

6. Biomass: Wood

Background

Wood is a substantial renewable resource that can be used as a fuel to generate electric power and other forms of energy products. Wood for use as fuel comes from a wide variety of sources. The Nation's forestland (or timberland) is the primary, and in most cases original, resource base for fuelwood. Wood for fuel use is also derived from private land clearing and silviculture and from urban tree and landscape residues. A third major wood resource is waste wood, which includes manufacturing and wood processing wastes, as well as construction and demolition debris.

Worldwide, one-half of the annual timber harvest is used for fuelwood, representing economic value of at least \$75 billion on a replacement fuel cost basis. Half the world's population uses wood for heating and cooking. In developing countries, fuelwood accounts for 90 percent of the timber harvested.¹⁷ In the United States, however, fuelwood and timber residues used for fuel amount to only about 25 percent of the timber harvest.

Other than hydroelectric power, wood and other biomass resources provide the largest source of renewable electricity and thermal energy produced today in the United States. U.S. biomass power plants account for about 6,500 megawatts of installed electric generating capacity and provide a significant amount of energy in the form of heat and steam from cogeneration. The amount of electric power produced from wood in 1992 was about 42,000 gigawatthours, using approximately 50 million tons of biomass fuel. The contribution to the U.S. energy supply was equivalent to nearly 200,000 barrels of oil per day.¹⁸

Wood Resources

Timberland Harvests

Before its colonization, the land now occupied by the United States included more than 1 billion acres of forests. By 1907, U.S. forests had been reduced to 759 million acres. In the 1920s and 1930s, forested land area began to stabilize, and it has remained relatively constant since then, totaling 737 million acres in 1992. In the case of fuelwood, no statistical linkage can be made between available resources (supply) and actual consumption. Very little information is available on fuelwood supply. Nevertheless, this chapter provides a qualitative profile and rough measure of fuelwood resources, with the caveat that the resulting data are only approximate. Consumption data (see Chapter 3) are more reliable, and some survey-supported numbers are available.

Analysis readily reveals the underlying difficulty of quantifying fuelwood supplies. The forest products industry is made up of thousands of suppliers and thousands of consumers—sometimes even within a given State. While some operators are large, many are very small, scattered, and autonomous. Most of the statistical resource data used here are either provided by or derived from forest resource assessment data published by the U.S. Forest Service. The most recent assessment by the Forest Service was for statistical year 1991.¹⁹

U.S. forest acreage currently represents 7 percent of the world's forests.²⁰ U.S. timberland contains the equivalent of about 858 billion cubic feet of roundwood,²¹ which is timber stock that typically consists of 92

¹⁷D.J. Brooks, *U.S. Forests in a Global Context*, U.S. Forest Service, General Technical Report No. RM-228 (Washington, DC, July 1993), p. 9.

¹⁸See Appendix D for detailed information on the procedures used by EIA to estimate biomass consumption levels.

¹⁹See Appendix E for additional information on wood resources.

²⁰U.S. Department of Agriculture, Forest Service, *RPA Assessment of the Forest and Rangeland Situation in the United States: 1993 Update*, Forest Resource Report No. 27 (Washington, DC, June 1994). Unless otherwise noted this publication is the source of the data in this section. The forest and wood-related terminology used in this report conforms to Forest Service definitions.

²¹Roundwood consists of logs, bolts, and other commercially viable sections of growing stock or salvable dead trees, generally more than five inches in diameter at breast height.

percent live, sound trees (called “growing stock”) and 8 percent rotten, cull, or “salvable” dead trees (Table 19). While a percentage of rotten, cull, or salvable dead timber may be suitable for lumber or veneer logs (which are used mainly in plywood manufacturing), most is used for pulp, fuel, and products that require only low-quality wood.

According to the last comprehensive Forest Service estimate, for statistical year 1991, roundwood harvested from U.S. timberland totaled 17.9 billion cubic feet. This set of Forest Service statistics specifically reports only fuelwood of roundwood class that was commercially harvested for use by primary wood-using mills²² or for fuel. About 18 percent of this quantity—about 62 million tons or 3.2 billion cubic feet—was used as fuelwood (Table 20), with an equivalent energy value of 871 trillion Btu (Table 21). Almost three times more nongrowing roundwood stock than growing roundwood stock was used for fuel, because, under prevailing market conditions, higher quality logs are used for value-added products. Some 28 percent of the roundwood harvest, or about 5 billion cubic feet, was used as pulpwood. Pulpwood is an important resource category of industrial wood energy, because about 30

percent of the volume of pulpwood consumed in the kraft pulp and paper manufacturing process is recoverable for energy in the form of black liquor. A rough approximation of the energy recovered from roundwood pulpwood in 1991 is about 370 trillion Btu. Roundwood is only one source of pulpwood and this estimate does not include energy recovered from both forest and nonforest residues that are used for pulpwood.

Other important wood resource categories reported by the Forest Service are the salvable wood from (1) living and dead stock cut or knocked down and left at the harvest site, (2) cull trees, (3) growing stock tops consisting of wood less than 4 inches in diameter, (4) growing stock trees less than 5 inches in diameter, and (5) growing stock removed from forestland by cultural operations or timberland clearing.²³ The Forest Service reports these categories as *logging residues* and *other removals*. Table 22 indicates that total wood supply available from these sources in 1991 was about 5 billion cubic feet. While there are few hard statistics that shed any light on the disposition of these resources, anecdotal evidence indicates that most of them are used for industrial boiler fuel, pulpwood, residential fuelwood,

Table 19. Net Volume of Timber by Region, Species Group, and Timber Class in the United States, 1992
(Million Cubic Feet)

