	31.92	66.16	76.30	19.76	21.23	25.10	26.82
Repairs	14.45	14.86	12.67	13.11	14.60	15.10	15.79	16.33	22.83	23.62	12.28	12.70	20.99	21.71
Purchased irrigation water	0.12	0.13	0.00	0.00	0.02	0.02	1.57	1.64	0.19	0.20	0.00	0.00	0.00	0.00
Interest on operating capital	4.76	4.94	4.66	4.85	4.95	5.16	3.94	4.08	5.46	5.71	4.84	5.05	4.68	4.85
Total, operating costs	**205.98**	**228.99**	**201.56**	**224.84**	**214.45**	**239.40**	**170.46**	**189.27**	**236.30**	**264.50**	**209.52**	**233.98**	**202.53**	**224.58**
Allocated overhead:														
Hired labor	2.19	2.26	1.46	1.51	3.14	3.25	3.42	3.54	3.79	3.92	1.21	1.25	6.33	6.55
Opportunity cost of unpaid labor	23.56	24.34	20.52	21.24	32.94	34.10	22.06	22.83	25.12	26.00	39.12	40.49	25.59	26.49
Capital recovery of machinery and equipment	66.71	69.77	63.59	66.73	63.68	66.83	72.66	76.25	86.23	90.49	59.77	62.73	66.93	70.24
Opportunity cost of land (rental rate)	90.84	97.21	103.16	110.48	75.90	81.28	58.82	62.99	69.67	74.61	61.75	66.13	53.80	57.62
Taxes and insurance	7.01	7.52	6.37	6.88	9.47	10.23	4.27	4.61	8.42	9.10	5.40	5.83	8.28	8.95
General farm overhead	13.45	13.88	12.57	13.00	18.30	18.93	9.53	9.86	13.09	13.54	10.92	11.30	17.45	18.05
Total, allocated overhead	**203.76**	**214.98**	**207.67**	**219.84**	**203.43**	**214.62**	**170.76**	**180.08**	**206.32**	**217.66**	**178.17**	**187.73**	**178.38**	**187.90**
Total, costs listed	**409.74**	**443.97**	**409.23**	**444.68**	**417.88**	**454.02**	**341.22**	**369.35**	**442.62**	**482.16**	**387.69**	**421.71**	**380.91**	**412.48**
Value of production less total costs listed	-57.87	24.97	-31.06	56.59	-149.65	-102.12	-36.32	35.64	-114.65	-4.29	-23.33	-10.88	-61.21	-54.48
Value of production less operating costs	145.89	239.95	176.61	276.43	53.78	112.50	134.44	215.72	91.67	213.37	154.84	176.85	117.17	133.42
Supporting information:														
Yield (bushels per planted acre)	138	143	151	155	106	108	122	127	119	140	136	121	115	100
Price (dollars per bushel at harvest)	2.54	3.27	2.50	3.23	2.50	3.23	2.48	3.16	2.73	3.39	2.63	3.36	2.78	3.58
Enterprise size (planted acres) [a]	250	250	281	281	128	128	341	341	322	322	77	77	146	146
Production practices: [a]														
Irrigated (percent)	12	12	5	5	5	5	21	21	48	48	2	2	13	13
Dryland (percent)	88	88	95	95	95	95	79	79	52	52	98	98	87	87

Source:
Economic Research Service, U.S. Department of Agriculture, http://www.ers.usda.gov/data/costsandreturns/testpick.htm.

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[a] Developed from survey base year, 2005.
[b] Cost of commercial fertilizers, soil conditioners, and manure.
[c] Cost of custom operations, technical services, and commercial drying.

Table 5.10
Oats: Area, Yield, Production, and Value, 1996-2007

Year	Area		Yield per harvested acre	Production	Marketing year average price per bushel received by farmers	Value of production
	Planted[a]	Harvested				
	1,000 Acres	1,000 Acres	Bushels	1,000 Bushels	Dollars	1,000 Dollars
1996	4,638	2,655	57.7	153,245	1.96	313,910
1997	5,068	2,813	59.5	167,246	1.60	273,284
1998	4,891	2,752	60.2	165,768	1.10	199,475
1999	4,668	2,445	59.6	145,628	1.12	174,307
2000	4,473	2,325	64.2	149,165	1.10	175,432
2001	4,401	1,911	61.5	117,602	1.59	197,181
2002	4,995	2,058	56.4	116,002	1.81	212,078
2003	4,597	2,220	65	144,383	1.48	224,910
2004	4,085	1,787	64.7	115,695	1.48	178,327
2005	4,246	1,823	63	114,878	1.63	195,150
2006	4,168	1,566	59.8	93,638	1.87	181,005
2007 [b]	3,760	1,505	60.9	91,599	2.50	228,613

Source:
U.S. Department of Agriculture. *2008 Agricultural Statistics*, Table 1-45 and annual, http://www.nass.usda.gov/Publications/Ag_Statistics/index.asp.

[a] Oats sown for all purposes, including oats sown in the preceding fall.
[b] Preliminary.

Table 5.11
Oats: Area, Yield, and Production, by State, 2005-2007

	Area planted[a]			Area harvested			Yield per harvested acre			Production		
	2005	2006	2007	2005	2006	2007	2005	2006	2007	2005	2006	2007
	1,000 Acres	1,000 Acres	1,000 Acres	1,000 Acres	1,000 Acres	1,000 Acres	Bushels	Bushels	Bushels	1,000 Bushels	1,000 Bushels	1,000 Bushels
Arizona	50	50	45	20	10	16	55	40	58	1,100	400	928
California	270	270	210	20	20	20	75	86	93	1,500	1,720	1,860
Colorado	75	85	75	15	10	10	75	70	80	1,125	700	800
Georgia	75	70	70	20	30	30	60	53	56	1,200	1,590	1,680
Idaho	90	90	70	20	20	20	64	72	61	1,280	1,440	1,220
Illinois	60	60	35	40	40	24	79	77	68	3,160	3,080	1,632
Indiana	20	25	25	9	14	8	69	80	55	621	1,120	440
Iowa	210	210	145	125	110	67	79	76	71	9,875	8,360	4,757
Kansas	100	100	90	40	40	35	59	45	38	2,360	1,800	1,330
Maine	32	31	31	28	30	30	70	55	70	1960	1650	2100
Michigan	90	80	70	75	65	55	61	62	58	4,575	4,030	3,190
Minnesota	310	290	270	205	200	180	62	56	60	12,710	11,200	10,800
Missouri	35	40	25	20	28	8	65	65	50	1,300	1,820	400
Montana	90	70	75	35	24	35	53	46	52	1,855	1,104	1,820
Nebraska	150	160	120	60	45	35	73	45	68	4380	2025	2380
New York	95	85	100	75	67	60	54	74	57	4,050	4,958	3,420
North Carolina	50	60	50	23	26	15	73	65	51	1,679	1,690	765
North Dakota	490	420	460	240	120	260	59	41	59	14,160	4,920	15,340
Ohio	80	70	75	60	55	55	60	75	62	3,600	4,125	3,410
Oklahoma	45	35	80	10	8	15	41	30	31	410	240	465
Oregon	40	50	60	18	20	22	78	95	93	1,404	1,900	2,046
Pennsylvania	140	135	115	110	110	80	55	64	56	6,050	7,040	4,480
South Carolina	35	33	33	20	18	13	59	55	52	1,180	990	676
South Dakota	380	380	330	180	95	125	72	57	74	12,960	5,415	9,250
Texas	690	760	710	110	100	100	43	37	40	4,730	3,700	4,000
Utah	50	45	35	7	7	5	73	77	85	511	539	425
Virginia	14	16	16	3	4	5	61	55	68	183	220	340
Washington	25	30	30	8	8	9	75	86	61	600	688	549
Wisconsin	400	370	270	215	230	160	64	63	67	13,760	14,490	10,720
Wyoming	55	48	40	12	12	8	50	57	47	600	684	376
US	**4,246**	**4,168**	**3,760**	**1,823**	**1,566**	**1,505**	**63**	**59.8**	**60.9**	**114,878**	**93,638**	**91,599**

Source:
U.S. Department of Agriculture. *2008 Agricultural Statistics*, Table 1-49, http://www.nass.usda.gov/Publications/Ag_Statistics/index.asp.

[a] Relates to the total area of oats sown for all purposes, including oats sown in the preceding fall.

Table 5.12
Oats Production Costs and Returns per Planted Acre by Region, Excluding Government Payments, 2006-2007[a]
(Dollars per planted acre)

Item	United States		Northern Great Plains		Prarie Gateway		Northern Crescent		Heartland	
	2006	2007	2006	2007	2006	2007	2006	2007	2006	2007
Gross value of production										
Primary product: Oats	106.1052	144.286	61.6003	136.6604458	47.32	68.221	122.18	130.46806	83.094914	133.632
Secondary product: Straw	51.22	36.38	12.75	19.96	3.85	3.87	75.19	52.26	51.16	52.94
Secondary product: Hay, silage, grazing	10.96	16.87	11.28	15.95	31.09	44.02	7.47	11.47	7.96	12.30
Total, gross value of production	**168.29**	**197.54**	**85.63**	**172.57**	**82.26**	**116.11**	**204.84**	**194.20**	**142.21**	**198.87**
Operating costs:										
Seed	9.31	9.99	6.48	7.57	7.23	8.44	10.26	11.99	9.76	11.40
Fertilizer [b]	26.85	29.29	12.07	15.10	36.47	45.64	32.88	41.14	20.91	26.17
Chemicals	1.93	2.26	3.23	3.28	0.83	0.85	2.10	2.13	1.72	1.74
Custom operations	8.85	7.40	2.45	2.55	2.67	2.78	10.49	10.93	11.00	11.46
Fuel, lube, and electricity	16.74	17.25	12.78	14.12	11.31	12.49	19.84	21.91	16.19	17.88
Repairs	11.70	12.41	13.10	13.55	9.64	9.98	12.31	12.74	11.27	11.66
Purchased irrigation water	2.92	2.40	0.78	0.80	0.25	0.26	1.85	1.92	5.73	5.93
Interest on operating inputs	1.88	1.81	1.22	1.28	1.64	1.80	2.15	2.30	1.84	1.93
Total, operating costs	**80.18**	**82.82**	**52.11**	**58.25**	**70.04**	**82.24**	**91.88**	**105.06**	**78.42**	**88.17**
Allocated overhead:										
Hired labor	0.77	0.67	0.34	0.35	0.36	0.38	1.49	1.54	0.20	0.20
Opportunity cost of unpaid labor	33.97	31.64	21.09	21.83	26.28	27.20	41.78	43.24	31.38	32.48
Capital recovery of machinery and equipment	54.49	58.73	61.51	64.55	43.66	45.82	54.33	57.01	56.33	59.11
Opportunity cost of land (rental rate)	63.83	67.09	44.22	50.93	35.04	40.36	59.92	69.02	84.19	96.97
Taxes and insurance	4.60	5.04	3.57	4.14	4.90	5.69	4.62	5.36	4.77	5.53
General farm overhead	8.37	8.26	7.15	7.39	5.24	5.42	8.92	9.23	9.18	9.49
Total, allocated overhead	**166.03**	**171.44**	**137.88**	**149.19**	**115.48**	**124.87**	**171.06**	**185.40**	**186.05**	**203.78**
Total, costs listed	**246.20**	**254.25**	**189.99**	**207.44**	**185.52**	**207.11**	**262.94**	**290.46**	**264.47**	**291.95**
Value of production less total costs listed	-77.92	-56.72	-104.36	-34.87	-103.26	-91.00	-58.10	-96.26	-122.25	-93.08
Value of production less operating costs	88.11	114.72	33.52	114.32	12.22	33.87	112.96	89.14	63.80	110.70
Supporting information:										
Yield (bushels per planted acre)	56.41499	58.86958	37	58	26	26	82	57	48	50
Price (dollars per bushel at harvest)	1.880797	2.450943	1.68	2.38	1.82	2.58	1.49	2.29	1.74	2.69
Enterprise size (planted acres) [a]	27	27	66	66	47	47	25	25	23	23
Production practices: [a]										
Irrigated (percent of acres)	1	1	1.88	1.88	5	5	0	0	0	0
Dryland (percent of acres)	99	99	98	98	95	95	100	100	100	100
Straw (percent of acres)	71	71	47	47	18.24	18.24	79	79	82	82

Source:
Economic Research Service, US Department of Agriculture, http://www.ers.usda.gov/data/costsandreturns/testpick.htm.

[a] Developed from survey base year, 2005.
[b] Cost of commercial fertilizers, soil conditioners, and manure.

Table 5.13
Rice[a]: Area, Yield, Production, and Value, 1996-2007

Year	Area: Planted	Area: Harvested	Yield per harvested acre	Production	Marketing year average price per cwt. received by farmers	Value of production
	1,000 Acres	1,000 Acres	Pounds	1,000 cwt.	Dollars	1,000 Dollars
1996	2,824	2,804	6,120	171,599	9.96	1,690,270
1997	3,125	3,103	5,897	182,992	9.70	1,756,136
1998	3,285	3,257	5,663	184,443	8.89	1,654,157
1999	3,531	3,512	5,866	206,027	5.93	1,231,207
2000	3,060	3,039	6,281	190,872	5.61	1,049,961
2001	3,334	3,314	6,496	215,270	4.25	925,055
2002	3,240	3,207	6,578	210,960	4.49	979,628
2003[b]	3,022	2,997	6,670	199,897	8.08	1,628,948
2004	3,347	3,325	6,988	232,362	7.33	1,701,822
2005	3,384	3,364	6,636	223,235	7.65	1,741,721
2006	2,838	2,821	6,868	193,736	9.96	1,982,696
2007	2,761	2,748	7,185	197,456	11.50	2,273,955

Source:
U.S. Department of Agriculture. *2008 Agricultural Statistics*, Table 1-21 and previous annual editions, http://www.nass.usda.gov/Publications/Ag_Statistics/index.asp

[a] Rough.
[b] Sweet rice yield and production included in 2003 as short grain but not in previous years.

Table 5.14
Rice: Area, Yield, and Production by State, 2005-2007

State[a]	Area Planted			Area harvested			Yield per harvested acre			Production		
	2005	2006	2007[b]	2005	2006	2007[b]	2005	2006	2007[b]	2005	2006	2007[b]
	1,000 Acres	1,000 Acres	1,000 Acres	1,000 Acres	1,000 Acres	1,000 Acres	Pounds	Pounds	Pounds	1,000 cwt.	1,000 cwt.	1,000 cwt.
Arkansas	1,643.0	1,406.0	1,331.0	1,635.0	1,400.0	1,325.0	6,650	6,850	7,130	108,792	95,917	94,487
California	528.0	526.0	534.0	526.0	523.0	533.0	7,380	7,660	8,220	38,836	40,040	43,822
Louisiana	530.0	350.0	380.0	525.0	345.0	378.0	5,900	5,820	6,140	30,983	20,093	23,222
Mississippi	265.0	190.0	190.0	263.0	189.0	189.0	6,400	7,000	7,450	16,832	13,230	14,081
Missouri	216.0	216.0	180.0	214.0	214.0	178.0	6,600	6,400	6,900	14,124	13,696	12,279
Texas	202.0	150.0	146.0	201.0	150.0	145.0	6,800	7,170	6,600	13,668	10,760	9,565
US	**3,384.0**	**2,838.0**	**2,761.0**	**3,364.0**	**2,821.0**	**2,748.0**	**6,636**	**6,868**	**7,185**	**223,235**	**193,736**	**197,456**

Source:
U.S. Department of Agriculture. *2008 Agricultural Statistics*, Table 1-27, http://www.nass.usda.gov/Publications/Ag_Statistics/index.asp.

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[a] States with no data are not listed.
[b] Preliminary.

Table 5.15
Rice Production Costs and Returns per Planted Acre by Region, Excluding Government Payments, 2006-2007[a]
(Dollars per planted acre)

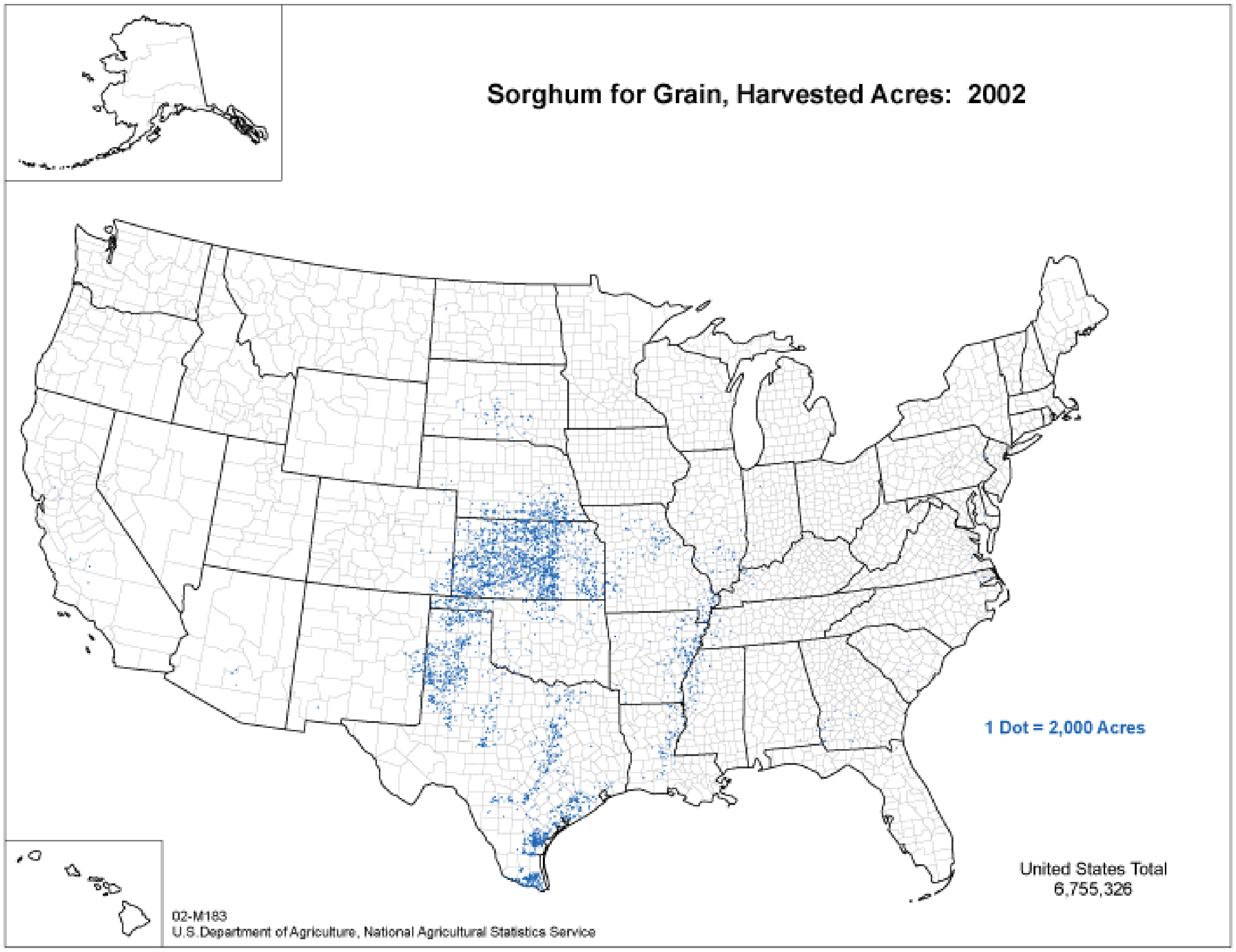
Item	United States		Ark Non-Delta		California		Mississippi River Delta		Gulf Coast	
	2006	2007	2006	2007	2006	2007	2006	2007	2006	2007
Gross value of production										
Primary product: Rice	623.14	776.99	596.18	734.06	715.63	951.56	628.92	761.67	587.88	564.68
Total, gross value of production	**623.14**	**776.99**	**596.18**	**734.06**	**715.63**	**951.56**	**628.92**	**761.67**	**587.88**	**564.68**
Operating costs:										
Seed	36.75	40.75	34.38	38.03	41.41	45.81	39.35	43.53	35.08	38.81
Fertilizer [b]	60.49	75.89	51.99	64.69	69.58	86.58	59.34	73.84	75.15	93.51
Chemicals	65.96	66.15	56.75	57.64	90.88	92.30	56.10	56.98	67.38	68.43
Custom operations	41.90	45.18	27.93	29.13	82.00	85.51	34.05	35.51	48.73	50.82
Fuel, lube, and electricity	95.90	105.60	102.66	113.40	63.72	70.39	97.23	107.40	111.17	122.80
Repairs	26.40	27.25	27.66	28.61	25.45	26.33	24.94	25.80	25.66	26.54
Purchased irrigation water	10.36	11.75	0.18	0.19	43.00	44.84	0.00	0.00	15.98	16.66
Commercial drying	20.61	21.99	12.90	14.92	32.49	38.69	10.47	12.13	35.41	31.70
Interest on operating inputs	8.11	8.35	7.24	7.43	9.98	10.12	7.46	7.68	9.10	9.35
Total, operating costs	**366.48**	**402.91**	**321.69**	**354.04**	**458.51**	**500.57**	**328.94**	**362.87**	**423.66**	**458.62**
Allocated overhead:										
Hired labor	18.42	19.21	19.61	20.30	23.72	24.55	19.77	20.46	9.18	9.50
Opportunity cost of unpaid labor	41.23	43.34	35.32	36.56	65.18	67.47	28.94	29.96	46.55	48.18
Capital recovery of machinery and equipment	96.80	101.52	98.55	103.42	101.22	106.23	89.75	94.19	95.13	99.83
Opportunity cost of land (rental rate)	118.31	128.70	89.46	95.80	234.25	250.86	84.48	90.47	109.98	117.78
Taxes and insurance	15.49	17.08	16.28	17.59	13.67	14.77	19.77	21.36	12.70	13.72
General farm overhead	24.24	24.84	19.13	19.79	34.46	35.65	26.89	27.82	21.38	22.12
Total, allocated overhead	**314.49**	**334.70**	**278.35**	**293.46**	**472.50**	**499.53**	**269.60**	**284.26**	**294.92**	**311.13**
Total, costs listed	**680.97**	**737.61**	**600.04**	**647.50**	**931.01**	**1,000.10**	**598.54**	**647.13**	**718.58**	**769.75**
Value of production less total costs listed	-57.83	39.38	-3.86	86.56	-215.38	-48.54	30.38	114.54	-130.70	-205.07
Value of production less operating costs	256.66	374.07	274.49	380.02	257.12	450.99	299.98	398.80	164.22	106.06
Supporting information:										
Price (dollars per cwt at harvest)	8.62	10.26	8	10	9	12	8	10	9	10
Yield (cwt per planted acre)	72.29	75.73	70.89	74.21	76.62	82.60	74.34	77.96	69.00	55.93
Enterprise size (planted acres) [a]	511	511	521	521	431	431	634	634	469	469

Source:
Economic Research Service, US Department of Agriculture, http://www.ers.usda.gov/data/costsandreturns/testpick.htm.

[a] Developed from survey base year, 2006.
[b] Cost of commercial fertilizers, soil conditioners, and manure.

Sorghum is currently a small contributor to ethanol production, but because it is largely grown in an area of the country that does not significantly overlap with corn production, it could become important in expanding the range of locations of ethanol production facilities.

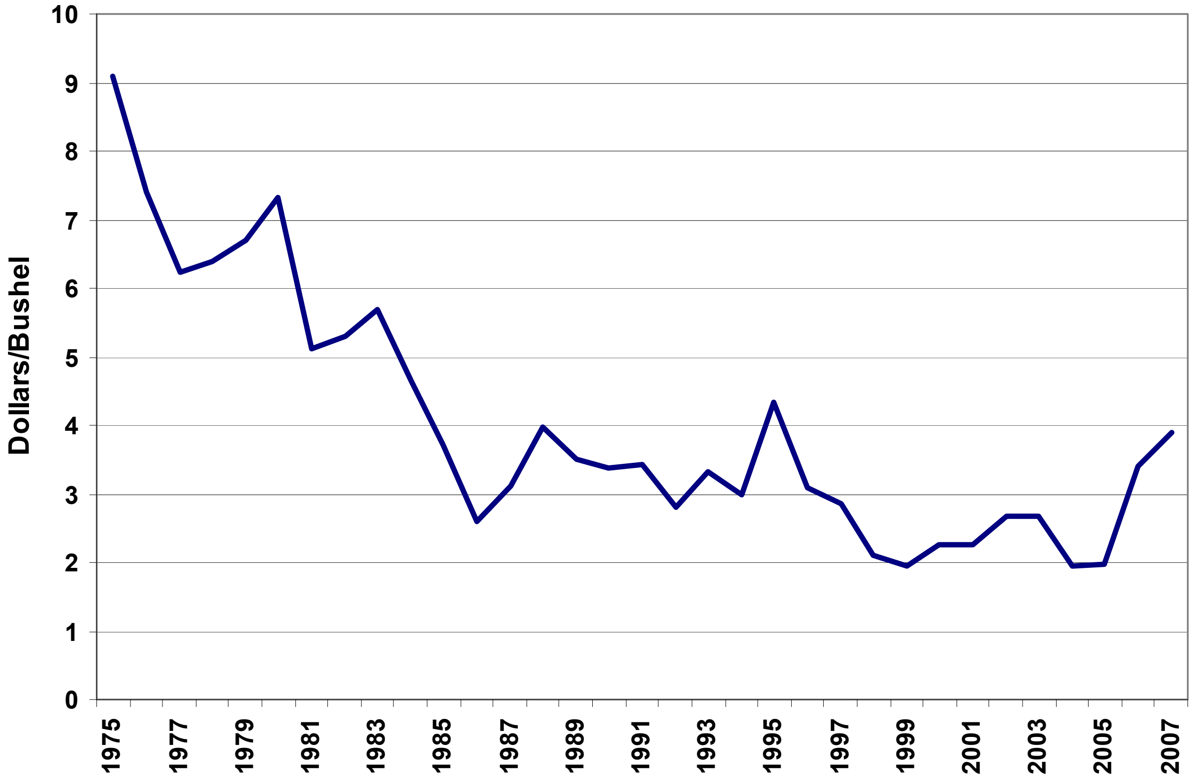
Figure 5.7
Sorghum for Grain, Harvested Acres, 2002



Source:
U.S. Department of Agriculture, National Agricultural Statistics Service, www.nass.usda.gov/research/atlas02/atlas-crops.html.

The price for sorghum declined from 1975 to 1999 but has stabilized and even shown some increase in recent years. Sorghum has a different geographic distribution than corn but has similar properties, making it a viable crop for the production of ethanol. The price fluctuation for sorghum is also very similar to that of corn.

Figure 5.8
Sorghum: Price per Bushel, 1975-2007
(Constant 2007 dollars)



Source:
U.S. Department of Agriculture, National Agricultural Statistics Service, http://www.nass.usda.gov/.

Sorghum is grown in areas that are generally too dry for unirrigated corn, thus potential resource areas for starch based ethanol can be expanded through use of sorghum. Grain weight per bushel is 56 lbs. at assumed harvest moisture content of 14%.

Table 5.16
Sorghum: Area, Yield, Production, and Value, 1996-2007

Year	Area Planted for all purposes[a]	Sorghum for grain[b]					Sorghum for silage		
		Area harvested	Yield per harvested acre	Production	Marketing year average price per cwt[cd]	Value of production[cd]	Area Harvested	Yield per harvested acre	Production
	1,000 Acres	1,000 Acres	Bushels	1,000 Bushels	Dollars	1,000 Dollars	1,000 Acres	Tons	1,000 Tons
1996	13,097	11,811	67.3	795,274	4.17	1,986,316	423	11.8	4,976
1997	10,052	9,158	69.2	633,545	3.95	1,408,534	412	13.1	5,385
1998	9,626	7,723	67.3	519,933	2.97	904,123	308	11.4	3,526
1999	9,288	8,544	69.7	595,166	2.80	937,081	320	11.6	3,716
2000	9,195	7,726	60.9	470,526	3.37	845,755	278	10.5	2,932
2001	10,248	8,579	59.9	514,040	3.46	978,783	352	11.0	3,860
2002	9,589	7,125	50.6	360,713	4.14	855,140	408	9.6	3,913
2003	9,420	7,798	52.7	411,237	4.26	964,978	343	10.4	3,552
2004	7,486	6,517	69.6	453,654	3.19	843,464	352	13.6	4,776
2005	6,454	5,736	68.5	392,933	3.33	737,038	311	13.6	4,218
2006	6,522	4,937	56.2	277,538	5.88	885,394	347	13.4	4,642
2007[d]	7,718	6,805	74.2	504,993	6.95	1,950,936	399	15.6	6,206

Source:
U.S. Department of Agriculture. *2008 Agricultural Statistics*, Table 1-62, http://www.nass.usda.gov/Publications/Ag_Statistics/index.asp.

[a] Grain and sweet sorghum for all uses, including syrup.
[b] Includes both grain sorghum for grain, and sweet sorghum for grain or seed.
[c] Based on the reported price of grain sorghum; cwt = 100 pounds.
[d] Preliminary.

Sorghum is used for ethanol production only in the two states that planted over 2 million acres, Kansas and Texas.

Table 5.17
Sorghum: Area, Yield, and Production, by State, 2005-2007

State	Area planted for all purposes			Sorghum for grain								
				Area harvested			Yield per harvested acre			Production		
	2005	2006	2007[a]	2005	2006	2007[a]	2005	2006	2007[a]	2005	2006	2007[a]
	1,000 Acres	1,000 Acres	1,000 Acres	1,000 Acres	1,000 Acres	1,000 Acres	Bushels	Bushels	Bushels	1,000 Bushels	1,000 Bushels	1,000 Bushels
Alabama	10	10	12	6	5	6	53	43	45	318	215	270
Arizona	23	24	45	7	7	21	95	95	95	665	665	1995
Arkansas	66	63	225	62	60	215	80	85	94	4,960	5,100	20,210
California	26	32	34	10	10	11	90	105	90	900	1,050	990
Colorado	160	280	220	110	130	150	31	26	37	3,410	3,380	5,550
Georgia	40	40	65	27	26	45	50	45	46	1,350	1,170	2,070
Illinois	85	75	80	83	72	77	92	89	81	7,636	6,408	6,237
Kansas	2,750	2,750	2,800	2,600	2,500	2,650	75	58	80	195,000	145,000	212,000
Kentucky	25	18	15	24	16	12	90	85	90	2,160	1,360	1,080
Louisiana	90	90	250	88	87	245	99	96	97	8,712	8,352	23,765
Mississippi	25	15	145	23	13	115	80	80	82	1,840	1,040	9,430
Missouri	135	100	110	130	95	105	76	85	96	9,880	8,075	10,080
Nebraska	340	370	350	250	240	240	87	80	98	21,750	19,200	23,520
New Mexico	120	110	105	97	60	75	45	35	40	4,365	2,100	3,000
North Carolina	16	17	15	13	13	9	50	47	60	650	611	540
Oklahoma	270	270	240	240	200	220	48	34	58	11,520	6,800	12,760
Pennsylvania	11	13	15	4	5	3	50	66	56	200	330	168
South Carolina	10	11	10	7	7	7	51	51	34	357	357	238
South Dakota	180	220	210	85	80	130	52	36	62	4,420	2,880	8,060
Tennessee	22	14	22	20	11	19	92	95	70	1,840	1,045	1,330
Texas	2,050	2,000	2,750	1,850	1,300	2,450	60	48	66	111,000	62,400	161,700
US	**6,454**	**6,522**	**7,718**	**5,736**	**4,937**	**6,805**	**68.5**	**56.2**	**74.2**	**392,933**	**277,538**	**504,993**

Source:
U.S. Department of Agriculture. *2006 Agricultural Statistics*, Table 1-62, http://www.nass.usda.gov/Publications/Ag_Statistics/index.asp.

[a] Preliminary.

The lower yields of sorghum grain results in lower profit in sorghum production compared to corn. Sorghum biomass production can be quite high, making it a potential source of crop residue in some areas of the country.

Table 5.18
Sorghum Production Costs and Returns per Planted Acre by Region, Excluding Government Payments, 2006-2007[a]
(Dollars per planted acre)

	United States		Heartland		Prairie Gateway		Fruitful Rim		Northern Great Plains	
Item	**2006**	**2007**	**2006**	**2007**	**2006**	**2007**	**2006**	**2007**	**2006**	**2007**
Gross value of production:										
Primary product: Sorghum	126.85	235.28	215.66	303.62	135	240.1	90.42	222.65	93.31	179.82
Secondary product: Sorgum silage	6.23	10.81	0	0	7.92	14.35	0	0	3.31	6.72
Total, gross value of production	**133.08**	**246.09**	**215.66**	**303.62**	**142.92**	**254.45**	**90.42**	**222.65**	**96.62**	**186.54**
Operating costs:										
Seed	5.38	5.62	8.87	9.18	4.96	5.13	6.46	6.68	6.93	7.17
Fertilizer[b]	25.8	30.11	50.9	59.1	25.14	29.19	27.49	31.92	21.92	25.45
Chemicals	18.07	18.15	20.28	20.92	20.56	21.21	7.5	7.74	14.46	14.92
Custom operations	9.91	10.4	5.93	6.18	9.95	10.38	10.79	11.25	7.78	8.11
Fuel, lube, and electricity	34.46	43.15	15.94	18.25	39.56	49.77	21.84	29.24	6.44	8.43
Repairs	17.76	18.35	15.96	16.51	18.84	19.49	15.98	16.53	8.37	8.66
Purchased irrigation water	0.11	0.14	0	0	0	0	0.6	0.63	0.16	0.17
Interest on operating inputs	2.63	2.78	2.79	2.87	2.81	2.98	2.14	2.29	1.56	1.61
Total, operating costs	**114.12**	**128.7**	**120.67**	**133.01**	**121.82**	**138.15**	**92.8**	**106.28**	**67.62**	**74.52**
Allocated overhead:										
Hired labor	5.04	5.69	2.39	2.47	3.48	3.6	13.95	14.44	0.6	0.62
Opportunity cost of unpaid labor	27.35	28.21	25.64	26.54	28.98	30	23.63	24.46	15.95	16.51
Capital recovery of machinery and equipment	64.34	67.48	56.87	59.68	66.91	70.22	60.06	63.03	43.03	45.16
Opportunity cost of land	34.4	36.92	66.08	70.77	33.4	35.77	35.05	37.54	36.62	39.22
Taxes and insurance	4.28	4.55	21.86	23.62	4.1	4.43	2.83	3.06	5.74	6.2
General farm overhead	8	8.4	27.03	27.96	6.82	7.06	10.46	10.82	11.19	11.58
Total, allocated overhead	143.41	151.25	199.87	211.04	143.69	151.08	145.98	153.35	113.13	119.29
Total costs listed	**257.53**	**279.95**	**320.54**	**344.05**	**265.51**	**289.23**	**238.78**	**259.63**	**180.75**	**193.81**
Value of production less total costs listed	-124.45	-33.86	-104.88	-40.43	-122.59	-34.78	-148.36	-36.98	-84.13	-7.27
Value of production less operating costs	18.96	117.39	94.99	170.61	21.1	116.3	-2.38	116.37	29	112.02
Supporting information:										
Sorghum Yield: bushels per planted acre	43	68	82	94	45	70	33	61	31	54
Price: dollars per bushel	2.95	3.46	2.63	3.23	3	3.43	2.74	3.65	3.01	3.33
Enterprise size (planted acres)[a]	297	297	125	125	68	269	785	785	272	272
Production practices:[a]										
Irrigated (percent)	11	11	6	6	13	13	13	13	13	13
Dryland (percent)	89	89	94	94	87	87	87	87	87	87

Source:
Economic Research Service, U.S. Department of Agriculture, http://www.ers.usda.gov/data/costsandreturns/testpick.htm.

