Biopower

Technology Description

Biopower, also called biomass power, is the generation of electric power from biomass resources – now usually urban waste wood, crop, and forest residues; and, in the future, crops grown specifically for energy production. Biopower reduces most emissions (including emissions of greenhouse gases-GHGs) compared with fossil fuel-based electricity. Because biomass absorbs CO_2 as it grows, the entire biopower cycle of growing, converting to electricity, and regrowing biomass can result in very low CO_2 emissions compared to fossil energy without carbon sequestration, such as coal, oil or natural gas. Through the use of residues, biopower systems can even represent a net sink for GHG emissions by avoiding methane emissions that would result from landfilling of the unused biomass.

Representative Technologies for Conversion of Feedstock to Fuel for Power and Heat

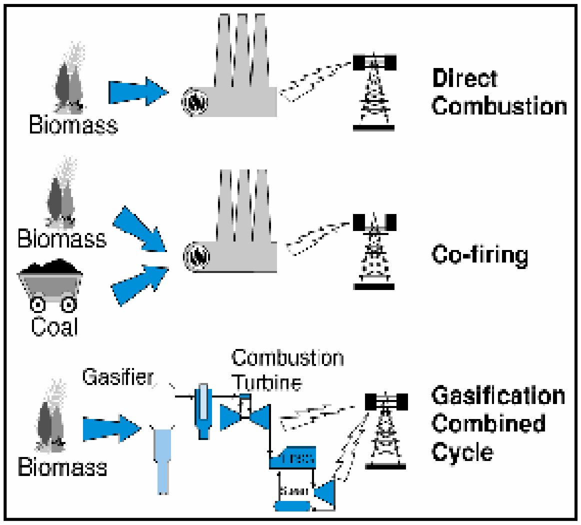
- *Homogenization* is a process by which feedstock is made physically uniform for further processing or for combustion (includes chopping, grinding, baling, cubing, and pelletizing).
- *Gasification* (via pyrolysis, partial oxidation, or steam reforming) converts biomass to a fuel gas that can be substituted for natural gas in combustion turbines or reformed into H_2 for fuel cell applications.
- *Anaerobic digestion* produces biogas that can be used in standard or combined heat and power (CHP) applications. Agricultural digester systems use animal or agricultural waste. Landfill gas also is produced anaerobically.
- *Biofuels production for power and heat* provides liquid-based fuels such as methanol, ethanol, hydrogen, or biodiesel.

Representative Technologies for Conversion of Fuel to Power and Heat

- Direct combustion systems burn biomass fuel in a boiler to produce steam that is expanded in a Rankine Cycle prime mover to produce power.
- Cofiring substitutes biomass for coal or other fossil fuels in existing coal-fired boilers.
- Biomass or biomass-derived fuels (e.g. syngas, ethanol, biodiesel) also can be burned in combustion turbines (Brayton cycle) or engines (Otto or Diesel cycle) to produce power.
- When further processed, biomass-derived fuels can be used by fuels cells to produce electricity

System Concepts

- CHP applications involve recovery of heat for steam and/or hot water for district energy, industrial processes, and other applications.



- Nearly all current biopower generation is based on direct combustion in small, biomass-only plants with relatively low electric efficiency (20%), although total system efficiencies for CHP can approach 90%. Most biomass direct-combustion generation facilities utilize the basic Rankine cycle for electric-power generation, which is made up of the steam generator (boiler), turbine, condenser, and pump.
- For the near term, cofiring is the most cost-effective of the power-only technologies. Large coal steam plants have electric efficiencies near 33%. The highest levels of coal cofiring (15% on a heat-input basis) require separate feed preparation and injection systems.
- Biomass gasification combined-cycle plants promise comparable or higher electric efficiencies (> 40%) using only biomass, because they involve gas turbines (Brayton cycle), which are more efficient than Rankine cycles, as is true for coal. Other technologies being developed include integrated gasification/fuel cell and biorefinery concepts.

Technology Applications

• The existing biopower sector – nearly 1,000 plants – is mainly comprised of direct-combustion plants, with an additional small amount of cofiring (six operating plants). Plant size averages 20 MW_e, and the biomass-to-electricity conversion efficiency is about 20%. Grid-connected electrical capacity has increased from less than 200 MW_e in 1978 to more than 9,700 MW_e in 2001. More than 75% of this power is generated in the forest products industry's CHP applications for process heat. Wood-fired systems account for close to 95% of this capacity. In addition, about 3,300 MW_e of municipal solid waste and landfill gas generating capacity exists. Recent studies estimate that on a life-cycle basis, existing biopower plants represent an annual net carbon sink of 4 MMTCe. Prices generally range from 8¢/kWh to 12¢/kWh.

Current Status

• CHP applications using a waste fuel are generally the most cost-effective biopower option. Growth is limited by availability of waste fuel and heat demand.