Region	All Timber			Growing Stock			Live Cull			Sound Dead		
	Total	Soft-wood	Hard-wood	Total	Soft-wood	Hard-wood	Total	Soft-wood	Hard-wood	Total	Soft-wood	Hard-wood
Northeast	132,717	36,690	96,027	121,800	33,580	88,220	9,122	2,305	6,817	1,796	805	990
North Central . . .	100,343	18,617	81,726	85,319	17,397	67,923	13,690	969	12,721	1,334	251	1,083
Southeast	130,760	52,636	78,124	120,872	51,931	68,941	9,518	481	9,036	371	224	147
South Central . . .	144,143	52,610	91,533	129,722	50,996	78,726	13,578	1,211	12,367	844	403	440
Great Plains	4,313	2,048	2,265	3,656	1,935	1,722	570	39	531	87	74	13
Intermountain . . .	120,010	110,399	9,611	106,582	99,552	7,030	5,667	4,402	1,265	7,761	6,445	1,316
Pacific NW and Alaska	165,721	149,114	16,607	160,024	144,371	15,653	2,138	1,201	937	3,560	3,542	18
Pacific SW and Hawaii	59,556	51,101	8,455	57,643	50,134	7,509	1,396	507	888	518	459	59
U.S. Total	857,565	473,215	384,349	785,617	449,895	335,722	55,678	11,116	44,562	16,270	12,205	4,066

Source: U.S. Department of Agriculture, Forest Service, *Forest Resources of the United States, 1992*, General Technical Report RM-234 (Revised) (Fort Collins, CO, June 1994), Table 11, pp. 46-47.

²²Sawmills, veneer mills, and pulp and paper mills are examples of primary mills.

²³D.S. Powell et al., *Forest Resources of the United States, 1992*, U.S. Forest Service, Technical Report RM-234 (Washington, DC, September 1993), pp. 114-116.

Table 20. Volume of Roundwood Products Harvested in the United States for Pulpwood and Fuelwood, by Region, Species Group and Timber Class, 1991
(Thousand Cubic Feet)

Region	Total of All Sources			Growing Stock			Other Sources		
	Total	Softwood	Hardwood	Total	Softwood	Hardwood	Total	Softwood	Hardwood
Northeast									
Pulpwood	521,903	246,167	275,736	410,925	191,952	218,973	110,978	54,215	56,763
Fuelwood	939,654	84,473	855,181	121,417	11,245	110,172	818,237	73,228	745,009
North Central									
Pulpwood	631,787	142,859	488,928	547,984	126,640	421,344	83,803	16,219	67,584
Fuelwood	745,157	33,993	711,164	105,253	6,559	98,694	639,904	27,434	612,470
Southeast									
Pulpwood	1,586,159	1,162,982	423,177	1,386,013	1,041,529	344,484	200,146	121,453	78,693
Fuelwood	444,066	53,436	390,630	259,853	28,900	230,953	184,213	24,536	159,677
South Central									
Pulpwood	1,810,075	1,076,094	733,981	1,651,639	1,009,962	641,677	158,436	66,132	92,304
Fuelwood	408,223	16,152	392,071	108,770	5,227	103,543	299,453	10,925	288,528
Great Plains									
Pulpwood	303	303	0	303	303	0	0	0	0
Fuelwood	58,560	2,635	55,925	3,718	361	3,357	54,842	2,274	52,568
Intermountain									
Pulpwood	29,668	29,518	150	28,160	28,010	150	1,508	1,508	0
Fuelwood	95,764	79,494	16,270	6,832	5,219	1,613	88,932	74,275	14,657
Pacific Northwest and Alaska									
Pulpwood	455,847	402,269	53,578	81,696	73,499	8,197	374,151	328,770	45,381
Fuelwood	256,494	174,077	82,417	152,725	95,507	57,218	103,769	78,570	25,199
Pacific Southwest and Hawaii									
Pulpwood	13,535	7,174	6,361	3,214	1,704	1,510	10,321	5,470	4,851
Fuelwood	238,750	161,575	77,175	89,362	76,667	12,695	149,388	84,908	64,480
U.S. Total									
Pulpwood	5,049,277	3,067,366	1,981,911	4,109,934	2,473,599	1,636,335	939,343	593,767	345,576
Fuelwood	3,186,668	605,835	2,580,833	847,930	229,685	618,245	2,338,738	376,150	1,962,588
U.S. Total Roundwood									
	17,889,347	11,180,887	6,708,460	14,041,025	9,848,125	4,192,900	3,848,322	1,332,762	2,515,560

Note: Pulpwood data is included in this table for separate analysis under another title.

Source: U.S. Department of Agriculture, Forest Service, *Forest Resources of the United States, 1992*, General Technical Report RM-234 (Revised) (Fort Collins, CO, June 1994), Table 36, pp. 110-111.

compost, mulch, and animal bedding. If wood chips used for pulpwood and the resulting black liquor byproduct are also considered, an energy value of at least 600 trillion Btu is represented by logging residues and other removals. Stumpage prices vary regionally and may fluctuate by as much as 40 percent over the

short term, even though demand remains flat over the long term.²⁴ Fuelwood normally has a lower value than saw timber, veneer wood, or pulpwood, and its price varies according to available wood supply and demand for such higher valued commodities.

²⁴R.G. Haight, *Technology Change and the Economics of Silvicultural Investment*, U.S. Forest Service, General Technical Report RM-232 (Washington, DC, August 1993), p. 3.