[a] Developed from survey base year, 2003.
[b] Commercial fertilizer and soil conditioners.

USDA's wheat baseline projections show a continuing rise in yield per harvested acre, but a leveling off of planted acres and net returns (over variable costs). This analysis is updated annually.

Table 5.19
Wheat Baseline Projections, 2006 – 2018

Item	2006/07	2007/08	2008/09	2009/10	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18
Area (million acres):												
Planted acres	57.3	60.4	65.0	60.0	58.5	57.5	56.5	56.5	56.0	56.0	55.5	55.5
Harvested acres	46.8	51.0	55.3	51.0	49.7	48.9	48.0	48.0	47.6	47.6	47.2	47.2
Yields (bushels per acre):												
Yield/harvested acre	38.7	40.5	42.5	42.8	43.1	43.4	43.7	44.0	44.3	44.6	44.9	45.2
Supply and use (million bushels):												
Beginning stocks	571	456	312	606	703	742	749	732	716	696	683	661
Production	1,812	2,067	2,350	2,185	2,140	2,120	2,100	2,110	2,110	2,125	2,120	2,135
Imports	122	90	100	100	105	105	110	110	115	115	120	120
Supply	2,505	2,613	2,762	2,891	2,948	2,967	2,959	2,952	2,941	2,936	2,923	2,916
Feed & residual	934	940	950	959	968	977	986	995	1,004	1,013	1,022	1,031
Food, seed, & industrial	81	86	81	79	78	76	76	76	76	75	75	75
Fuel alcohol use[a]	125	125	175	200	210	215	215	215	215	215	215	215
Domestic	1,140	1,151	1,206	1,238	1,256	1,268	1,277	1,286	1,295	1,303	1,312	1,321
Exports	909	1,150	950	950	950	950	950	950	950	950	950	950
Total use	2,049	2,301	2,156	2,188	2,206	2,218	2,227	2,236	2,245	2,253	2,262	2,271
Ending stocks	456	312	606	703	742	749	732	716	696	683	661	645
Stocks/use ratio, percent	22.3	13.6	28.1	32.1	33.6	33.8	32.9	32.0	31.0	30.3	29.2	28.4
Prices (dollars per bushel):												
Farm price	4.26	6.10	5.50	5.00	4.65	4.50	4.50	4.50	4.55	4.55	4.60	4.65
Loan rate	2.75	2.75	2.75	2.75	2.75	2.75	2.75	2.75	2.75	2.75	2.75	2.75
Variable costs of production (dollars):												
Per acre	85.50	93.84	98.38	101.32	103.01	104.63	106.10	107.43	109.10	110.79	112.49	114.10
Per bushel	2.21	2.32	2.31	2.37	2.39	2.41	2.43	2.44	2.46	2.48	2.51	2.52
Returns over variable costs (dollars per acre):												
Net returns[a]	79.36	153.21	135.37	112.68	97.41	90.67	90.55	90.57	92.47	92.14	94.05	96.08

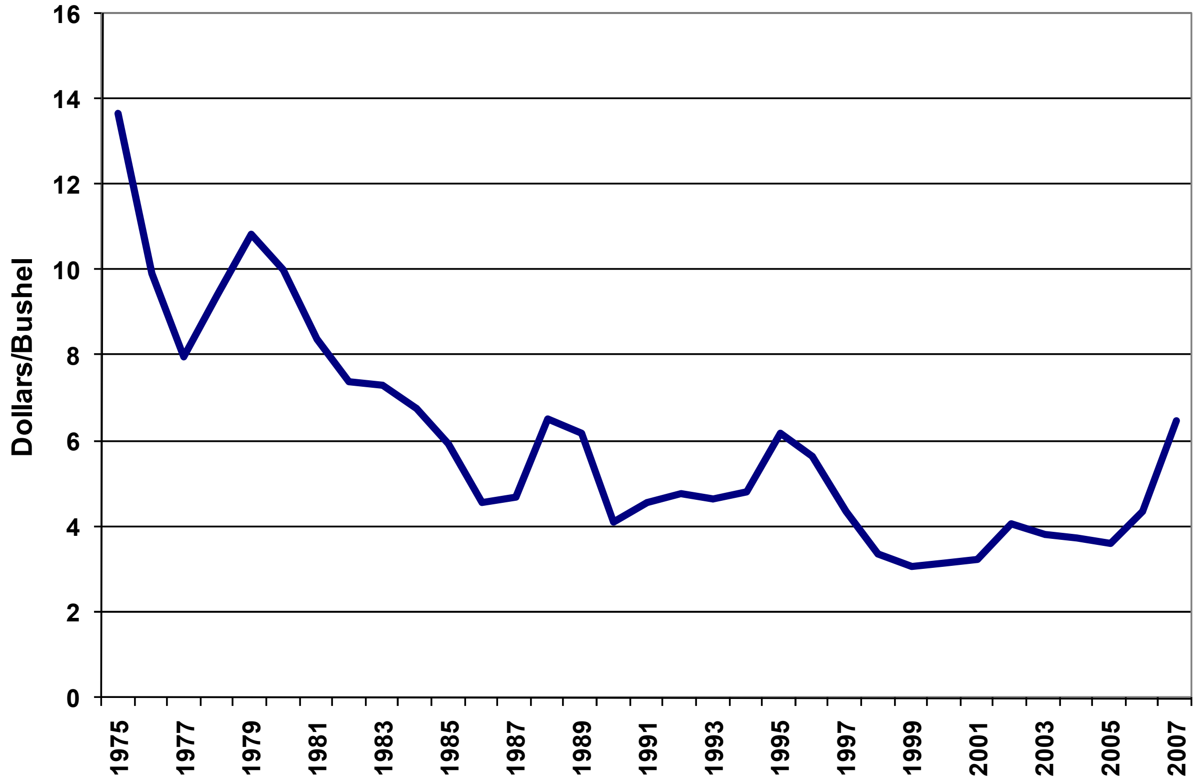
Source:

U.S. Department of Agriculture. 2008. *Long-Term Agricultural, Projection Tables to 2018*, February, Table 12; *U.S. Wheat Long-Term Projections*, http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1192.

Note: Marketing year beginning June 1 for corn.

Overall, the price for wheat has been declining due to improvements in farming techniques.

Figure 5.9
Wheat: Price per Bushel, 1975-2007
(Constant 2007 dollars)



Source:
U.S. Department of Agriculture, National Agricultural Statistics Service, http://www.nass.usda.gov/.

Table 5.20
Wheat: Area, Yield, Production, and Value, 1996-2007

Year	Area		Yield per harvested acre	Production	Marketing year average price per bushel received by farmers[b]	Value of production[b]
	Planted[a]	harvested				
	1,000 Acres	1,000 Acres	Bushels	1,000 Bushels	Dollars	1,000 Dollars
1996	75,105	62,819	36.3	2,277,388	4.30	9,782,238
1997	70,412	62,840	39.5	2,481,466	3.38	8,286,741
1998	65,821	59,002	43.2	2,547,321	2.65	6,780,623
1999	62,664	53,773	42.7	2,295,560	2.48	5,586,675
2000	62,549	53,063	42.0	2,228,160	2.62	5,771,786
2001	59,432	48,473	40.2	1,947,453	2.78	5,412,834
2002	60,318	45,824	35.0	1,605,878	3.56	5,637,416
2003	62,141	53,063	44.2	2,344,760	3.40	7,929,039
2004	59,674	49,999	43.2	2,158,245	3.40	7,283,324
2005	57,229	50,119	42.0	2,104,690	3.42	7,171,441
2006	57,344	46,810	38.7	1,812,036	4.26	7,710,014
2007	60,433	51,011	40.5	2,066,722	6.65	13,669,482

Source:
U.S. Department of Agriculture. *2008 Agricultural Statistics*, Table 1-2 and previous annual editions, http://www.nass.usda.gov/Publications/Ag_Statistics/index.asp.

[a] Includes area seeded in preceding fall for winter wheat.
[b] Includes allowance for loans outstanding and purchases by the Government valued at the average loan and purchase rate, by States, where applicable.

Table 5.21
Wheat: Area, Yield, and Production, by State, 2005-2007

State	Area planted[a]			Area harvested			Yield per harvested acre			Production		
	2005	2006	2007	2005	2006	2007	2005	2006	2007	2005	2006	2007
	1,000 Acres	1,000 Acres	1,000 Acres	1,000 Acres	1,000 Acres	1,000 Acres	Bushels	Bushels	Bushels	1,000 Bushels	1,000 Bushels	1,000 Bushels
Alabama	100	100	120	45	45	80	50.0	58.0	43.0	2,250	2,610	3,440
Arizona	85	79	86	81	76	83	99.5	99.7	99.5	8,060	7,580	8,260
Arkansas	220	365	820	160	305	700	52.0	61.0	41.0	8,320	18,605	28,700
California	570	520	585	369	315	315	76.3	66.5	83.6	28,155	20,935	26,325
Colorado	2,570	2,170	2,520	2219	1,919	2369	24.4	21.6	40.3	54,035	41,515	95,520
Delaware	52	48	57	51	45	55	70.0	67.0	68.0	3,570	3,015	3,740
Florida	18	8	13	8	5	9	45.0	42.0	57.0	360	210	513
Georgia	280	230	360	140	120	230	52.0	49.0	40.0	7,280	5,880	9,200
Idaho	1,260	1,255	1,235	1,200	1,195	1,175	83.8	75.6	71.2	100,590	90,315	83,675
Illinois	630	930	1,000	600	910	890	61.0	67.0	57.0	36,600	60,970	50,730
Indiana	360	470	420	340	460	370	72.0	69.0	57.0	24,480	31,740	21,090
Iowa	20	25	35	15	18	28	50.0	66.0	50.0	750	1,188	1,400
Kansas	10,000	9,800	10,400	9,500	9,100	8,600	40.0	32.0	33.0	380,000	291,200	283,800
Kentucky	390	430	440	300	320	250	68.0	71.0	49.0	20,400	22,720	12,250
Louisiana	110	115	235	100	105	220	48.0	53.0	54.0	4,800	5,565	11,880
Maryland	155	210	220	140	125	170	66.0	68.0	68.0	9,240	8,500	11,560
Michigan	600	660	560	590	650	540	66.0	73.0	65.0	38,940	47,450	35,100
Minnesota	1,820	1,750	1,765	1,745	1,695	1,710	41.0	47.4	47.0	71,470	80,340	80,430
Mississippi	70	85	370	65	73	330	50.0	59.0	56.0	3,250	4,307	18,480
Missouri	590	1,000	1,050	540	910	880	54.0	54.0	43.0	29,160	49,140	37,840
Montana	5,340	5,300	5,170	5,235	5,215	5,065	36.8	29.4	29.6	192,480	153,075	149,820
Nebraska	1,850	1,800	2,050	1,760	1,700	1,960	39.0	36.0	43.0	68,640	61,200	84,280
Nevada	14	23	23	8	10	13	100.6	105.6	100.0	805	1,056	1,300
New Jersey	28	25	31	23	22	28	53.0	60.0	51.0	1,219	1,320	1,428
New Mexico	450	440	490	270	120	300	36.0	32.0	26.0	9,720	3,840	7,800
New York	100	105	100	95	95	85	54.0	61.0	52.0	5,130	5,795	4,420
North Carolina	560	560	630	435	420	500	57.0	59.0	40.0	24,795	24,780	20,000
North Dakota	9,090	8,800	8,595	8,835	8,290	8,405	34.4	30.4	35.7	303,765	251,770	300,050
Ohio	860	990	820	830	960	730	71.0	68.0	63.0	58,930	65,280	45,990
Oklahoma	5,700	5,700	5,900	4,000	3,400	3,500	32.0	24.0	28.0	128,000	81,600	98,000
Oregon	955	880	875	895	845	855	59.8	52.6	54.7	53,560	44,440	46,785
Pennsylvania	150	160	170	145	150	155	54.0	59.0	58.0	7,830	8,850	8,990
South Carolina	170	130	160	165	123	135	52.0	50.0	31.0	8,580	6,150	4,185
South Dakota	3,315	3,310	3,509	3,193	2,576	3,328	41.8	32.6	44.3	133,420	84,090	147,516
Tennessee	240	280	420	150	190	260	56.0	64.0	41.0	8,400	12,160	10,660
Texas	5,500	5,550	6,200	3,000	1,400	3,800	32.0	24.0	37.0	96,000	33,600	140,600
Utah	163	144	146	148	136	132	48.0	45.0	48.6	7,099	6,120	6,420
Virginia	180	190	230	160	155	205	63.0	68.0	64.0	10,080	10,540	13,120
Washington	2,280	2,280	2,170	2,225	2,225	2,137	62.6	62.9	60.2	139,300	140,050	128,722
West Virginia	7	8	8	5	6	6	60.0	61.0	58.0	300	366	348
Wisconsin	208	261	299	182	240	278	56.4	76.2	68.0	10,262	18,290	18,910
Wyoming	169	158	146	152	141	130	30.7	27.5	26.5	4,665	3,879	3,445
US	**57,229**	**57,344**	**60,433**	**50,119**	**46,810**	**51,011**	**42.0**	**38.7**	**40.5**	**2,104,690**	**1,812,036**	**2,066,722**

Source:
U.S. Department of Agriculture. *2008 Agricultural Statistics*, Table 1-6, http://www.nass.usda.gov/Publications/Ag_Statistics/index.asp.

[a] Includes area planted preceding fall.

Table 5.22
Wheat: Supply and Disappearance, 1996-2007
(Million bushels)

Year (beginning September 1)	Supply				Disappearance						Ending stocks May 31
					Domestic use						
	Beginning stocks	Production	Imports	Total	Food	Seed	Feed	Total	Exports	Total disappearance	
1996	376	2,277	92	2,746	891	102	308	1,301	1,002	2302	444
1997	444	2,481	95	3,020	914	92	251	1,257	1,040	2,298	722
1998	722	2,547	103	3,373	909	81	391	1,381	1,046	2,427	946
1999	946	2,296	95	3,336	929	92	279	1,300	1,086	2,386	950
2000	950	2,228	90	3,268	950	79	300	1,330	1,062	2,392	876
2001	876	1,947	108	2,931	926	83	182	1,192	962	2,154	777
2002	777	1,606	77	2,460	919	84	116	1,119	850	1,969	491
2003	491	2,345	63	2,899	912	80	203	1,194	1,158	2353	546
2004	546	2,158	71	2,775	907	78	182	1,169	1,066	2,235	540
2005	540	2,105	81	2,726	915	78	160	1,152	1,003	2,155	571
2006	571	1,812	122	2,505	934	81	125	1,140	909	2,049	456
2007 [c]	456	2,067	90	2,613	940	86	125	1,151	1,150	2,301	312

Source:
U.S. Department of Agriculture. *2008 Agricultural Statistics*, Table 1-7, and previous annual editions, http://www.nass.usda.gov/Publications/Ag_Statistics/index.asp.

[a] Imports and exports include flour and other products expressed in wheat equivalent.
[b] Approximates feed and residual use and includes negligible quantities used for distilled spirits.
[c] Preliminary. Totals may not add due to independent rounding.

Like corn and soybeans, the price per bushel of wheat rose considerably between 2006 and 2007.

Table 5.23
Wheat: Marketing Year Average Price and Value, by State, Crop of 2005, 2006, and 2007

State[a]	Marketing year average price per bushel 2005	2006	2007[b]	Value of production 2005	2006	2007[b]
	Dollars	Dollars	Dollars	1,000 Dollars	1,000 Dollars	1,000 Dollars
Alabama	3.10	3.95	5.15	6,975	10,310	17,716
Arizona	4.19	4.85	6.95	33,756	36,774	57,370
Arkansas	3.32	3.52	4.95	27,622	65,490	142,065
California	3.74	4.14	5.90	104,458	86,686	156,139
Colorado	3.43	4.54	6.35	185,921	189,027	607,844
Delaware	3.01	3.27	5.90	10,746	9,859	22,066
Florida	3.10	3.15	4.30	1,116	662	2,206
Georgia	3.05	3.70	5.70	22,204	21,756	52,440
Idaho	3.31	4.16	6.95	330,372	375,608	582,478
Illinois	3.24	3.40	5.45	118,584	207,298	276,479
Indiana	3.15	3.41	5.45	77,112	108,233	114,941
Iowa	3.10	3.35	5.25	2,325	3,980	7,350
Kansas	3.31	4.56	6.20	1,257,800	1,327,872	1,759,560
Kentucky	3.31	3.45	5.75	67,524	78,384	70,438
Louisiana	3.20	3.60	5.20	15,360	20,034	61,776
Maryland	3.12	3.43	5.95	28,829	29,155	68,782
Michigan	3.13	3.41	5.35	121,882	161,805	187,785
Minnesota	3.66	4.55	7.35	261,440	364,404	589,145
Mississippi	3.30	3.52	4.30	10,725	15,161	79,464
Missouri	3.35	3.52	5.35	97,686	172,973	202,444
Montana	3.63	4.54	7.60	698,286	693,854	1,138,176
Nebraska	3.36	4.57	6.20	230,630	279,684	522,536
Nevada	3.28	4.15	6.50	2,638	4,356	8,425
New Jersey	3.25	3.80	5.25	3,962	5,016	7,497
New Mexico	3.25	4.55	5.50	31,590	17,472	42,900
New York	3.34	4.03	6.75	17,134	23,354	29,835
North Carolina	3.07	3.26	4.90	76,121	80,783	98,000
North Dakota	3.55	4.50	7.70	1,077,147	1,130,352	2,332,400
Ohio	3.16	3.35	5.50	186,219	218,688	252,945
Oklahoma	3.39	4.70	6.30	433,920	383,520	617,400
Oregon	3.35	4.48	7.70	177,361	198,411	360,245
Pennsylvania	3.50	3.52	6.60	27,405	31,152	59,334
South Carolina	2.80	3.05	4.55	24,024	18,758	19,042
South Dakota	3.65	4.44	6.55	484,694	374,316	960,515
Tennessee	3.34	3.53	4.90	28,056	42,925	52,234
Texas	3.44	4.47	6.30	330,240	150,192	885,780
Utah	3.80	4.85	7.80	27,002	29,385	50,124
Virginia	2.91	3.24	5.45	29,333	34,150	71,504
Washington	3.32	4.49	7.60	456,316	625,821	978,287
West Virginia	3.07	3.50	5.70	921	1,281	1,984
Wisconsin	2.90	3.47	5.30	29,775	63,490	100,433
Wyoming	3.48	4.53	6.40	16,230	17,583	21,398
US	**3.42**	**4.26**	**6.65**	**7,171,441**	**7,710,014**	**13,669,482**

Source:
U.S. Department of Agriculture. *2008 Agricultural Statistics*, Table 1-10,
http://www.nass.usda.gov/Publications/Ag_Statistics/index.asp.

[a] States with no data are not listed.
[b] Preliminary.

Table 5.24
Wheat Production Costs and Returns per Planted Acre by Region, Excluding Government Payments, 2006-2007a
(Dollars per planted acre)

Item	United States 2006	United States 2007	Northern Great Plains 2006	Northern Great Plains 2007	Prarie Gateway 2006	Prarie Gateway 2007	Basin and Range 2006	Basin and Range 2007	Fruitful Rim 2006	Fruitful Rim 2007	Northern Crescent 2006	Northern Crescent 2007	Heartland 2006	Heartland 2007
Gross value of production														
Primary product: Wheat grain	136.784	196.35	138.61	221.408	95.89	142.13	198.258	294.58	219.584	323.19	221.776	343.116	217.848	279.306
Secondary product: Silage, straw, grazing	7.23	7.76	3.03	3.25	8.56	9.19	3.30	3.54	10.12	10.87	24.39	26.18	14.62	15.70
Total, gross value of production	**144.01**	**204.11**	**141.64**	**224.66**	**104.45**	**151.32**	**201.56**	**298.12**	**229.70**	**334.06**	**246.17**	**369.30**	**232.47**	**295.01**
Operating costs:														
Seed	8.46	9.77	8.71	10.22	5.86	6.87	11.70	13.72	9.99	11.71	21.71	25.46	17.22	20.19
Fertilizer	28.44	35.33	24.26	30.36	24.80	31.04	39.18	49.02	32.01	40.06	58.60	73.33	56.35	70.52
Chemicals	8.84	8.82	15.08	15.32	3.97	4.03	14.78	15.01	9.30	9.44	5.69	5.78	5.09	5.17
Custom operations[c]	6.71	6.79	6.97	7.08	6.40	6.50	6.42	6.52	6.98	7.09	10.95	11.13	6.03	6.13
Fuel, lube, and electricity	17.81	19.77	9.10	10.05	22.10	24.41	13.59	15.01	55.45	61.25	10.94	12.08	8.68	9.59
Repairs	12.42	12.86	10.53	10.88	13.48	13.94	13.38	13.83	19.17	19.81	11.35	11.73	9.46	9.78
Purchased irrigation water	0.33	0.33	0.11	0.11	0.08	0.08	0.81	0.85	2.93	3.06	0.81	0.85	0.56	0.59
Interest on operating inputs	2.00	2.10	1.80	1.88	1.84	1.95	2.40	2.55	3.27	3.41	2.89	3.14	2.49	2.73
Total, operating costs	**85.01**	**95.77**	**76.56**	**85.90**	**78.53**	**88.82**	**102.26**	**116.51**	**139.10**	**155.83**	**122.94**	**143.50**	**105.88**	**124.70**
Allocated overhead:														
Hired labor	2.49	2.57	1.92	1.99	2.43	2.51	4.21	4.36	7.53	7.80	1.24	1.28	1.09	1.13
Opportunity cost of unpaid labor	21.69	22.52	14.90	15.42	25.22	26.11	28.27	29.26	35.18	36.42	26.01	26.93	17.51	18.12
Capital recovery of machinery and equipment	51.33	53.71	47.69	50.05	49.38	51.82	62.10	65.18	81.64	85.68	57.09	59.92	49.98	52.45
Opportunity cost of land (rental rate)	40.86	43.54	38.73	41.76	30.60	33.00	52.19	56.28	78.09	84.21	67.48	72.78	74.67	80.53
Taxes and insurance	6.86	7.88	8.71	10.11	4.94	5.73	8.73	10.13	8.71	10.11	9.85	11.43	6.32	7.33
General farm overhead	8.54	8.74	9.74	10.07	6.72	6.95	9.10	9.41	12.09	12.50	15.24	15.76	8.96	9.27
Total, allocated overhead	**131.77**	**138.96**	**121.69**	**129.40**	**119.29**	**126.12**	**164.60**	**174.62**	**223.24**	**236.72**	**176.91**	**188.10**	**158.53**	**168.83**
Total, costs listed	**216.78**	**234.73**	**198.25**	**215.30**	**197.82**	**214.94**	**266.86**	**291.13**	**362.34**	**392.55**	**299.85**	**331.60**	**264.41**	**293.53**
Value of production less total costs listed	-72.77	-30.62	-56.61	9.36	-93.37	-63.62	-65.30	6.99	-132.64	-58.49	-53.68	37.70	-31.94	1.48
Value of production less operating costs	59.00	108.34	65.08	138.76	25.92	62.50	99.30	181.61	90.60	178.23	123.23	225.80	126.59	170.31
Supporting information:														
Yield (bushels per planted acre)	33.2	37.4	33	41	22	28	52	52	58	57	66	71	63	53
Price (dollars per bushel at harvest)	4.12	5.25	4.15	5.44	4.30	5.04	3.82	5.72	3.76	5.70	3.34	4.86	3.48	5.26
Enterprise size (planted acres)[a]	412	412	618	618	443	443	858	858	584	584	87	87	104	104
Production practices:[a]														
Winter wheat (percent of acres)	67	67	27	27	100	100	75	75	72	72	93	93	83	83
Spring wheat (percent of acres)	28	28	61	61	0	0	25	25	27	27	7	7	17	17
Durum wheat (percent of acres)	[c]	[c]	12	12	0	0	0	0	[c]	[c]	0	0	0	0
Irrigated (percent of acres)	5	5	[c]	[c]	7	7	8	8	23	23	0	0	0	0
Dryland (percent of acres)	95	95	99	99	93	93	92	92	67	67	100	100	100	100
Straw (percent of acres)	7	7	5	5	[c]	[c]	6	6	13	13	42	42	23	23

Source:
Economic Research Service, U.S. Department of Agriculture, http://www.ers.usda.gov/data/costsandreturns/testpick.htm.

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[a] Developed from survey base year, 2004.
[b] Cost of commercial fertilizers, soil conditioners, and manure.
[c] 0.1 to less than 5 percent.

Table 5.25
Oil per Acre Production for Various Crops

Plant	Latin Name	Oil/ Acre (gallons)	Plant	Latin Name	Oil/ Acre (gallons)
Oil Palm	Elaeis guineensis	610	Rice	Oriza sativa L.	85
Macauba Palm	Acrocomia aculeata	461	Buffalo Gourd	Cucurbita foetidissima	81
Pequi	Caryocar brasiliense	383	Safflower	Carthamus tinctorius	80
Buriti Palm	Mauritia flexuosa	335	Crambe	Crambe abyssinica	72
Oiticia	Licania rigida	307	Sesame	Sesamum indicum	71
Coconut	Cocos nucifera	276	Camelina	Camelina sativa	60
Avocado	Persea americana	270	Mustard	Brassica alba	59
Brazil Nut	Bertholletia excelsa	245	Coriander	Coriandrum sativum	55
Macadamia Nut	Macadamia terniflora	230	Pumpkin Seed	Cucurbita pepo	55
Jatropa	Jatropha curcas	194	Euphorbia	Euphorbia lagascae	54
Babassu Palm	Orbignya martiana	188	Hazelnut	Corylus avellana	49
Jojoba	Simmondsia chinensis	186	Linseed	Linum usitatissimum	49
Pecan	Carya illinoensis	183	Coffee	Coffea arabica	47
Bacuri	Platonia insignis	146	Soybean	Glycine max	46
Castor Bean	Ricinus communis	145	Hemp	Cannabis sativa	37
Gopher Plant	Euphorbia lathyris	137	Cotton	Gossypium hirsutum	33
Piassava	Attalea funifera	136	Calendula	Calendula officinalis	31
Olive Tree	Olea europaea	124	Kenaf	Hibiscus cannabinus L.	28
Rapeseed	Brassica napus	122	Rubber Seed	Hevea brasiliensis	26
Opium Poppy	Papaver somniferum	119	Lupine	Lupinus albus	24
Peanut	Ariachis hypogaea	109	Palm	Erythea salvadorensis	23
Cocoa	Theobroma cacao	105	Oat	Avena sativa	22
Sunflower	Helianthus annuus	98	Cashew Nut	Anacardium occidentale	18
Tung Oil Tree	Aleurites fordii	96	Corn	Zea mays	18

Source:
Hill, Amanda, Al Kurki and Mike Morris. 2006. *Biodiesel: The Sustainability Dimensions*, ATTRA Publication, National Center for Appropriate Technology, Butte, Montana, Pages 4-5.

Table 5.26
Cotton: Area, Yield, Production, and Value, 1996-2007

Year	Area: Planted	Area: Harvested	Yield per harvested acre	Production	Marketing year average price per pound received by farmers	Value of production
	1,000 Acres	1,000 Acres	Pounds	1,000 bales[a].	Cents	1,000 Dollars
1996	14,653	12,888	705	18,942	70.50	6,408,144
1997	13,898	13,406	673	18,793	66.20	5,975,585
1998	13,393	10,684	625	13,918	61.70	4,119,911
1999	14,874	13,425	607	16,968	46.80	3,809,560
2000	15,517	13,053	632	17,188	51.60	4,260,417
2001	15,769	13,828	705	20,303	32.00	3,121,848
2002	13,958	12,417	665	17,209	45.70	3,777,132
2003	13,480	12,003	730	18,255	63.00	5,516,761
2004	13,659	13,057	855	23,251	44.70	4,993,565
2005	14,245	13,803	831	23,890	49.70	5,695,217
2006	15,274	12,732	814	21,588	48.40	5,013,238
2007[b]	10,830	10,492	871	19,033	56.90	5,196,688

Source:
U.S. Department of Agriculture. *2008 Agricultural Statistics*, Table 2-1 and previous annual editions, http://www.nass.usda.gov/Publications/Ag_Statistics/index.asp.

[a] 480 pound net weight bales.
[b] Preliminary.

Table 5.27
Cotton: Area, Yield, and Production by State, 2005-2007

State and cotton classification	Area Planted			Area Harvested			Yield per Harvested Acre			Production[a]		
	2005	2006	2007[b]	2005	2006	2007[b]	2005	2006	2007[b]	2005	2006	2007[b]
Upland:	1,000 Acres	1,000 Acres	1,000 Acres	1,000 Acres	1,000 Acres	1,000 Acres	Pounds	Pounds	Pounds	1,000 bales[c]	1,000 bales[c]	1,000 bales[c]
Alabama	550	575	400	545	560	385	747	579	499	848	675	400
Arizona	230	190	170	229	188	168	1,289	1,420	1,429	615	556	500
Arkansas	1,050	1,170	860	1,040	1,160	850	1,016	1,045	1,062	2,202	2,525	1,880
California	430	285	195	428	283	194	1,194	1,321	1,559	1,065	779	630
Florida	86	103	85	85	101	81	762	789	652	135	166	110
Georgia	1,220	1,400	1,030	1,210	1,370	995	849	818	796	2,140	2,334	1,650
Kansas	74	115	47	66	110	43	638	511	558	88	117	50
Louisiana	610	635	335	600	630	330	878	946	1,004	1,098	1,241	690
Mississippi	1,210	1,230	660	1,200	1,220	655	859	829	975	2,147	2,107	1,330
Missouri	440	500	380	438	496	379	947	953	975	864	985	770
New Mexico	56	50	46	51	48	42	1,016	930	1,234	108	93	108
North Carolina	815	870	500	810	865	490	852	713	769	1,437	1,285	785
Oklahoma	255	320	175	240	180	165	716	541	945	358	203	325
South Carolina	266	300	180	265	298	158	743	697	486	410	433	160
Tennessee	640	700	515	635	695	510	848	945	579	1,122	1,368	615
Texas	5,950	6,400	4,900	5,600	4,100	4,700	723	679	827	8,440	5,800	8,100
Virginia	93	105	60	92	104	59	955	717	854	183	155	105
Total	**13,975**	**14,948**	**10,538.0**	**13,534**	**12,408**	**10,204**	**825**	**806**	**857**	**23,260**	**20,822**	**18,208**
American-Pima:												
Arizona	4	7	3	4	7	3	820	919	960	7	13	5
California	230	275	260	229	274	257	1,170	1,204	1,419	558	687	760
New Mexico	12	13	5	12	13	5	918	768	1,123	22	20	11
Texas	25	31	25	24	30	24	870	720	980	44	45	49
Total	270	326	292	269	324	288	1,127	1,136	1,374	631	765	825
U.S. Total	**14,245**	**15,274**	**10,830**	**13,803**	**12,732**	**10,492**	**831**	**814**	**871**	**23,890**	**21,588**	**19,033**

Source:

U.S. Department of Agriculture, *2008 Agricultural Statistics*, Table 2-2, http://www.nass.usda.gov/Publications/Ag_Statistics/index.asp.

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[a] Production ginned and to be ginned.
[b] Preliminary.
[c] 480-pound net weight bale.