• Biomass cofiring with coal ($50 - 250/kW of biomass capacity) is the most near-term option for large-scale use of biomass for power-only electricity generation. Cofiring also reduces sulfur dioxide and nitrogen oxide emissions. In addition, when cofiring crop and forest-product residues, GHG emissions are reduced by a greater percentage (e.g. 23% GHG emissions reduction with 15% cofiring).

• Biomass gasification for large-scale (20-100MW_e) power production is being commercialized. It will be an important technology for cogeneration in the forest-products industries (which project a need for biomass and black liquor CHP technologies with a higher electric-thermal ratio), as well as for new baseload capacity. Gasification also is important as a potential platform for a biorefinery.

• Small biopower and biodiesel systems have been used for many years in the developing world for electricity generation. However, these systems have not always been reliable and clean. DOE is developing systems for village-power applications and for developed-world distributed generation that are efficient, reliable, and clean. These systems range in size from 3kW to 5MW and completed field verification by 2003.

• Approximately 15 million to 21 million gallons of biodiesel are produced annually in the United States.

• Utility and industrial biopower generation totaled more than 60 billion kWh in 2001, representing about 75% of nonhydroelectric renewable generation. About two-thirds of this energy is derived from wood and wood wastes, while one-third of the biopower is from municipal solid waste and landfill gas. Industry consumes more than 2.1 quadrillion Btu of primary biomass energy.

Technology History

• In the latter part of the 19^{th} century, wood was the primary fuel for residential, commercial, and transportation uses. By the 1950s, other fuels had supplanted wood. In 1973, wood use had dropped to 50 million tons per year.

• At that point, the forest products and pulp-and-paper industries began to use wood with coal in new plants and switched to wood-fired steam power generation.

• The Public Utility Regulatory Policies Act (PURPA) of 1978 stimulated the development of nonutility cogeneration and small-scale plants to in the wood-processing and pulp-and-paper sectors and increased supply of power to the grid.

• The combination of low natural gas prices, improved economies of scale in combined cycle palns, and withdrawal of incentives in the late 1980s, led to annual installations declining from about 600 MW in 1989, to 300-350MW in 1990.

• There are now nearly 1,000 wood-fired plants in the United States, with about two-thirds of those providing power (and heat) for on-site uses only.

Technology Future

The levelized cost of electricity (in constant 1997$/kWh) for biomass direct-fired and gasification configurations are projected to be:

	2000	2010	2020
Direct-fired	7.5	7.0	5.8
Gasification	6.7	6.1	5.4

Source: *Renewable Energy Technology Characterizations*, EPRI TR-109496, 1997.

- R&D directions include:

Gasification – This technology requires extensive field verification in order to be adopted by the relatively conservative utility and forest-products industries, especially to demonstrate integrated operation of biomass gasifier with advanced-power generation (turbines and/or fuel cells). Integration of gasification into a biorefinery platform is a key new research area.

Small Modular Systems – Small-scale systems for distributed or minigrid (for premium or village power) applications will be increasingly in demand.

Cofiring – The DOE biopower program is moving away from research on cofiring, as this technology has reached a mature status. However, continued industry research and field verifications are needed to address specific technical and nontechnical barriers to cofiring. Future technology development will benefit from finding ways to better prepare, inject, and control biomass combustion in a coal-fired boiler. Improved methods for combining coal and biomass fuels will maximize efficiency and minimize emissions. Systems are expected to include biomass cofiring up to 5% of natural gas combined-cycle capacity.

Source: National Renewable Energy Laboratory. *U.S. Climate Change Technology Program. Technology Options: For the Near and Long Term.* DOE/PI-0002. November 2003 (draft update, September 2005).

Biomass

Market Data

Cumulative Generating Capability, by Type (MW)

Source: Energy Information Administration (EIA), EIA, *Annual Energy Review 2004*, DOE/EIA-0384(2004) (Washington, D.C., August 2005), Tables 8.11a and 8.11c, and world data from United Nations Development Program, World Energy Assessment, 2000, Table 7.25.

	1980	1985	1990	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
U.S. Electric Power Sector													
Municipal Solid Waste[1]	N/A	151	1,852	2,733	2,600	2,528	2,636	2,614	2,789	2,993	2,949	2,842	2,856
Wood and Other Biomass[2]	78	200	964	1,451	1,425	1,452	1,438	1,484	1,486	1,487	1,410	1,389	1,389
U.S. Cogenerators[3]													
Municipal Solid Waste[1]			659	786	998	1,062	1,058	1,046	1,094	834	842	961	961
Wood and Other Biomass[2]			4,585	5,298	5,382	5,472	5,364	5,311	4,655	4,394	4,399	4,482	4,502
U.S. Total													
Municipal Solid Waste[1]	NA	151	2,511	3,519	3,598	3,590	3,694	3,660	3,883	3,827	3,845	3,803	3,817
Wood and Other Biomass[2]	78	200	5,549	6,750	6,808	6,924	6,802	6,795	6,141	5,882	5,844	5,871	5,891
Biomass Total	78	351	8,061	10,269	10,405	10,515	10,495	10,454	10,024	9,709	9,689	9,674	9,708
Rest of World Total[4]							29,505						
World Total							40,000						

[1] Municipal solid waste, landfill gas, sludge waste, tires, agricultural byproducts, and other biomass.