Table 21. Approximate Weight and Energy Yield of Roundwood Fuelwood for Roundwood Harvested in the United States for Fuelwood, by Region, Species Group, and Timber Class, 1991
(Million Tons)

Region	Total of All Sources			Growing Stock			Other Sources ^a		
	Total	Softwoods	Hardwoods	Total	Softwoods	Hardwoods	Total	Softwoods	Hardwoods
Northeast	18.58	1.48	17.10	2.40	0.20	2.20	16.18	1.21	14.90
North Central	14.82	0.60	14.22	2.09	0.11	1.97	12.73	0.40	12.25
Southeast	8.75	0.94	7.81	5.13	0.51	4.62	3.62	0.43	3.19
South Central	8.12	0.28	7.84	2.16	0.09	2.07	5.96	0.19	5.77
Great Plains	1.16	0.46	1.12	0.07	0.01	0.06	1.09	0.04	1.05
Intermountain	1.72	1.39	0.33	0.12	0.09	0.03	1.59	1.30	0.29
Pacific Northwest and Alaska .	4.70	3.05	1.65	2.82	1.67	1.14	1.91	1.38	0.54
Pacific Southwest and Hawaii	4.37	2.83	1.54	1.60	1.34	0.25	2.78	1.49	1.29
U.S. Total Fuelwood	62.22	10.60	51.62	16.38	4.02	12.37	45.87	6.85	39.29
Approximate Total Energy Yield^b (trillion Btu) .	870.80	148.40	722.60	229.40	56.30	173.10	642.20	95.90	550.10

^aWeight is derived from Forest Service volume data, reported according to *wet basis* air dry moisture content of 12 percent to 13 percent, multiplying by Forest Service conversion standards of 35 pounds per cubic foot for softwoods and 40 pounds per cubic foot for hardwoods.

^bBased on an EIA-estimated energy yield of approximately 14 million Btu per ton.

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

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

Nonforest Residues

Private Clearing and Silviculture

Wood is salvaged for fuel by private owners from woodlots, farm fence rows, cropland clearing, orchards, and various operations of private urban silviculture. Comprehensive information on the disposition of wood from these sources is not available, while anecdotal evidence indicates that this wood represents an important component of residential fuelwood supply and is also commonly chipped for boiler fuel or pulpwood.²⁵ A Forest Service study of residential fuelwood use in Michigan revealed that rural woodlands in heavily forested areas supplied more than 94 percent of the residential firewood for those areas. In addition, 84 percent of the firewood supply of a more heavily populated region of the State was cut locally within that region. While general conclusions cannot be drawn from evidence of this type, it does appear that cutting

from private land and various types of urban clearing are probably more important sources of residential firewood than cutting by commercial harvesters on forestland. The Michigan study indicated that production of firewood by households was 20 times greater than production by commercial harvesters.²⁶

Urban Tree and Landscape Residues

Urban tree and landscape residues consist of tree limbs, tops, brush, leaves, stumps, and grass clippings. They are generated by commercial tree care firms, municipal tree trimming operations, electric utility power line maintenance departments, municipal park and recreation departments, orchards, and landscapers. These residues, unrecovered, make up about 18 percent of the municipal solid waste stream and represent a serious disposal problem for landfills.²⁷ Alternative uses include processing for mulch, compost, wood products such as animal litter and bedding, and fuel. It has been

²⁵U.S. Forest Service, *RPA Assessment of the Forest and Rangeland Situation in the United States: 1993 Update*, Forest Resource Report No. 27 (Washington, DC, June 1994), p. 34.

²⁶B. Smith and A. Weatherspoon, *Production and Sources of Residential Fuelwood in Michigan*, U.S. Forest Service, Resource Bulletin NC-122 (Washington, DC, October 1990), pp. 3-4.

²⁷However, wood improves the energy content of the municipal solid waste stream. See Chapter 8 for a detailed discussion of this issue.

Table 22. Wood Supply from Logging Residues and Other Removals from Noncommercial Growing Stock and Other Sources, 1991
(Thousand Cubic Feet)

Region	Total	Logging Residues		Other Removals	
		Growing Stock ^a	Other Sources ^b	Growing Stock ^c	Other Sources ^d
Northeast					
Softwood	236,305	23,757	176,180	19,886	16,482
Hardwood	392,139	73,584	200,176	61,442	56,937
North Central					
Softwood	55,043	8,360	9,836	24,990	11,857
Hardwood	486,647	106,819	77,722	165,954	136,152
Southeast					
Softwood	469,279	148,057	62,528	227,202	31,492
Hardwood	773,809	171,107	199,422	237,915	165,365
South Central					
Softwood	492,101	169,198	241,437	60,977	20,489
Hardwood	997,142	205,628	535,703	117,500	138,311
Great Plains					
Softwood	2,655	2,443	12	138	62
Hardwood	7,784	1,305	757	3,554	2,168
Intermountain					
Softwood	71,501	71,501	0	0	0
Hardwood	943	943	0	0	0
Pacific Northwest & Alaska					
Softwood	786,024	284,247			
Hardwood	18,598	5,344	488,555	0	11,673
			10,483	0	2,122
Pacific Southwest & Hawaii					
Softwood	164,887	65,035	98,682	1,549	1,059
Hardwood	18,185	7,422	10,763	649	0
U.S. Total	4,973,042	1,344,750	2,112,256	921,867	594,169

^aGrowing stock volume cut or knocked down during harvesting operations and left at harvest site.

^bWood volume other than growing stock cut or knocked down during harvesting operations but left on the ground. This volume is net of wet rot and advanced dry rot, and excludes old punky logs; essentially, it consists of material sound enough to chip. It includes dead and cull tees, tops above the 4-inch growing-stock top, and trees smaller than 5 inches in diameter at breast height and excludes stumps and limbs.

^cGrowing stock removed by cultural operations or timberland clearing not counted under harvesting of commercial growing stock.

^dWood volume other than growing stock removed by cultural operations and timber clearing; provisions of footnote (b) apply.

Source: U.S. Department of Agriculture, Forest Service, *Forest Resources of the United States, 1992*, General Technical Report RM-234 (Revised) (Fort Collins, CO, June 1994), Table 38, pp. 114-115.

estimated that about 200 million cubic yards a year are produced by all the sources generating this category. Firewood and boiler fuel (as products) and wood burned for energy by the producer of the residue are recovered from this resource. Total recovered energy from urban tree and landscape residues amounts to about 45 trillion Btu, or the equivalent of about 7 million barrels of oil per year.²⁸ Additionally, recovery of these residues for fuel and other products avoids the economic and environmental costs to society of land-filling.