Table 5.28
Cotton Production Costs and Returns per Planted Acre by Region, Excluding Government Payments, 2006-2007[a]
(Dollars per planted acre)

Item	United States 2006	United States 2007	Heartland 2006	Heartland 2007	Prarie Gateway 2006	Prarie Gateway 2007	Southern Seaboard 2006	Southern Seaboard 2007	Fruitful Rim 2006	Fruitful Rim 2007	Mississippi Portal 2006	Mississippi Portal 2007	Eastern Uplands 2006	Eastern Uplands 2007
Gross value of production														
Primary product: Cotton	254.84	357.99	276.50	394.06	252.08	332.66	180.20	299.42	227.22	348.93	208.80	477.29	194.48	243.85
Secondary product: Cottonseed														
Total, gross value of production	**254.84**	**357.99**	**276.50**	**394.06**	**252.08**	**332.66**	**180.20**	**299.42**	**227.22**	**348.93**	**208.80**	**477.29**	**194.48**	**243.85**
Operating costs:														
Seed	32.30	38.92	32.01	38.54	34.67	41.75	34.36	41.37	30.69	36.96	31.44	37.86	30.23	36.40
Fertilizer[b]	13.05	16.06	12.73	15.84	19.62	24.41	6.15	7.65	7.63	9.49	21.11	26.27	34.76	43.25
Chemicals	14.46	14.56	14.38	14.60	13.92	14.14	12.47	12.66	12.94	13.14	11.49	11.67	15.75	16.00
Custom operations	6.01	6.38	5.27	5.58	8.17	8.64	5.05	5.34	7.69	8.14	7.24	7.66	5.34	5.65
Fuel, lube, and electricity	13.51	14.76	10.99	12.14	12.45	13.75	10.12	11.18	26.34	29.10	11.66	12.88	9.98	11.02
Repairs	11.80	12.13	10.59	10.96	10.53	10.89	12.27	12.69	16.85	17.43	10.50	10.86	9.62	9.95
Purchased irrigation water	0.11	0.11	0.00	0.00	0.00	0.00	0.00	0.00	1.54	1.63	0.00	0.00	0.00	0.00
Interest on operating capital	2.17	2.31	2.04	2.19	2.36	2.54	1.91	2.04	2.46	2.60	2.22	2.40	2.51	2.74
Total, operating costs	**93.41**	**105.23**	**88.01**	**99.85**	**101.72**	**116.12**	**82.33**	**92.93**	**106.14**	**118.49**	**95.66**	**109.60**	**108.19**	**125.01**
Allocated overhead:														
Hired labor	1.78	1.80	1.15	1.19	1.17	1.21	1.50	1.55	1.90	1.97	2.70	2.79	2.65	2.74
Opportunity cost of unpaid labor	15.20	15.70	14.33	14.83	16.71	17.30	13.21	13.67	19.03	19.70	16.63	17.21	17.43	18.04
Capital recovery of machinery and equipment	60.38	63.22	58.48	61.37	52.98	55.60	65.82	69.07	72.62	76.21	54.77	57.48	51.25	53.78
Opportunity cost of land (rental rate)	86.17	92.92	101.33	108.52	70.99	76.02	46.65	49.96	60.64	64.94	56.61	60.62	39.18	41.96
Taxes and insurance	7.93	8.55	7.94	8.58	9.99	10.79	6.89	7.44	8.01	8.65	6.16	6.66	6.83	7.38
General farm overhead	13.22	13.79	13.50	13.97	17.36	17.96	10.75	11.12	14.72	15.23	13.14	13.59	10.04	10.39
Total, allocated overhead	184.68	195.98	196.73	208.46	169.20	178.88	144.82	152.81	176.92	186.70	150.01	158.35	127.38	134.29
Total costs listed	**278.09**	**301.21**	**284.74**	**308.31**	**270.92**	**295.00**	**227.15**	**245.74**	**283.06**	**305.19**	**245.67**	**267.95**	**235.57**	**259.30**
Value of production less total costs listed	-23.25	56.78	-8.24	85.76	-18.84	37.65	-46.95	53.68	-55.84	43.75	-36.87	209.34	-41.09	-15.45
Value of production less operating costs	161.43	252.76	188.49	294.22	150.36	216.53	97.87	206.49	121.08	230.45	113.14	367.69	86.29	118.84
Supporting information:														
Cotton Yield (pounds per planted acre)	686	855	946	965	436	809	737	704	1291	1501	931	914	563	480
Price (dollars per pound)	0.47	0.55	0.49	0.54	0.46	0.55	0.48	0.55	0.46	0.55	0.49	0.55	0.44	0.53
Cottonseed Yield (pounds per planted acre)	1,113	1,407	1,530	1,561	706	1,308	1,193	1,140	2,088	2,428	1,505	1,479	912	777
Price (dollars per pound)	0.06	0.07657	0.0505	0.0813	0.06	0.08	0.0458	0.074	0.0892	0.08	0.05	0.08	0.04	0.07
Enterprise size (planted acres)[a]	740	740	893	893	764	764	535	535	614	614	1016	1016	807	807
Production practices:[a]														
Irrigated (percent)	31	31	51	51	31	31	16	16	45	45	33	33	4	4
Dryland (percent)	69	69	49	49	69	69	84	84	55	55	67	67	96	96

Source:
Economic Research Service, U.S. Department of Agriculture, http://www.ers.usda.gov/data/costsandreturns/testpick.htm.

[a] Developed from survey base year, 2003.
[b] Commercial fertilizer, soil conditioners, and manure.

USDA's 2008 soybean baseline projections do not specifically show oil produced for use as a biofuel and do not reflect in the projections the probable increase in demand for soybean oil as a biofuel which is anticipated due to the Energy Policy Act of 2005. It is likely that future USDA soybean baseline projections will reflect the market changes.

Table 5.29
Soybeans and Products Baseline Projections, 2006-2018

Item	2006/07	2007/08	2008/09	2009/10	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18
Area (million acres):												
Planted	75.5	63.7	71.0	69.5	69.0	68.5	68.5	68.5	68.0	68.0	68.0	68.0
Harvested	74.6	62.8	70.1	68.6	68.1	67.6	67.6	67.6	67.1	67.1	67.1	67.1
Yield/harvested acre (bushels)	42.7	41.3	42.1	42.6	43.0	43.5	43.9	44.4	44.8	45.3	45.7	46.2
Supply (million bushels)												
Beginning stocks, Sept 1	449	573	210	219	210	202	193	199	204	204	203	201
Production	3,188	2,594	2,950	2,920	2,930	2,935	2,970	3,000	3,005	3,035	3,065	3,095
Imports	9	6	6	4	4	4	4	4	4	4	4	4
Total supply	3,647	3,173	3,166	3,143	3,144	3,141	3,167	3,203	3,213	3,243	3,272	3,300
Disposition (million bushels)												
Crush	1,806	1,825	1,865	1,895	1,920	1,950	1,975	2,000	2,020	2,045	2,070	2,095
Seed and residual	149	163	177	173	172	173	174	174	174	175	176	177
Exports	1,118	975	905	865	850	825	820	825	815	820	825	825
Total disposition	3,074	2,963	2,947	2,933	2,942	2,948	2,969	2,999	3,009	3,040	3,071	3,097
Carryover stocks, August 31												
Total ending stocks	573	210	219	210	202	193	199	204	204	203	201	204
Stocks/use ratio, percent	18.6	7.1	7.4	7.2	6.9	6.5	6.7	6.8	6.8	6.7	6.5	6.6
Prices (dollars per bushel)												
Loan rate	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00
Soybean price, farm	6.43	9.00	8.85	8.90	8.75	8.80	8.80	8.80	8.85	8.90	8.95	9.00
Variable costs of production (dollars):												
Per acre	96.75	105.46	109.45	112.63	113.94	115.19	116.39	117.50	118.84	120.20	121.58	122.90
Per bushel	2.27	2.55	2.60	2.64	2.65	2.65	2.65	2.65	2.65	2.65	2.66	2.66
Returns over variable costs (dollars per acre):												
Net returns	178	266	263	267	262	268	270	273	278	283	287	293
Soybean oil (million pounds)												
Beginning stocks, Oct. 1	3,010	2,912	2,017	1,882	1,967	1,967	1,987	1,947	1,872	1,782	1,757	1,772
Production	20,484	20,715	21,215	21,575	21,880	22,240	22,545	22,850	23,100	23,405	23,710	24,020
Imports	40	40	50	60	70	80	90	100	110	120	130	140
Total supply	23,533	23,667	23,282	23,517	23,917	24,287	24,622	24,897	25,082	25,307	25,597	25,932
Domestic disappearance	18,721	20,100	20,150	20,300	20,550	20,775	21,100	21,400	21,650	21,900	22,150	22,400
For methyl ester [a]	2,794	4,200	4,200	4,200	4,250	4,250	4,350	4,400	4,400	4,400	4,400	4,400
Exports	1,900	1,550	1,250	1,250	1,400	1,525	1,575	1,625	1,650	1,650	1,675	1,700
Total demand	20,621	21,650	21,400	21,550	21,950	22,300	22,675	23,025	23,300	23,550	23,825	24,100
Ending stocks, Sept. 30	2,912	2,017	1,882	1,967	1,967	1,987	1,947	1,872	1,782	1,757	1,772	1,832
Soybean oil price ($/lb)	0.3102	0.3950	0.3850	0.3850	0.3825	0.3825	0.3825	0.3825	0.3850	0.3850	0.3850	0.3850
Soybean meal (thousand short	314	351	300	300	300	300	300	300	300	300	300	300
Beginning stocks, Oct. 1	43,021	43,384	44,385	45,085	45,735	46,385	46,985	47,560	48,135	48,710	49,310	49,910
Production	155	165	165	165	165	165	165	165	165	165	165	165
Imports	43,489	43,900	44,850	45,550	46,200	46,850	47,450	48,025	48,600	49,175	49,775	50,375
Total supply	34,288	35,300	35,850	36,400	36,950	37,500	38,050	38,625	39,200	39,775	40,375	40,975
Domestic disappearance	8,850	8,300	8,700	8,850	8,950	9,050	9,100	9,100	9,100	9,100	9,100	9,100
Exports	43,138	43,600	44,550	45,250	45,900	46,550	47,150	47,725	48,300	48,875	49,475	50,075
Total demand	351	300	300	300	300	300	300	300	300	300	300	300
Ending stocks, Sept. 30	205	250	240	243	237	238	238	239	239	240	242	243
Soybean meal price ($/ton)	174.17	177.50	200.00	205.00	205.00	195.00	192.50	190.00	188.50	186.50	185.00	185.00
Crushing yields (pounds per bushel)												
Soybean oil	11.34	11.35	11.38	11.39	11.40	11.41	11.42	11.43	11.44	11.45	11.46	11.47
Soybean meal	47.64	47.54	47.60	47.60	47.60	47.60	47.60	47.60	47.60	47.60	47.60	47.60
Crush margin ($ per bushel)	1.98	1.43	1.24	1.25	1.25	1.23	1.23	1.25	1.23	1.22	1.21	1.20

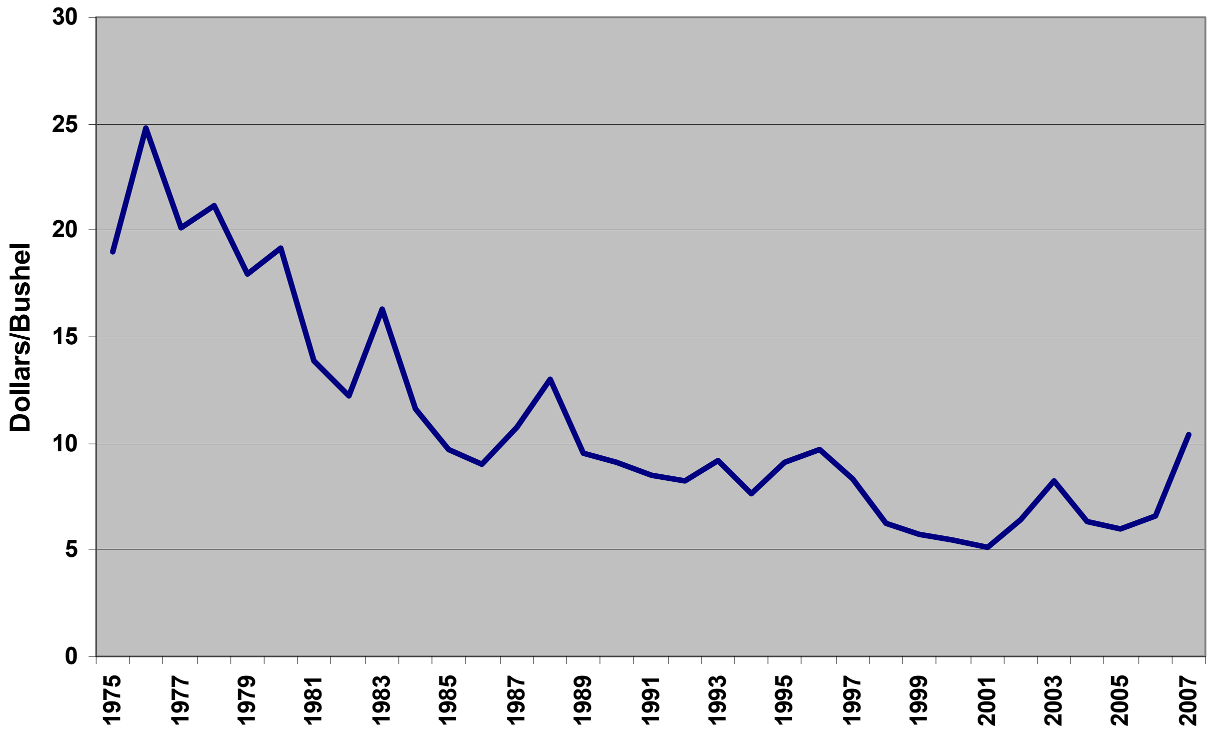
Source:

U.S.Department of Agriculture. 2008. *Agricultural Baseline Projections to 2014*, Table 13, February; U.S. soybean and products, http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1192

[a] Soybean oil used for methyl ester for production of biodiesel, history from the U.S. Department of Commerce.

The price for soybeans has declined since the mid 70s but has shown a modest increase since reaching a low of about five dollars a bushel in 2001.

Figure 5.10
Soybeans: Price per Bushel, 1975-2007
(Constant 2007 dollars)



Source:
U.S. Department of Agriculture, National Agricultural Statistics Service, http://www.nass.usda.gov/.

In 2001, only 5 million gallons of biodiesel fuel was produced requiring a very small amount of all soybeans harvested. By 2007, about 450 million gallons of biodiesel fuel was produced with about 90% being derived from soybeans. At a conversion rate of 1.5 gallons of biodiesel per bushel of soybeans[a]*, the total bushels of soybeans used in biodiesel production was approximately 675 million bushels.*

Table 5.30
Soybeans: Area, Yield, Production, and Value, 1996-2007

Year	Area Planted	Soybeans for beans				
		Area harvested	Yield per acre	Production	Marketing year average price per bushel raised by farmers	Value of production
	1,000 Acres	1,000 Acres	Bushels	1,000 Bushels	Dollars	1,000 Dollars
1996	64,195	63,349	37.6	2,380,274	7.35	17,439,971
1997	70,005	69,110	38.9	2,688,750	6.47	17,372,628
1998	72,025	70,441	38.9	2,741,014	4.93	13,493,891
1999	73,730	72,446	36.6	2,653,758	4.63	12,205,352
2000	74,266	72,408	38.1	2,757,810	4.54	12,466,572
2001	74,075	72,975	39.6	2,890,682	4.38	12,605,717
2002	73,963	72,497	38.0	2,756,147	5.53	15,252,691
2003	73,404	72,476	33.9	2,453,665	7.34	18,013,753
2004	75,208	73,958	42.2	3,123,686	5.74	17,894,948
2005	72,032	71,251	43.0	3,063,237	5.66	17,269,138
2006	75,522	74,602	42.7	3,188,247	6.43	20,415,948
2007	63,631	62,820	41.2	2,585,207	10.40	26,752,197

Source:
U.S. Department of Agriculture. *2008 Agricultural Statistics*, Table 3-32,
http://www.nass.usda.gov/Publications/Ag_Statistics/index.asp.

[a] National Biodiesel Board.

Soybean production is highly variable by state, with the Mid-west producing the largest amount. States with the highest production levels are Illinois and Iowa.

Table 5.31
Soybeans: Area, Yield, and Production, by State, 2005-2007

State	Area planted			Soybeans for beans								
				Area harvested			Yield per harvested acre			Production		
	2005	2006	2007	2005	2006	2007	2005	2006	2007	2005	2006	2007
	1,000 Acres	1,000 Acres	1,000 Acres	1,000 Acres	1,000 Acres	1,000 Acres	Bushels	Bushels	Bushels	1,000 Bushels	1,000 Bushels	1,000 Bushels
Alabama	150	160	190	145	150	180	33.0	20.0	21.0	4,785	3,000	3,780
Arizona	3,030	3,110	2,830	3,000	3,070	2,790	34.0	35.0	36.0	102,000	107,450	100,440
Delaware	185	180	150	182	177	145	26.0	31.0	24.0	4,732	5,487	3,480
Florida	9	7	14	8	5	12	32.0	27.0	24.0	256	135	288
Georgia	180	155	285	175	140	275	26.0	25.0	30.0	4,550	3,500	8,250
Illinois	9,500	10,100	8,200	9,450	10,050	8,150	46.5	48.0	43.0	439,425	482,400	350,450
Indiana	5,400	5,700	4,700	5,380	5,680	4,680	49.0	50.0	45.0	263,620	284,000	210,600
Iowa	10,050	10,150	8,550	10,000	10,100	8,520	52.5	50.5	51.5	525,000	510,050	438,780
Kansas	2,900	3,150	2,600	2,850	3,080	2,550	37.0	32.0	33.0	105,450	98,560	84,150
Kentucky	1,250	1,380	1,100	1,240	1,370	1,080	43.0	44.0	26.0	53,320	60,280	28,080
Louisiana	880	870	605	850	840	590	34.0	35.0	42.0	28,900	29,400	24,780
Maryland	480	470	400	470	465	380	34.0	34.0	27.0	15,980	15,810	10,260
Michigan	2,000	2,000	1,750	1,990	1,990	1,740	38.5	45.0	39.0	76,615	89,550	67,860
Minnesota	6,900	7,350	6,250	6,800	7,250	6,150	45.0	44.0	41.0	306,000	319,000	252,150
Mississippi	1,610	1,670	1,450	1,590	1,650	1,420	36.5	26.0	40.0	58,035	42,900	56,800
Missouri	4,950	5,150	4,600	4,910	5,110	4,550	37.0	38.0	37.0	181,670	194,180	168,350
Nebraska	4,700	5,050	3,800	4,660	5,010	3,770	50.5	50.0	50.5	235,330	250,500	190,385
New Jersey	95	88	81	91	86	79	28.0	35.0	31.0	2,548	3,010	2,449
New York	190	200	205	188	198	203	42.0	46.0	38.0	7,896	9,108	7,714
North Carolina	1,490	1,370	1,420	1,460	1,360	1,360	27.0	32.0	21.0	39,420	43,520	28,560
North Dakota	2,950	3,900	3,050	2,900	3,870	2,990	36.0	31.0	35.0	104,400	119,970	104,650
Ohio	4,500	4,650	4,150	4,480	4,620	4,130	45.0	47.0	47.0	201,600	217,140	194,110
Oklahoma	325	310	185	305	215	175	26.0	17.0	24.0	7,930	3,655	4,200
Pennsylvania	430	430	425	420	425	420	41.0	40.0	41.0	17,220	17,000	17,220
South Carolina	430	400	450	420	390	425	20.5	29.0	19.0	8,610	11,310	8,075
South Dakota	3,900	3,950	3,200	3,850	3,850	3,180	35.0	34.0	42.0	134,750	130,900	133,560
Tennessee	1,130	1,160	1,040	1,100	1,130	970	38.0	39.0	18.0	41,800	44,070	17,460
Texas	260	225	86	230	155	82	26.0	24.0	37.0	5,980	3,720	3,034
Virginia	530	520	500	510	510	480	30.0	31.0	27.0	15,300	15,810	12,960
West Virginia	18	17	15	17	16	14	35.0	42.0	33.0	595	672	462
Wisconsin	1,610	1,650	1,350	1,580	1,640	1,330	44.0	44.0	39.0	69,520	72,160	51,870
US	**72,032**	**75,522**	**63,631**	**71,251**	**74,602**	**62,820**	**43.0**	**42.7**	**41.2**	**3,063,237**	**3,188,247**	**2,585,207**

Source:
U.S. Department of Agriculture. *2008 Agricultural Statistics*, Table 3-37, and previous annual editions, http://www.nass.usda.gov/Publications/Ag_Statistics/index.asp.

In 2006, soybean stocks and production reached its greatest level during the period 1995-2006.

Table 5.32
Soybeans: Supply and Disappearance, 1995-2006
(Thousand bushels)

Year beginning September	Supply				
	Stocks by Position				
	Farm	Terminal market, interior mill, elevator, and warehouse	Total	Production	Total[a]
1995	105,130	229,684	334,814	2,174,254	2,513,524
1996	59,523	123,935	183,458	2,380,274	2,572,636
1997	43,600	88,233	131,833	2,688,750	2,825,589
1998	84,300	115,499	199,799	2,741,014	2,944,334
1999	145,000	203,482	348,482	2,653,758	3,006,411
2000	112,500	177,662	290,162	2,757,810	3,051,540
2001	83,500	164,247	247,747	2,890,682	3,140,749
2002	62,700	145,361	208,061	2,756,147	2,968,869
2003	58,000	120,329	178,329	2,453,665	2,637,556
2004	29,400	83,014	112,414	3,123,686	3,241,678
2005	99,700	156,038	255,738	3,063,237	3,322,347
2006[b]	176,300	273,026	449,326	3,188,247	3,646,607

Table continued

Year beginning September	Disappearance			
	Crushed[c]	Seed, feed and residual	Exports	Total
1995	1,369,541	111,441	849,084	2,330,066
1996	1,436,961	118,954	885,888	2,440,803
1997	1,596,980	154,476	874,334	2,625,790
1998	1,589,787	201,414	804,651	2,595,852
1999	1,577,650	165,194	973,405	2,716,249
2000	1,639,670	168,252	995,871	2,803,793
2001	1,699,741	169,296	1,063,651	2,932,688
2002	1,614,787	131,380	1,044,372	2,790,540
2003	1,529,699	108,892	886,551	2,525,142
2004	1,696,081	192,702	1,097,156	2,985,940
2005	1,738,852	194,291	939,879	2,873,021
2006[b]	1,806,204	149,604	1,118,021	3,073,829

Source:
U.S. Department of Agriculture. *2008 Agricultural Statistics*, Table 3-35, and previous annual editions, http://www.nass.usda.gov/Publications/Ag_Statistics/index.asp.

[a] Includes imports, beginning with 1988.
[b] Preliminary.
[c] Reported by the U.S. Department of Commerce.

Prices for soybeans used for biodiesel production may vary for each mill depending on whether the mills are owned by farmer's cooperatives or whether the soybeans are purchased on the open market. The average price per bushel rose by about 77 cents from 2005 to 2006 and then rose sharply by nearly 4 dollars between 2006 and 2007.

Table 5.33
Soybeans for Beans: Marketing Year Average Price and Value, by State, Crop of 2005, 2006, and 2007

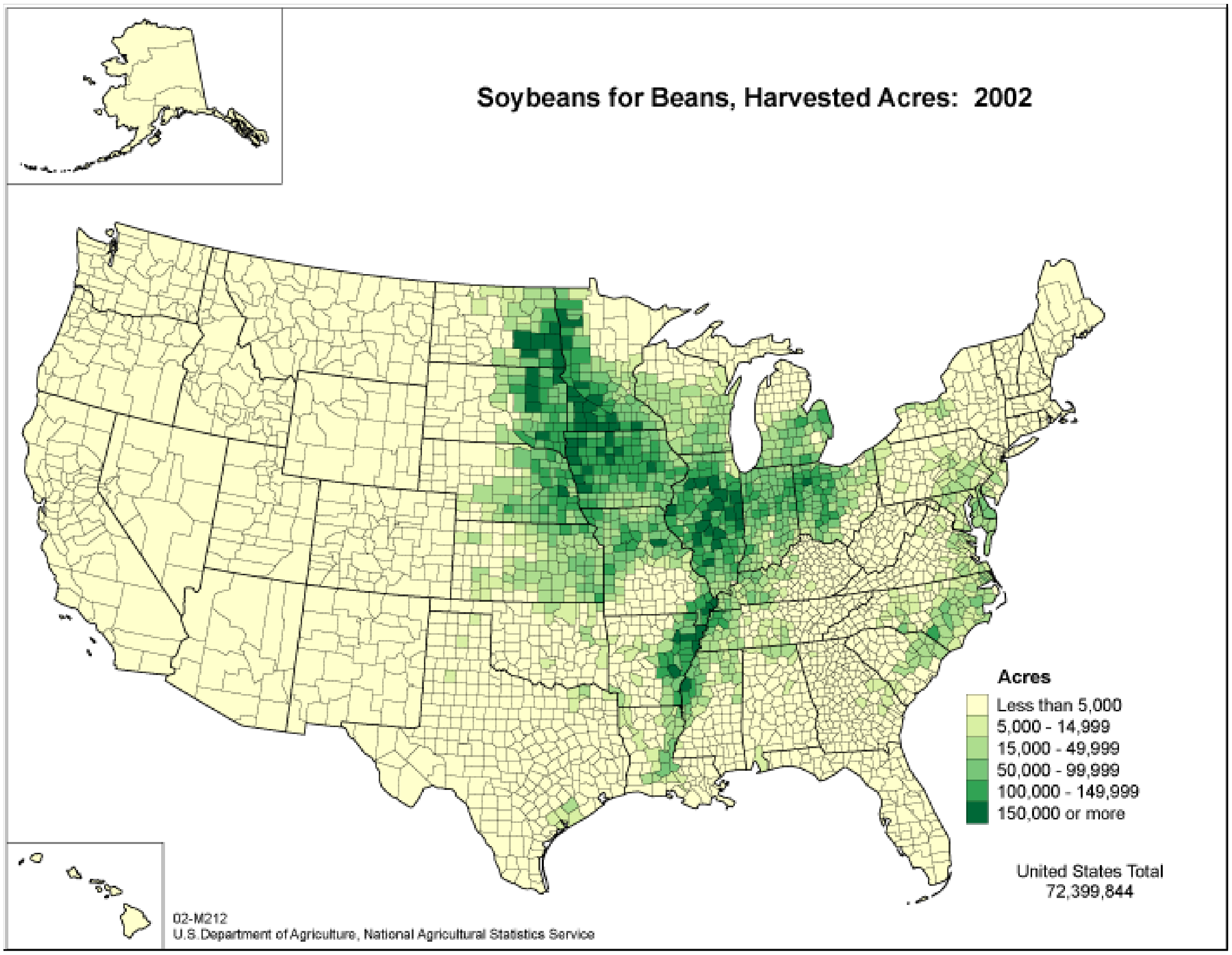
State[a]	Marketing year average price per bushel 2005	2006	2007[b]	Value of production 2005	2006	2007[b]
	Dollars	Dollars	Dollars	1,000 Dollars	1,000 Dollars	1,000 Dollars
Alabama	5.95	6.85	10.50	28,471	20,550	39,690
Arkansas	5.92	6.41	9.80	603,840	688,755	984,312
Delaware	5.65	6.60	10.60	26,736	36,214	36,888
Florida	5.40	6.25	8.90	1,382	844	2,563
Georgia	5.50	6.85	9.75	25,025	23,975	80,438
Illinois	5.76	6.68	11.00	2,531,088	3,222,432	3,854,950
Indiana	5.78	6.53	10.50	1,523,724	1,854,520	2,211,300
Iowa	5.54	6.58	10.90	2,908,500	3,356,129	4,782,702
Kansas	5.45	6.37	10.60	574,703	627,827	891,990
Kentucky	5.86	6.68	10.70	312,455	402,670	300,456
Louisiana	5.97	5.94	8.85	172,533	174,636	219,303
Maryland	5.53	6.40	10.50	88,369	101,184	107,730
Michigan	5.73	6.27	9.85	439,004	561,479	668,421
Minnesota	5.53	6.26	10.10	1,692,180	1,996,940	2,546,715
Mississippi	5.92	6.23	9.25	343,567	267,267	525,400
Missouri	5.67	6.47	10.50	1,030,069	1,256,345	1,767,675
Nebraska	5.55	6.05	9.95	1,306,082	1,515,525	1,894,331
New Jersey	5.65	6.25	9.75	14,396	18,813	23,878
New York	5.20	6.19	9.75	41,059	56,379	75,212
North Carolina	5.64	6.35	10.50	222,329	276,352	299,880
North Dakota	5.37	5.98	9.80	560,628	717,421	1,025,570
Ohio	5.74	6.46	10.10	1,157,184	1,402,724	1,960,511
Oklahoma	5.45	6.35	9.60	43,219	23,209	40,320
Pennsylvania	5.60	6.25	9.75	96,432	106,250	167,895
South Carolina	5.55	6.80	10.00	47,786	76,908	80,750
South Dakota	5.39	6.03	9.80	726,303	789,327	1,308,888
Tennessee	5.73	6.30	10.50	239,514	277,641	183,330
Texas	5.45	5.40	9.00	32,591	20,088	27,306
Virginia	5.53	6.54	10.50	84,609	103,397	136,080
West Virginia	5.49	6.40	9.90	3,267	4,301	4,574
Wisconsin	5.64	6.04	9.70	392,093	435,846	503,139
US	**5.66**	**6.43**	**10.40**	**17,269,138**	**20,415,948**	**26,752,197**

Source:
U.S. Department of Agriculture. *2008 Agricultural Statistics*, Table 3-39, http://www.nass.usda.gov/Publications/Ag_Statistics/index.asp.

[a] States with no data are not listed.
[b] Preliminary.

Soybean production area is similar to corn production area, with the addition of more area in North and South Dakota and along the Mississippi Delta.

Figure 5.11
Soybeans for Beans, Harvested Acres in the United States, 2002



Source:
U.S. Department of Agriculture, National Agricultural Statistics Service,
http://www.nass.usda.gov/research/atlas02/atlas-crops.html.

As with all agricultural crops, soybean costs and returns per acre vary by region. In general, soybean returns are a little less than returns for corn when only operating costs are considered.

Table 5.34
Soybean Production Costs and Returns per Planted Acre by Region, Excluding Government Payments, 2006-2007[a]
(Dollars per planted acre)

Item	United States		Heartland		Northern Crescent		Northern Great Plains		Prarie Gateway		Eastern Uplands		Southern Seaboard		Mississippi Portal	
	2006	2007	2006	2007	2006	2007	2006	2007	2006	2007	2006	2007	2006	2007	2006	2007
Gross value of production																
Primary product: Soybeans	254.84	357.99	276.50	394.06	252.08	332.66	180.20	299.42	227.22	348.93	208.80	477.29	194.48	243.85	213.84	293.65
Total, gross value of production	**254.84**	**357.99**	**276.50**	**394.06**	**252.08**	**332.66**	**180.20**	**299.42**	**227.22**	**348.93**	**208.80**	**477.29**	**194.48**	**243.85**	**213.84**	**293.65**
Operating costs:																
Seed	32.30	38.92	32.01	38.54	34.67	41.75	34.36	41.37	30.69	36.96	31.44	37.86	30.23	36.40	32.59	39.24
Fertilizer[b]	13.05	16.06	12.73	15.84	19.62	24.41	6.15	7.65	7.63	9.49	21.11	26.27	34.76	43.25	13.00	16.18
Chemicals	14.46	14.56	14.38	14.60	13.92	14.14	12.47	12.66	12.94	13.14	11.49	11.67	15.75	16.00	18.57	18.86
Custom operations	6.01	6.38	5.27	5.58	8.17	8.64	5.05	5.34	7.69	8.14	7.24	7.66	5.34	5.65	9.15	9.68
Fuel, lube, and electricity	13.51	14.76	10.99	12.14	12.45	13.75	10.12	11.18	26.34	29.10	11.66	12.88	9.98	11.02	26.66	29.45
Repairs	11.80	12.13	10.59	10.96	10.53	10.89	12.27	12.69	16.85	17.43	10.50	10.86	9.62	9.95	17.89	18.51
Purchased irrigation water	0.11	0.11	0.00	0.00	0.00	0.00	0.00	0.00	1.54	1.63	0.00	0.00	0.00	0.00	0.00	0.00
Interest on operating capital	2.17	2.31	2.04	2.19	2.36	2.54	1.91	2.04	2.46	2.60	2.22	2.40	2.51	2.74	2.80	2.96
Total, operating costs	**93.41**	**105.23**	**88.01**	**99.85**	**101.72**	**116.12**	**82.33**	**92.93**	**106.14**	**118.49**	**95.66**	**109.60**	**108.19**	**125.01**	**120.66**	**134.88**
Allocated overhead:																
Hired labor	1.78	1.80	1.15	1.19	1.17	1.21	1.50	1.55	1.90	1.97	2.70	2.79	2.65	2.74	6.68	6.91
Opportunity cost of unpaid labor	15.20	15.70	14.33	14.83	16.71	17.30	13.21	13.67	19.03	19.70	16.63	17.21	17.43	18.04	18.13	18.77
Capital recovery of machinery and equipment	60.38	63.22	58.48	61.37	52.98	55.60	65.82	69.07	72.62	76.21	54.77	57.48	51.25	53.78	68.95	72.36
Opportunity cost of land (rental rate)	86.17	92.92	101.33	108.52	70.99	76.02	46.65	49.96	60.64	64.94	56.61	60.62	39.18	41.96	64.34	68.90
Taxes and insurance	7.93	8.55	7.94	8.58	9.99	10.79	6.89	7.44	8.01	8.65	6.16	6.66	6.83	7.38	7.50	8.10
General farm overhead	13.22	13.79	13.50	13.97	17.36	17.96	10.75	11.12	14.72	15.23	13.14	13.59	10.04	10.39	9.71	10.04
Total, allocated overhead	184.68	195.98	196.73	208.46	169.20	178.88	144.82	152.81	176.92	186.70	150.01	158.35	127.38	134.29	175.31	185.08
Total costs listed	**278.09**	**301.21**	**284.74**	**308.31**	**270.92**	**295.00**	**227.15**	**245.74**	**283.06**	**305.19**	**245.67**	**267.95**	**235.57**	**259.30**	**295.97**	**319.96**
Value of production less total costs listed	-23.25	56.78	-8.24	85.76	-18.84	37.65	-46.95	53.68	-55.84	43.75	-36.87	209.34	-41.09	-15.45	-82.13	-26.30
Value of production less operating costs	161.43	252.76	188.49	294.22	150.36	216.53	97.87	206.49	121.08	230.45	113.14	367.69	86.29	118.84	93.18	158.78
Supporting information:																
Yield (bushels per planted acre)	46	45	50	48	46	41	34	38	42	42	36	57	34	30	36	37
Price (dollars per bushel at harvest)	5.54	7.95529	5.53	8.2173	5.48	8.02	5.3	7.7989	5.41	8.21	5.8	8.3226	5.72	8.21	5.94	7.87
Enterprise size (planted acres)[a]	303	303	299	299	164	164	164	164	254	254	321	321	240	240	676	676
Production practices:[a]																
Irrigated (percent)	9	9	4	4	2	2	2	2	32	32	6	6	0	0	38	38
Dryland (percent)	91	91	96	96	98	98	98	98	68	68	94	94	100	100	62	62

Source:
Economic Research Service, U.S. Department of Agriculture, http://www.ers.usda.gov/data/costsandreturns/testpick.htm.

