Biomass Combined Heat and Power Catalog of Technologies

U. S. Environmental Protection Agency
Combined Heat and Power Partnership

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v.1.1

Foreword

The U.S. Environmental Protection Agency (EPA) Combined Heat and Power (CHP) Partnership is a voluntary program that seeks to reduce the environmental impact of power generation by promoting the use of CHP. CHP is an efficient, clean, and reliable approach to generating power and thermal energy from a single fuel source. CHP can increase operational efficiency and decrease energy costs, while reducing the emissions of greenhouse gases, which contribute to global climate change. The CHP Partnership works closely with energy users, the CHP industry, state and local governments, and other stakeholders to support the development of new projects and promote their energy, environmental, and economic benefits.

This version 1.1 deletes references to the CO_2 benefits of combusting biomass pending a final EPA determination on how to evaluate CO_2 emissions from the combustion of biomass.

The partnership provides resources about CHP technologies, incentives, emission profiles, and other information on its Web site at www.epa.gov/chp. For more information, contact:

Susan Wickwire
202 343 9155
wickwire.susan@epa.gov

Report prepared by: Energy and Environmental Analysis, Inc., an ICF International Company, and Eastern Research Group, Inc. (ERG) for the U. S. Environmental Protection Agency, Combined Heat and Power Partnership, September 2007.

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Acronyms & Abbreviations

AC	alternating current
Btu	British thermal unit(s)
C&D	construction and demolition
CCAR	California Climate Action Registry
CDM	clean development mechanism
CHP	combined heat and power
cfm	cubic feet per minute
CI	compression ignition
CIBO	Council of Industrial Boiler Owners
CO	carbon monoxide
CO_2	carbon dioxide
DOE	U.S. Department of Energy
EPA	U.S. Environmental Protection Agency
EPRI	Electric Power Research Institute
ft^3	cubic foot
GHG	greenhouse gases
HHV	high heating value
hr	hour(s)
Hz	Hertz
IC	internal combustion
IGCC	integrated gasification combined cycle
IPCC	Intergovernmental Panel on Climate Change
kW	kilowatt(s)
kWh	kilowatt-hour(s)
lb	pound(s)
LFG	landfill gas
LMOP	Landfill Methane Outreach Program
MCFC	molten carbonate fuel cell
Mlb	thousand pounds
MMBtu	million British thermal units
MSW	municipal solid waste
MW	megawatt(s)
MWh	megawatt-hour(s)
N_2O	nitrous oxide
NO_X	nitrogen oxides
NRCS	Natural Resource Conservation Service
O&M	operations and maintenance
ORC	organic Rankine cycle
PAFC	phosphoric acid fuel cell
PEMFC	proton exchange membrane fuel cell
PM	particulate matter
ppm	parts per million
psig	pounds per square inch gauge
scf	standard cubic foot
SI	spark ignition
SO_2	sulfur dioxide
SOFC	solid oxide fuel cell

UNFCCC	United Nations Framework Convention on Climate Change
USDA	U.S. Department of Agriculture
WWTF	wastewater treatment facility

1. Introduction and Overview

1.1 Biomass for Power and Heat Generation

As part of its efforts to reduce the environmental impacts of energy production and use, the U.S. Environmental Protection Agency (EPA) has engaged in outreach and technical assistance to broadly increase understanding and use of highly efficient combined heat and power (CHP) applications through the efforts of the CHP Partnership program. Over the past three years, market and policy forces have driven strong interest and early implementation of new biomass-fueled CHP projects by Partners and other clean energy stakeholders. In the interest of continuing the trend toward greater utilization of biomass fuels to power clean, efficient electricity and thermal energy generation, this document provides resource owners, facility managers, developers, policymakers, and other interested parties with a detailed technology characterization of biomass CHP systems. The report reviews the technical and economic characterization of biomass resources, biomass preparation, energy conversion technologies, power production systems, and complete integrated systems.

There are many potential advantages to using biomass instead of fossil fuels for meeting energy needs. Specific benefits depend upon the intended use and fuel source, but often include: greenhouse gas and other air pollutant reductions, energy cost savings, local economic development, waste reduction, and the security of a domestic fuel supply. In addition, biomass is more flexible (e.g., can generate both power and heat) and reliable (as a non-intermittent resource) as an energy option than many other sources of renewable energy.