Waste Wood

Waste from Primary and Secondary Wood Mills

Primary mills include sawmills, veneer mills, and pulp mills. Secondary mills include manufacturers of dimension lumber, trusses and building components, flooring, windows and doors, cabinets, pallets, poles and fencing, barrels, boats, highway transport trailers, manufactured homes, musical instruments, etc. Waste products include chips, slabs, edges, sawdust, and

²⁸J. Whittier et al., *Urban Tree Residues: Results of the First National Inventory* (NEOS Corporation, 1994).

planer shavings. Because many of the mill waste residues are clean—in contrast with such wastes as construction and demolition debris or treated lumber—they are often a source of the wood chips used by pulp and paper mills.²⁹

Mill waste residues are used primarily as fuel, with the next most important application being use as pulp and fiber for making paper products. The paper production process yields a byproduct known as “black liquor,” which is also a source of energy. Pulp and paper mills use large quantities of wood bark, edgings, and residues from their own log-stripping operations for fuel, and also buy them from facilities such as sawmills. Total annual estimated energy production from primary mill wood residues used for fuel is 744 trillion Btu (Table 23).

A comprehensive survey by the Tennessee Valley Authority (TVA) of mill residues in the Tennessee Valley region provides a good profile of residue uses (Table 24). Sawmills are the largest generator of mill wood waste, and finding uses for excess sawdust is a problem for sawmills. Some entrepreneurs have taken advantage of this resource as a raw material in the manufacture of densified wood fuel products, such as briquettes and pellets, which are used in both residential stoves and industrial boilers.

Construction and Demolition Debris

Construction and demolition debris, which makes up 10 to 15 percent of the municipal solid waste stream, includes wood, ferrous and nonferrous metals, corrugated cardboard, plastics such as wire and cable sheathing, brick, rock, and concrete. Combustible construction and demolition debris includes materials such as dimension lumber, plywood, appliance packing cartons, cardboard, wire and cable sheathing, old railroad ties, and demolished wooden bridges. Wood typically makes up about 40 percent of total construction and demolition wastes, and its uses include serving as boiler fuel and providing raw material for wood pellets.³⁰ Of the 31 million tons of construction and demolition debris generated each year, 8 million tons is wood, representing an energy potential of about 150 trillion Btu. The amount of wood contained in construction and demolition debris is expected to reach 9.5 million tons by the year 2000.³¹ However, environmental regulations restrict the recovery of fuelwood from such debris to processing sites that can separate clean wood from treated wood.

Wood from Pallets and Containers

Pallets represent a large percentage of the wood used in shipping. Point sources for pallet wastes are harbor

Table 23. Weight of Bark and Residue from Primary Wood-Using Mills Used for Fuel by Region, Species Type, and Material Used for Fuel, 1991
(Thousand Dry Tons)

Region	Total Residue			Bark Residue			Coarse Material			Fine Materials		
	Total	Soft-wood	Hard-wood	Total	Soft-wood	Hard-wood	Total	Soft-wood	Hard-wood	Total	Soft-wood	Hard-wood
Northeast	5,055	1,544	3,511	886	229	657	1,905	840	1,065	2,264	475	1,789
North Central . . .	3,544	420	3,124	1,421	258	1,163	1,073	88	985	1,050	74	976
Southeast	9,722	7,027	2,695	4,650	3,339	1,311	572	280	292	4,500	3,408	1,092
South Central . . .	13,736	8,260	5,476	8,238	5,379	2,859	758	183	575	4,740	2,698	2,042
Great Plains	108	66	42	56	44	12	35	10	25	17	12	5
Intermountain . . .	1,888	1,886	22	885	881	4	229	218	11	774	767	7
Pacific Northwest and Alaska	7,136	6,919	217	2,966	2,889	77	1,875	1,800	75	2,295	2,230	65
Pacific Southwest and Hawaii	3,610	3,580	30	1,143	1,133	10	1,157	1,147	10	1,310	1,300	10
U.S. Total	44,799	29,682	15,117	20,245	14,152	6,093	7,604	4,566	3,038	16,950	10,964	5,986
Total Estimated Energy Content 743.7 Trillion Btu												

Source: United States Forest Service, *Forest Resource of the United States* (GTR-RM-234, 1992).

²⁹Southeast Regional Biomass Energy Program, *A Sourcebook on Wood Waste Recovery and Recycling in the Southeast* (June 1994), p. IV-5.

³⁰L. Perez, “Amazing Recyclability of Construction & Demolition Wastes,” *Solid Waste Technologies*, Vol. VII, No. 1 (January/February 1994), pp. 12-18.

³¹“Growing Demand for Wood Fiber,” *Wood Recycler* (June 1994), p. 6.