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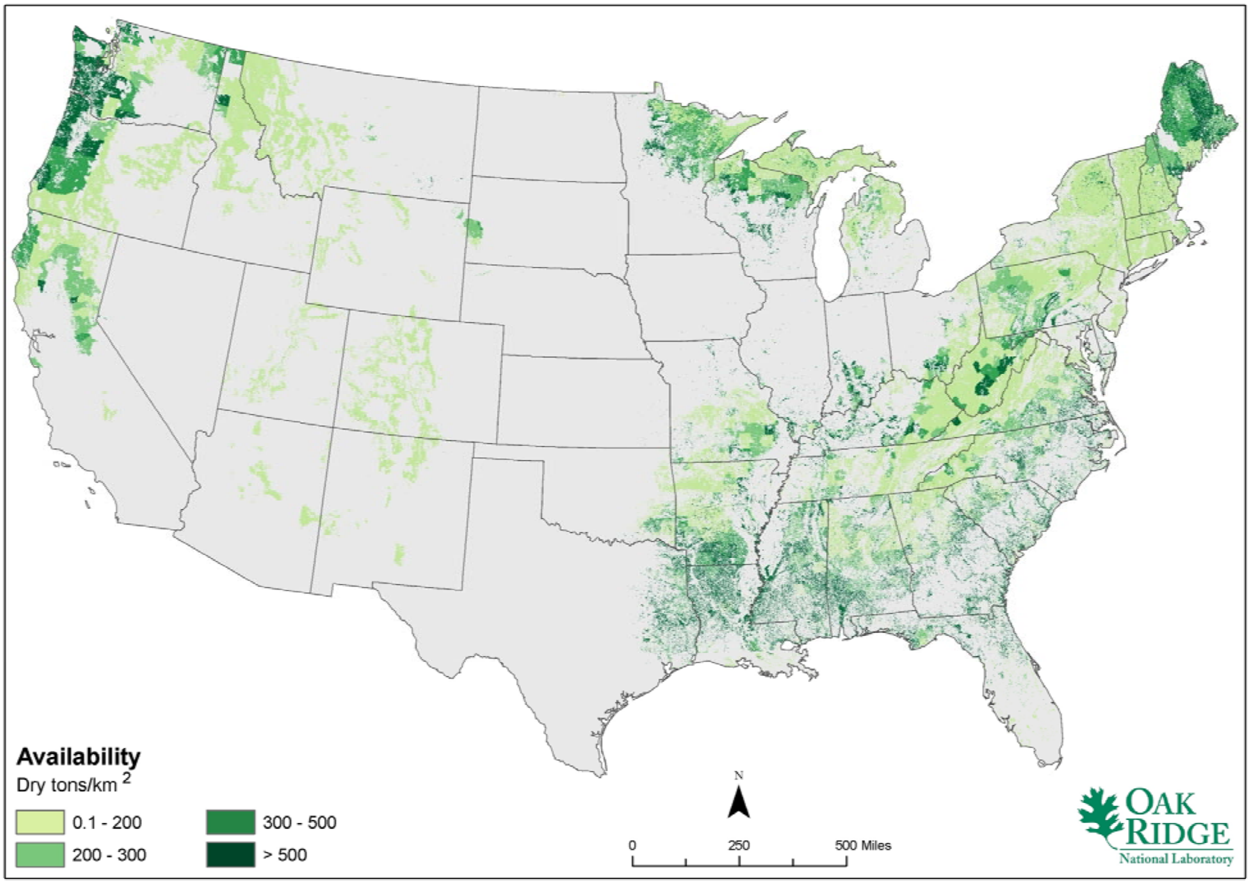
[a] Developed from survey base year, 2006.
[b] Commercial fertilizer, soil conditioners, and manure.

Logging residues are the unused portions of growing-stock and non-growing-stock trees cut or killed by logging and left in the woods.

Figure 5.12
Total Availability of Logging Residue from Timberlands, 2007

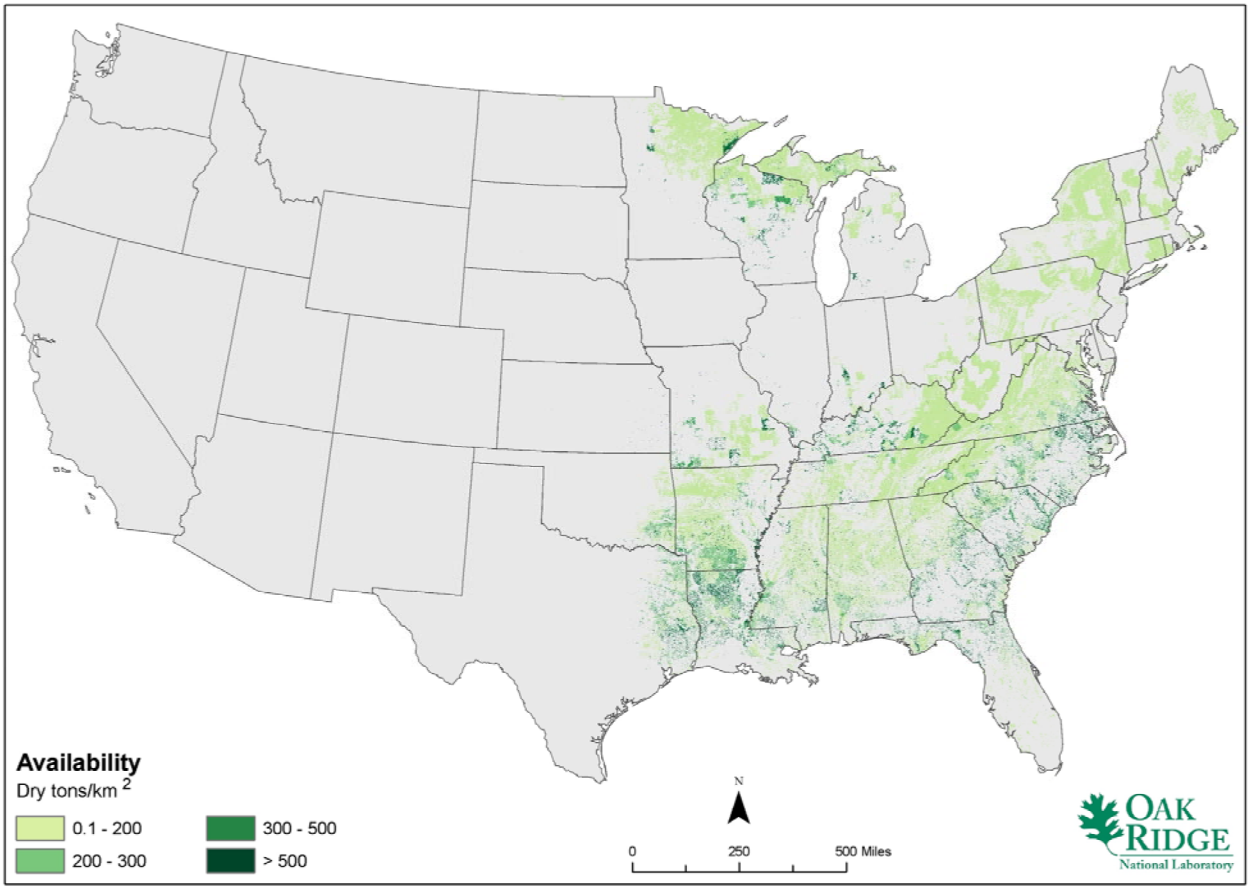


Source:
U.S. Department of Agriculture, Forest Service. 2007. *Timber Products Output Mapmaker Version 1.0*.

Note: Map created by Bioenergy Resource and Engineering Systems Program, Oak Ridge National Laboratory.

Fuel treatment thinnings are the material generated from fuel treatment operations and thinnings designed to reduce the risk of loss to wildfire on timberlands. Timberland is forestland that is capable of producing in excess of 20 cubic feet per acre per year of industrial products in natural stands and is not withdrawn from timber utilization by statute or administrative regulation. These lands are distributed throughout the United States. As with logging residues, economics, site-specific characteristics and costs affect the recoverability of this material.

Figure 5.13
Total Availability of Fuel Treatment Thinnings from Timberlands, 2007

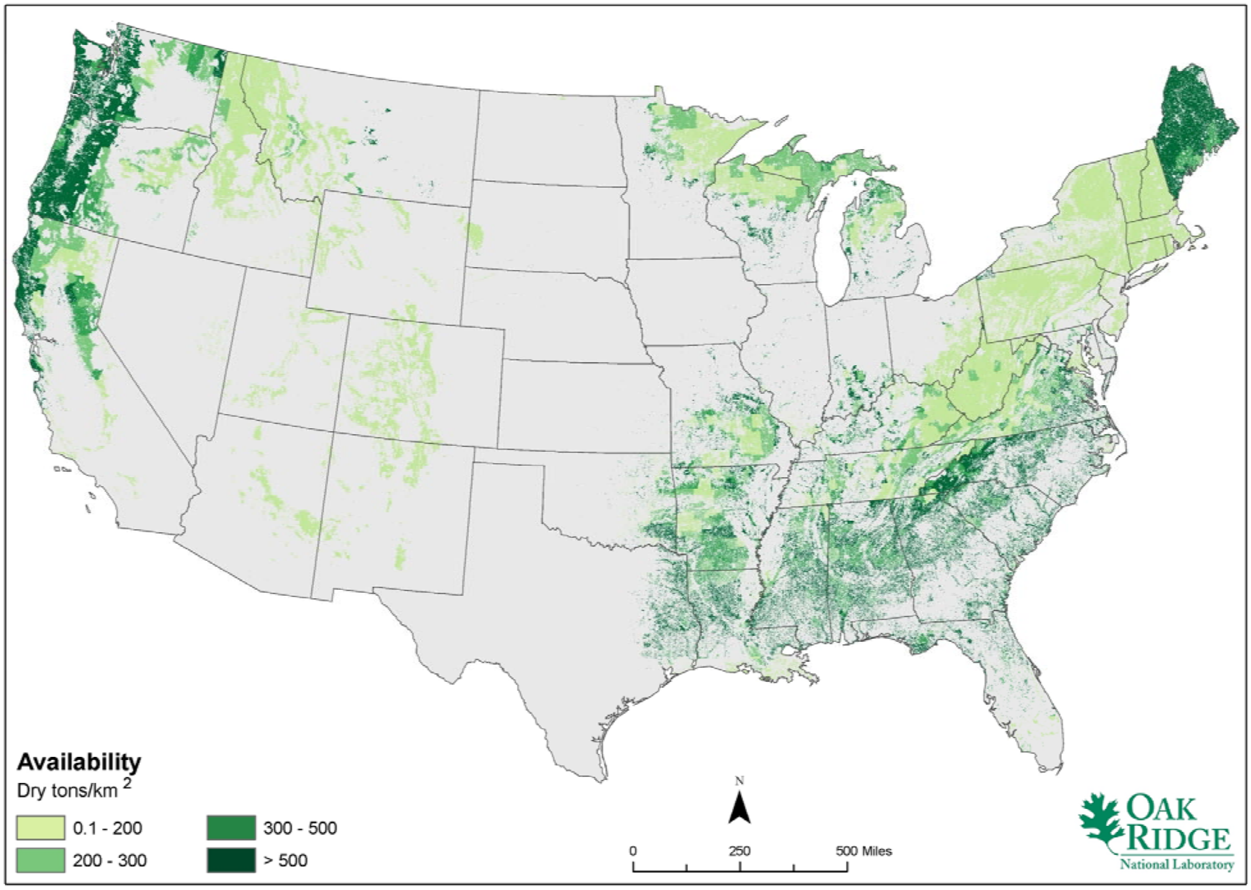


Source:
U.S. Department of Agriculture, Forest Service. 2007. *Timber Products Output Mapmaker Version 1.0*.

Note: Map created by Bioenergy Resource and Engineering Systems Program, Oak Ridge National Laboratory.

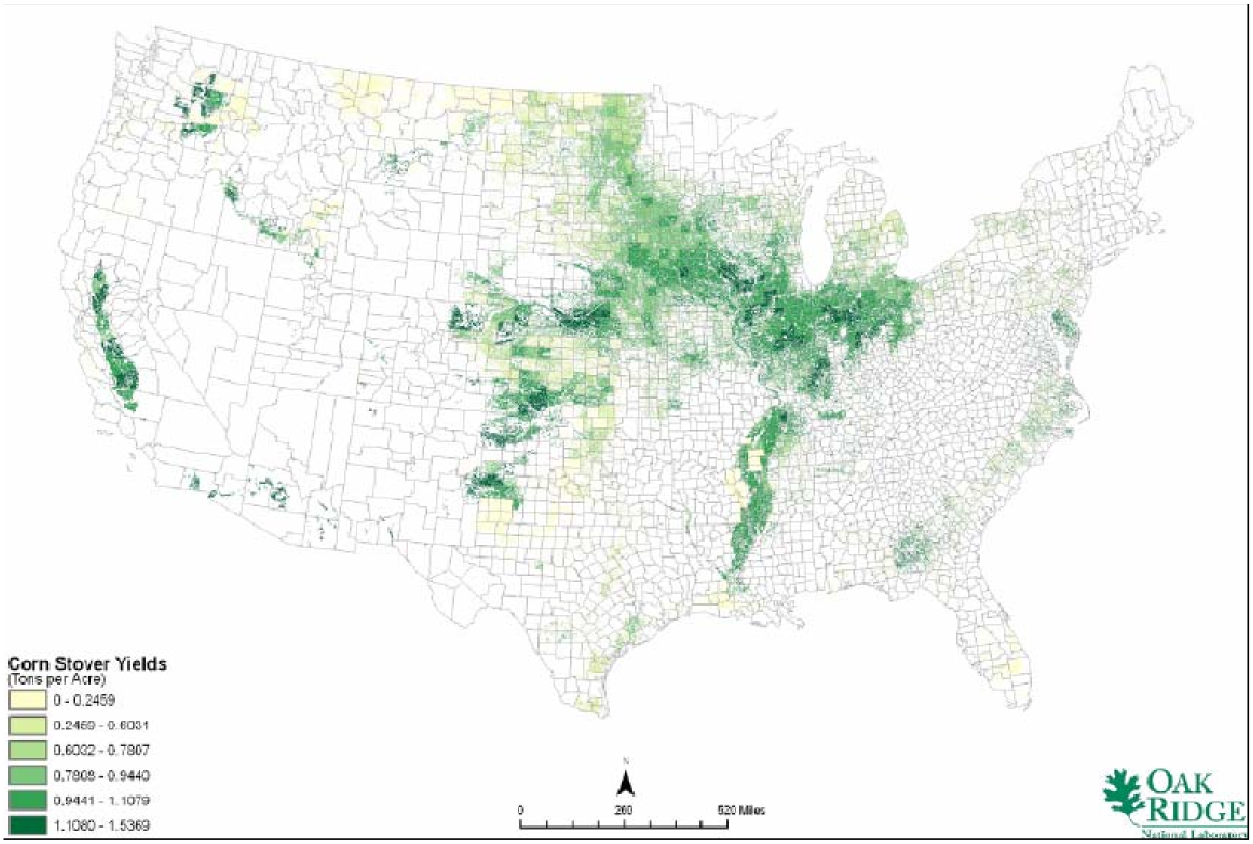
Other removal residues are the unutilized wood volume from cut or otherwise killed growing stock, from cultural operations such as pre-commercial thinnings, or from timberland clearing. Does not include volume removed from inventory through reclassification of timberland to productive reserved forest land.

Figure 5.14
Total Availability of Other Removal Residue from Timberlands, 2007



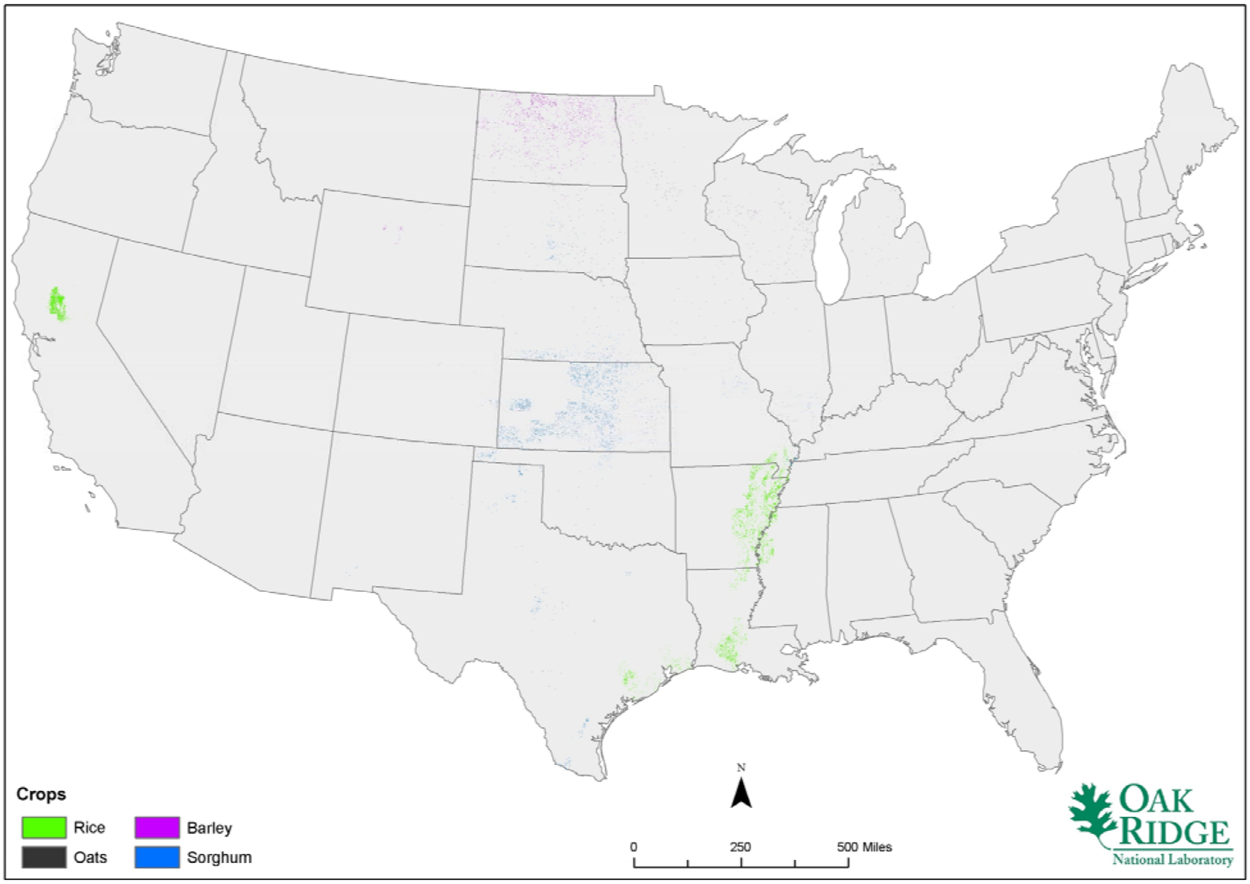
Source:
Bioenergy Resource and Engineering Systems Program, Oak Ridge National Laboratory.

Figure 5.15
Total Availability of Corn Stover Residue, 2007



Source:
Bioenergy Resource and Engineering Systems Program, Oak Ridge National Laboratory.

Figure 5.16
Other Crop Residues, 2008



Source:
Bioenergy Resource and Engineering Systems Program, Oak Ridge National Laboratory.

SECONDARY BIOMASS FEEDSTOCKS

Residues and byproduct streams from food, feed, fiber, wood, and materials processing plants are the main source of secondary biomass. Secondary biomass feedstocks differ from primary biomass feedstocks in that the secondary feedstocks are a by-product of processing of the primary feedstocks. By "processing" it is meant that there is substantial physical or chemical breakdown of the primary biomass and production of by-products. "Processors" may be factories or animals. Field processes such as harvesting, bundling, chipping or pressing do not cause a biomass resource that was produced by photosynthesis (e.g., tree tops and limbs) to be classified as secondary biomass.

Specific examples of secondary biomass includes sawdust from sawmills, black liquor (which is a by-product of paper making), and cheese whey (which is a by-product of cheese making processes). Manures from concentrated animal feeding operations are collectable secondary biomass resources. Vegetable oils used for biodiesel that are derived directly from the processing of oilseeds for various uses are also a secondary biomass resource.

It is difficult to find good direct sources of information on secondary biomass resources. In most cases, one has to estimate availability based on information and assumptions about the industries or companies generating the biomass. These estimates can be inaccurate because the amount of material that is a by-product to a given process can change over time as processes become more efficient or new uses are found for some by-product components.

The estimates provided in this Data Book were generated either by industries using secondary biomass to make a marketable fuel (e.g., the pellet fuel industry), or were generated by Forest Service staff using the Timber Product Output database http://www.fia.fs.fed.us/tools-data/tools/. This database is based on wood harvest and use inventories conducted every 5 years; the 2002 inventory is the latest source of information. The wood already used for energy provides insight on current bioenergy produced and the "unused" biomass represents wood that is already collected and potentially very easy to make available for additional energy production. Though a relatively small amount, it would likely be some of the first wood used if bioenergy use is accelerated in the U.S.

Information on black liquor production and use for energy is kept and tracked by the forest products industry but is proprietary. An estimate of black liquor production could be made based on publicly available information on pulp mills. However, any current listing of pulp mills in operation will be out-of-date within a month or two of publication because of the frequent closing of mills that is occurring. Thus, though a very important resource for bioenergy production today, no attempt is made to include a state level estimate of black liquor production in this book.

Source:
Lynn Wright, Oak Ridge, TN.

The Forest Service's State and Private Forestry, Technology Marketing Unit, at the agency has awarded grants to stimulate utilization of woody biomass, especially of wood from areas needing hazardous fuels reduction. The projects are small and often support the purchase of equipment by small companies. The primary objective of the Forest Service is to increase the removal and use of small diameter wood from forests. Only 2007 and 2008 projects are shown in this summary. A report is available on the status of projects funded in 2005 and 2006. We have categorized the projects by whether the activity concerns feedstock supply, or production of bioenergy or bioproducts.

Table 5.35
U.S. Forest Service - Woody Biomass Utilization Grantees 2007 & 2008

Company Name	Location	Award $$	Project Name (shortened)/descriptions
		2008 Grant Summary	
Feedstock Supply			
Nevada Div. of Forestry	Carson City, NV	250,000	Western Nevada Biomass Transportation Project
Northridge Forest Products	Mora, NM	250,000	Woody Biomass Utilization (thinning and harvesting)
Watershed Research and Training Center	Hayfork, CA	245,000	Establishing Mechanical Harvesting Capacity for Restoration of Forest
Coquille Tribe	North Bend, OR	250,000	Use of Roll On/Off Container System to Capture Biomass and Reduce Fuel Treatment Costs
Osler Logging, Inc.	Bozeman, MT	250,000	Haul Truck Acquisition for Woody Biomass Production
Perkins Timber Harvesting	Williams, AZ	250,000	Increasing Capacity to Harvest Woody Biomass (purchase of a harvester/forwarder)
Kootenai Business Park Ind. Dist	Libby, MT	250,000	Biomass Production/Purchase of truck scales, grinder and chip bin
Quicksilver Contracting	Bend, OR	250,000	Portable Chip Trailer Chipper to Facilite Interstate Transportation of Woody Biomass
Bioenergy			
Bear Mountain Forest Products	Portland, OR	250,000	New Market for Low-Value Biomass Through Wood Briquette Production
Bioproducts			
Winner's Circle Soil Products	Taylor, AZ	250,000	Wood Shavings Packing Project
K&B Timberworks, Inc	Reserve, NM	250,000	Woody Biomass Equipment Improvement/ Purchase of a Helle Scragg Mill
Big Sky Shavings	Hall, MT	250,000	Additional Capacity for Biomass Utilization (expanding a wood shavings mill)
Marks Ranch and Lumber	Clancy, MT	211,000	Improve Recovery and Utilization of Sawlogs (purchase a thin-kerf bandsaw)
Sandford Logging, Inc	Spearfish, SD	250,000	Post and Pole Manuracturing Plant
UpStream 21 Corp	Portland, OR	250,000	Log Merchandizing Facility
Renewable Fiber, Inc	Ft. Lupton, CO	250,000	Wood Shaving Plant Upgrade
Diamond Ridge Lumber	Caldwell, ID	168,200	Forest Restoration Activities/ Purchase of security equipment for animal shaving and sawmill

Table Continued on Next Page

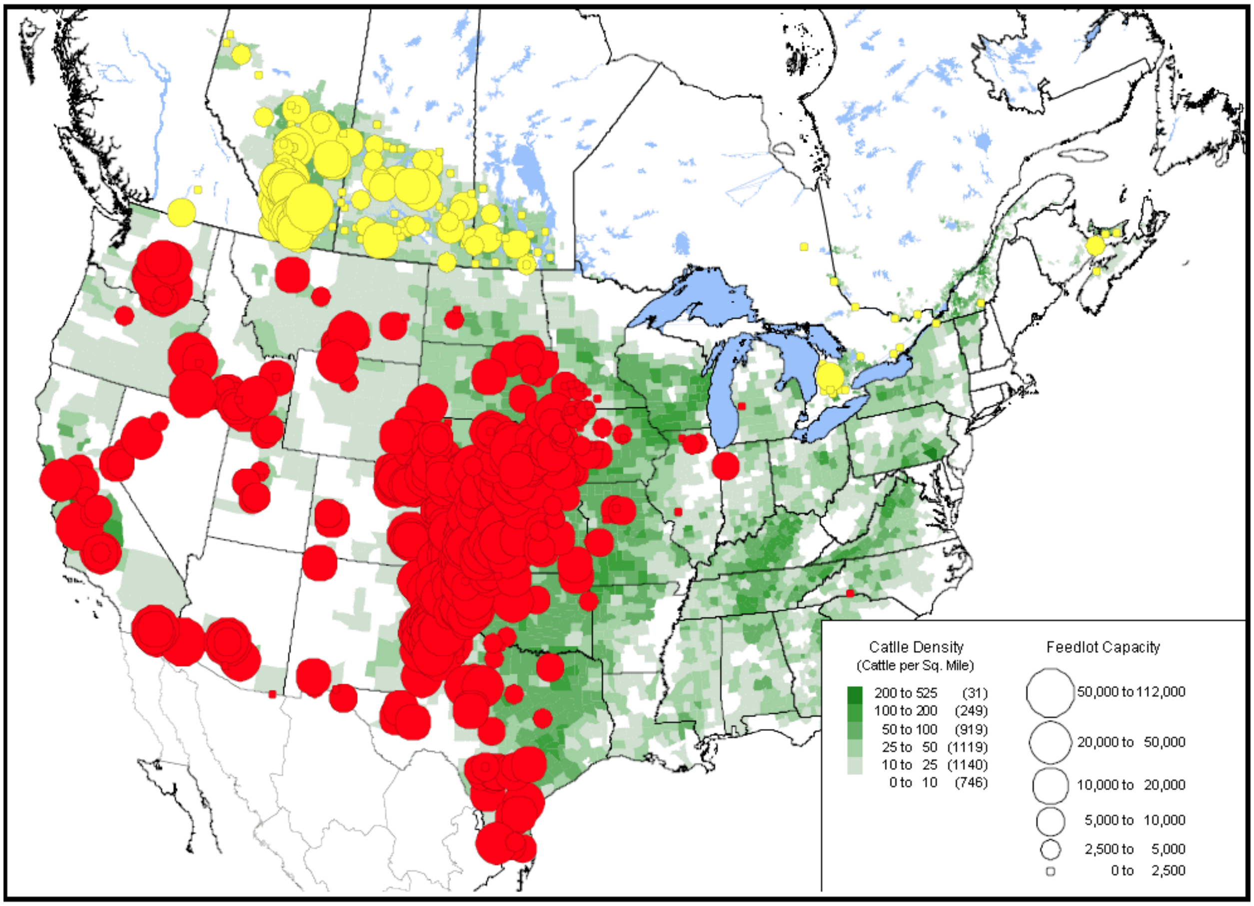
Table 5.37 (Continued)
U.S. Forest Service - Woody Biomass Utilization Grantees 2007 & 2008

Company Name	Location	Award $$	Project Name (shortened)/descriptions
		2007 Grant Summary	
Feedstock Supply			
Intrinergy, LLC	Ashland, VA	250,000	Establish a supply of woody biomass feedstock from Desoto National Forest
Olguin's Sawmill, Inc	El Prado, NM	250,000	Forest Restoration Activity/ purchase of a feller buncher and planer
Mt. Taylor Millwork, Inc	Milan, NM	250,000	Woody Biomass Utilization, Forest Restoration, and Tamarisk Eradication Project/buy chipper
Barala Timber	Las Vegas, NM	250,000	Diversified Woody Biomass Utilization/purchase of excavator mounted feller-buncher and horizontal grinder
Dept. Forestry, NCSU	Raleigh, NC	247,802	Machine System Development for Harvesting Woody Biomass and Reducing Hazardous Fuels
Baker Timber Products	Rapid City, SD	250,000	Forest Biomass to Ethanol/funds for purchase of wood
John Jump Trucking	Kalispell, MT	250,000	Transfer Truck Acquisition/buy trucks
Bioenergy			
Kane Area School District	Kane, PA	250,000	School District Woody Biomass Utilization Project
St Maries Joint School District	St. Maries, ID	250,000	School District Heating Project
Elk Regional Health System	St. Mary, PA	250,000	Elk Regional Health System Alternative Fuels Project (heating and cooling system)
Mountain Parks, Electric, Inc	Granby, CO	243,500	Development of a 3-4 MW Woody Biomass CHP facility/ supporting design, verification and specifications
Mescalero Forest Products	Mescalero, NM	250,000	Forest Products Pellet Mill/purchase of a pellet plant and marketing of pellets for energy
Bioproducts			
Malheur Lumber Company	John Day, OR	250,000	Small Log Value Added Shaving Facility
JTS Animal Bedding	Redmond, OR	250,000	Animal Bedding Small Pine Utilization Project
High County Green Waste, LLC	Lakeside, AZ	249,400	Serving Biomass Markets from Fire Hazard Mitigation Activities/equipment purchases for using biomass
Parma Post & Pole, Inc	Parma, ID	245,180	Small Diameter Doweling Expansion Operation/equipment purchase for biomass use
Woodland Restoration, Inc/North Slop Sustainable Wood LLC	Missoula, MT	248,950	Developing National Market for Larch and Fir Flooring from Small Diameter Trees
Bearlodge Forest Products, Inc	Hulett, WY	250,000	Manufacturing Pallet Parts from Hazardous Fuel Reductions/pallet making equipment purchase
Southwest Forest Products	Phoenix, AZ	250,000	Increased Utilization and Market Development/purchase and installation of a debarking system
Forest Fuels Solutions	Salmon, ID	250,000	Post and Pole Manufacturing/equipment purchases
Healty Forests, Healty Community (HFHC) Utilization Program	Portland, OR	250,000	HFHC will provide strategic financial and technical assistance to 4 local projects treating at risk forests and processing the small diameter wood.
Mountain Valley Lumber	Saguache, CO	179,260	Woody Biomass Equipment Acquisition and Installation/purchase of a dowel mill
Piute County Dept. of Econ. Dev	Junction, UT	249,800	Woody Biomass Utilization/ financing to develop a process and manufacturing incubator park
Kuykendall and Sons	Tres Piedras, NM	250,000	Equipment Expansion for Woody Biomass Utilization/mill upgrade equipment
Ranch Creek Limited	Granby, CO	144,000	Low-value Timer Utilization/purchase of a log lathe for producing house logs

Source:
U.S. Forest Service State & Private Forestry Technology Marketing Unit Web site, http://www.fpl.fs.fed.us/tmu/index.html.

The map below showing feedlot capacity and distribution throughout the United States is important as an indication of manure availability.

Figure 5.17
Feedlot Capacity and Distribution, 2004



Source:
U.S. Department of Agriculture. 2008. *U.S. Biobased Products Market Potential and Projections through 2025*, Page 224, OCE-2008-1, February.

The Forest Service classifies primary mill residues into three categories: bark, coarse residues (chunks and slabs) and fine residues (shavings and sawdust). These mill residues are excellent sources of biomass for cellulosic ethanol because they tend to be clean, uniform, concentrated, have low moisture content, and are already located at a processing facility. These traits make mill residues excellent feedstocks for energy and biomass needs as well.