Biomass fuels are typically used most efficiently and beneficially when generating both power and heat through CHP. CHP, also known as cogeneration, is the simultaneous production of electricity and heat from a single fuel source, such as biomass/biogas, natural gas, coal, or oil. CHP provides:

- **Distributed generation** of electrical and/or mechanical power.
- **Waste-heat recovery** for heating, cooling, or process applications.
- **Seamless system integration** for a variety of technologies, thermal applications, and fuel types into existing building infrastructure.

CHP is not a single technology, but an integrated energy system that can be modified depending on the needs of the energy end user. The hallmark of all well-designed CHP systems is an increase in the efficiency of fuel use. By using waste heat recovery technology to capture a significant proportion of heat created as a byproduct in electricity generation, CHP systems typically achieve total system efficiencies of 60 to 80 percent for producing electricity and thermal energy. These efficiency gains improve the economics of using biomass fuels, as well as produce other environmental benefits. More than 60 percent of current biomass-powered electricity generation in the United States is in the form of CHP.[1]

[1] Energy and Environmental Analysis, Inc., 2006.

The industrial sector currently produces both steam or hot water and electricity from biomass in CHP facilities in the paper, chemical, wood products, and food-processing industries. These industries are major users of biomass fuels; utilizing the heat and steam in their processes can improve energy efficiency by more than 35 percent. The biggest industrial user of bioenergy is the forest products industry, which consumes 85 percent of all wood waste used for energy in the United States. Manufacturing plants that utilize forest products can typically generate more than half of their own energy from woody waste products and other renewable sources of fuel (e.g., wood chips, black liquor).

Most of the electricity, heat, and steam produced by industrial facilities are consumed on site; however, some manufacturers that produce more electricity than they need on site sell excess power to the grid. Wider use of biomass resources will directly benefit many companies that generate more residues (e.g., wood or processing wastes) than they can use internally. New markets for these excess materials may support business expansion as the residues are purchased for energy generation purposes or new profit centers of renewable energy production may diversify and support the core business of these companies.

1.2 Biomass Feedstocks

The success of any biomass-fueled CHP project is heavily dependent on the availability of a suitable biomass feedstock. Biomass feedstocks are widely available in both rural and urban settings and can include:

Rural Resources:

- Forest residues and wood wastes
- Crop residues
- Energy crops
- Manure biogas

Urban Resources:

- Urban wood waste
- Wastewater treatment biogas
- Municipal solid waste (MSW) and landfill gas (LFG)
- Food processing residue

Feedstocks vary widely in their sources and fuel characteristics and therefore vary in typical considerations for their utilization. Various biomass resources can require different approaches to collection, storage, and transportation, as well as different considerations regarding the conversion process and power generation technology that they would most effectively fuel.

Of the 9,709 megawatts (MW) of biomass electric capacity in the United States in 2004, about 5,891 MW were from wood and wood wastes; 3,319 MW of generating capacity was from MSW and LFG; and 499 MW of capacity was attributable to other biomass, such as agricultural residues, sludge, anaerobic digester gas, and other sources.[2]

[2] Energy Information Administration, 2006.

1.3 Biomass Conversion

Biomass can be used in its solid form or gasified for heating applications or electricity generation, or it can be converted into liquid or gaseous fuels. Biomass conversion refers to the process of converting biomass feedstocks into energy that will then be used to generate electricity and/or heat.

Multiple commercial, proven and cost effective technologies for converting biomass feedstocks to electricity and heat are currently available in the United States (see **Table 1-1**). These technologies include anaerobic digesters for animal waste or wastewater, and three types of direct-fired boiler systems that have been used for decades for converting woody biomass: fixed bed boilers, fluidized bed boilers, and cofiring applications. Some of these boiler technologies are extremely clean and can result in electricity production of up to 50 megawatts (MW)—enough electricity to power 50,000 homes.[3]

Additionally, an emerging class of biomass conversion technologies is becoming available that converts woody biomass feedstocks to useable fuel through gasification processes. These technologies, called fixed bed gasifiers and fluidized bed gasifiers, are becoming commercialized and are currently in limited use producing syngas for power and heat. Rapid commercialization may be seen in the near future as these gasification technologies are expected to be used in integrated gasification combined cycle (IGCC) coal plants and within some of the thermochemical (cellulosic) biorefineries built in the United States in the next two to ten years (see **Table 1-1**). Modular versions—smaller than 5 MW—of both direct-fired boiler and gasification technologies are also being developed, though they are at earlier stages of commercialization.

[3] In contrast, coal-fired power plants are generally sized in the 100 MW to 1,000 MW range.