Table 24. Production and Disposition of Wood Residues in the Tennessee Valley by Primary and Secondary Mills in 1979

Production of Residues	Percent of Total Produced	Percent of Total Unused
Sawmills	56.6	74.3
Pulp, Paper & Paperboard	20.2	7.3
Dimension Lumber, Flooring	4.6	5.1
Furniture	5.6	3.9
Planing Mills	3.9	2.5
Miscellaneous Wood Products	3.9	2.2
Pallets & Containers	2.9	3.5
Special Product Sawmills	1.1	0.5
Prefabricated Buildings & Mobile Homes	0.6	0.5
Plywood & Veneer	0.3	0.1
Boats, Sporting Goods, & Games	0.2	0.1
Total	100.0	100.0
Disposition of Residues	Percent of Total	
Used for Pulp & Fiber	24.0	
Metallurgical Use	1.4	
Used for Industrial Fuel	33.5	
Used for Domestic Fuel	7.6	
Miscellaneous Use	10.6	
Unused	22.9	
Total	100.0	

Source: Tennessee Valley Authority, Division of Land and Forest Resources, *Production and Use of Industrial Wood and Bark Residues in the Tennessee Valley, 1979*, Technical Note B45, April 1991, pp. 3-4. While this information is somewhat dated, a literature search revealed a scarcity of similar detailed information, and it is useful for providing a profile of one regional forest product infrastructure.

and port authorities, redistribution centers, furniture movers, common carriers, computer manufacturers, major department and retail stores, and warehouses. Because of their construction, pallets and containers recovered for fuel are most likely to be hammermilled to remove metal fasteners and then chipped for boiler fuel. (The same applies to wood from construction and demolition debris.)

In 1990, according to the Forest Service, one-third to one-half of all hardwood lumber consumption was by the pallet industry. The National Wooden Pallet and Container Association (NWPCA) estimates that 540.7 million wooden pallets were manufactured in 1991, 565.6 million in 1992, and 599.0 million in 1993.³² About 60 percent of the pallets made in the United States in 1990 were of heavy-duty construction and

were intended to be used for as long as possible; about 40 percent were of lighter construction and were intended to be “one-way.”³³ More recently, according to the NWPCA, environmental considerations are leading to an ongoing decrease in the production of one-way or single-use pallets, and the reuse of heavy-duty pallets and the establishment of user pools are growing. The NWPCA believes that one-way pallets probably will disappear by the year 2000.

A recent survey of the pallet manufacturing industry by the Virginia Polytechnic Institute indicated that 44 percent of the respondents conducted recycling operations, and that heavy-duty or “multi-use” pallets constituted 90 percent of their activity in 1992.³⁴ The survey data indicated that more than 3 million wooden pallets, equivalent to 48.5 million board feet of lumber,

³²Telephone conversation with William Sardo of the NWPCA (August 31, 1994).

³³U.S. Forest Service, *An Analysis of the Timber Situation in the United States 1989-2040*, General Technical Report RM-199 (Washington, DC, December 1990), p. 226.

³⁴E. Hansen et al., *Recycling in the U.S. Pallet Industry: 1992* (Blacksburg, VA: Virginia Polytechnic Institute, Center for Forest Products Marketing, October 1993).

were ground or chipped by pallet manufacturers in 1992 for use as fuel.

Wood Pellets³⁵

Wood pellets, manufactured from finely ground wood fiber, represent a growing biomass fuel market. Wood pellets are typically 1/4-inch to 5/16-inch in diameter by about 3/4-inch in length and weigh more than 40 pounds per cubic foot. They are generally bagged and wholesaled to feed and seed stores and residential fuel distributors to be resold for use in pellet stoves.

Sales of pellet stoves and wood pellets have increased rapidly in the past 10 years. Currently, there are 67 pellet manufacturers. Fifty-nine of these plants reported their sales, which are reflected in Table 25. The average price for pellets was \$100/ton, representing wholesale revenues of about \$50 million to manufacturers. About 70,000 pellet stoves were sold in 1993 and 88,000 were purchased in 1994. Total U.S. inventory of pellet stoves was estimated to be 330,000 by the end of 1994. Total heat energy produces by pellet stoves in 1994 can be roughly estimated to have been 8 trillion Btu, replacing the equivalent of over one million barrels of imported crude oil. Sales of pellet stoves continue to be very good and this industry is expected to grow in the near

term. Pellet stoves benefit from extremely good combustion efficiency and emissions characteristics.

The Biomass Power Industry

The biomass power industry is a decentralized, loosely knit coalition of firms, such as independent power producers, electric utilities, engineering and construction firms that use or develop biomass products, and fuel suppliers. Unlike many large utilities, biomass power producers typically are not vertically integrated (where one firm owns supply, generation, and distribution facilities) but, rather, are horizontally integrated in some areas, such as construction and engineering firms that specialize in biomass projects or provide turbines and other specialized components. Most biomass power companies today are independent power producers or are in the forest industry.

The Energy Policy Act of 1992 offers a production tax credit of 1.5 cents per kilowatthour to biomass power producers that purchase biomass fuels from “closed-loop systems.” A closed-loop system has been interpreted to mean an energy crop farm. Today, there are no such facilities in existence to allow capture of the tax credit, although several have been proposed recently.

Table 25. Regional Distribution of Pellet Fuel Sales, 1992-1993
(Tons)

Region	1993-1994	1992-1993	Percent Change	1993-1994 U.S. Market Share (percent)
Northeast	62,000	35,000	77	12
Southeast	21,000	16,000	31	5
Great Lakes	26,000	11,000	136	5
Central	18,000	21,000	-14	4
Mountain	130,000	145,000	-10	26
Pacific	239,000	198,000	21	48
U.S. Total	496,000	426,000	16	100
Energy Yield (17 MM Btu per Ton)	8.4 x 10 ⁹	7.2 x 10 ⁹	17	--

Sources: Great Lakes Regional Biomass Energy Program, *Wood Pelletization Sourcebook: A Sample Business Plan for the Potential Pellet Manufacturer*, March 1995, p. 9.