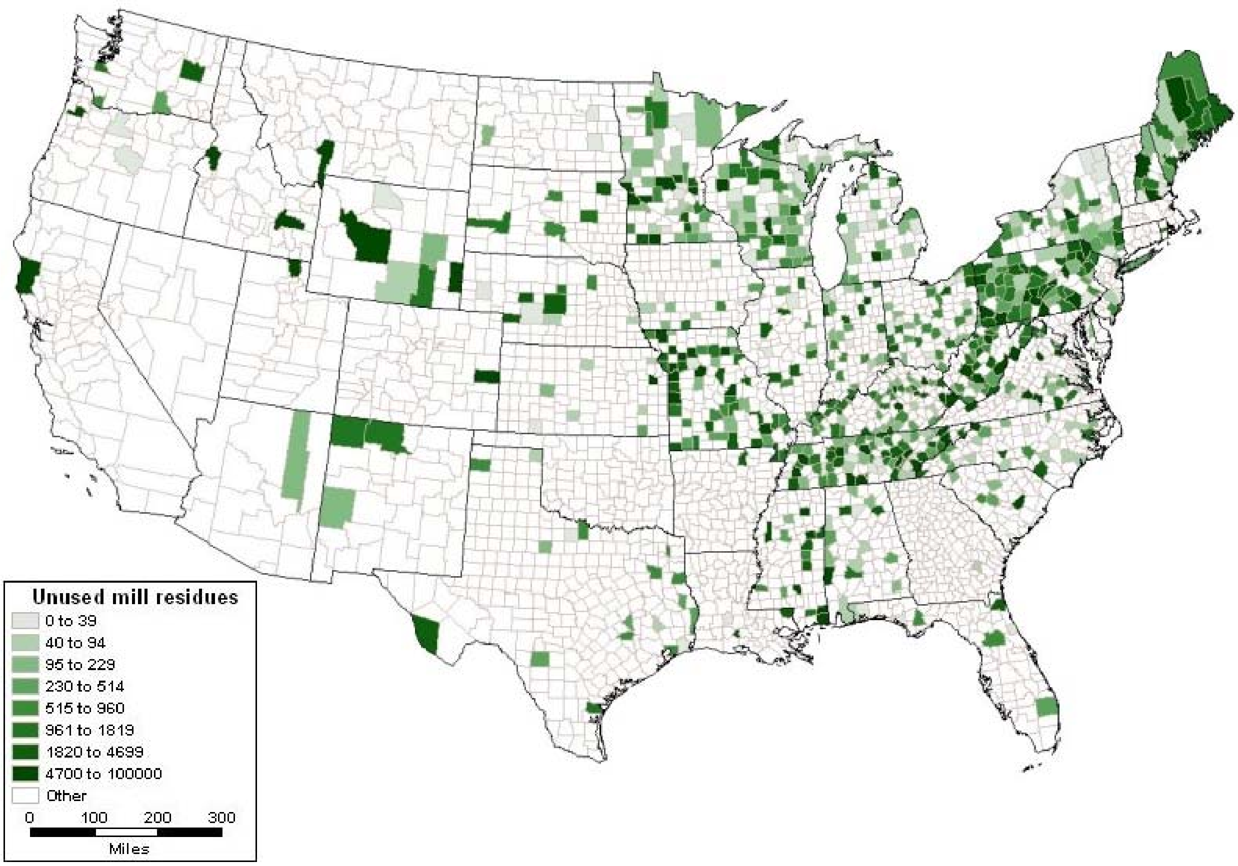
Table 5.36
Primary Mill Residue Production and Use by State, 2007
(Dry tons)

State	Total residue produced	Fiber byproducts	Fuel byproducts	Miscellaneous byproducts	Unused mill residues
Alabama	6,770,270	2,319,180	3,990,970	453,010	7,120
Arizona	97,190	31,920	520	63,400	1,350
Arkansas	5,372,030	2,456,840	2,710,020	192,280	12,890
California	3,629,030	1,476,540	1,665,350	422,040	65,090
Colorado	113,930	31,680	21,990	57,960	2,300
Connecticut	45,860	3,440	5,080	33,390	3,950
Delaware	21,500	0	2,560	18,940	0
Florida	2,513,390	847,310	1,171,030	492,860	2,200
Georgia	6,994,830	2,972,760	2,889,040	1,087,890	45,140
Idaho	2,219,550	1,265,060	825,880	122,610	6,010
Illinois	282,420	61,060	97,910	104,920	18,520
Indiana	766,650	243,420	150,360	362,240	10,630
Iowa	181,810	3,280	28,460	149,910	160
Kansas	27,500	5,530	3,000	10,250	8,720
Kentucky	1,550,470	432,260	463,290	599,730	55,200
Louisiana	4,611,930	1,756,760	2,677,480	147,610	30,080
Maine	506,010	190,440	166,820	106,270	42,480
Maryland	222,510	40,070	12,330	153,030	17,070
Massachusetts	126,770	23,340	41,200	62,230	0
Michigan	1,850,630	517,590	946,470	372,800	13,760
Minnesota	1,232,550	133,450	996,530	75,700	26,880
Mississippi	6,542,100	2,423,340	3,284,510	739,120	95,140
Missouri	1,146,430	206,690	148,650	711,310	79,790
Montana	1,510,080	1,075,350	286,000	139,600	9,140
Nebraska	46,710	0	7,800	33,930	4,970
Nevada	0	0	0	0	0
New Hampshire	335,450	82,920	125,670	119,850	7,020
New Jersey	8,720	0	1,340	5,950	1,440
New Mexico	114,000	58,000	8,710	42,390	4,900
New York	1,236,310	210,720	453,000	545,200	27,390
North Carolina	5,249,660	2,229,160	1,772,510	1,235,180	12,810
North Dakota	430	0	80	90	260
Ohio	352,880	40,670	140,010	149,600	22,600
Oklahoma	826,190	282,710	466,650	76,340	500
Oregon	7,577,270	5,439,820	1,559,250	561,870	16,320
Pennsylvania	1,628,140	351,080	419,530	686,560	170,970
Rhode Island	15,310	0	290	14,640	390
South Carolina	2,808,670	1,140,530	1,454,330	212,760	1,050
South Dakota	230,500	148,030	31,730	48,440	2,290
Tennessee	2,009,600	622,210	844,040	355,770	187,580
Texas	4,843,870	1,686,570	2,728,800	425,480	3,020
Utah	41,110	360	5,240	31,070	4,440
Vermont	104,440	59,940	44,500	0	0
Virginia	2,897,960	1,130,530	1,211,790	516,280	39,370
Washington	5,278,350	2,682,220	1,593,360	981,320	21,450
West Virginia	843,300	272,170	281,230	171,120	118,780
Wisconsin	1,708,220	357,640	947,400	342,770	60,410
Wyoming	219,840	96,940	44,910	43,980	34,010
Total	**86,712,401**	**35,409,538**	**36,727,621**	**13,279,682**	**1,295,560**

Source:
U.S. Department of Agriculture, Forest Service. 2007. "Timber Products Output Mapmaker Version 1.0."

Although the mill residues shown in the map below are currently unused, they represent a source of biomass that could be utilized fairly easily compared with other sources of biomass.

Figure 5.18
Unused Mill Residues in the U.S. by County



Source:
U.S. Department of Agriculture, Forest Service. 2007. *Timber Products Output Mapmaker Version 1.0*.

Note: Map created by Bioenergy Resource and Engineering Systems Program, Oak Ridge National Laboratory.

Table 5.37
Pellet Fuel Shipments from Pellet Fuel Manufacturers
(Tons)

Region	1994-1995	1995-1996	1996-1997	1997-1998	1998-1999	1999-2000	2000-2001	2001-2002	2002-2003[a]	2003-2004[a]	2004-2005[a]
Pacific	293,000	262,000	228,000	236,000	231,000	235,500	204,000	229,000	269,000	241,000	183,323
Mountain	120,000	123,000	108,000	108,000	120,000	89,000	121,000	130,000	105,000	131,000	101,509
Central	15,000	19,000	36,000	49,000	31,000	17,500	43,000	39,000	49,000	76,000	49,176
Great Lakes	24,000	36,000	45,000	22,000	27,000	19,100	26,000	44,000	41,000	53,000	56,656
Northeast	84,000	107,000	143,000	154,000	135,000	147,000	197,000	226,000	254,000	272,000	241,344
Southeast	34,000	39,000	49,000	49,000	58,000	62,000	63,000	59,000	43,000	43,000	35,772
Total	**570,000**	**586,000**	**609,000**	**618,000**	**602,000**	**570,100**	**654,000**	**727,000**	**761,000**	**816,000**	**667,780**

Source:
http://www.pelletheat.org/3/industry/marketResearch.html#

[a] Represents heating season, not annual season. 1st Quarter April-June; 2nd Quarter July-September; 3rd Quarter October-December; 4th Quarter January-March.

Shipments of pellet appliances nearly quadrupled between 1998 and 2006 while cordwood appliance shipments have remained relatively level although, by volume, cordwood appliances are by far the largest share of wood burning appliances.

Table 5.38
Pellet and Cordwood Appliance Shipments from Manufacturers, 1998-2007

	Pellet Appliances	% Change	**Cordwood Appliances**	% Change
1998	34,000	a	652,500	a
1999	18,360	-46%	795,767	22%
2000	30,970	69%	609,332	-23%
2001	53,473	73%	637,856	5%
2002	33,978	-36%	534,406	-16%
2003	48,669	43%	503,699	-6%
2004	67,467	39%	498,630	-1%
2005	118,746	76%	561,696	13%
2006	133,105	12%	525,097	-7%
2007	54,032	-59%	361,492	-30%

Source:
Hearth, Patio & Barbecue Association, http://www.hpba.org/index.php?id=238.

[a] Data not available.

TERTIARY BIOMASS FEEDSTOCKS

Tertiary biomass includes post consumer residues and wastes, such as fats, greases, oils, construction and demolition wood debris, other waste wood from the urban environments, as well as packaging wastes, municipal solid wastes, and landfill gases.

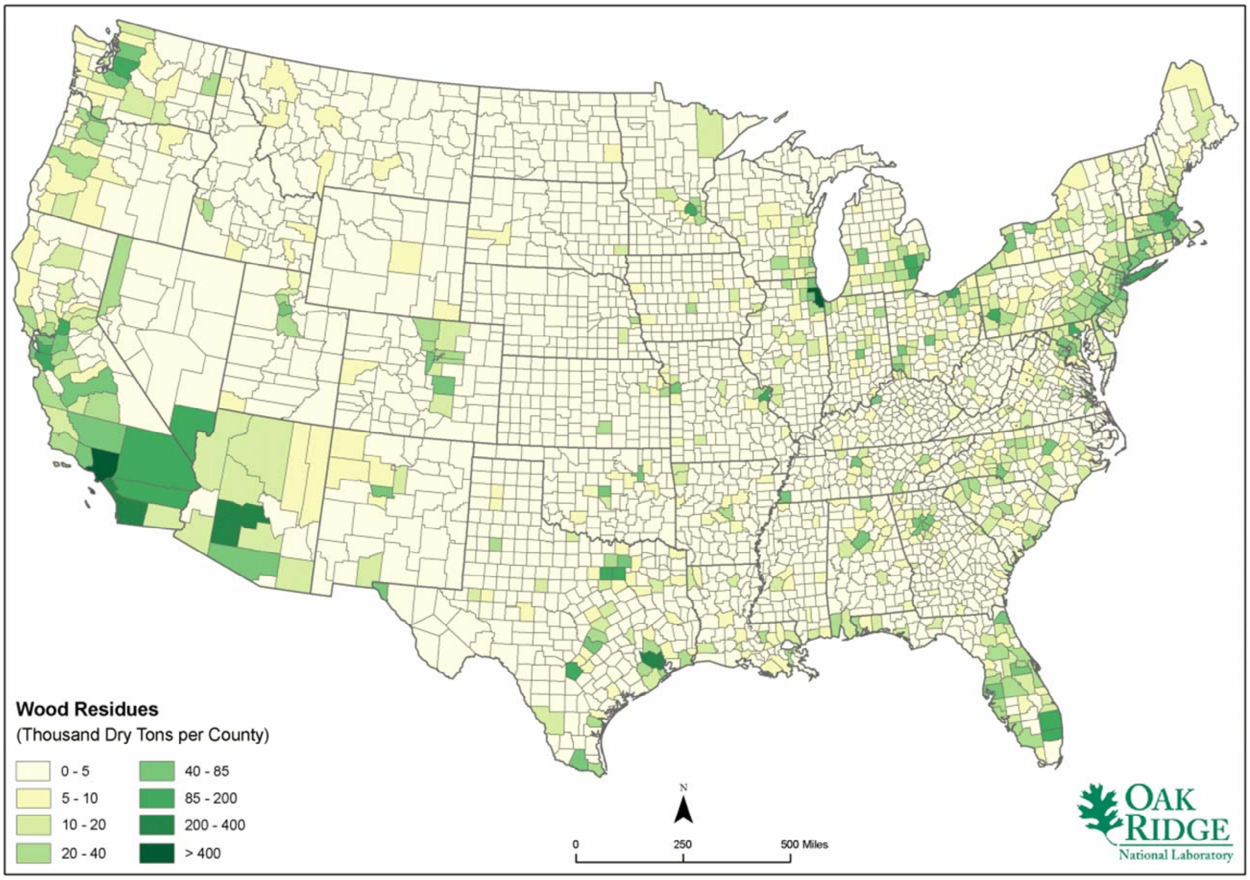
The category “other wood waste from the urban environment” could include trimmings from urban trees, which technically fits the definition of primary biomass. However, because this material is normally handled as a waste stream along with other post-consumer wastes from urban environments (and included in those statistics), it makes the most sense to consider it to be part of the tertiary biomass stream.

The proper categorization of fats and greases may be debatable since those are byproducts of the reduction of animal biomass into component parts. However, since we are considering animals to be a type of biomass processing factory, and since most fats and greases, and some oils, are not available for bioenergy use until after they become a post-consumer waste stream, it seems appropriate for them to be included in the tertiary biomass category. Vegetable oils derived from processing of plant components and used directly for bioenergy (e.g. soybean oil used in biodiesel) would be a secondary biomass resource, though amounts being used for bioenergy are most likely to be tracked together with fats, greases and waste oils.

Source:
Lynn Wright, Oak Ridge, TN.

Construction and demolition produce a sizeable amount of biomass material, though; recovery and use of those materials pose economic challenges.

Figure 5.19
Total Construction and Demolition Debris Wood Residues, 2007



Source:
McKeever, D. 2004. "Inventories of Woody Residues and Solid Wood Waste in the United States, 2002," *Ninth International Conference*, Inorganic-Bonded Composite Materials. Vancouver, British Columbia.

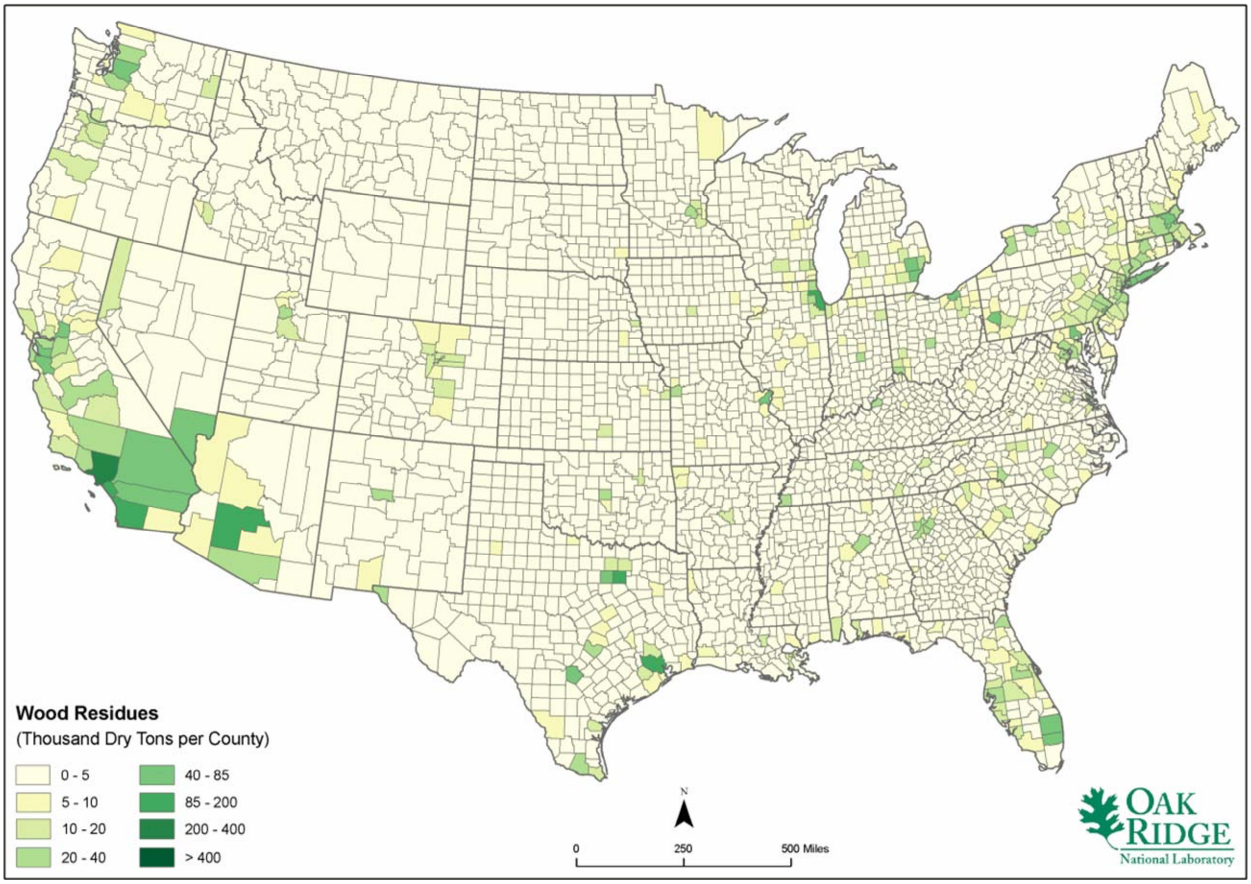
Notes: Estimates based on McKeever (2004) updated using U.S. Census data on "Characteristics of New Housing" and "Residential Improvement and Repair Statistics.

National estimates distributed to counties based on population.

Map created by Bioenergy Resource and Engineering Systems Program, Oak Ridge National Laboratory.

Urban wood wastes include wood (discarded furniture, pallets, containers, packaging materials and lumber scraps), yard and tree trimmings, and construction and demolition wood. This can be a significant

Figure 5.20
Total Municipal Solid Waste Wood Residues, 2007



Sources:

U.S. Environmental Protection Agency. 2007. *Municipal Solid Waste in the United States: 2007: Facts and Figures*, Office of Solid Waste. EPA530-R-08-010. November.

McKeever, D. 2004. "Inventories of Woody Residues and Solid Wood Waste in the United States, 2002," *Ninth International Conference*, Inorganic-Bonded Composite Materials, Vancouver, British Columbia.

Notes: Estimates based on an update of McKeever (2004) using EPA (2007).

National estimates distributed to counties based on population.

Map created by Bioenergy Resource and Engineering Systems Program, Oak Ridge National Laboratory.

Landfill gas is becoming a more prominent source of energy; all but nine states are using landfill gas to some extent. There are a number of states that are utilizing the majority of landfill sites available to them.

Table 5.39
Landfill Gas Projects and Candidate Landfills by State, July 2008

State	Operational Projects	Candidate Landfills
Alabama	3	20
Alaska	0	1
Arizona	3	13
Arkansas	3	4
California	73	36
Colorado	0	9
Connecticut	2	5
Delaware	3	a
Florida	11	22
Georgia	9	22
Hawaii	0	8
Idaho	2	2
Illinois	35	23
Indiana	19	15
Iowa	4	11
Kansas	5	6
Kentucky	6	18
Louisiana	4	8
Maine	1	2
Maryland	5	10
Massachusetts	20	3
Michigan	28	9
Minnesota	6	7
Mississippi	1	12
Missouri	8	16
Montana	1	4
Nebraska	2	4
Nevada	0	5
New Hampshire	5	3
New Jersey	17	2
New Mexico	2	1
New York	19	13
North Carolina	14	34
North Dakota	1	1
Ohio	17	18
Oklahoma	4	11
Oregon	6	4
Pennsylvania	27	15
Rhode Island	2	a
South Carolina	7	15
South Dakota	0	2
Tennessee	6	11
Texas	22	55
Utah	3	5
Vermont	3	a
Virginia	18	12
Washington	6	8
West Virginia	0	9
Wisconsin	23	10
Wyoming	0	1
U.S. Total	**456**	**525**

Source:
WPA's Landfill Methane Outreach Program, July 10, 2008, http://www.epa.gov/landfill/proj/.

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a No data available.

APPENDIX A

CONVERSIONS

Table A.1
Lower and Higher Heating Values of Gas, Liquid and Solid Fuels

Fuels	Lower Heating Value (LHV) [1]			Higher Heating Value (HHV) [1]			Density
Gaseous Fuels @ 32 F and 1 atm	**Btu/ft3 [2]**	**Btu/lb [3]**	**MJ/kg [4]**	**Btu/ft3 [2]**	**Btu/lb [3]**	**MJ/kg [4]**	**grams/ft3**
Natural gas	983	20,267	47.141	1089	22,453	52.225	22.0
Hydrogen	290	51,682	120.21	343	61,127	142.18	2.55
Still gas (in refineries)	1458	20,163	46.898	1,584	21,905	50.951	32.8
Liquid Fuels	**Btu/gal [2]**	**Btu/lb [3]**	**MJ/kg [4]**	**Btu/gal [2]**	**Btu/lb [3]**	**MJ/kg [4]**	**grams/gal**
Crude oil	129,670	18,352	42.686	138,350	19,580	45.543	3,205
Conventional gasoline	116,090	18,679	43.448	124,340	20,007	46.536	2,819
Reformulated or low-sulfur gasoline	113,602	18,211	42.358	121,848	19,533	45.433	2,830
CA reformulated gasoline	113,927	18,272	42.500	122,174	19,595	45.577	2,828
U.S. conventional diesel	128,450	18,397	42.791	137,380	19,676	45.766	3,167
Low-sulfur diesel	129,488	18,320	42.612	138,490	19,594	45.575	3,206
Petroleum naphtha	116,920	19,320	44.938	125,080	20,669	48.075	2,745
NG-based FT naphtha	111,520	19,081	44.383	119,740	20,488	47.654	2,651
Residual oil	140,353	16,968	39.466	150,110	18,147	42.210	3,752
Methanol	57,250	8,639	20.094	65,200	9,838	22.884	3,006
Ethanol	76,330	11,587	26.952	84,530	12,832	29.847	2,988
Butanol	99,837	14,775	34.366	108,458	16,051	37.334	3,065
Acetone	83,127	12,721	29.589	89,511	13,698	31.862	2,964
E-Diesel Additives	116,090	18,679	43.448	124,340	20,007	46.536	2,819
Liquefied petroleum gas (LPG)	84,950	20,038	46.607	91,410	21,561	50.152	1,923
Liquefied natural gas (LNG)	74,720	20,908	48.632	84,820	23,734	55.206	1,621
Dimethyl ether (DME)	68,930	12,417	28.882	75,610	13,620	31.681	2,518
Dimethoxy methane (DMM)	72,200	10,061	23.402	79,197	11,036	25.670	3,255
Methyl ester (biodiesel, BD)	119,550	16,134	37.528	127,960	17,269	40.168	3,361
Fischer-Tropsch diesel (FTD)	123,670	18,593	43.247	130,030	19,549	45.471	3,017
Renewable Diesel I (SuperCetane)	117,059	18,729	43.563	125,294	20,047	46.628	2,835
Renewable Diesel II (UOP-HDO)	122,887	18,908	43.979	130,817	20,128	46.817	2,948
Renewable Gasoline	115,983	18,590	43.239	124,230	19,911	46.314	2,830
Liquid Hydrogen	30,500	51,621	120.07	36,020	60,964	141.80	268
Methyl tertiary butyl ether (MTBE)	93,540	15,094	35.108	101,130	16,319	37.957	2,811
Ethyl tertiary butyl ether (ETBE)	96,720	15,613	36.315	104,530	16,873	39.247	2,810
Tertiary amyl methyl ether (TAME)	100,480	15,646	36.392	108,570	16,906	39.322	2,913
Butane	94,970	19,466	45.277	103,220	21,157	49.210	2,213
Isobutane	90,060	19,287	44.862	98,560	21,108	49.096	2,118
Isobutylene	95,720	19,271	44.824	103,010	20,739	48.238	2,253
Propane	84,250	19,904	46.296	91,420	21,597	50.235	1,920
Solid Fuels	**Btu/ton [2]**	**Btu/lb [5]**	**MJ/kg [4]**	**Btu/ton [2]**	**Btu/lb [5]**	**MJ/kg [4]**	
Coal (wet basis) [6]	19,546,300	9,773	22.732	20,608,570	10,304	23.968	
Bituminous coal (wet basis) [7]	22,460,600	11,230	26.122	23,445,900	11,723	27.267	
Coking coal (wet basis)	24,600,497	12,300	28.610	25,679,670	12,840	29.865	
Farmed trees (dry basis)	16,811,000	8,406	19.551	17,703,170	8,852	20.589	
Herbaceous biomass (dry basis)	14,797,555	7,399	17.209	15,582,870	7,791	18.123	
Corn stover (dry basis)	14,075,990	7,038	16.370	14,974,460	7,487	17.415	
Forest residue (dry basis)	13,243,490	6,622	15.402	14,164,160	7,082	16.473	
Sugar cane bagasse	12,947,318	6,474	15.058	14,062,678	7,031	16.355	
Petroleum coke	25,370,000	12,685	29.505	26,920,000	13,460	31.308	

Source:

GREET Transportation Fuel Cycle Analysis Model, GREET 1.8b, developed by Argonne National Laboratory, Argonne, IL, released May 8, 2008. http://www.transportation.anl.gov/software/GREET/index.html

Notes:

[1] The lower heating value (also known as net calorific value) of a fuel is defined as the amount of heat released by combusting a specified quantity (initially at 25°C) and returning the temperature of the combustion products to 150°C, which assumes the latent heat of vaporization of water in the reaction products is not recovered. The LHV are the useful calorific values in boiler combustion plants and are frequently used in Europe.

[2] Btu = British thermal unit.

[3] The heating values for gaseous fuels in units of Btu/lb are calculated based on the heating values in units of Btu/ft3 and the corresponding fuel density values. The heating values for liquid fuels in units of Btu/lb are calculated based on heating values in units of Btu/gal and the corresponding fuel density values.

[4] The heating values in units of MJ/kg, are converted from the heating values in units of Btu/lb.

Table A.1 (Continued)
Lower and Higher Heating Values of Gas, Liquid and Solid Fuels

[5] For solid fuels, the heating values in units of Btu/lb are converted from the heating values in units of Btu/ton.
[6] Coal characteristics assumed by GREET for electric power production.
[7] Coal characteristics assumed by GREET for hydrogen and Fischer-Tropsch diesel production.

Table A.2
Heat Content Ranges for Various Biomass Fuels (dry weight basis[a]) with English and Metric Units

Fuel type & source	English			Metric[b]			
		Higher Heating Value		Higher Heating Value		Lower Heating Value	
	Btu/lb[c]	Btu/lb	MBtu/ton	kJ/kg	MJ/kg	kJ/kg	MJ/kg
Agricultural Residues							
Corn stalks/stover (1,2,6)	7,487	7,587 - 7,967	15.2 - 15.9	*17,636 - 18,519*	*17.6 - 18.5*	16,849 - 17,690	16.8 - 18.1
Sugarcane bagasse (1,2,6)	7,031	7,450 - 8,349	14.9 - 16.7	*17,317 - 19,407*	*17.3 - 19.4*	17,713 - 17,860	17.7 - 17.9
Wheat straw (1,2,6)		*6,964 - 8,148*	13.9 - 16.3	16,188 - 18,940	16.1 - 18.9	15,082 - 17,659	15.1 - 17.7
hulls, shells, prunings (2,3)		6,811 - 8,838	13.6 - 17.7	*15,831 - 20,543*	*15.8 - 20.5*		
fruit pits (2-3)		8,950 - 10,000	17.9 - 20.0				
Herbaceous Crops	7,791						
Miscanthus (6)				18,100 - 19,580	18.1 - 19.6	17,818 - 18,097	17.8 - 18.1
switchgrass (1,3,6)		7,754 - 8,233	15.5 - 16.5	*18,024 - 19,137*	*18.0 - 19.1*	16,767 - 17,294	16.8 - 18.6
Other grasses (6)				18,185 - 18,570	18.2 - 18.6	16,909 - 17,348	16.9 - 17.3
Bamboo (6)				19,000 - 19,750	19.0 - 19.8		
Woody Crops	8,852						
Black locust (1,6)		8,409 - 8,582	16.8 - 17.2	*19,546 - 19,948*	*19.5 - 19.9*	18,464	18.5
eucalyptus (1,2,6)		*8,174* - 8,432	16.3 - 16.9	19,000 - *19,599*	*19.0 - 19.6*	17,963	18.0
hybrid poplar (1,3,6)		*8,183* - 8,491	*16.4* - 17.0	19,022 - *19,737*	*19.0 - 19.7*	17,700	17.7
willow (2,3,6)		7,983 - 8,497	16.0 - 17.0	18,556 - 19,750	18.6 - 19.7	16,734 - 18,419	16.7 - 18.4
Forest Residues	7,082						
Hardwood wood (2,6)		8,017 - 8,920	16.0 - 17.5	*18,635 - 20,734*	*18.6 - 20.7*		
Softwood wood (1,2,3,4,5,6)		8,000 - 9,120	16.0 - 18.24	*18,595 - 21,119*	*18.6 - 21.1*	17,514 - 20,768	17.5 - 20.8
Urban Residues							
MSW (2,6)		5,644 - 8,542	11.2 - 17.0	*13,119 - 19,855*	*13.1 - 19.9*	11,990 - 18,561	12.0 - 18.6
RDF (2,6)		*6,683 - 8,563*	*13.4 - 17.1*	15,535 - 19,904	15.5 - 19.9	14,274 - 18,609	14.3 - 18.6
newspaper (2,6)		8,477 - 9,550	17 - 19.1	*19,704 - 22,199*	19.7 - 22.2	18,389 - 20,702	18.4 - 20.7
corrugated paper (2,6)		7,428 -7,939	14.9 - 15.9	17,265 - 18,453	17.3 - 18.5	17,012	
waxed cartons (2)		11,727 - 11,736	23.5 - 23.5	*27,258 - 27,280*	*27.3*	25,261	

Sources:
[1] http://www1.eere.energy.gov/biomass/feedstock_databases.html
[2] Jenkins, B. 1993. *Properties of Biomass*, Appendix to Biomass Energy Fundamentals, EPRI Report TR-102107, January.
[3] Jenkins, B., L. Baxter, T. Miles, Jr. and T. Miles T. 1998. *Combustion Properties of Biomass, Fuel Processing Technology 54*, pg. 17-46.
[4] Tillman, David. 1978. *Wood as an Energy Resource*, Academic Press, New York.
[5] Bushnell, D. 1989. *Biomass Fuel Characterization: Testing and Evaluating the Combustion Characteristics of Selected Biomass Fuels*, BPA report.
[6] http://www.ecn.nl/phyllis

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[a] This table attempts to capture the variation in reported heat content values (on a dry weight basis) in the United States and European literature based on values in the Phyllis database, the U.S. DOE/EERE feedstock database, and selected literature sources. Table A.3 of this document provides information on heat contents of materials "as received" with varying moisture contents.

[b] Metric values include both HHV and LHV since Europeans normally report the LHV (or net calorific values) of biomass fuels.

[c] HHV assumed by GREET model given in Table A.1 of this document

*The heating value of any fuel is the heat release per unit mass when the fuel initially at 25°C (77°F) reacts completely with oxygen, and the products are returned to 25°C (77°F). The heating value is reported as the higher heating value (HHV) when the water is condensed or as the lower heating value (LHV) when the water is not condensed. The LHV is obtained from the HHV by subtracting the heat of vaporization of water in the products. Thus: LHV = HHV – ((mH20/ mfuel)*hfg) where m = mass and hfg is the latent heat of vaporization of water at 25°C (77°F) which equals 2,440 kJ/kg water (1,050 Btu/lbm). The water includes moisture in the fuel as well as water formed from hydrogen in the fuel.*

The HHV and LHV provided in Tables 1 and 2 of the Biomass Energy Data Book, Appendix A assume that the fuels contain 0% water. Since recently harvested wood fuels usually contain 30 to 55% water it is useful to understand the effect of moisture content on the heating value of wood fuels. The table below shows the effect of percent moisture content (MC) on the higher heating value as-fired (HHV-AF) of a wood sample starting at 8,500 Btu/lb (oven-dry).

Table A.3
The Effect of Fuel Moisture on Wood Heat Content[a]

Moisture Content (MC) wet basis (%)	0	15	20	25	30	35	40	45	50	55	60
Higher Heating Value as fired (HHV-AF) Btus/lb	8,500	7,275	6,800	6,375	5,950	5,525	5,100	4,575	4,250	3,825	3,400

Sources:

[1] Borman, G.L. and K.W. Ragland. 1998. *Combustion Engineering*. McGraw-Hill, 613 pp.

[2] Maker, T.M. 2004. *Wood-Chip Heating Systems: A Guide for Institutional and Commercial Biomass Installations*. (Revised 2004 by Biomass Energy Resource Center).

[3] American Pulpwood Association, Southern Division Office. 1980. *The Forester's Wood Energy Handbook*..

Notes: Moisture contents (MC) wet and dry weight basis are calculated as follows:

MC (dry basis) = 100 (wet weight-dry weight)/dry weight;
MC (wet basis) = 100 (wet weight – dry weight)/wet weight;
To convert MC wet basis to MC dry basis: MC(dry) = 100xMC(wet) /100-MC(wet);
To convert MC dry basis to MC wet basis: MC(wet)= 100 x MC(dry)/100 +MC(dry).

Some sources report heat contents of fuels "as-delivered" rather than at 0% moisture for practical reasons. Because most wood fuels have bone dry (oven-dry) heat contents in the range of 7,600 to 9,600 Btu/lb (15,200,000 to 19,200,000 Btu/ton or 18 to 22 GJ/Mg), lower values will always mean that some moisture is included in the delivered fuel. Grass fuels are usually delivered at < 20% MC.

[a] If the oven-dry HHV (Btu /lb)is known (e.g. 8,500) then the HHV-AF can be calculated as follows: oven-dry HHV x (1-MC wet basis/100).

Table A.4
Forestry Volume Unit to Biomass Weight Considerations

Biomass is frequently estimated from forestry inventory merchantable volume data, particularly for purposes of comparing regional and national estimates of aboveground biomass and carbon levels. Making such estimations can be done several ways but always involves the use of either conversion factors or biomass expansion factors (or both combined) as described by figure 1 below. Figure 2 clarifies the issue further by defining what is included in each category of volume or biomass units.

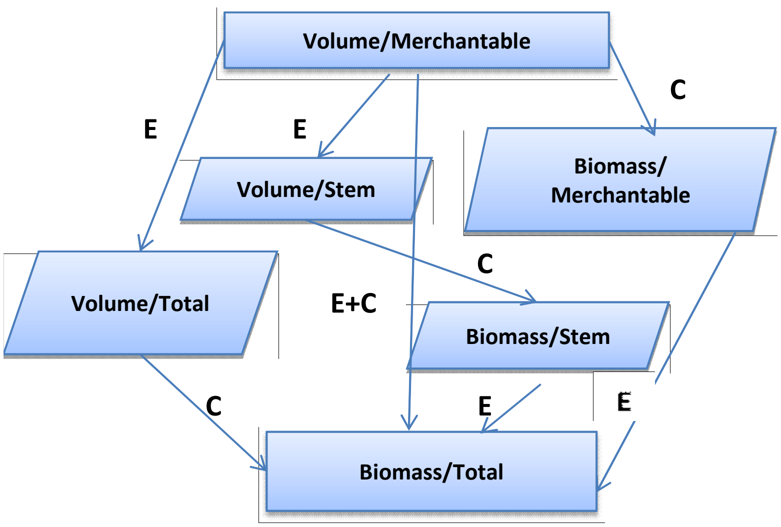

Figure 1 Source: Somogyi Z. et al. Indirect methods of large-scale biomass estimation. Eur J Forest Res (2006) DOI 10.1007/s10342-006-0125-7

Unfortunately definitions used in figure 1 are not standardized worldwide, but figure 2 below demonstrates definitions used in the United States for forest inventory data. The <u>merchantable volume</u> provided by forest inventory reports commonly refers only to the underbark volume or biomass of the main stem above the stump up to a 4 inch (10 cm) top. Merchantable stem volume can be converted (symbolized by C in Fig. 1) to merchantable biomass. Both merchantable volume and biomass must be expanded (symbolized by E on the diagram) to include the bark for stem volume or biomass. Further expansion is needed to obtain the <u>total volume or biomass</u> which includes stem, bark, stump, branches and foliage, especially if evergreen trees are being measured. When estimating biomass available for bioenergy, the foliage is not included and the stump may or may not be appropriate to include depending on whether harvest occurs at ground level or higher.
Both conversion and expansion factors can be used together to translate directly between merchantable volumes per unit area and total biomass per unit area (see table A5, Appendix A) .