[2] Wood, black liquor, and other wood waste.

[3] Data include electric power sector and end-use sector (industrial and commercial) generators.

[4] Number derived from subtracting U.S. total from the world total. Figures may not add due to rounding.

U.S. Annual Installed Generating Capability, by Type (MW)

Source: *Renewable Electric Plant Information System (REPiS)*, Version 7, NREL, 2003.

	1980	1985	1990	1995	1996	1997	1998	1999	2000	2001	2002	2003[1]
Agricultural Waste[2]	22.6	20.1	0	4.0	0	21.6	0	0	0	0	0	0
Biogas[3]	0.1	58.6	51.3	17.5	74.8	92.7	87.3	107.6	43.8	66.8	30.2	23.1
Municipal Solid Waste[4]	50.0	117.2	260.3	94.5	0	0	0	22.0	0	0	0	30.0
Wood Residues[5]	260.4	254.8	299.4	66.5	91.6	40.0	90.3	13.0	0	11.3	38.8	0
Total	333.0	450.7	611.0	182.5	166.4	154.3	177.6	142.6	43.8	78.1	69.0	53.1

U.S. Cumulative Generating Capability, by Type[6] (MW)

Source: *Renewable Electric Plant Information System (REPiS)*, Version 7, NREL, 2003.

	1980	1985	1990	1995	1996	1997	1998	1999	2000	2001	2002	2003[1]
Agricultural Waste[2]	40	92	165	351	351	373	373	373	373	373	373	373
Biogas[3]	18	117	361	526	601	694	781	889	933	999	1,030	1,053
Municipal Solid Waste[4]	263	697	2,172	2,948	2,948	2,948	2,948	2,970	2,970	2,970	2,970	3,000
Wood Residues[5]	3,576	4,935	6,305	7,212	7,303	7,343	7,434	7,447	7,447	7,458	7,497	7,497
Total	3,897	5,840	9,003	11,037	11,203	11,358	11,535	11,678	11,722	11,800	11,869	11,922

Note: The data in this table does not match data in the previous table, due to different coverage ratios in EIA and REPIS databases.

[1] 2003 data not complete as REPiS database is updated through 2002.

[2] Agricultural residues, cannery wastes, nut hulls, fruit pits, nut shells

[3] Biogas, alcohol (includes butahol, ethanol, and methanol), bagasse, hydrogen, landfill gas, livestock manure, wood gas (from wood gasifier)

[4] Municipal solid waste (includes industrial and medical), hazardous waste, scrap tires, wastewater sludge, refused-derived fuel

[5] Timber and logging residues (includes tree bark, wood chips, saw dust, pulping liquor, peat, tree pitch, wood or wood waste)

[6] There are an additional 65.45 MW of Ag Waste, 5.445 MW of Bio Gas, and 483.31 MW of Wood Residues that are not accounted for here because they have no specific online date.

Generation from Cumulative Capacity, by Type (Million kWh)	Source: EIA, *Annual Energy Review 2003*, Tables 8.2a and 8.2c, and world data from United Nations Development Program, World Energy Assessment, 2000, Table 7.25.												
	1980	**1985**	**1990**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
U.S. Electric Power Sector													
Municipal Solid Waste[1]	158	640	10,245	16,326	16,078	16,397	16,963	17,112	17,592	17,221	17,359	18,141	17,809
Wood and Other Biomass[2]	275	743	5,327	5,885	6,493	6,468	6,644	7,254	7,301	6,571	7,265	7,402	7,475
U.S. Cogenerators[3]													
Municipal Solid Waste[1]			2,904	4,079	4,834	5,312	5,485	5,460	5,540	4,543	5,498	5,889	4,938
Wood and Other Biomass[2]			26,939	30,636	30,307	30,480	29,694	29,787	30,294	28,629	31,400	29,735	29,820
U.S. Total													
Municipal Solid Waste[1]	158	640	13,149	20,405	20,911	21,709	22,448	22,572	23,131	21,765	22,857	23,736	22,747
Wood and Other Biomass[2]	275	743	32,266	36,521	36,800	36,948	36,338	37,041	37,595	35,200	38,665	37,529	37,295
Biomass Total	433	1,383	45,415	56,926	57,712	58,658	58,786	59,613	60,726	56,964	61,522	61,265	60,042
Rest of World Total[4]							101,214						
World Total							160,000						

[1] Municipal solid waste, landfill gas, sludge waste, tires, agricultural byproducts, and other biomass.