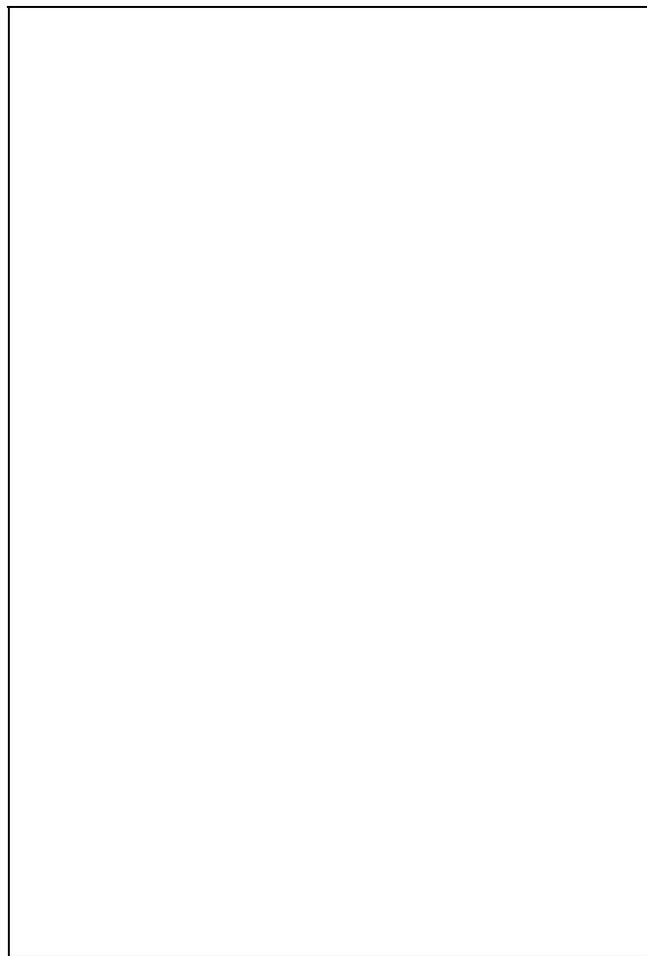
³⁵Great Lakes Regional Biomass Energy Program, *Wood Pelletization Sourcebook: A Sample Business Plan for the Potential Pellet Manufacturer*, March 1995.

Prospects for Wood Energy

The Federal Government began to encourage the development and use of renewable power, including biomass-generated electricity, after the energy crises of the 1970s. Accordingly, the wood energy industry grew along with many other alternative energy industries throughout the 1980s and early 1990s. Biomass power grew to approximately 6,500 megawatts of generating capacity in 1989 from less than 200 megawatts in 1979.³⁶ About 1,000 wood-fired power plants are currently operating in the United States; however, only a third of these offer electricity for sale.³⁷ The remainder are owned and operated by major industrial firms, mostly in the pulp and paper industry, which operate plants to provide in-house steam, heat, and electrical power. Most biomass installations are independent power producers and cogeneration systems with 10 to 25 megawatts capacity.³⁸ Several larger power plants (40 to 50 megawatts) are operating today, and future power plants promise to be larger. Significant technical and economic benefits are associated with larger plants.

In the past several years, however, a variety of factors have combined to limit the viability of biomass power. Electric utilities have gone from a condition of undercapacity to adequate capacity. Coal prices are relatively low (about \$1.00 to \$1.50 per million Btu) and the utility avoided cost for coal-fired electricity can be as low as 2 to 3 cents per kilowatt-hour, whereas the breakeven range for biomass power may be in the range of 4 to 7 cents per kilowatt-hour. Many utilities are not renewing expired purchase contracts with small producers. Section 29 of the Internal Revenue Service code (which provides for a 1.5-cent-per-kilowatt-hour tax credit for biomass-based electricity generation) is due to expire December 31, 1995, and extension is currently being debated in Congress. In addition to these factors, the problems of small power producers in the Western United States have been compounded by a limited supply of waste wood for fuel use, due to forest management constraints on logging.

On the other hand, the pulp and paper industry, which is by far the largest consumer of biomass among independent power producers, may not be as strongly affected by the above developments as are other power producers. Pulp and paper facilities are large rather than small in operating scale, and the wood and wood byproducts they burn for power and steam are largely



Three-year-old hybrid poplars, planted for paper pulp and energy, at James River Corporation's Lower Columbia River Fiber Farm.

waste materials that would otherwise represent a disposal problem. Also, much of the power generated by pulp and paper mills is consumed by the mills themselves.

Biomass Technologies and Resources Today

Although today's biomass power generation systems use direct combustion Rankine cycle technology, which is the same technology used in thermal-steam systems for coal-fired plants, technology improvements over the past 20 years in the paper and forest products industry have led to improvements in energy efficiency. Through significant investments in new biomass and recovery boilers, fossil fuel use has been reduced by almost 45

³⁶U.S. Department of Energy, *Electricity from Biomass: National Biomass Power Program Five-Year Plan (FY 1994-FY 1998)* (Washington, DC, April 1993), p. 15.

³⁷National Wood Energy Association, *Biomass Database* (March 1994).

³⁸Utility Data, Inc., *COGEN 0994 File* (September 1994).

percent and biomass use increased to now supply over 56 percent of the industry's energy needs. The industry is one of the two leading industry cogenerators, providing over half of its electricity requirements from over 9,000 megawatts of installed capacity. The paper industry was among the first to install circulating fluidized-bed boilers and combined cycle cogeneration, and is now involved in the research and development of biomass gasification.

Biomass fuels, primarily wood, fired in these systems are supplied by the forest and agricultural sector. A significant portion of the biomass power industry is comprised of cogenerators in the pulp and paper industry. These cogenerators use black liquor, bark and wood residues as fuel. Most wood fuels from the forestry and agricultural sectors have a high moisture content (up to 50 percent) and low heating value (4,000 to 5,000 Btu per pound). Urban wood wastes are generally drier (between 5 and 15 percent moisture content) and have a higher heating value (6,000 to 8,000 Btu per pound), with the exception of fresh wood trimmings, which are similar to forest residues.