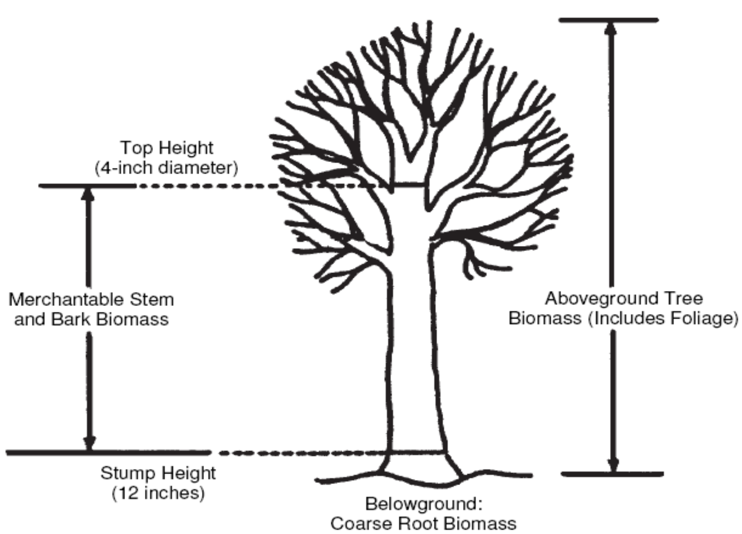

Figure 2 Source: Jenkins, JC, Chojnacky DC, Heath LS, Birdsey RA. Comprehensive Database of Diameter-based Biomass Regressions for North American Tree Species. United States Department of Agriculture, Forest Service General Technical Report NE-319, pp 1-45 (2004)

Table A.5
Estimation of Biomass Weights from Forestry Volume Data

Simple volume to weight conversion

An equation for estimation of merchantable biomass from merchantable volume assuming the specific gravity and moisture content are known and the specific gravity basis corresponds to the moisture content of the volume involved.

Weight = (volume) * (specific gravity) * (density of H_2O) * (1+MC^{od}/100)

where volume is expressed in cubic feet or cubic meters,

where the density of water is 62.4 lb/ft^3 or 1000 kg/m^3,

where MC^{od} equals oven dry moisture content.

for example the weight of fiber in an oven dry log of 44 ft^3 with a specific gravity of 0.40 =

40 ft^3*0.40 * 62.4 lb ft^3 * (1+0/100) equals 1,098 lb or 0.549 dry ton

Source: Briggs D. 1994. Forest Products Measurements and Conversion Factors, Chapter 1. College of Forest Resources University of Washington. http://www.ruraltech.org/projects/conversions/briggs_conversions/briggs_book.asp

Specific gravity (SG) is a critical element of the volume to biomass estimation equation. The SG content should correspond to the moisture content of the volume involved. SG varies considerably from species to species, differs for wood and bark, and is closely related to the moisture content as explained in graphs and tables in Briggs (1994). The wood specific gravity of species can be found in several references though the moisture content basis is not generally given. Briggs (1994) suggests that a moisture content of 12% is the standard upon which many wood properties measurements are based.

Biomass expansion factors for estimating total aboveground biomass Mg ha^{-1} from growing stock volume data (m^3 ha^{-1})

Methods for estimating total aboveground dry biomass per unit area from growing stock volume data in the USDA ForestService FIA database were described by Schroeder et. al (1997). The growing stock volume was by definition limited to trees > than or equal to 12.7 cm diameter. It is highly recommended that the paper be studied for details of how the biomass expansion factors (BEF) for oak-hickory and beech-birch were developed.

The BEFs for the two forest types were combined and reported as:

BEF = EXP (1.912 - 0.344*lnGSV) **GSV = growing stock volume m^3 ha^{-1}**

R2 = 0.85, n = 208 forest units , std. error of estimate = 0.109.

The result is curvilinear with BEF values ranging from 3.5 to 1.5 for stands with very low growing stock volume and approaching the value of 1 at high growing stock volumes. Minimum BEFs for the forest types evaluated are estimated to be about 0.61 to 0.75.

Source: Schroeder P, Brown S, Mo J, Birdsey R, Cieszewski C. 1997. Biomass estimation for temperate broadleaf forests of the US using forest inventlry data. Forest Science 43, 424-434.

Table A.6
Forestry Volume Unit to Biomass Weight Examples
(Selected Examples from the North Central Region)

Species Group	Specific gravity wood[a]	Specific gravity bark[a]	Green MC wood & bark (%)	Green weight wood & bark lb/ft^3	Dry weight wood & bark lb/ft^3	Green weight of solid cord[b] (lbs)	Green weight of solid cord[b] (tons)[c]	Air-dry tons per solid cord[b] 15% MC[c]	Oven-dry tons per solid cord 0% MC[c]
Softwood									
Southern Pine	0.47	0.32	50	64	32	5,056	2.5	1.5	1.3
Jack Pine	0.40	0.34	47	54	29	4,266	2.1	1.3	1.1
Red Pine	0.41	0.24	47	54	29	4,266	2.1	1.3	1.1
White Pine	0.37	0.49	47	53	28	4,187	2.1	1.3	1.1
Hardwood									
Red Oak	0.56	0.65	44	73	41	5,767	2.9	1.9	1.6
Beech	0.56	0.56	41	64	38	5,056	2.5	1.7	1.5
Sycamore	0.46	0.45	55	62	28	4,898	2.4	1.3	1.1
Cottonwood	0.37	0.43	55	59	27	4,661	2.3	1.2	1.0
Willow	0.34	0.43	55	56	25	4,424	2.2	1.1	1.0

Source:
Smith, B. 1985. *Factors and Equations to Estimate Forest Biomass in the North Central Region*, Research Paper NC-268, U.S. Department of Agriculture, Forest Service, North Central Experimental Station. (This paper quotes many original literature sources for the equations and estimates.)

Note: A caution: In extensive online research for reference sources that could provide guidance on estimating biomass per unit area from volume data (e.g., m3, ft3 or board ft), several sources of conversion factors and "rules of thumb" were found that provided insufficient information to discern whether the reference was applicable to estimation of biomass availability. For instance moisture contents were not associated with either the volume or the weight information provided. These "rule of thumb" guides can be useful when fully understood by the user, but they can be easily misinterpreted by someone not understanding the guide's intent. For this reason, most simple "rules of thumb guides" are not useful for converting forest volume data to biomass estimates.

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[a] The SG numbers are based on weight oven-dry and volume when green (Smith, 1985; table 1) of wood and bark respectively. Wood and bark are combined for other columns (Smith, 1985, table 2).

[b] A standard solid cord for the north central region was determined by Smith, 1985 to be 79 ft3 rather than the national average of 80 ft3 as used in table A9 in appendix A.

[c] The green weight values in lbs provided by the Smith (1985) paper were converted to green tons, air-dry tons and oven-dry tons for convenience of the user.

Table A.7
Stand Level Biomass Estimation

Biomass estimation at the individual field or stand level is relatively straight forward, especially if being done for plantation grown trees that are relatively uniform in size and other characteristics. The procedure involves first developing a biomass equation that predicts individual tree biomass as a function of diameter at breast height (dbh), or of dbh plus height. Secondly, the equation parameters (dbh and height) need to be measured on a sufficiently large sample size to minimize variation around the mean values, and thirdly, the mean individual tree weight results are scaled to the area of interest based on percent survival or density information (trees per acre or hectare). Regression estimates are developed by directly sampling and weighing enough trees to cover the range of sizes being included in the estimation. They often take the form of:

ln Y (weight in kg) = -factor 1 + factor 2 x ln X (where X is dbh or dbh^2 *+height/100) Regression equations can be found for many species in a wide range of literature. Examples for trees common to the Pacific Northwest are provided in reference 1 below. The equations will differ depending on whether foliage or live branches are included, so care must be taken in interpreting the biomass data. For plantation trees grown on cropland or marginal cropland it is usually assumed that tops and branches are included in the equations but that foliage is not. For trees harvested from forests on lower quality land, it is usually recommended that tops and branches should not be removed (see reference 2 below) in order to maintain nutrient status and reduce erosion potential, thus biomass equations should assume regressions based on the stem weight only.*

Sources:

[1] Briggs, D. 2008. *Forest Products Measurements and Conversion Factors*. College of Forest Resources University of Washington. Available as of 9/29/2008 at: http://www.ruraltech.org/projects/conversions/briggs_conversions/briggs_book.asp

[2] Pennsylvania Department of Conservation and Natural Resources. 2007. *Guidance on Harvesting Woody Biomass for Energy in Pennsylvania*. September. Available as of 9-29-08 at: http://www.dcnr.state.pa.us/PA_Biomass_guidance_final.pdf

Table A.8
Number of Trees per Acre and per Hectare by Various Tree Spacing Combinations

Spacing (feet) =	Trees per Acre =	Spacing (meters)=	Trees per Hectare[a]	Spacing (meters)=	Trees per Hectare	Spacing (ft and in) =	Trees per Acre[b]
1 x 1	43,560	0.3 x 0 .3	107,637	0.1 x 0.1	1,000,000	4" x 4 "	405,000
2 x 2	10,890	0.6 x 0.6	26,909	0.23 x 0.23	189,035	9" x 9 "	76,559
2 x 4	5,445	0.6 x 1.2	13,455	0.3 x 0.3	107,593	1' x 1'	43,575
3 x 3	4,840	0.9 x 0.9	11,960	0.5 x 0.5	40,000	1'8" x 1'8"	16,200
4 x 4	2,722	1.2x 1.2	6,726	0.5 x 1.0	20,000	1'8" x 3'3"	8,100
4 x 5	2,178	1.2 x 1.5	5,382	0.5 x 2.0	10,000	1'8" x 6'7"	4,050
4 x 6	1,815	1.2 x 1.8	4,485	0.75 x 0.75	17,778	2'6" x 2'6"	7,200
4 x 7	1,556	1.2 x 2.1	3,845	0.75 x 1.0	13,333	2'6" x 3'3"	5,400
4 x 8	1,361	1.2 x 2.4	3,363	0.75 x 1.5	8,889	2'5" x 4'11"	3,600
4 x 9	1,210	1.2 x 2.7	2,990	1.0 x 1.0	10,000	3'3" x 3'3"	4,050
4 x 10	1,089	1.2 x 3.0	2,691	1.0 x 1.5	6,667	3'3" x 4'11"	2,700
5 x 5	1,742	1.5 x 1.5	4,304	1.0 x 2.0	5,000	3'3" x 6'6"	2,025
5 x 6	1,452	1.5 x 1.8	3,588	1.0 x 3.0	3,333	3'3" x 9'10"	1,350
5 x 7	1,245	1.5 x 2.1	3,076	1.5 x 1.5	4,444	4'11"x4'11"	1,800
5 x 8	1,089	1.5 x 2.4	2,691	1.5 x 2.0	3,333	4'11"x 6'6"	1,350
5 x 9	968	1.5 x 2.7	2,392	1.5 x 3.0	2,222	4'11"x9'10"	900
5 x 10	871	1.5 x 3.0	2,152	2.0 x 2.0	2,500	3'3" x 3'3"	1,013
6 x 6	1,210	1.8 x 1.8	2,990	2.0 x 2.5	2,000	3'3" x 8'2"	810
6 x 7	1,037	1.8 x 2.1	2,562	2.0 x 3.0	1,667	3'3" x 9'10"	675
6 x 8	908	1.8 x 2.4	2,244	2.0 x 4.0	1,250	3'3" x 13'1"	506
6 x 9	807	1.8 x 2.7	1,994	2.5 x 2.5	1,600	8'2" x 8'2"	648
6 x 10	726	1.8 x 3.0	1,794	2.5 x 3.0	1,333	8'2" x 9'10"	540
6 x 12	605	1.8 x 3.7	1,495	3.0 x 3.0	1,111	9'10"x9'10"	450
7 x 7	889	2.1 x 2.1	2,197	3.0 x 4.0	833	9'10"x13'1"	337
7 x 8	778	2.1 x 2.4	1,922	3.0 x 5.0	666	9'10"x13'1"	270
7 x 9	691	2.1 x 2.7	1,707	4.0 x 4.0	625	13'1" x 13'1"	253
7 x 10	622	2.1 x 3.0	1,537	5.0 x 5.0	400	16'5" x 16'5"	162
7 x 12	519	3.1 x 3.7	1,282				
8 x 8	681	2.4 x 2.4	1,683				
8 x 9	605	2.4 x 2.7	1,495				
8 x 10	544	2.4 x 3.0	1,344				
8 x 12	454	2.4 x 3.7	1,122				
9 x 9	538	2.7 x 2.7	1,329				
9 x 10	484	2.7 x 3.0	1,196				
9 x 12	403	2.7 x 3.7	996				
10 x 10	436	3.0 x 3.0	1,077				
10 x 12	363	3.0 x 3.7	897				
10 x 15	290	3.0 x 4.5	717				
12 x 12	302	3.7 x 3.7	746				
12 x 15	242	3.7 x4.6	598				

[a] The spacing is approximated to nearest centimeter but trees per hectare = trees per acre x 2.471

[b] The spacing is approximated to nearest inch but trees per acre = trees per hectare x 0.405

Table A.9
Wood and Log Volume to Volume Conversion Factors

	TO						
FROM	**standard cord**	**solid cord**	**cunit**	**board foot**	**1,000 board feet**	**cubic foot average**	**cubic meters average**
standard cord	1	1.6	1.28	1,536	1.536	128	3.6246
solid cord	0.625	1	0.8	960	0.96	80[a]	2.2653
cunit	0.7813	1.25	1	1,200	1.2	100	2.832
board foot	0.00065	0.00104	0.00083	1	0.001	0.0833	0.0024
1,000 board feet	0.651	1.0416	0.8333	1,000	1	83.33	2.3598
cubic foot	0.0078	0.0125	0.01	12	0.012	1	0.0283
cubic meters	0.2759	0.4414	0.3531	423.77	0.4238	35.3146	1

Source:
www.unitconversion.org, verified with several other sources.

Brief Definitions of the Forestry Measures:
A standard cord is 4 ft x 4 ft x 8 ft stack of roundwood including bark and air
A solid cord is the net volume of roundwood in a standard cord stack
A cunit is 100 cubic feet of solid wood
1 board foot (bf) is a plank of lumbar measuring 1 inch x 1 foot x 1 foot (1/12 ft3)
1000 board feet (MBF) is a standard measure used to buy and sell lumber
1 cubic foot of lumber is a 1 ft x 1 ft x 1 ft cube
1 cubic meter of lumber is a 1 m x 1 m x 1 m cube

Notes: The conversions in this table are only suitable for converting volume units of harvested roundwood or processed sawtimber to approximate alternative volume units, but not for estimating standing volume biomass.

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[a] The estimate of 80 cubic feet (or 2.26 cubic meters) in a solid cord is an average value for stacked lumber and also for hardwood roundwood with bark. Values for all roundwood wood types with and without bark can range from 60 to 95 cubic feet or (1.69 to 2.69 cubic meters), depending on wood species, moisture content and other factors.

[b] The relationship of 83.3 cubic feet per 1000 board ft is correct if one is converting the stacked board feet to a cubic volume, however some forestry "rules of thumb" stated that 1000 board feet is equal to 183 cubic feet with a range of 160 to 220. The explanation for the difference is unclear.

To use these conversion factors, first decide the mill type, which is based on equipment; then determine the average scaling diameter of the logs. If the equipment indicates a mill type B and the average scaling diameter is 13 inches, then look in section B, line 2. This line shows that for every thousand board feet of softwood lumber sawed, 0.42 tons of bark, 1.18 tons of chippable material, and 0.92 tons of fines are produced, green weight. Equivalent hard hardwood and soft hardwood data are also given. Converting factors for shavings are omitted as they are zero for sawmills.

Table A.10
Estimating Tons of Wood Residue per Thousand Board Feet of Lumber Produced by Sawmills, by Species and Type of Residue

		Softwood[c]						**Hard hardwood**[c]						**Soft hardwood**[c]					
		Bark		Chippable		Fine[f]		Bark		Chipable		Fine		Bark		Chipable		Fine	
Mill Type[a]	Small end diameter[b]	G[d]	OD[e]	G	OD	G	OD	G	OD	G	OD	G	OD	G	OD	G	OD	G	OD
	1	0.46	0.31	1.57	0.78	0.98	0.48	0.84	0.59	1.84	1.04	1.26	0.71	0.58	0.41	1.27	0.72	0.86	0.49
A, B, C, H,	2	0.42	0.29	1.18	0.58	0.92	0.45	0.72	0.51	1.53	0.87	1.34	0.76	0.50	0.35	1.06	0.60	0.91	0.52
and I	3	0.41	0.28	1.07	0.53	1.00	0.49	0.56	0.39	1.17	0.66	1.08	0.61	0.39	0.27	0.81	0.46	0.74	0.42
	4	0.31	0.21	0.88	0.43	0.91	0.45	0.49	0.35	1.03	0.58	1.05	0.60	0.34	0.24	0.72	0.41	0.72	0.41
	1	0.29	0.20	1.57	0.78	0.90	0.45	0.84	0.59	1.84	1.04	0.92	0.52	0.58	0.41	1.27	0.72	0.63	0.36
	2	0.29	0.20	1.18	0.58	0.76	0.38	0.72	0.51	1.53	0.87	0.84	0.48	0.50	0.35	1.06	0.60	0.58	0.33
D and E	3	0.29	0.20	1.07	0.53	0.71	0.35	0.56	0.39	1.17	0.66	0.84	0.48	0.39	0.27	0.81	0.46	0.58	0.33
	4	0.29	0.20	0.88	0.43	0.64	0.32	0.49	0.35	1.03	0.58	0.80	0.45	0.34	0.24	0.72	0.41	0.55	0.31
	1	0.29	0.20	1.57	0.78	0.98	0.48	0.84	0.59	1.84	1.04	1.26	0.71	0.58	0.41	1.27	0.72	0.86	0.49
	2	0.29	0.20	1.18	0.58	0.92	0.45	0.72	0.51	1.53	0.87	1.34	0.76	0.50	0.35	1.06	0.60	0.91	0.52
	3	0.29	0.20	1.07	0.53	1.00	0.49	0.56	0.39	1.17	0.66	1.08	0.61	0.39	0.27	0.81	0.46	0.74	0.42
F	4	0.29	0.20	0.88	0.43	0.91	0.45	0.49	0.35	1.03	0.58	1.05	0.60	0.34	0.24	0.72	0.41	0.72	0.41
	1	0.29	0.20	1.90	0.94	0.57	0.28	0.84	0.59	2.23	1.28	0.53	0.28	0.58	0.41	1.54	0.88	0.36	0.20
	2	0.29	0.20	1.34	0.66	0.60	0.30	0.72	0.51	1.72	0.98	0.65	0.37	0.50	0.35	1.19	0.68	0.45	0.25
G	3	0.29	0.20	1.17	0.58	0.61	0.30	0.56	0.39	1.29	0.73	0.72	0.41	0.39	0.27	0.89	0.51	0.50	0.28
	4	0.29	0.20	0.98	0.48	0.54	0.28	0.49	0.35	1.15	0.65	0.68	0.38	0.34	0.24	0.80	0.46	0.47	0.26

Source:
Ellis, Bridgette K. and Janice A. Brown. 1984. *Production and Use of Industrial Wood and Bark Residues in the Tennessee Valley Region*, Tennessee Valley Authority, August.

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[a] Mill Type: A. Circular headsaw with or without trim saw; B. Circular headsaw with edger and trim saw; C. Circular headsaw with vertical band resaw, edger, trim saw; D. Band headsaw with edger, trim saw; E. Band headsaw with horizontal band resaw, edger, trim saw; F. Band headsaw with cant gangsaw, edger, trim saw; G. Chipping head rig; H. Round log mill; I. Scragg mill.

[b] Average small-end log (scaling) diameter classes: 1. 5-10 inches; 2. 11-13 inches; 3. 14-16 inches; 4. 17 inches and over.

[c] See Appendix A for species classification, i.e., softwood, hard hardwood, and soft hardwood.

[d] G = green weight, or initial condition, with the moisture content of the wood as processed

[e] OD = Oven Dry. It is the weight at zero percent moisture.

[f] Fine is sawdust and other similar size material.

Table A.11
Estimating Tons of Wood Residue per Thousand Board Feet of Wood Used for Selected Products

Type of Plant	Bark	% MC	Chipable[b]	% MC	Shavings	% MC	Fine[c]	%MC
	Softwood[a]							
Planing mill	-	-	0.05	19	0.42	19	-	-
Wood chip mill[d]	0.60	50	-	-	-	-	-	-
Wooden furniture frames	-	-	0.22	12	0.25	12	0.05	12
Shingles & cooperage stock	0.42	50	1.29	100	-	-	1.01	100
Plywood	-	-	0.13	9	-	-	0.21	9
Veneer	0.42	50	1.77	100	-	-	-	-
Pallets and skids	-	-	0.42	60	0.21	60	0.07	60
Log homes	-	-	0.17	80	-	-	0.05	80
Untreated posts, poles, and pilings	0.46	50	0.40	100	-	-	0.05	100
Particleboard	0.60	60	-	-	-	-	0.21	6
Pulp, paper, and paperboard	0.60	70	-	-	-	-	-	-
	Hard hardwood[a]							
	Bark	% MC	Chipable[b]	% MC	Shavings	% MC	Fine[c]	%MC
Planing mill	-	-	0.06	19	0.54	19	-	-
Wood chip mill	0.90	60	-	-	-	-	-	-
Hardwood flooring	-	-	0.12	6	0.57	6	-	-
Wooden furniture frames	-	-	0.31	9	0.36	9	0.07	9
Shingles & cooperage stock	0.56	60	1.66	70	-	-	1.47	70
Plywood	-	-	0.16	9	-	-	0.26	9
Veneer	0.72	60	2.70	70	-	-	-	-
Pallets and skids	-	-	0.50	60	0.25	60	0.08	60
Pulp, paper, and paperboard	0.90	60	-	-	-	-	-	-
	Soft hardwood[a]							
	Bark	% MC	Chipable[b]	% MC	Shavings	% MC	Fine[c]	%MC
Planing mill	-	-	0.04	19	0.40	19	-	-
Wood chip mill	0.62	88	-	-	-	-	-	-
Wooden furniture frames	-	-	0.22	9	0.26	9	0.05	9
Plywood	-	-	0.13	9	-	-	0.21	9
Veneer	0.50	88	2.13	95	-	-	-	-
Pallets and skids	-	-	0.34	60	0.17	60	0.06	60
Particleboard	0.60	60	-	-	-	-	0.21	6
Pulp, paper, and paperboard	0.62	88	-	-	-	-	-	-

Source:
Ellis, Bridgette K. and Janice A. Brown. 1984. *Production and Use of Industrial Wood and Bark Residues in the Tennessee Valley Region*, Tennessee Valley Authority, August.

Notes: For shingles and cooperage stock the table indicates that for every thousand board feet of softwood logs used, 1.29 tons of chippable material could be expected, with an average moisture content (MC) of 100%, based on ovendry weight. If the Average MC of the wood used is greater or less than 100%, proportionally greater or lesser weight of material could be expected.

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[a] For definitions of species, see next page

[b] Chippable is material large enough to warrant size reduction before being used by the paper, particleboard, or metallurgical industries.

[c] Fines are considered to be sawdust or sanderdust.

[d] For chipping mills with debarkers only

Table A.12
Area and Length Conversions

Area

Multiply	by	To Obtain
acres (ac)[a]	0.4047	hectares
hectares (ha)	2.4710	acres
hectares (ha)	0.0039	square miles
hectares (ha)	10000	square meters
square kilometer (km^2)	247.10	acres
square kilometer (km^2)	0.3861	square miles
square kilometer (km^2)	100	hectares
square mile (mi^2)	258.9990	hectares.
square mile (mi^2)	2.5900	square kilometers
square mile (mi^2)	640	acres
square yards (yd^2)	0.8361	square meters
square meters (m^2)	1.1960	square yards
square foot (ft^2)	0.0929	square meters
square meters (m^2)	10.7639	square feet
square inchs (in^2)	6.4516	square centimeters (exactly).
square decimeter (dm^2)	15.5000	square inches
square centimeters (cm^2)	0.1550	square inches
square millimeter (mm^2)	0.0020	square inches
square feet (ft^2)	929.03	square centimeters
square rods (rd^2), sq pole, or sq perch	25.2930	square meters

Length

Multiply	by	To Obtain
miles (mi)	1.6093	kilometers
miles (mi)	1,609.34	meters
miles (mi)	1,760.00	yards
miles (mi)	5,280.00	feet
kilometers (km)	0.6214	miles
kilometers (km)	1,000.00	meters
kilometers (km)	1,093.60	yards
kilometers (km)	3,281.00	feet
feet (ft)	0.3048	meters
meters (m)	3.2808	feet
yard (yd)	0.9144	meters
meters (m)	1.0936	yards
inches (in)	2.54	centimeters
centimeters (cm)	0.3937	inches

Source:
National Institute of Standards and Technology, General Tables of Units and Measurements, http://ts.nist.gov/WeightsAndMeasures/Publications/upload/h4402_appenc.pdf.

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[a] An acre is a unit of area containing 43,560 square feet. It is not necessarily square, or even rectangular. But, if it is square, then the length of a side is equal to the square root of 43,560 or about 208.71 feet.

Table A.13
Mass Units and Mass per Unit Area Conversions

Mass

Multiply	by	To Obtain
ounces (oz)	28.3495	grams
grams (gm)	0.0353	ounces
pounds (lbs)	0.4536	kilograms
pounds (lbs)	453.6	grams
kilograms (kg)	2.2046	pounds
kilograms (kg)	0.0011	U.S. or short tons,
metric tons or tonne (t)[a]	1	megagram (Mg)
metric tons or tonne (t)	2205	pounds
metric tons or tonne (t)	1000	kilograms
metric tons or tonne (t)	1.102	short tons
metric tons or tonne (t)	0.9842	long tons
U.S. or short tons, (ts)	2000	pounds
U.S. or short tons, (ts)	907.2	kilograms
U.S. or short tons, (ts)	0.9072	megagrams
U.S. or short tons, (ts)	0.8929	Imperial or long tons
Imperial or long tons (tl)	2240	pounds
Imperial or long tons (tl)	1.12	short tons
Imperial or long tons (tl)	1016	kilograms
Imperial or long tons (tl)	1.016	megagrams

Mass per Unit Area

Multiply	by	To Obtain
megagram per hectare (Mg ha^{-1})	0.4461	short tons per acre
kilograms per square meter (kg m-1)	4.461	short tons per acre
tons (short US) per acre (t ac^{-1})	2.2417	megagram per hectare
tons (short US) per acre (t ac^{-1})	0.2241	kilograms per square meter
kilograms per square meter (kg m-1)	0.2048	pounds per square foot
pounds per square foot (lb ft^2)	4.8824	kilogram per square meter
kilograms per square meter (kg m-1)	21.78	short tons per acre
kilogram per hectare (kg ha^{-1})	0.892	pounds per acre
pounds per acre (lb ac^{-1})	1.12	kilogram per hectare

Source:
Web sites www.gordonengland.co.uk/conversion and www.convert-me.com/en/convert and the Family Farm Series Publication, *Vegetable Crop Production* at Web site www.sfc.ucdavis.edu/pubs/Family_Farm_Series/Veg/Fertilizing/appendix.html#tables.

[a] The proper SI unit for a metric ton or tonne is megagram (MG) however "t" is commonly used in practice as in dt ha-1 for dry ton per hectare. Writers in the United States also normally use "t" for short ton as in dt ac-1 for dry ton per acre, so noting the context in the interpretation of "t" is important.

Table A.14
Distance and Velocity Conversions

1 inch (in)	= 0.0833 ft	1 centimeter (cm)	= 0.3937 in
	= 0.0278 yd		= 0.0328 ft
	= 2.54 cm		= 0.0109 yd
	= 0.0254 m		= 0.01 m
1 foot (ft)	= 12.0 in.	1 meter (m)	= 39.3700 in
	= 0.3333 yd		= 3.2808 ft
	= 30.48 cm		= 1.0936 yd
	= 0.3048 m		= 100 cm
1 mile (mi)	= 63360 in.	1 kilometer (km)	= 39370 in.
	= 5280 ft		= 3281 ft
	= 1760 yd		= 1093.6 yd
	= 1609 m		= 0.6214 mile
	= 1.609 km		= 1000 m

1 in/hr = 2.54 cm/hr
1cm/hr = 0.3937 in/hr
1 ft/sec = 0.3048 m/s = 0.6818 mph = 1.0972 km/h
1 m/sec = 3.281 ft/s = 2.237 mph = 3.600 km/h
1 km/h = 0.9114 ft/s = 0.2778 m/s = 0.6214 mph
1 mph = 1.467 ft/s = 0.4469 m/s = 1.609 km/h

Source:
Davis, S.C., S.W. Diegel and R.G. Boundy. 2008. *Transportation Energy Data Book: Edition 27*, ORNL-6981, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Table A.15
Capacity, Volume and Specific Volume Conversions[a]

Capacity and Volume

1 U.S. gallon (gal)	=	3.785	liters (L)	1 liter (L)	=	0.2642	US gal
	=	4	US quarts (qt)		=	0.22	UK gal
	=	0.8327	UK gallon (gal)		=	1.056	US qt
	=	0.0238	barrels oil (bbl)		=	0.00629	bbl (oil)
	=	0.0039	cubic meters (m^3)		=	61.02	in^3
	=	0.1337	cubic feet (ft^3)		=	0.03531	ft^3
	=	231	cubic inches (in^3)		=	0.001	m^3
1 imperial (UK) gallon (gal)	=	4.546	liters	1 barrel (bbl) oil	=	158.97	L
	=	4.803	US qt		=	168	US qt
	=	1.201	US gal		=	42	US gal
	=	0.0286	bbl (oil)		=	34.97	UK gal
	=	0.0045	m^3		=	0.15897	m^3
	=	0.1605	ft^3		=	5.615	ft^3
	=	277.4	$in.^3$			9702	$in.^3$
1 cubic meter (m^3)	=	264.172	US gal	1 cubic foot (ft^3)	=	7.4805	US gal
	=	1000	L			28.3168	L
	=	1056	US qt			29.9221	US qt
	=	6.2898	bbl (oil)			0.1781	bbl (oil)
	=	35.3145	ft^3			0.0283	m^3
		1.3079	yd^3			0.037	yd^3
1 cubic centimeter (cm^3)	=	0.061	in^3	1 cubic inches (in^3)	=	16.3872	cm^3
1 Liter (L) dry volume	=	1.8161	US pint (pt)	1 US bushel	=	64	US pt
	=	0.908	US qt		=	32	US qt
	=	0.1135	US peck (pk)		=	35.239	L
	=	0.1099	UK pk		=	4	US pk
	=	0.0284	US bushel (bu)		=	3.8757	UK pk
	=	0.0275	UK bu		=	0.9700	UK bu
	=	0.0086	US bbl dry		=	0.3947	US bbl dry
1 barrell (dry)	=	13.1248	US pk	1 barrell (dry)	=	12.7172	UK pk
	=	3.2812	US bu		=	3.1793	UK bu

[a] Forestry unit relationships are provided in Table A.9

Specific Volume

1 US gallon per pound	=	0.8326	UK gal/lb	1 liter per kilogram	=	0.0997	UK gal/lb
(gal/lb)	=	0.1337	ft^3/lb	(L/kg)	=	0.1118	US gal/lb
	=	8.3454	L/kg		=	0.016	ft^3/lb
	=	0.0083	L/g		=	0.0353	ft^3/kg
	=	0.0083	m^3/kg		=	1	m^3/kg
	=	8.3451	cm^3/g		=	1000	cm^3/g

Source:
Web sites www.gordonengland.co.uk/conversion/power.html and www.unitconversion.org were used to make or check conversions.

[a] Forestry unit relationships are provided in Table A.9 .

Table A.16
Power Unit Conversions

Per second basis

	TO					
FROM	hp	hp-metric	kW	kJ s^{-1}	Btu_{IT} s^{-1}	$kcal_{IT}$ s^{-1}
Horsepower	1	1.014	0.746	0.746	0.707	0.1780
Metric horsepower	0.986	1	0.736	0.736	0.697	0.1757
Kilowatt	1.341	1.360	1	1	0.948	0.2388
kilojoule per sec	1.341	1.359	1	1	0.948	0.2388
Btu_{IT} per sec	1.415	1.434	1.055	1.055	1	0.2520
Kilocalories $_{IT}$ per sec	5.615	5.692	4.187	4.187	3.968	1

Per hour basis

	TO					
FROM	hp	hp- metric	kW	J hr^{-1}	Btu_{IT} hr^{-1}	$kcal_{IT}$ hr^{-1}
Horsepower	1	1.014	0.746	268.5×10^{4}	2544	641.19
Metric horsepower	0.986	1	0.736	265.8×10^{4}	2510	632.42
kilowatt	1.341	1.360	1	360×10^{4}	3412	859.85
Joule per hr	3.73×10^{-7}	3.78×10^{-7}	2.78×10^{-7}	1	9.48×10^{-4}	2.39×10^{-4}
Btu_{IT} per hr	3.93×10^{-4}	3.98×10^{-4}	2.93×10^{-4}	1055	1	0.2520
Kilocalories $_{IT}$ per hr	1.56×10^{-3}	1.58×10^{-3}	1.163×10^{-3}	4187	3.968	1

Sources:
www.unitconversion.org/unit_converter/power.html and www.gordonengland.co.uk/conversion/power.html were used to make conversions.

Note: The subscript "IT" stands for International Table values, which are only slightly different from thermal values normally subscripted "th". The "IT" values are most commonly used in current tables and generally are not subscripted, but conversion calculators usually include both.