[2] Wood, black liquor, and other wood waste.

[3] Data include electric power sector and end-use sector (industrial and commercial) generators.

[4] Number derived from subtracting U.S. total from the world total. Figures may not add due to rounding.

U.S. Annual Energy Consumption for Electricity Generation (Trillion Btu)	Source: EIA, *Annual Energy Review 2004*, Tables 8.4b and 8.4c												
	1980	**1985**	**1990**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**
Electric-Power Sector	4.5	14.4	285.9	388.0	397.3	408.3	412.0	415.5	420.7	430.4	494.1	493.1	492.4
Commercial Sector[1]			16.7	22.3	32.1	34.3	32.7	33.5	26.5	22.6	28.5	30.6	32.2
Industrial Sector[1]			351.0	385.3	407.1	380.7	362.0	373.0	378.8	379.6	481.5	378.7	567.8
Total Biomass	4.5	14.4	653.5	795.6	836.5	823.3	806.8	822.0	825.9	832.6	1,004.1	902.4	1,092.4

Data include wood (wood, black liquor, and other wood waste) and waste (municipal solid waste, landfill gas, sludge waste, tires, agricultural byproducts, and other biomass).

[1] Data includes combined-heat-and-power (CHP) and electricity-only plants.

Technology Performance

Source: *Renewable Energy Technology Characterizations*, EPRI TR-109496, 1997.

Efficiency		1980	1990	1995[1]	2000	2005	2010	2015[2]	2020
Capacity Factor (%)	Direct-fired			80.0	80.0	80.0	80.0	80.0	80.0
	Cofired			85.0	85.0	85.0	85.0	85.0	85.0
	Gasification			80.0	80.0	80.0	80.0	80.0	80.0
Efficiency (%)	Direct-fired			23.0	27.7	27.7	27.7	30.8	33.9
	Cofired			32.7	32.5	32.5	32.5	32.5	32.5
	Gasification			36.0	36.0	37.0	37.0	39.3	41.5
Net Heat Rate (kJ/kWh)	Direct-fired			15,280	13,000	13,000	13,000	11,810	10,620
	Cofired			11,015	11,066	11,066	11,066	11,066	11,066
	Gasification			10,000	10,000	9,730	9,730	9,200	8,670

Cost		1980	1990	1995[1]	2000	2005	2010	2015	2020
Total Capital Cost ($/kW)	Direct-fired			1,965	1,745	1,510	1,346	1,231	1,115
	Cofired[3]			272	256	241	230	224	217
	Gasification			2,102	1,892	1,650	1,464	1,361	1,258
Feed Cost ($/GJ)	Direct-fired			2.50	2.50	2.50	2.50	2.50	2.50
	Cofired[3]			-0.73	-0.73	-0.73	-0.73	-0.73	-0.73
	Gasification			2.50	2.50	2.50	2.50	2.50	2.50
Fixed Operating Cost ($/kW-yr)	Direct-fired			73.0	60.0	60.0	60.0	54.5	49.0
	Cofired[3]			10.4	10.1	9.8	9.6	9.5	9.3
	Gasification			68.7	43.4	43.4	43.4	43.4	43.4
		1980	1990	1995[1]	2000	2005	2010	2015	2020
Variable Operating Costs ($/kWh)	Direct-fired			0.009	0.007	0.007	0.007	0.006	0.006
	Cofired[3]			-0.002	-0.002	-0.002	-0.002	-0.002	-0.002
	Gasification			0.004	0.004	0.004	0.004	0.004	0.004
Total Operating Costs ($/kWh)	Direct-fired			0.055	0.047	0.047	0.047	0.043	0.039
	Cofired[3]			-0.008	-0.008	-0.008	-0.009	-0.009	-0.009
	Gasification			0.040	0.036	0.036	0.036	0.034	0.033
Levelized Cost of Energy ($/kWh)	Direct-fired			0.087	0.075		0.070		0.058
	Cofired[3]			N/A	N/A	N/A	N/A	N/A	N/A
	Gasification			0.073	0.067		0.061		0.054

[1] Data is for 1997, the base year of the Renewable Energy Technology Characterizations analysis.

[2] Number derived by interpolation.

[3] Note that cofired cost characteristics represent only the biomass portion of costs for capital and incremental costs above conventional costs for Operations & Maintenance (O&M), and assume $9.14/dry tonne biomass and $39.09/tonne coal, a heat input from biomass at 19,104 kJ/kg, and that variable O&M includes an SO2 credit valued at $110/tonne SO2. No cofiring COE is reported in the *RETC*.