Most biomass power plants operating today are characterized by low boiler efficiencies (65 to 75 percent) and low net plant efficiencies (20 to 25 percent). Beyond the fuel characteristics, the small size of most facilities contributes to the low efficiencies. Resource limitations and capacity caps promulgated under the Public Utility Regulatory Policies Act of 1978 (PURPA) limited biomass-fired plants to 50 megawatts; thus, the designs have not harnessed economies of scale, such as reheat steam loops and multistage feedwater heating. Some gasification technologies, which gasify biomass and burn the gases, have been used successfully in small-scale commercial applications, but they have not yet been integrated into large power plant designs. The Vermont Gasification Project at the McNeil Power Plant in Burlington may be the first large-scale utility demonstration of the new, higher efficiency, gasification technology.

Coal-fired power plants have also co-fired biomass with coal for many years. Recent data from controlled test burns promise significant reductions in sulfur dioxide emissions, and perhaps nitrogen oxide emissions,

although the latter results are still experimental. The benefits of sulfur dioxide reductions, coupled with carbon dioxide recycling, have increased the interest in co-firing within the utility industry. Co-firing biomass with fossil fuels, however, may require boiler modifications,³⁹ electrostatic precipitator improvements, and changes in fuel handling systems. Nonetheless, this option may be an attractive and cost-effective emission reduction strategy, particularly because of the reduced sulfur dioxide emissions. In the future, even natural gas could be co-fired with gasified biomass, enhancing fuel substitution strategies.

One issue that continues to create technical difficulties for direct-fired systems is alkali fouling. Alkaline compounds, such as potassium and sodium, contained in the biomass melt at low temperatures (for boilers). When the molten or partially molten ash particles come in contact with the boiler walls or the heat exchanger tubes, they cool and form glass-like coatings that reduce the boiler efficiency over time. Wood fuels generally minimize this phenomenon, but other biomass fuels, such as straw and agricultural products, still present a technological challenge to the industry.

Future Biomass Power Technologies

Future biomass power technologies include co-firing,⁴⁰ fast pyrolysis systems,⁴¹ and gasification systems⁴² for use in fueling combustion turbines and fuel cells.⁴³ Cofiring, especially in coal-fired plants, provides a promising avenue for increased biomass use by electric utilities, because it reduces sulfur dioxide and carbon monoxide emissions. Currently, independent power producers account for the majority of biomass use for electricity generation, but their role is threatened by the possible wholesale expiration of their PURPA contracts with utilities. The potential benefits of wood co-firing may be offset for utilities by the increasing pressure they are expected to experience as a result of deregulation and increased competition from some independent power producers (primarily, combined-cycle natural-gas-fired plants).

Gasification involves the transformation of solid biomass into a gaseous state, followed by burning in advanced gas turbines, such as combined-cycle turbines,

³⁹Cyclone boilers are more tolerant of fuel differences than are pulverized coal boilers.

⁴⁰D. Tillman et al., "Cofiring Wood Waste and Coal in Cyclone Boilers: Test Results and Prospects," in *Proceedings of Second Biomass Conference of the America* (Portland, OR, August 1995), pp. 382-389.

⁴¹T. Bridgewater and C. Peacocke, "Biomass Fast Pyrolysis," in *Proceedings of Second Biomass Conference of the America* (Portland, OR, August 1995), pp. 1037-1046.

⁴²C.T. Donovan and J.E. Fehrs, "Recent Utility Efforts To Develop Advanced Gasification Biomass Power Generation Facilities," in *Proceedings of Second Biomass Conference of the America* (Portland, OR, August 1995), pp. 702-710.

⁴³D. Patel, G. Steinfeld, and B. Baker, "Direct Fuel Cell: A High-Efficiency Power Generator for Biofuels," in *Proceedings of Bioenergy '94* (Reno, NV, October 1994), pp. 495-501.

which have overall efficiencies of 40 percent or higher. Specific areas of research and development include improving hot gas cleanup to remove alkaline compounds, identifying the source of turbine blade deposits, and identifying methods to remove particulates through temperature control using mechanical systems and feedstock additives. Demonstration units have been tested, and the first commercial-scale gasifier is planned for 1996 in Burlington, Vermont. These systems have the potential to reduce biomass power costs to levels competitive with natural gas.

Fast pyrolysis produces "biocrude," a liquid similar to crude oil, by subjecting the biomass to extreme pressure and temperatures. Research agendas include determining the combustion characteristics of various types of biocrude made from different biomass resources, understanding the interactions between fast pyrolysis conditions and the resulting characteristics of the oils, validating combustion tests, removing ash, and developing acid-resistant components.

Several types of fuel cells are under development (phosphoric acid, molten carbonate, and solid oxide fuel cells), and several are in commercial use, fueled by natural gas, methanol, or ethanol feedstocks.^{44,45} Fuel cells produce electricity through chemical reactions, as opposed to combustion, and can approach efficiencies of 60 percent, making them very attractive options. Gas or fuel quality is a particular concern for fuel cell manufacturers and operators, since small amounts of contaminants create significant problems. Much of the research in hot gas cleanup for gasification will be applicable to fuel cells. Also, programs to produce ethanol or methanol from biomass will significantly affect the economics of fuel cell operations. Expanded availability and lower cost of feedstocks will expand fuel cell opportunities.

Obstacles to Continued Growth

The key barriers to growth of biomass power today are high delivered fuel costs compared with fossil fuels, lack of public awareness of biomass power technologies, fuel supply reliability issues, and a lack of understanding the environmental impacts of the technologies and fuel supply systems. The complexity of biomass power infrastructure systems is also a challenge for utilities that are more familiar with well-established coal and natural gas fuel markets.

⁴⁴Morgantown Energy Technology Center, *Fuel Cells: Addressing America's Future Power Needs* (Morgantown, WV, not dated).

⁴⁵Morgantown Energy Technology Center, *Fuel Cells: A Handbook*, Revision 3, DOE/METC-94/1006 (Morgantown, WV, January 1994).