Table A.17
Small Energy Units and Energy per Unit Weight Conversions

Energy Units

FROM	TO: MJ	J	k W h	Btu_{IT}	cal_{IT}
megajoule (MJ)	1	1×10^{6}	0.278	947.8	238845
joule (J)[a]	1×10^{-6}	1	0.278×10^{-6}	9.478×10^{-4}	0.239
Kilowatt hours (k W h)	3.6	3.6×10^{6}	1	3412	859845
Btu_{IT}	1.055×10^{-3}	1055.055	2.93×10^{-4}	1	251.996
$calorie_{IT}$ (cal_{IT})		4.186	1.163×10^{-6}	3.97×10^{-3}	1

Energy per Unit Weight

FROM	TO: $J\ kg^{-1}$	kJ kg-1	$cal_{IT}\ g^{-1}$	$Btu_{IT}\ lb^{-1}$
joule per kilogram ($J\ kg^{-1}$)	1	0.001	2.39×10^{-4}	4.299×10^{-4}
kilojoules per kilogram($kJ\ kg^{-1}$)	1000	1	0.2388	0.4299
$calorie_{th}$ per gram ($cal_{IT}\ g^{-1}$)	4186.8	4.1868	1	1.8
Btu_{IT} per pound ($Btu_{IT}\ lb^{-1}$)	2326	2.326	0.5555	1

Commonly used related energy unit conversions:
1 Quadrillion Btu's (Quad) = 1×10^{15} Btu = 1.055 Exajoules (EJ) = 1.055×10^{18} J
1 Million Btu's (MMbtu) = 1×10^{6} Btu = 1.055 Gigajoules (GJ) = 1.055×10^{9} J
1000 Btu per pound x 2000 lbs per ton = 2 MMbtu per ton = 2.326 GJ per Mg, e.g.,
8500 Btu per pound (average HHV of wood) = 17 MMbtu per ton = 19.8 GJ per Mg

Sources:
www.gordonengland.co.uk/conversion/power.html and
www.convert-me.com/en/convert/power and
www.unitconversion.org/unit_converter/fuel-efficiency-mass were used to make or check conversions.

Note: The subscript "IT" stands for International Table values, which are only slightly different from thermal values normally subscripted "th". The "IT" values are most commonly used in current tables and generally are not subscripted, but conversion calculators ususally include both.

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[a] One joule is the exact equivalent of one Newton meter (Nm) and one Watt second.

Table A.18
Large Energy Unit Conversions

To:	Terajoules	Giga-calories	Million tonnes of oil equivalent	Million Btu	Gigawatt-hours
From:	*multiply by:*				
Terajoules	1	238.8	2.388×10^{-5}	947.8	0.2778
Gigacalories	4.1868×10^{-3}	1	10^{-7}	3.968	1.163×10^{-3}
Million tonnes of oil equivalent	4.1868×10^{4}	107	1	3.968×10^{7}	11,630
Million Btu	1.0551×10^{-3}	0.252	2.52×10^{-8}	1	2.931×10^{-4}
Gigawatthours	3.6	860	8.6×10^{-5}	3412	1

Source:
Davis, S.C., et al., *Transportation Energy Data Book: Edition 27*, Appendix B.7. ORNL-6981, Oak Ridge National Laboratory, Oak Ridge, TN. 2008

Table A.19
Alternative Measures of Greenhouse Gases

1 pound methane, measured in carbon units (CH_4)	=	1.333 pounds methane, measured at full molecular weight (CH_4)
1 pound carbon dioxide, measured in carbon units (CO_2-C)	=	3.6667 pounds carbon dioxide, measured at full molecular weight (CO_2)
1 pound carbon monoxide, measured in carbon units (CO-C)	=	2.333 pounds carbon monoxide, measured at full molecular weight (CO)
1 pound nitrous oxide, measured in nitrogen units (N_2O-N)	=	1.571 pounds nitrous oxide, measured at full molecular weight (N_2O)

Source:
Davis, S.C., S.W. Diegel and R.G. Boundy. 2008. *Transportation Energy Data Book: Edition 27*, Appendix B.9, ORNL-6981, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Table A.20
Fuel Efficiency Conversions

MPG	Miles/liter	Kilometers/L	L/100 kilometers
10	2.64	4.25	23.52
15	3.96	6.38	15.68
20	5.28	8.50	11.76
25	6.60	10.63	9.41
30	7.92	12.75	7.84
35	9.25	14.88	6.72
40	10.57	17.00	5.88
45	11.89	19.13	5.23
50	13.21	21.25	4.70
55	14.53	23.38	4.28
60	15.85	25.51	3.92
65	17.17	27.63	3.62
70	18.49	29.76	3.36
75	19.81	31.88	3.14
80	21.13	34.01	2.94
85	22.45	36.13	2.77
90	23.77	38.26	2.61
95	25.09	40.38	2.48
100	26.42	42.51	2.35
105	27.74	44.64	2.24
110	29.06	46.76	2.14
115	30.38	48.89	2.05
120	31.70	51.01	1.96
125	33.02	53.14	1.88
130	34.34	55.26	1.81
135	35.66	57.39	1.74
140	36.98	59.51	1.68
145	38.30	61.64	1.62
150	39.62	63.76	1.57
Formula	MPG/3.785	MPG/[3.785/1.609]	235.24/MPG

Source:
Davis, S.C., S.W. Diegel and R.G. Boundy. 2008. *Transportation Energy Data Book: Edition 27*, Appendix B.13, ORNL-6981, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Table A.21
SI Prefixes and Their Values

	Value	Prefix	Symbol
One million million millionth	10^{-18}	atto	a
One thousand million millionth	10^{-15}	femto	f
One million millionth	10^{-12}	pico	p
One thousand millionth	10^{-9}	nano	n
One millionth	10^{-6}	micro	µ
One thousandth	10^{-3}	milli	m
One hundredth	10^{-2}	centi	c
One tenth	10^{-1}	deci	d
One	10^{0}		
Ten	10^{1}	deca	da
One hundred	10^{2}	hecto	h
One thousand	10^{3}	kilo	k
One million	10^{6}	mega	M
One billion[a]	10^{9}	giga	G
One trillion[a]	10^{12}	tera	T
One quadrillion[a]	10^{15}	peta	P
One quintillion[a]	10^{18}	exa	E

Source:
Davis, S.C., S.W. Diegel and R.G. Boundy. 2008. *Transportation Energy Data Book: Edition 27*, Appendix B.14, ORNL-6981, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

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[a] Care should be exercised in the use of this nomenclature, especially in foreign correspondence, as it is either unknown or carries a different value in other countries. A "billion," for example, signifies a value of 10^{12} in most other countries.

Table A.22
Metric Units and Abbreviations

Quantity	Unit name	Symbol
Energy	joule	J
Specific energy	joule/kilogram	J/kg
Specific energy consumption	joule/kilogram•kilometer	J/(kg•km)
Energy consumption	joule/kilometer	J/km
Energy economy	kilometer/kilojoule	km/kJ
Power	kilowatt	kW
Specific power	watt/kilogram	W/kg
Power density	watt/meter^3	W/m^3
Speed	kilometer/hour	km/h
Acceleration	meter/second^2	m/s^2
Range (distance)	kilometer	km
Weight	kilogram	kg
Torque	newton•meter	N•m
Volume	meter^3	m^3
Mass; payload	kilogram	kg
Length; width	meter	m
Brake specific fuel consumption	kilogram/joule	kg/J
Fuel economy (heat engine)	liters/100 km	L/100 km

Source:
Davis, S.C., S.W. Diegel and R.G. Boundy. 2008. *Transportation Energy Data Book: Edition 27*, Appendix B.15, ORNL-6981, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Table A.23
Cost per Unit Conversions

Multiply	by	To Obtain
$/ton	1.1023	$/Mg
$/Mg	0.9072	$/ton
$/Mbtu	0.9407	$/GJ
$/GJ	1.0559	$/Mbtu

APPENDIX B

BIOMASS CHARACTERISTICS

APPENDIX B: BIOMASS CHARACTERISTICS

Biomass feedstocks and fuels exhibit a wide range of physical, chemical, and agricultural process engineering properties. Despite their wide range of possible sources, biomass feedstocks are remarkably uniform in many of their fuel properties, compared with competing feedstocks such as coal or petroleum. For example, there are many kinds of coals whose gross heating value ranges from 20 to 30 GJ/tonne (gigajoules per metric tonne; 8600-12900 Btu/lb). However, nearly all kinds of biomass feedstocks destined for combustion fall in the range 15-19 GJ/tonne (6450-8200 Btu/lb). For most agricultural residues, the heating values are even more uniform – about 15-17 GJ/tonne (6450-7300 Btu/lb); the values for most woody materials are 18-19 GJ/tonne (7750-8200 Btu/lb). Moisture content is probably the most important determinant of heating value. Air-dried biomass typically has about 15-20% moisture, whereas the moisture content for oven-dried biomass is around 0%. Moisture content is also an important characteristic of coals, varying in the range 2-30%. However, the bulk density (and hence energy density) of most biomass feedstocks is generally low, even after densification – between about 10 and 40% of the bulk density of most fossil fuels – although liquid biofuels have comparable bulk densities.

Most biomass materials are easier to gasify than coal, because they are more reactive, with higher ignition stability. This characteristic also makes them easier to process thermochemically into higher-value fuels such as methanol or hydrogen. Ash content is typically lower than for most coals, and sulphur content is much lower than for many fossil fuels. Unlike coal ash, which may contain toxic metals and other trace contaminants, herbaceous ash may be used as a soil amendment to help replenish nutrients removed by harvest. A few biomass feedstocks stand out for their peculiar properties, such as high silicon or alkali metal contents – these may require special precautions for harvesting, processing and combustion equipment. Note also that mineral content can vary as a function of soil type and the timing of feedstock harvest. In contrast to their fairly uniform physical properties, biomass fuels are rather heterogeneous with respect to their chemical elemental composition.

Among the liquid biomass fuels, biodiesel (vegetable oil ester) is noteworthy for its similarity to petroleum-derived diesel fuel, apart from its negligible sulfur and ash content. Bioethanol has only about 70% the heating value of petroleum distillates such as gasoline, but its sulfur and ash contents are also very low. Both of these liquid fuels have lower vapor pressure and flammability than their petroleum-based competitors – an advantage in some cases (e.g. use in confined spaces such as mines) but a disadvantage in others (e.g. engine starting at cold temperatures).

Sources for further information:

US DOE Biomass Feedstock Composition and Property Database.
PHYLLIS - database on composition of biomass and waste.
Nordin, A. (1994) Chemical elemental characteristics of biomass fuels. Biomass and Bioenergy 6, 339-347.

Source:

All information in Appendix B was taken from a fact sheet by Jonathan Scurlock, Oak Ridge National Laboratory, Bioenergy Feedstock Development Programs. P.O. Box 2008, Oak Ridge, TN 37831-6407

Table B.1
Characteristics of Selected Feedstocks and Fuels

		Cellulose (Percent)	Hemi-cellulose (Percent)	Lignin (Percent)	Extractives (Percent)
Bioenergy Feedstocks	Corn stover[a]	30 - 38	19 - 25	17 - 21	3.3 - 11.9
	Sweet sorghum	27	25	11	
	Sugarcane bagasse[a]	32 - 43	19 - 25	23 - 28	1.5 - 5.5
	Sugarcane leaves	b	b	b	
	Hardwood	45	30	20	
	Softwood	42	21	26	
	Hybrid poplar[a]	39 - 46	17 - 23	21 - 8	1.6 - 6.9
	Bamboo	41-49	24-28	24-26	
	Switchgrass[a]	31 - 34	24 - 29	17 - 22	4.9 - 24.0
	Miscanthus	44	24	17	
	Giant Reed	31	30	21	
Liquid Biofuels	Bioethanol	N/A	N/A	N/A	N/A
	Biodiesel	N/A	N/A	N/A	N/A
Fossil Fuels	Coal (low rank; lignite/sub-bituminous)	N/A	N/A	N/A	N/A
	Coal (high rank bituminous/anthracite)	N/A	N/A	N/A	N/A
	Oil (typical distillate)	N/A	N/A	N/A	N/A

Source:
Oak Ridge National Laboratory, Bioenergy Feedstock Development Program. P.O. Box 2008, Oak Ridge, TN 37831-6407 (compiled by Jonathon Scurlock in 2002, updated by Lynn Wright in 2008).

Notes: N/A = Not Applicable.

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[a] Updated using http://www1.eere.energy.gov/biomass/feedstock_databases.html
[b] Data not available.

Table B.1 (Continued)
Characteristics of Selected Feedstocks and Fuels

		Ash %	Sulfur (Percent)	Potassium (Percent)	Ash melting temperature [some ash sintering observed] (C)
Bioenergy Feedstocks	Corn stover[a]	9.8 - 13 5	0.06 - 0.1	b	b
	Sweet sorghum	5.5	b	b	b
	Sugarcane bagasse[a]	2.8 - 9.4	0.02 - 0.03	0.73-0.97	b
	Sugarcane leaves	7.7	b	b	b
	Hardwood	0.45	0.009	0.04	[900]
	Softwood	0.3	0.01	b	b
	Hybrid poplar[a]	0.4 - 2.4	0.02 - 0.03	0.3	1,350
	Bamboo	0.8 - 2.5	0.03 - 0.05	0.15 - 0.50	b
	Switchgrass[a]	2.8 - 7.5	0.07 - 0.11	b	1,016
	Miscanthus	1.5 - 4.5	0.1	0.37 - 1.12	1,090 [600]
	Giant reed	5 - 6	0.07	b	b
Liquid Biofuels	Bioethanol	b	<0.01	b	N/A
	Biodiesel	<0.02	<0.05	<0.0001	N/A
Fossil Fuels	Coal (low rank; lignite/sub-bituminous)	5 - 20	1.0 - 3.0	0.02 - 0.3	~1,300
	Coal (high rank bituminous/anthracite)	1 - 10	0.5 - 1.5	0.06 - 0.15	~1,300
	Oil (typical distillate)	0.5 - 1.5	0.2 - 1.2	b	N/A

Source:
Oak Ridge National Laboratory, Bioenergy Feedstock Development Program. P.O. Box 2008, Oak Ridge, TN 37831-6407 (compiled by Jonathon Scurlock in 2002, updated by Lynn Wright in 2008).

Notes: N/A = Not Applicable.

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[a] Updated using http://www1.eere.energy.gov/biomass/feedstock_databases.html
[b] Data not available.

Table B.1 (Continued)
Characteristics of Selected Feedstocks and Fuels

		Cellulose fiber length (mm)	Chopped density at harvest (kg/m^3)	Baled density [compacted bales] (kg/m^3)
Bioenergy Feedstocks	Corn stover[a]	1.5	b	b
	Sweet sorghum	b	b	b
	Sugarcane bagasse[a]	1.7	50 - 75	b
	Sugarcane leaves	b	25 - 40	b
	Hardwood	1.2	b	b
	Softwood	b	b	b
	Hybrid poplar[a]	1 - 1.4	150 (chips)	b
	Bamboo	1.5 - 3.2	b	b
	Switchgrass[a]	b	108	105 - 133
	Miscanthus	b	70 - 100	130 - 150 [300]
	Giant reed	1.2	b	b
Liquid Biofuels				(typical bulk densities or range given below)
	Bioethanol	N/A	N/A	790
	Biodiesel	N/A	N/A	875
Fossil Fuels	Coal (low rank; lignite/sub-bituminous)	N/A	N/A	700
	Coal (high rank bituminous/anthracite)	N/A	N/A	850
	Oil (typical distillate)	N/A	N/A	700 - 900

Source:
Oak Ridge National Laboratory, Bioenergy Feedstock Development Program. P.O. Box 2008, Oak Ridge, TN 37831-6407 (compiled by Jonathon Scurlock in 2002, updated by Lynn Wright in 2008).

Notes: N/A = Not Applicable.

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[a] Updated using http://www1.eere.energy.gov/biomass/feedstock_databases.html
[b] Data not available.

APPENDIX C

SUSTAINABILITY

APPENDIX C: SUSTAINABILITY

SUSTAINABLE BIOMASS CROP PRODUCTION RESEARCH

Biomass, especially wood, has been used by mankind for thousands of years to provide heat and cooking fuel (bioenergy) with the resource being derived primarily from forested areas. Throughout the history of mankind, excessive removals of wood for lumber, fiber, energy, or other needs have led to severe environmental degradation in many parts of the world. Thus in the late 1970's when the oil supply disruptions caused the U.S. government to begin to support research on biomass feedstocks for fuels and chemicals, the renewability of the bioenergy resources was an important criteria. All of the projects initiated as a result of the U.S. Department of Energy's (DOE's) first biomass research solicitation in 1977 were directed toward evaluating the potential for wood production and harvest scenarios that would supply renewable and sustainable bioenergy resources.

However renewability and sustainability are not entirely synonymous terms and the meaning of sustainability was just beginning to be debated. Environmental scientists of Oak Ridge National Laboratory, which managed the biomass feedstock research for DOE, published one of the first analyses addressing environmental implications of biomass energy systems (Braunstein et al., 1981). While there was, and continues to be, debate about what truly signifies a sustainable system, it was with a high level of environmental sensitivity in the 1980's, that DOE's biomass feedstock research efforts focused on screening for high-yield woody crops that could be produced on cropland or cropland pasture and result in environmental benefits. By the mid 1980's the DOE research program began screening > 30 herbaceous biomass crop species including high-yield annuals as well as many different types of perennial grasses primarily on marginal cropland. Erosion reduction potential, soil carbon increase potential, and other environmental factors were considered in the process of selecting crops for further development.

The research program resulted in the selection of crop production systems that minimized land area requirements, minimized chemical inputs, and increased soil carbon storage relative to most food crop production techniques in the mid to late 1990's. A special issue of the journal Biomass and Bioenergy (Vol. 14, No. 4, 1998) contained several papers by energy crop researchers summarizing what was known and what information was needed to ensure the development and implementation of environmentally beneficial biomass production systems.

The Department of Energy's Biomass Program continues, in 2008, to be committed to developing the technologies, processes and systems needed to sustainably convert a broad range of cellulosic feedstocks into clean, abundant biofuels. Program literature states that it aims to develop processes and products that reduce carbon emissions, protects human health and the environment, and add value to the biofuel life cycle. As a consequence current feedstock research has the following objectives.

1. Explore a range of non-food feedstocks.
2. Improve understanding of regional factors tied to feedstock production (e.g., soil types, fertilizer requirements, climatic conditions, land use, and water issues).
3. Develop technology to harvest biomass components efficiently while maintaining soil health.
4. Foster forestry practices that enhance long-term forest vitality.
5. Evaluate the economic, social and environmental aspects of emerging technologies and infrastructure for the large-scale production and use of biofuels.

Most agriculture, forestry and plants sciences researchers working on developing bioenergy feedstock supply systems conclude that some substantial amount of biomass feedstocks can be produced and supplied in a way that meets sustainability criteria. Differences of opinion exist on how much can be sustainably produced, details of production techniques for specific areas, and worldwide impacts resulting from competition for land. These questions are stimulating additional research and analysis. Documents referred to above, as well as several recent documents addressing topics related to the sustainability of biomass production systems, are listed below.

Braunsetin, H.M., P. Kanciruk, R.D. Roop, F.E. Sharples, J.S. Tatum and K.M. Oakes. 1981. *Biomass Energy Systems and the Environment*, Pergamon Press.

Tolbert, V., Guest Editorial. 1998. *Biomass and Bioenergy*, 14(4). (Several papers of interest can be found in this issue).

Selected Reports of Committees or Working Groups on Biomass Sustainability:

The Royal Society 2008. *Sustainable Biofuels: Prospects and Challenges*. ISBN 978 0 85403 662 2, available online at:

National Research Council. 2008. *Water Implications of Biofuels Production in the United States,* ISBN: 978-0-309-11361-8, 86 pages. Free executive summary available online.

Selected Publications of Interest Relevant to Energy Crop Sustainability:

Heller, M.C., G.A. Keoleian and T.A. Volk. 2003. "Life Cycle Assessment of a Willow Bioenergy Cropping System," *Biomass and Bioenergy*, 25:147-165.

Johnson, J.M.F., D.C. Reicosky, R.R. Allmaras, D. Archer and W.W. Wilhelm. 2006. "A Matter of Balance: Conservation and Renewable Energy," *J Soil and Water Conservation*, 63(4): 125A-129A.

Johnson, J.M.F., M.D. Coleman, R. Gesch, A. Jaradat, R. Mitchell, D. Reicosky and W.W. Wilhelm. 2007. "Biomass-Bioenergy Crops in the United States: A Changing Paradigm," *The Americas Journal of Plant Science and Biotechnology*, 1(1): 1-28.

Mann, L. and V. Tolbert. 2000. "Soil Sustainability in Renewable Biomass Plantings," *Ambio*, 29(8): 492-498.

Robertson, P., V.H. Dale, O.C. Doering, S.P. Hamburg, J.M. Melillo, M.M. Wander, W.J. Parton, R. Pouyat, P.R. Adler, J. Barney, R.M. Cruse, C.S. Duke, P.M. Fearnside, R.F. Follett, H.K. Gibbs, J. Goldemberg, D. Mladenoff, D. Ojima, M.W. Palmer, A. Sharpley, L. Wallace, K.C. Weathers, J.A. Wiens and W.W. Wilhelm. 2008. "Sustainable Biofuels Redux," *Science*, 3 October.

Searchinger, T., R. Heimlich, R.A. Haughton, F. Dong, A. Elobeid, J. Fabiosa, S. Tokgoz, D. Hayes and Tun-Hsiang Yu. 2008. "Use of U.S. Croplands for Biofuels Increases Greenhouse Gases through Emissions from Land Use Change," *ScienceExpress* online publication, 7 February, 10.1126/Science.1151861. Available at: www.sciencemag.org

Tilman, D., J. Hill and C. Lehman. 2006. "Carbon-Negative Biofuels from Low-Input High-Diversity Grassland Biomass," *Science*, 314: 1598-1600.

GLOSSARY

Agricultural Residue - Agricultural crop residues are the plant parts, primarily stalks and leaves, not removed from the fields with the primary food or fiber product. Examples include corn stover (stalks, leaves, husks, and cobs); wheat straw; and rice straw. With approximately 80 million acres of corn planted annually, corn stover is expected to become a major biomass resource for bioenergy applications.

Air dry - The state of dryness at equilibrium with the water content in the surrounding atmosphere. The actual water content will depend upon the relative humidity and temperature of the surrounding atmosphere.

Alcohol - The family name of a group of organic chemical compounds composed of carbon, hydrogen, and oxygen. The molecules in the series vary in chain length and are composed of a hydrocarbon plus a hydroxyl group. Alcohol includes methanol and ethanol.

Alkaline metals - Potassium and sodium oxides (K_2O + NaO_2) that are the main chemicals in biomass solid fuels that cause slagging and fouling in combustion chambers and boilers.

Anaerobic digestion - Decomposition of biological wastes by micro-organisms, usually under wet conditions, in the absence of air (oxygen), to produce a gas comprising mostly methane and carbon dioxide.

Annual removals - The net volume of growing stock trees removed from the inventory during a specified year by harvesting, cultural operations such as timber stand improvement, or land clearing.

ASABE Standard X593 - The American Society of Agricultural and Biological Engineers (ASABE) in 2005 produced a new standard (Standard X593) entitled "Terminology and Definitions for Biomass Production, Harvesting and Collection, Storage, Processing, Conversion and Utilization." The purpose of the standard is to provide uniform terminology and definitions in the general area of biomass production and utilization. This standard includes many terminologies that are used in biomass feedstock production, harvesting, collecting, handling, storage, pre-processing and conversion, bioenergy, biopower and bioproducts. The terminologies were reviewed by many experts from all of the different fields of biomass and bioenergy before being accepted as part of the standard. The full-text is included on the online Technical Library of ASABE (http://asae.frymulti.com); members and institutions holding a site license can access the online version. Print copies may be ordered for a fee by calling 269-429-0300, e-mailing martin@asabe.org, or by mail at: ASABE, 2950 Niles Rd., St. Joseph, MI 49085.

Asexual reproduction - The naturally occurring ability of some plant species to reproduce asexually through seeds, meaning the embryos develop without a male gamete. This ensures the seeds will produce plants identical to the mother plant.

Avoided costs - An investment guideline describing the value of a conservation or generation resource investment by the cost of more expensive resources that a utility would otherwise have to acquire.

Baghouse - A chamber containing fabric filter bags that remove particles from furnace stack exhaust gases. Used to eliminate particles greater than 20 microns in diameter.

Barrel of oil equivalent - (BOE) The amount of energy contained in a barrel of crude oil, i.e. approximately 6.1 GJ (5.8 million Btu), equivalent to 1,700 kWh. A "petroleum barrel" is a liquid measure equal to 42 U.S. gallons (35 Imperial gallons or 159 liters); about 7.2 barrels are equivalent to one tonne of oil (metric).

Biobased product - The term 'biobased product,' as defined by Farm Security and Rural Investment Act (FSRIA), means a product determined by the U.S. Secretary of Agriculture to be a commercial or industrial product (other than food or feed) that is composed, in whole or in significant part, of biological products or renewable domestic agricultural materials (including plant, animal, and marine materials) or forestry materials.

Biochemical conversion - The use of fermentation or anaerobic digestion to produce fuels and chemicals from organic sources.

Biological oxygen demand (BOD) - An indirect measure of the concentration of biologically degradable material present in organic wastes. It usually reflects the amount of oxygen consumed in five days by biological processes breaking down organic waste.

Biodiesel - Fuel derived from vegetable oils or animal fats. It is produced when a vegetable oil or animal fat is chemically reacted with an alcohol.

Bioenergy - Useful, renewable energy produced from organic matter - the conversion of the complex carbohydrates in organic matter to energy. Organic matter may either be used directly as a fuel, processed into liquids and gasses, or be a residual of processing and conversion.

Bioethanol - Ethanol produced from biomass feedstocks. This includes ethanol produced from the fermentation of crops, such as corn, as well as cellulosic ethanol produced from woody plants or grasses.

Biorefinery - A facility that processes and converts biomass into value-added products. These products can range from biomaterials to fuels such as ethanol or important feedstocks for the production of chemicals and other materials. Biorefineries can be based on a number of processing platforms using mechanical, thermal, chemical, and biochemical processes.

Biofuels - Fuels made from biomass resources, or their processing and conversion derivatives. Biofuels include ethanol, biodiesel, and methanol.

Biogas - A combustible gas derived from decomposing biological waste under anaerobic conditions. Biogas normally consists of 50 to 60 percent methane. See also landfill gas.

Biogasification or biomethanization - The process of decomposing biomass with anaerobic bacteria to produce biogas.

Biomass - Any organic matter that is available on a renewable or recurring basis, including agricultural crops and trees, wood and wood residues, plants (including aquatic plants), grasses, animal manure, municipal residues, and other residue materials. Biomass is generally produced in a sustainable manner from water and carbon dioxide by photosynthesis. There are three main categories of biomass - primary, secondary, and tertiary.

Biomass energy - See Bioenergy.

Biomass processing residues - Byproducts from processing all forms of biomass that have significant energy potential. For example, making solid wood products and pulp from logs produces bark, shavings and sawdust, and spent pulping liquors. Because these residues are already collected at the point of processing, they can be convenient and relatively inexpensive sources of biomass for energy.

Biopower - The use of biomass feedstock to produce electric power or heat through direct combustion of the feedstock, through gasification and then combustion of the resultant gas, or through other thermal conversion processes. Power is generated with engines, turbines, fuel cells, or other equipment.

Biorefinery - A facility that processes and converts biomass into value-added products. These products can range from biomaterials to fuels such as ethanol or important feedstocks for the production of chemicals and other materials. Biorefineries can be based on a number of processing platforms using mechanical, thermal, chemical, and biochemical processes.

Bone dry - Having zero percent moisture content. Wood heated in an oven at a constant temperature of 100°C (212°F) or above until its weight stabilizes is considered bone dry or oven dry.

Bottoming cycle - A cogeneration system in which steam is used first for process heat and then for electric power production.

Bound nitrogen - Some fuels contain about 0.1-5 % of organic bound nitrogen which typically is in forms of aromatic rings like pyridine or pyrrole.

Black liquor - Solution of lignin-residue and the pulping chemicals used to extract lignin during the manufacture of paper.

British thermal unit - (Btu) A non-metric unit of heat, still widely used by engineers. One Btu is the heat energy needed to raise the temperature of one pound of water from 60°F to 61°F at one atmosphere pressure. 1 Btu = 1055 joules (1.055 kJ).

BTL - Biomass-to-Liquids.

Bulk density - Weight per unit of volume, usually specified in pounds per cubic foot.

Bunker - A storage tank.

Buyback Rate - The price a utility pays to purchase electricity from an independent generator.

By-product - Material, other than the principal product, generated as a consequence of an industrial process or as a breakdown product in a living system.

Capacity factor - The amount of energy that a power plant actually generates compared to its maximum rated output, expressed as a percentage.

Carbonization - The conversion of organic material into carbon or a carbon-containing residue through pyrolysis.

Carbon Cycle - The carbon cycle includes the uptake of carbon dioxide by plants through photosynthesis, its ingestion by animals and its release to the atmosphere through respiration and decay of organic materials. Human activities like the burning of fossil fuels contribute to the release of carbon dioxide in the atmosphere.

Carbon dioxide (CO_2) - A colorless, odorless, non-poisonous gas that is a normal part of the ambient air. Carbon dioxide is a product of fossil fuel combustion.

Catalyst - A substance that increases the rate of a chemical reaction, without being consumed or produced by the reaction. Enzymes are catalysts for many biochemical reactions.

Cellulose - The main carbohydrate in living plants. Cellulose forms the skeletal structure of the plant cell wall.

Chemical oxygen demand (COD) - The amount of dissolved oxygen required to combine with chemicals in wastewater. A measure of the oxygen equivalent of that portion of organic matter that is susceptible to oxidation by a strong chemical oxidizing agent.

Closed-loop biomass - Crops grown, in a sustainable manner, for the purpose of optimizing their value for bioenergy and bioproduct uses. This includes annual crops such as maize and wheat, and perennial crops such as trees, shrubs, and grasses such as switchgrass.

Cloud point - The temperature at which a fuel, when cooled, begins to congeal and take on a cloudy appearance due to bonding of paraffins.

Coarse materials - Wood residues suitable for chipping, such as slabs, edgings, and trimmings.

Combustion turbine - A type of generating unit normally fired by oil or natural gas. The combustion of the fuel produces expanding gases, which are forced through a turbine, which produces electricity by spinning a generator.

Commercial species - Tree species suitable for industrial wood products.

Condensing turbine - A turbine used for electrical power generation from a minimum amount of steam. To increase plant efficiency, these units can have multiple uncontrolled extraction openings for feed-water heating.

Conservation reserve program - CRP provides farm owners or operators with an annual per-acre rental payment and half the cost of establishing a permanent land cover in exchange for retiring environmentally sensitive cropland from production for 10 to 15 years. In 1996, Congress reauthorized CRP for an additional round of contracts, limiting enrollment to 36.4 million acres at any time. The 2002 Farm Act increased the enrollment limit to 39 million acres. Producers can offer land for competitive bidding based on an Environmental Benefits Index (EBI) during periodic signups, or can automatically enroll more limited acreages in practices such as riparian buffers, field windbreaks, and grass strips on a continuous basis. CRP is funded through the Commodity Credit Corporation (CCC).

Construction and Demolition (C&D) Debris - Building materials and solid waste from construction, deconstruction, remodeling, repair, cleanup or demolition operations.

Coppicing - A traditional method of woodland management, by which young tree stems are cut down to a low level, or sometimes right down to the ground. In subsequent growth years, many new shoots will grow up, and after a number of years the cycle begins again and the coppiced tree or stool is ready to be harvested again. Typically a coppice woodland is harvested in sections, on a rotation. In this way each year a crop is available.

Cord - A stack of wood comprising 128 cubic feet (3.62 m^3); standard dimensions are 4 x 4 x 8 feet, including air space and bark. One cord contains approximately 1.2 U.S. tons (oven-dry) = 2400 pounds = 1089 kg.

Corn Distillers Dried Grains (DDG) - is obtained after the removal of ethanol by distillation from the yeast fermentation of a grain or a grain mixture by separating the resultant coarse grain fraction of the whole stillage and drying it by methods employed in the grain distilling industry.

Cropland - Total cropland includes five components: cropland harvested, crop failure, cultivated summer fallow, cropland used only for pasture, and idle cropland.

Cropland used for crops - Cropland used for crops includes cropland harvested, crop failure, and cultivated summer fallow. **Cropland harvested** includes row crops and closely sown crops; hay and silage crops; tree fruits, small fruits, berries, and tree nuts; vegetables and melons; and miscellaneous other minor crops. In recent years, farmers have double-cropped about 4 percent of this acreage. **Crop failure** consists mainly of the acreage on which crops failed because of weather, insects, and diseases, but includes some land not harvested due to lack of labor, low market prices, or other factors. The acreage planted to cover and soil improvement crops not intended for harvest is excluded from crop failure and is considered idle. **Cultivated summer fallow** refers to cropland in sub-humid regions of the West cultivated for one or more seasons to control weeds and accumulate moisture before small grains are planted. This practice is optional in some areas, but it is a requirement for crop production in the drier cropland areas of the West. Other types of fallow, such as cropland planted with soil improvement crops but not harvested and cropland left idle all year, are not included in cultivated summer fallow but are included as idle cropland.

Cropland pasture - Land used for long-term crop rotation. However, some cropland pasture is marginal for crop uses and may remain in pasture indefinitely. This category also includes land that was used for pasture before crops reached maturity and some land used for pasture that could have been cropped without additional improvement.

Cull tree - A live tree, 5.0 inches in diameter at breast height (d.b.h.) or larger that is non-merchantable for saw logs now or prospectively because of rot, roughness, or species. (See definitions for rotten and rough trees.)

dbh - The diameter measured at approximately breast high from the ground.

Deck - (also known as "landing", "ramp", "set-out") An area designated on a logging job for the temporary storage, collection, handling, sorting and/or loading of trees or logs.

Denatured - In the context of alcohol, it refers to making alcohol unfit for drinking without impairing its usefulness for other purposes.

Deoxygenation - A chemical reaction involving the removal of molecular oxygen (O^2) from a reaction mixture or solvent.

Digester - An airtight vessel or enclosure in which bacteria decomposes biomass in water to produce biogas.

Dimethyl ether - Also known as methoxymethane, methyl ether, wood ether, and DME, is a colorless, gaseous ether with with an ethereal smell. Dimethyl ether gas is water soluble and has the formula CH_3OCH_3. Dimethyl ether is used as an aerosol spray propellant. Dimethyl ether is also a clean-burning alternative to liquified petroleum gas, liquified natural gas, diesel and gasoline. It can be made from natural gas, coal, or biomass.