1.4 Report Layout

The report is organized into the following chapters:

Chapter 2: **Basic First Steps and Considerations**—This chapter provides an overview of basic considerations that need to be taken into account when beginning to evaluate the viability of biomass-fueled electricity and thermal energy generation.

Chapter 3: **Biomass Resources**—This chapter presents a discussion of the various types of biomass resources, locations, characteristics, resource potential, and costs.

Chapter 4: **Biomass Preparation**—This chapter describes the receiving, processing, and treatment systems required for preparing biomass feedstocks and biogas for use as a power generation fuel. Equipment configurations and capital and operating costs are outlined.

Chapter 5: **Biomass Conversion Technologies**—This chapter describes configurations, cost, and performance for the two basic biomass conversion approaches: combustion and gasification. In addition, a brief discussion of small modular biomass conversion technologies is presented.

Chapter 6: **Power Generation Technologies**—This chapter provides basic cost and performance information for power generation technologies with heat recovery, and special considerations for selecting and operating these technologies on biomass or biogas fuels.

Chapter 7: **Representative Biomass CHP System Cost and Performance Profiles—** This chapter provides an integration of resource, preparation, conversion, and power and heat production system costs into integrated biomass-fueled CHP facilities. Capital costs, operating costs, fuel costs, and typical energy balances, including power and heat production options, are described. This chapter provides a starting point for conducting a preliminary economic screening of possible biomass energy production options.

Additional biomass-related resources and tools created by the EPA CHP Partnership are listed in Appendix B.

Table 1-1. Commercialization Status of Biomass Conversion Systems for Power and Heat Generation
This table identifies the major biomass conversion technologies and associated prime mover technologies for CHP applications. The commercial status of each technology for biomass applications is described.

Energy Conversion Technology	Conversion Technology Commercialization Status	Integrated CHP Technology (Prime Mover)	Prime Mover Commercialization Status
Anaerobic Digestion			
Anaerobic digester (from animal feeding operations or wastewater treatment facilities)	Commercial technology	Internal combustion engine	Commercial technology
		Microturbine	Commercial technology
		Gas turbine	Commercial technology
		Fuel cell	Commercial introduction
		Stirling engine	Emerging
Direct Combustion—Boilers			
Fixed bed boilers (stoker)	Commercial technology – Stoker boilers have long been a standard technology for biomass as well as coal, and are offered by a number of manufacturers.	Steam turbine	Commercial technology
Fluidized bed boilers	Commercial technology – Until recently fluidized bed boiler use has been more widespread in Europe than the United States. Fluidized bed boilers are a newer technology, but are commercially available through a number of manufacturers, many of whom are European-based.		
Cofiring	Commercial technology – Cofiring biomass with coal has been successful in a wide range of boiler types including cyclone, stoker, pulverized coal, and bubbling and circulating fluidized bed boilers.		
Modular* direct combustion technology	Commercial technology – Small boiler systems commercially available for space heating. A small number of demonstration projects in CHP configuration.	Small steam turbine	Commercial technology
		Organic Rankine cycle	Emerging technology – Some "commercial" products available.
		"Entropic" cycle	Research and development (R&D) status
		Hot air turbine	R&D status

*Small, packaged, pre-engineered systems (smaller than 5 MW).

Energy Conversion Technology	Conversion Technology Commercialization Status	Integrated CHP Technology (Prime Mover)	Prime Mover Commercialization Status
Gasification			
Fixed bed gasifiers	Emerging technology – The actual number of biomass gasification systems in operation worldwide is unknown, but is estimated to be below 25.	Gas turbines – simple cycle	Prime movers have been commercially proven with natural gas and some medium heating value biogas.
Fluidized bed gasifiers	A review of gasifier manufacturers in Europe, USA, and Canada identified 50 manufacturers offering commercial gasification plants from which 75 percent of the designs were fixed bed; 20 percent of the designs were fluidized bed systems.	Gas turbines – combined cycle	Operation on low heating value biogas and the effects of impurities on prime mover reliability and longevity need to be demonstrated.
		Large internal combustion (IC) engines	
Modular* gasification technology	Emerging technology – A small number of demonstration projects supported with research, design, and development funding.	IC engine	Commercial technology – But operation on very low heating value biogas needs to be demonstrated.
		Microturbine	
		Fuel cell	Commercial introduction
		Stirling engine	Emerging technology
Modular* hybrid gasification/combustion	Emerging technology – Limited commercial demonstration.	Small steam turbine	Commercial technology – But integrated system emerging.

*Small, packaged, pre-engineered systems (smaller than 5 MW).