⁴⁶U.S. Department of Energy, *Electricity from Biomass: National Biomass Power Program Five-Year Plan (FY 1994-FY 1998)* (Washington, DC, April 1993), p. 2.

⁴⁷U.S. Department of Agriculture, Forest Service, *Carbon Storage and Accumulation in United States Forest Ecosystems*, General Technical Report WO-59 (Washington, DC, August 1992), p. 3.

The technology can be improved significantly as well. Today's low efficiencies and smaller power plants could be replaced by larger facilities and technological advances currently being investigated by industry and by Department of Energy research and development activities.

Economic Benefits of Biomass Power

Although use of biomass for power generation probably has only a modest effect on energy imports, it diversifies domestic fuel resources, offering new industry development potential in rural areas or areas outside of conventional fuel supplies (coal, oil, and natural gas). States with significant biomass resources (such as California, Maine, Georgia, Minnesota, Oregon, Washington, and Michigan) benefit from using local resources rather than exporting dollars outside the State to coal- or oil-producing regions. The direct jobs generated in a wide variety of sectors can diversify local job opportunities. New industry sectors, such as information technology, engineering design and construction, equipment manufacturing, systems controls, electronic design, and others can be developed, based on local resources. The indirect impact on jobs and economic growth can be significant. According to a recent study of the direct and indirect economic benefits of biomass power in the United States, 6,500 megawatts of biomass power production capacity resulted in a net impact of more than \$1.8 billion in personal income and corporate income in 1992.⁴⁶ Today, more than 66,000 jobs are supported by this industry. Other benefits, such as Federal, State, and local taxes are also generated.

Environmental Aspects of Wood

Biomass is important in connection with possible global warming. Through photosynthesis, biomass removes carbon from the atmosphere, thus reducing the amount of atmospheric carbon dioxide, a major contributor to the possibility of global warming. When biomass is burned to produce energy, the stored carbon is released, but the next growing cycle absorbs carbon from the atmosphere once again. This "carbon cycle" offers a unique potential for mitigating any global warming.

U.S. forest ecosystems contain nearly 58 billion tons of carbon and represent an important environmental resource for reducing atmospheric carbon dioxide.⁴⁷ In

the United States, live trees are currently accumulating carbon from the atmosphere at an average rate of 1,252 pounds per acre per year, representing a 2.7-percent yearly increase in sequestered carbon. Society realizes an annual “bonus” of 117 million tons of carbon sequestered additionally—the estimated net annual increase stored by forest systems. This is the amount of carbon left stored after the total quantity accumulated by live and dead trees (508 million tons) minus the carbon removed by timber harvest, land clearing, and

fuelwood production. However, 117 million tons of carbon is equivalent to only 9 percent of total annual U.S. atmospheric carbon emissions.⁴⁸

Biomass combustion does produce ash, but it results in less ash than coal combustion does, reducing ash disposal costs and landfill space requirements. The biomass ash can also be used as a soil additive on farmland.

⁴⁸U.S. Department of Agriculture, Forest Service, *Carbon Storage and Accumulation in United States Forest Ecosystems*, General Technical Report WO-59 (Washington, DC, August 1992), pp. 3-6.

Biomass Milestones

1890	Wood as a primary fuel supply	Wood was the primary fuel for residential, commercial, and transportation uses.
1930	Wood displaced by new fuels	Kerosene and fuel oil began displacing wood for some commercial, transportation, and residential uses.
1950	More new fuels displacing wood	Electricity and natural gas displaced wood heat in homes and commercial buildings.
1973	Wood use at all-time low	Higher oil and gas prices and oil embargoes hit the country at the time that wood consumption for energy was at an all-time low of roughly 50 million tons per year.
1974	Rise in woodstove sales, switching by some industries from coal to waste wood	The oil crises of 1973-74 prompted significant increases in woodstove sales for residential use. The paper and pulp industry also began to install wood and black liquor boilers for steam and power displacing fuel oil and coal.
1978	Public Utility Regulatory Policies Act (PURPA) passed	PURPA guaranteed nonutility generators a market to sell power by mandating that utilities pay "avoided cost" rates for any power supplied by a qualifying facility.
1984	Startup of Burlington Electric plant	Burlington Electric (Burlington, Vermont) built a 50-megawatt wood-fired plant with electricity production as the primary purpose. This plant was the first of several built since 1984.
1985	Standard Offer #4 contracts begin	The Californian biomass power industry began to grow, eventually adding 850 megawatts of power due to fuel cost escalation clauses in the Standard Offer #4 contracts which were based on predicted oil costs of \$100 a barrel. These 10-year contracts guaranteed power purchase rates.
1989-90	First trials of direct wood-fired gas turbines conducted	Pilot direct wood-fired gas turbine plants were tried for the first time by Canadian Solifuels, Inc. (in Canada) and Aerospace Research Corporation (in the United States).
1990	Biomass generating capacity at 6,000 megawatts	Electricity generating capacity from biomass (not including municipal solid waste) reached 6 gigawatts. Of 190 biomass-fired electricity generating facilities, 184 were nonutility generators, mostly wood and paper plants.
1992	Rise in biomass prices to \$55 per dry ton in California	The industry overbuilt capacity, with little regard for supply limitations, resulting in escalating feedstock prices as the last of the Standard Offer #4 contract power plants came on line. New sources of biomass eventually reduced costs to an average of \$35 per dry ton.

1994	Hot gas cleanup identified as key to gasification success.	Successful operation of several biomass gasification tests identified hot gas cleanup as key to widespread adoption of the technology. Promising high efficiencies were achieved.
1995	Half of the California biomass power industry shut down	As of the end of August 1995, 15 biomass power plants (500 megawatts) had been closed through sales or buyout of their Standard Offer #4 agreements, primarily as a cost reduction strategy by the local utilities required to buy the power, which had sometimes risen to more than 10 cents per kilowatthour, depending on the contract.