Discount rate - A rate used to convert future costs or benefits to their present value.

Distillers Dried Grains (DDG) - The dried grain byproduct of the grain fermentation process, which may be used as a high-protein animal feed.

Distillers Wet Grains (DWG) - is the product obtained after the removal of ethyl alcohol by distillation from the yeast fermentation of corn.

Distributed generation - The Generation of electricity from many small on-site energy sources. It has also been called also called dispersed generation, embedded generation or decentralized generation.

Downdraft gasifier - A gasifier in which the product gases pass through a combustion zone at the bottom of the gasifier.

Dutch oven furnace - One of the earliest types of furnaces, having a large, rectangular box lined with firebrick (refractory) on the sides and top. Commonly used for burning wood. Heat is stored in the refractory and radiated to a conical fuel pile in the center of the furnace.

Effluent - The liquid or gas discharged from a process or chemical reactor, usually containing residues from that process.

Emissions - Waste substances released into the air or water. See also Effluent.

Energy crops - Crops grown specifically for their fuel value. These include food crops such as corn and sugarcane, and nonfood crops such as poplar trees and switchgrass. Currently, two types of energy crops are under development; short-rotation woody crops, which are fast-growing hardwood trees harvested in 5 to 8 years, and herbaceous energy crops, such as perennial grasses, which are harvested annually after taking 2 to 3 years to reach full productivity.

Enzyme - A protein or protein-based molecule that speeds up chemical reactions occurring in living things. Enzymes act as catalysts for a single reaction, converting a specific set of reactants into specific products.

Ethanol (CH_5OH) - Otherwise known as ethyl alcohol, alcohol, or grain-spirit. A clear, colorless, flammable oxygenated hydrocarbon with a boiling point of 78.5 degrees Celsius in the anhydrous state. In transportation, ethanol is used as a vehicle fuel by itself (E100 – 100% ethanol by volume), blended with gasoline (E85 – 85% ethanol by volume), or as a gasoline octane enhancer and oxygenate (E10 -- 10% ethanol by volume).

Exotic species - Introduced species not native or endemic to the area in question.

Externality - A cost or benefit not accounted for in the price of goods or services. Often "externality" refers to the cost of pollution and other environmental impacts.

Fast pyrolysis - Thermal conversion of biomass by rapid heating to between 450 and 600 degrees Celsius in the absence of oxygen.

Fatty acids - A group of chemical compounds characterized by a chain made up of carbon and hydrogen atoms and having a carboxylic acid (COOH) group on one end of the molecule. They differ from each other in the number of carbon atoms and the number and location of double bonds in the chain. When they exist unattached to the other compounds, they are called free fatty acids.

Feedstock - A product used as the basis for manufacture of another product.

Feller-buncher - A self-propelled machine that cuts trees with giant shears near ground level and then stacks the trees into piles to await skidding.

Fermentation - Conversion of carbon-containing compounds by micro-organisms for production of fuels and chemicals such as alcohols, acids, or energy-rich gases.

Fiber products - Products derived from fibers of herbaceous and woody plant materials. Examples include pulp, composition board products, and wood chips for export.

Fischer-Tropsch Fuels - Liquid hydrocarbon fuels produced by a process that combines carbon monoxide and hydrogen. The process is used to convert coal, natural gas and low-value refinery products into a high-value diesel substitute fuel.

Fine materials - Wood residues not suitable for chipping, such as planer shavings and sawdust.

Firm power - (firm energy) Power which is guaranteed by the supplier to be available at all times during a period covered by a commitment. That portion of a customer's energy load for which service is assured by the utility provider.

Flash pyrolysis - See fast pyrolysis.

Flash vacuum pyrolysis (FVP) - Thermal reaction of a molecule by exposing it to a short thermal shock at high temperature, usually in the gas phase.

Flow control - A legal or economic means by which waste is directed to particular destinations. For example, an ordinance requiring that certain waste be sent to a landfill is waste flow control.

Flow rate - The amount of fluid that moves through an area (usually pipe) in a given period of time.

Fluidized-bed boiler - A large, refractory-lined vessel with an air distribution member or plate in the bottom, a hot gas outlet in or near the top, and some provisions for introducing fuel. The fluidized bed is formed by blowing air up through a layer of inert particles (such as sand or limestone) at a rate that causes the particles to go into suspension and continuous motion. The super-hot bed material increased combustion efficiency by its direct contact with the fuel.

Fly ash - Small ash particles carried in suspension in combustion products.

Forest land - Land at least 10 percent stocked by forest trees of any size, including land that formerly had such tree cover and that will be naturally or artificially regenerated. Forest land includes transition zones, such as areas between heavily forested and nonforested lands that are at least 10 percent stocked with forest trees and forest areas adjacent to urban and built-up lands. Also included are pinyon-juniper and chaparral areas in the West and afforested areas. The minimum area for classification of forest land is 1 acre. Roadside, streamside, and shelterbelt strips of trees must have a crown width of at least 120 feet to qualify as forest land. Unimproved roads and trails, streams, and clearings in forest areas are classified as forest if less than 120 feet wide.

Forestry residues - Includes tops, limbs, and other woody material not removed in forest harvesting operations in commercial hardwood and softwood stands, as well as woody material resulting from forest management operations such as precommercial thinnings and removal of dead and dying trees.

Forest health - A condition of ecosystem sustainability and attainment of management objectives for a given forest area. Usually considered to include green trees, snags, resilient stands growing at a moderate rate, and endemic levels of insects and disease. Natural processes still function or are duplicated through management intervention.

Forwarder - A self-propelled vehicle to transport harvested material from the stump area to the landing. Trees, logs, or bolts are carried off the ground on a stake-bunk, or are held by hydraulic jaws of a clam-bunk. Chips are hauled in a dumpable or open-top bin or chip-box.

Fossil fuel - Solid, liquid, or gaseous fuels formed in the ground after millions of years by chemical and physical changes in plant and animal residues under high temperature and pressure. Oil, natural gas, and coal are fossil fuels.

Fouling - The coating of heat transfer surfaces in heat exchangers such as boiler tubes caused by deposition of ash particles.

Fuel cell - A device that converts the energy of a fuel directly to electricity and heat, without combustion.

Fuel cycle - The series of steps required to produce electricity. The fuel cycle includes mining or otherwise acquiring the raw fuel source, processing and cleaning the fuel, transport, electricity generation, waste management and plant decommissioning.

Fuel Treatment Evaluator (FTE) - A strategic assessment tool capable of aiding the identification, evaluation, and prioritization of fuel treatment opportunities.

Fuelwood - Wood used for conversion to some form of energy, primarily for residential use.

Furnace - An enclosed chamber or container used to burn biomass in a controlled manner to produce heat for space or process heating.

Gasohol - A mixture of 10% anhydrous ethanol and 90% gasoline by volume; 7.5% anhydrous ethanol and 92.5% gasoline by volume; or 5.5% anhydrous ethanol and 94.5% gasoline by volume. There are other fuels that contain methanol and gasoline, but these fuels are not referred to as gasohol.

Gas turbine - (combustion turbine) A turbine that converts the energy of hot compressed gases (produced by burning fuel in compressed air) into mechanical power. Often fired by natural gas or fuel oil.

Gasification - A chemical or heat process to convert a solid fuel to a gaseous form.

Gasifier - A device for converting solid fuel into gaseous fuel. In biomass systems, the process is referred to as pyrolitic distillation. See Pyrolysis.

Genetic selection - Application of science to systematic improvement of a population, e.g. through selective breeding.

Gigawatt (GW) - A measure of electrical power equal to one billion watts (1,000,000 kW). A large coal or nuclear power station typically has a capacity of about 1 GW.

Global Climate Change - Global climate change could result in sea level rises, changes to patterns of precipitation, increased variability in the weather, and a variety of other consequences. These changes threaten our health, agriculture, water resources, forests, wildlife, and coastal areas.

Global warming - A term used to describe the increase in average global temperatures due to the greenhouse effect.

Grassland pasture and range - All open land used primarily for pasture and grazing, including shrub and brush land types of pasture; grazing land with sagebrush and scattered mesquite; and all tame and native grasses, legumes, and other forage used for pasture or grazing. Because of the diversity in vegetative composition, grassland pasture and range are not always clearly distinguishable from other types of pasture and range. At one extreme, permanent grassland may merge with cropland pasture, or grassland may often be found in transitional areas with forested grazing land.

Greenhouse effect - The effect of certain gases in the Earth's atmosphere in trapping heat from the sun.

Greenhouse gases - Gases that trap the heat of the sun in the Earth's atmosphere, producing the greenhouse effect. The two major greenhouse gases are water vapor and carbon dioxide. Other greenhouse gases include methane, ozone, chlorofluorocarbons, and nitrous oxide.

Green Power - Electricity that is generated from renewable energy sources is often referred to as “green power.” Green power products can include electricity generated exclusively from renewable resources or, more frequently, electricity produced from a combination of fossil and renewable resources. Also known as “blended” products, these products typically have lower prices than 100 percent renewable products. Customers who take advantage of these options usually pay a premium for having some or all of their electricity produced from renewable resources.

Green Power Purchasing/Aggregation Policies - Municipalities, state governments, businesses, and other non-residential customers can play a critical role in supporting renewable energy technologies by buying electricity from renewable resources. At the local level, green power purchasing can mean buying green power for municipal facilities, streetlights, water pumping stations and other public infrastructure. Several states require that a certain percentage of electricity purchased for state government buildings come from renewable resources. A few states allow local governments to aggregate the electricity loads of the entire community to purchase green power and even to join with other communities to form an even larger green power purchasing block. This is often referred to as "Community Choice." Green power purchasing can be achieved via utility green pricing programs, green power marketers (in states with retail competition), special contracts, or community aggregation.

Grid - An electric utility company's system for distributing power.

Growing stock - A classification of timber inventory that includes live trees of commercial species meeting specified standards of quality or vigor. Cull trees are excluded. When associated with volume, includes only trees 5.0 inches in d.b.h. and larger.

Habitat - The area where a plant or animal lives and grows under natural conditions. Habitat includes living and non-living attributes and provides all requirements for food and shelter.

Hammermill - A device consisting of a rotating head with free-swinging hammers which reduce chips or wood fuel to a predetermined particle size through a perforated screen.

Hardwoods - Usually broad-leaved and deciduous trees.

Heat rate - The amount of fuel energy required by a power plant to produce one kilowatt-hour of electrical output. A measure of generating station thermal efficiency, generally expressed in Btu per net kWh. It is computed by dividing the total Btu content of fuel burned for electric generation by the resulting net kWh generation.

Heat transfer efficiency - useful heat output released / actual heat produced in the firebox.

Heating value - The maximum amount of energy that is available from burning a substance.

Hectare - Common metric unit of area, equal to 2.47 acres. 100 hectares = 1 square kilometer.

Hemicellulose — Hemicellulose consists of short, highly branched chains of sugars. In contrast to cellulose, which is a polymer of only glucose, a hemicellulose is a polymer of five different sugars. It contains five-carbon sugars (usually D-xylose and L-arabinose) and six-carbon sugars (D-galactose, D-glucose, and D-mannose) and uronic acid. The sugars are highly substituted with acetic acid. The branched nature of hemicellulose renders it amorphous and relatively easy to hydrolyze to its constituent sugars compared to cellulose. When hydrolyzed, the hemicellulose from hardwoods or grasses releases products high in xylose (a five-carbon sugar). The hemicellulose contained in softwoods, by contrast, yields more six-carbon sugars.

Herbaceous - Non-woody type of vegetation, usually lacking permanent strong stems, such as grasses, cereals and canola (rape).

HFCS - High fructose corn syrup.

Higher heating value - (HHV) The maximum potential energy in dry fuel. For wood, the range is from 7,600 to 9,600 Btu/lb, and grasses are typically in the 7,000-7,500 Btu/lb range.

Hog - A chipper or mill which grinds wood into an acceptable form to be used for boiler fuel.

Horsepower - (electrical horsepower; hp) A unit for measuring the rate of mechanical energy output, usually used to describe the maximum output of engines or electric motors. 1 hp = 550 foot-pounds per second = 2,545 Btu per hour = 745.7 watts = 0.746 kW

Hydrocarbon - A compound containing only hydrogen and carbon. The simplest and lightest forms of hydrocarbon are gaseous. With greater molecular weights they are liquid, while the heaviest are solids.

Hydrolysis - A process of breaking chemical bonds of a compound by adding water to the bonds.

Idle cropland - Land in cover and soil improvement crops, and cropland on which no crops were planted. Some cropland is idle each year for various physical and economic reasons. Acreage diverted from crops to soil-conserving uses (if not eligible for and used as cropland pasture) under federal farm programs is included in this component. Cropland enrolled in the Federal Conservation Reserve Program (CRP) is included in idle cropland.

Incinerator - Any device used to burn solid or liquid residues or wastes as a method of disposal. In some incinerators, provisions are made for recovering the heat produced.

Inclined grate- A type of furnace in which fuel enters at the top part of a grate in a continuous ribbon, passes over the upper drying section where moisture is removed, and descends into the lower burning section. Ash is removed at the lower part of the grate.

Incremental energy costs - The cost of producing and transporting the next available unit of electrical energy. Short run incremental costs (SRIC) include only incremental operating costs. Long run incremental costs (LRIC) include the capital cost of new resources or capital equipment.

Independent power producer - A power production facility that is not part of a regulated utility.

Indirect liquefaction - Conversion of biomass to a liquid fuel through a synthesis gas intermediate step.

Industrial wood - All commercial roundwood products except fuelwood.

Invasive species - A species that has moved into an area and reproduced so aggressively that it threatens or has replaced some of the original species.

Iodine number - A measure of the ability of activated carbon to adsorb substances with low molecular weights. It is the milligrams of iodine that can be adsorbed on one gram of activated carbon.

Joule - Metric unit of energy, equivalent to the work done by a force of one Newton applied over a distance of one meter (= 1 kg m^2/s^2). One joule (J) = 0.239 calories (1 calorie = 4.187 J).

Kilowatt - (kW) A measure of electrical power equal to 1,000 watts. 1 kW = 3412 Btu/hr = 1.341 horsepower. See also watt.

Kilowatt hour - (kWh) A measure of energy equivalent to the expenditure of one kilowatt for one hour. For example, 1 kWh will light a 100-watt light bulb for 10 hours. 1 kWh = 3412 Btu.

Landfill gas - A type of biogas that is generated by decomposition of organic material at landfill disposal sites. Landfill gas is approximately 50 percent methane. See also biogas.

Landing - A cleared working area on or near a timber harvest site at which processing steps are carried out.

Legume - Any plant belonging to the leguminous family. Characterized by pods as fruits and root nodules enabling the storage of nitrogen.

Levelized life-cycle cost - The present value of the cost of a resource, including capital, financing and operating costs, expressed as a stream of equal annual payments. This stream of payments can be converted to a unit cost of energy by dividing the annual payment amount by the annual kilowatt-hours produced or saved. By levelizing costs, resources with different lifetimes and generating capabilities can be compared.

Lignin - Structural constituent of wood and (to a lesser extent) other plant tissues, which encrusts the cell walls and cements the cells together.

Live cull - A classification that includes live cull trees. When associated with volume, it is the net volume in live cull trees that are 5.0 inches in d.b.h. and larger.

Logging residues - The unused portions of growing-stock and non-growing-stock trees cut or killed by logging and left in the woods.

Lower heating value (LHV) - The potential energy in a fuel if the water vapor from combustion of hydrogen is not condensed.

Megawatt - (MW) A measure of electrical power equal to one million watts (1,000 kW). See also watt.

Merchantable - Logs from which at least some of the volume can be converted into sound grades of lumber ("standard and better" framing lumber).

Methanol - A Methyl alcohol having the chemical formula CH30H. Also known as wood alcohol, methanol is usually produced by chemical conversion at high temperatures and pressures. Although usually produced from natural gas, methanol can be produced from gasified biomass (syngas).

Mill/kWh - A common method of pricing electricity in the U.S. Tenths of a U.S. cent per kilowatt hour.

Mill residue - Wood and bark residues produced in processing logs into lumber, plywood, and paper.

MMBtu - One million British thermal units.

Moisture content - (MC) The weight of the water contained in wood, usually expressed as a percentage of weight, either oven-dry or as received.

Moisture content, dry basis - Moisture content expressed as a percentage of the weight of oven-dry wood, i.e.: [(weight of wet sample - weight of dry sample) / weight of dry sample] x 100

Moisture content, wet basis - Moisture content expressed as a percentage of the weight of wood as-received, i.e.: [(weight of wet sample - weight of dry sample) / weight of wet sample] x 100

Monoculture - The cultivation of a single species crop.

Municipal solid waste (MSW) - Garbage. Refuse offering the potential for energy recovery; includes residential, commercial, and institutional wastes.

National Environmental Policy Act (NEPA) - A federal law enacted in 1969 that requires all federal agencies to consider and analyze the environmental impacts of any proposed action. NEPA requires an environmental impact statement for major federal actions significantly affecting the quality of the environment. NEPA requires federal agencies to inform and involve the public in the agency´s decision making process and to consider the environmental impacts of the agency´s decision.

Net Metering - For those consumers who have their own electricity generating units, net metering allows for the flow of electricity both to and from the customer through a single, bi-directional meter. With net metering, during times when the customer's generation exceeds his or her use, electricity from the customer to the utility offsets electricity consumed at another time. In effect, the customer is using the excess generation to offset electricity that would have been purchased at the retail rate. Under most state rules, residential, commercial, and industrial customers are eligible for net metering, but some states restrict eligibility to particular customer classes.

Net present value - The sum of the costs and benefits of a project or activity. Future benefits and costs are discounted to account for interest costs.

Nitrogen fixation - The transformation of atmospheric nitrogen into nitrogen compounds that can be used by growing plants.

Nitrogen oxides (NOx) - Gases consisting of one molecule of nitrogen and varying numbers of oxygen molecules. Nitrogen oxides are produced from the burning of fossil fuels. In the atmosphere, nitrogen oxides can contribute to the formation of photochemical ozone (smog), can impair visibility, and have health consequences; they are thus considered pollutants.

Noncondensing, controlled extraction turbine - A turbine that bleeds part of the main steam flow at one (single extraction) or two (double extraction) points.

Nonforest land - Land that has never supported forests and lands formerly forested where use of timber management is precluded by development for other uses. (Note: Includes area used for crops, improved pasture, residential areas, city parks, improved roads of any width and adjoining clearings, powerline clearings of any width, and 1- to 4.5-acre areas of water classified by the Bureau of the Census as land. If intermingled in forest areas, unimproved roads and nonforest strips must be more than 120 feet wide, and clearings, etc., must be more than 1 acre in area to qualify as nonforest land.)

Nonattainment area - Any area that does not meet the national primary or secondary ambient air quality standard established by the Environmental Protection Agency for designated pollutants, such as carbon monoxide and ozone.

Nonindustrial private - An ownership class of private lands where the owner does not operate wood-using processing plants.

Oilseed crops - Primarily soybeans, sunflower seed, canola, rapeseed, safflower, flaxseed, mustard seed, peanuts and cottonseed, used for the production of cooking oils, protein meals for livestock, and industrial uses.

Old growth - Timber stands with the following characteristics; large mature and over-mature trees in the overstory, snags, dead and decaying logs on the ground, and a multi-layered canopy with trees of several age classes.

Open-loop biomass - Biomass that can be used to produce energy and bioproducts even though it was not grown specifically for this purpose. Examples of open-loop biomass include agricultural livestock waste and residues from forest harvesting operations and crop harvesting.

Organic compounds - Chemical compounds based on carbon chains or rings and also containing hydrogen, with or without oxygen, nitrogen, and other elements.

Other forest land - Forest land other than timberland and reserved forest land. It includes available forest land, which is incapable of annually producing 20 cubic feet per acre of industrial wood under natural conditions because of adverse site conditions such as sterile soils, dry climate, poor drainage, high elevation, steepness, or rockiness.

Other removals - Unutilized wood volume from cut or otherwise killed growing stock, from cultural operations such as precommercial thinnings, or from timberland clearing. Does not include volume removed from inventory through reclassification of timberland to productive reserved forest land.

Other sources - Sources of roundwood products that are not growing stock. These include salvable dead, rough and rotten trees, trees of noncommercial species, trees less than 5.0 inches d.b.h., tops, and roundwood harvested from non-forest land (for example, fence rows).

Oxygenate - A substance which, when added to gasoline, increases the amount of oxygen in that gasoline blend. Includes fuel ethanol, methanol, and methyl tertiary butyl ether (MTBE).

Particulate - A small, discrete mass of solid or liquid matter that remains individually dispersed in gas or liquid emissions. Particulates take the form of aerosol, dust, fume, mist, smoke, or spray. Each of these forms has different properties.

Photosynthesis - Process by which chlorophyll-containing cells in green plants concert incident light to chemical energy, capturing carbon dioxide in the form of carbohydrates.

Pilot scale - The size of a system between the small laboratory model size (bench scale) and a full-size system.

Poletimber trees - Live trees at least 5.0 inches in d.b.h. but smaller than sawtimber trees.

Pour point - The minimum temperature at which a liquid, particularly a lubricant, will flow.

Prescribed fire - Any fire ignited by management actions to meet specific objectives. Prior to ignition, a written, approved prescribed fire plan must exist, and National Environmental Protection Act requirements must be met.

Present value - The worth of future receipts or costs expressed in current value. To obtain present value, an interest rate is used to discount future receipts or costs.

Primary wood-using mill - A mill that converts roundwood products into other wood products. Common examples are sawmills that convert saw logs into lumber and pulp mills that convert pulpwood roundwood into wood pulp.

Process heat - Heat used in an industrial process rather than for space heating or other housekeeping purposes.

Producer gas - Fuel gas high in carbon monoxide (CO) and hydrogen (H2), produced by burning a solid fuel with insufficient air or by passing a mixture of air and steam through a burning bed of solid fuel.

Proximate analysis - An analysis which reports volatile matter, fixed carbon, moisture content, and ash present in a fuel as a percentage of dry fuel weight.

Public power - The term used for not-for-profit utilities that are owned and operated by a municipality, state or the federal government.

Public utility commissions - State agencies that regulate investor-owned utilities operating in the state.

Public utility regulatory policies act - (PURPA) A federal law requiring a utility to buy the power produced by a qualifying facility at a price equal to that which the utility would otherwise pay if it were to build its own power plant or buy power from another source.

Pulpwood - Roundwood, whole-tree chips, or wood residues that are used for the production of wood pulp.

Pulp chips - Timber or residues processed into small pieces of wood of more or less uniform dimensions with minimal amounts of bark.

Pyrolysis - The thermal decomposition of biomass at high temperatures (greater than 400° F, or 200° C) in the absence of air. The end product of pyrolysis is a mixture of solids (char), liquids (oxygenated oils), and gases (methane, carbon monoxide, and carbon dioxide) with proportions determined by operating temperature, pressure, oxygen content, and other conditions.

Quad: One quadrillion Btu (10^{15} Btu) = 1.055 exajoules (EJ), or approximately 172 million barrels of oil equivalent.

Reburning - Reburning entails the injection of natural gas, biomass fuels, or other fuels into a coal-fired boiler above the primary combustion zone—representing 15 to 20 percent of the total fuel mix—can produce NOx reductions in the 50 to 70 percent range and SO2 reductions in the 20 to 25 percent range. Reburning is an effective and economic means of reducing NOx emissions from all types of industrial and electric utility boilers. Reburning may be used in coal or oil boilers, and it is even effective in cyclone and wet-bottom boilers, for which other forms of NOx control are either not available or very expensive.

Recovery boiler - A pulp mill boiler in which lignin and spent cooking liquor (black liquor) is burned to generate steam.

Refractory lining - A lining, usually of ceramic, capable of resisting and maintaining high temperatures.

Refuse-derived fuel - (RDF) Fuel prepared from municipal solid waste. Noncombustible materials such as rocks, glass, and metals are removed, and the remaining combustible portion of the solid waste is chopped or shredded. RDF facilities process typically between 100 and 3,000 tons of MSW per day.

Renewable diesel - Defined in the Internal Revenue Code (IRC) as fuel produced from biological material using a process called "thermal depolymerization" that meets the fuel specification requirements of ASTM D975 (petroleum diesel fuel) or ASTM D396 (home heating oil). Produced in free-standing facilities.

Renewable Fuel Standards - Under the Energy Policy Act of 2005, EPA is responsible for promulgating regulations to ensure that gasoline sold in the United States contains a minimum volume of renewable fuel. A national Renewable Fuel Program (also known as the Renewable Fuel Standard Program, or RFS Program) will increase the volume of renewable fuel required to be blended into gasoline, starting with 4.0 billion gallons in calendar year 2006 and nearly doubling to 7.5 billion gallons by 2012. The RFS program was developed in collaboration with refiners, renewable fuel producers, and many other stakeholders.

Renewables Portfolio Standards/Set Asides - Renewables Portfolio Standards (RPS) require that a certain percentage of a utility's overall or new generating capacity or energy sales must be derived from renewable resources, i.e., 1% of electric sales must be from renewable energy in the year 200x. Portfolio Standards most commonly refer to electric sales measured in megawatt-hours (MWh), as opposed to electric capacity measured in megawatts(MW). The term "set asides" is frequently used to refer to programs where a utility is required to include a certain amount of renewables capacity in new installations.

Reserve margin - The amount by which the utility's total electric power capacity exceeds maximum electric demand.

Residues - Bark and woody materials that are generated in primary wood-using mills when roundwood products are converted to other products. Examples are slabs, edgings, trimmings, sawdust, shavings, veneer cores and clippings, and pulp screenings. Includes bark residues and wood residues (both coarse and fine materials) but excludes logging residues.

Return on investment- (ROI) The interest rate at which the net present value of a project is zero. Multiple values are possible.

Rotation - Period of years between establishment of a stand of timber and the time when it is considered ready for final harvest and regeneration.

Rotten tree - A live tree of commercial species that does not contain a saw log now or prospectively primarily because of rot (that is, when rot accounts for more than 50 percent of the total cull volume).

Rough tree - (a) A live tree of commercial species that does not contain a saw log now or prospectively primarily because of roughness (that is, when sound cull, due to such factors as poor form, splits, or cracks, accounts for more than 50 percent of the total cull volume) or (b) a live tree of noncommercial species.

Roundwood products - Logs and other round timber generated from harvesting trees for industrial or consumer use.

Saccharification - The process of breaking down a complex carbohydrate, such as starch or cellulose, into its monosaccharide components.

Salvable dead tree - A downed or standing dead tree that is considered currently or potentially merchantable by regional standards.

Saplings - Live trees 1.0 inch through 4.9 inches in d.b.h.

Saturated steam- Steam at boiling temperature for a given pressure.

Secondary wood processing mills - A mill that uses primary wood products in the manufacture of finished wood products, such as cabinets, moldings, and furniture.

Shaft horsepower - A measure of the actual mechanical energy per unit time delivered to a turning shaft. See also horsepower.

Silviculture - Theory and practice of controlling the establishment, composition, structure and growth of forests and woodlands.

Slagging - The coating of internal surfaces of fireboxes and in boilers from deposition of ash particles.

Softwood - Generally, one of the botanical groups of trees that in most cases have needle-like or scale-like leaves; the conifers; also the wood produced by such trees. The term has no reference to the actual hardness of the wood. The botanical name for softwoods is gymnosperms.

Sound dead - The net volume in salvable dead trees.

Species - A group of organisms that differ from all other groups of organisms and that are capable of breeding and producing fertile offspring. This is the smallest unit of classification for plants and animals.

spp. - This notation means that many species within a genus are included but not all.

SRIC - Short rotation intensive culture - the growing of tree crops for bioenergy or fiber, characterized by detailed site preparation, usually less than 10 years between harvests, usually fast-growing hybrid trees and intensive management (some fertilization, weed and pest control, and possibly irrigation).

Stand - (of trees) A tree community that possesses sufficient uniformity in composition, constitution, age, spatial arrangement, or condition to be distinguishable from adjacent communities.

Stand density - The number or mass of trees occupying a site. It is usually measured in terms of stand density index or basal area per acre.

Starch - A naturally abundant nutrient carbohydrate, found chiefly in the seeds, fruits, tubers, roots, and stem pith of plants, notably in corn, potatoes, wheat, and rice, and varying widely in appearance according to source but commonly prepared as a white amorphous tasteless powder.

Steam turbine- A device for converting energy of high-pressure steam (produced in a boiler) into mechanical power which can then be used to generate electricity.

Stover - The dried stalks and leaves of a crop remaining after the grain has been harvested.

Sulfur Dioxide (SO2) - Formed by combustion of fuels containing sulfur, primarily coal and oil. Major health effects associated with SO2 include asthma, respiratory illness, and aggravation of existing cardiovascular disease. SO2 combines with water and oxygen in the atmosphere to form acid rain, which raises the acid levels of lakes and streams, affecting the ability of fish and some amphibians to survive. It also damages sensitive forests and ecosystems, particularly in the eastern part of the United States. It also accelerates the decay of buildings. Making electricity is responsible for two-thirds of all Sulfur Dioxide.

Superheated steam - Steam which is hotter than boiling temperature for a given pressure.

Surplus electricity- Electricity produced by cogeneration equipment in excess of the needs of an associated factory or business.

Sustainable- An ecosystem condition in which biodiversity, renewability, and resource productivity are maintained over time.

Synthetic ethanol - Ethanol produced from ethylene, a petroleum by-product.

Systems benefit charge - A small surcharge collected through consumer electric bills that are designated to fund certain "public benefits" that are placed at risk in a more competitive industry. Systems benefit charges typically help to fund renewable energy, research and development, and energy efficiency.

Therm - A unit of energy equal to 100,000 Btus (= 105.5 MJ); used primarily for natural gas.

Thermal NOx - Nitrous Oxide (NOx) emissions formed at high temperature by the reaction of nitrogen present in combustion air. cf. fuel NOx.

Thermochemical conversion - Use of heat to chemically change substances from one state to another, e.g. to make useful energy products.

Timberland - Forest land that is producing or is capable of producing crops of industrial wood, and that is not withdrawn from timber utilization by statute or administrative regulation. Areas qualifying as timberland are capable of producing more than 20 cubic feet per acre per year of industrial wood in natural stands. Currently inaccessible and inoperable areas are included.

Timber Product Output Database Retrieval System (TPO) - Developed in support of the 1997 Resources Planning Act (RPA) Assessment, this system acts as an interface to a standard set of consistently coded TPO data for each state and county in the country. This set of national TPO data consists of 11 data variables that describe for each county the roundwood products harvested, the logging residues left behind, the timber otherwise removed, and the wood and bark residues generated by its primary wood-using mills.

Tipping fee - A fee for disposal of waste.

Ton, Tonne - One U.S. ton (short ton) = 2,000 pounds. One Imperial ton (long ton or shipping ton) = 2,240 pounds. One metric tonne(tonne) = 1,000 kilograms (2,205 pounds). One oven-dry ton or tonne (ODT, sometimes termed bone-dry ton/tonne) is the amount of wood that weighs one ton/tonne at 0% moisture content. One green ton/tonne refers to the weight of undried (fresh) biomass material - moisture content must be specified if green weight is used as a fuel measure.

Topping cycle - A cogeneration system in which electric power is produced first. The reject heat from power production is then used to produce useful process heat.

Topping and back pressure turbines - Turbines which operate at exhaust pressure considerably higher than atmospheric (noncondensing turbines). These turbines are often multistage types with relatively high efficiency.

Total Solids - The amount of solids remaining after all volatile matter has been removed from a biomass sample by heating at 105°C to constant weight.

Transesterification - A chemical process which reacts an alcohol with the triglycerides contained in vegetable oils and animal fats to produce biodiesel and glycerin.

Traveling grate- A type of furnace in which assembled links of grates are joined together in a perpetual belt arrangement. Fuel is fed in at one end and ash is discharged at the other.

Trommel screen - A revolving cylindrical sieve used for screening or sizing compost, mulch, and solid biomass fuels such as wood chips.

Tub grinder - A shredder used primarily for woody, vegetative debris. A tub grinder consists of a hammermill, the top half of which extends up through the stationary floor of a tub. As the hammers encounter material, they rip and tear large pieces into smaller pieces, pulling the material down below the tub floor and ultimately forcing it through openings in a set of grates below the mill. Various sized openings in the removable grates are used to determine the size of the end product.

Turbine - A machine for converting the heat energy in steam or high temperature gas into mechanical energy. In a turbine, a high velocity flow of steam or gas passes through successive rows of radial blades fastened to a central shaft.

Turn down ratio- The lowest load at which a boiler will operate efficiently as compared to the boiler's maximum design load.

Ultimate analysis - A description of a fuel´s elemental composition as a percentage of the dry fuel weight.

Unmerchantable wood - Material which is unsuitable for conversion to wood products due to poor size, form, or quality.

Urban wood waste - Woody biomass generated from tree and yard trimmings, the commercial tree care industry, utility line thinning to reduce wildfire risk or to improve forest health, and greenspace maintenance.

Volatile matter - Those products, exclusive of moisture, given off by a material as a gas or vapor, determined by definite prescribed methods that may vary according to the nature of the material. One definition of volatile matter is part of the proximate analysis group usually determined as described in ASTM D 3175.

Volatile organic compounds (VOC) - Non-methane hydrocarbon gases, released during combustion or evaporation of fuel.

Waste streams - Unused solid or liquid by-products of a process.

Water-cooled vibrating grate - A boiler grate made up of a tuyere grate surface mounted on a grid of water tubes interconnected with the boiler circulation system for positive cooling. The structure is supported by flexing plates allowing the grid and grate to move in a vibrating action. Ashes are automatically discharged.

Watershed - The drainage basin contributing water, organic matter, dissolved nutrients, and sediments to a stream or lake.

Watt - The common base unit of power in the metric system. One watt equals one joule per second, or the power developed in a circuit by a current of one ampere flowing through a potential difference of one volt. One Watt = 3.412 Btu/hr. See also kilowatt.

Wheeling - The process of transferring electrical energy between buyer and seller by way of an intermediate utility or utilities.

Whole-tree chips - Wood chips produced by chipping whole trees, usually in the forest. Thus the chips contain both bark and wood. They are frequently produced from the low-quality trees or from tops, limbs, and other logging residues.

Whole-tree harvesting - A harvesting method in which the whole tree (above the stump) is removed.

Yarding - The initial movement of logs from the point of felling to a central loading area or landing.