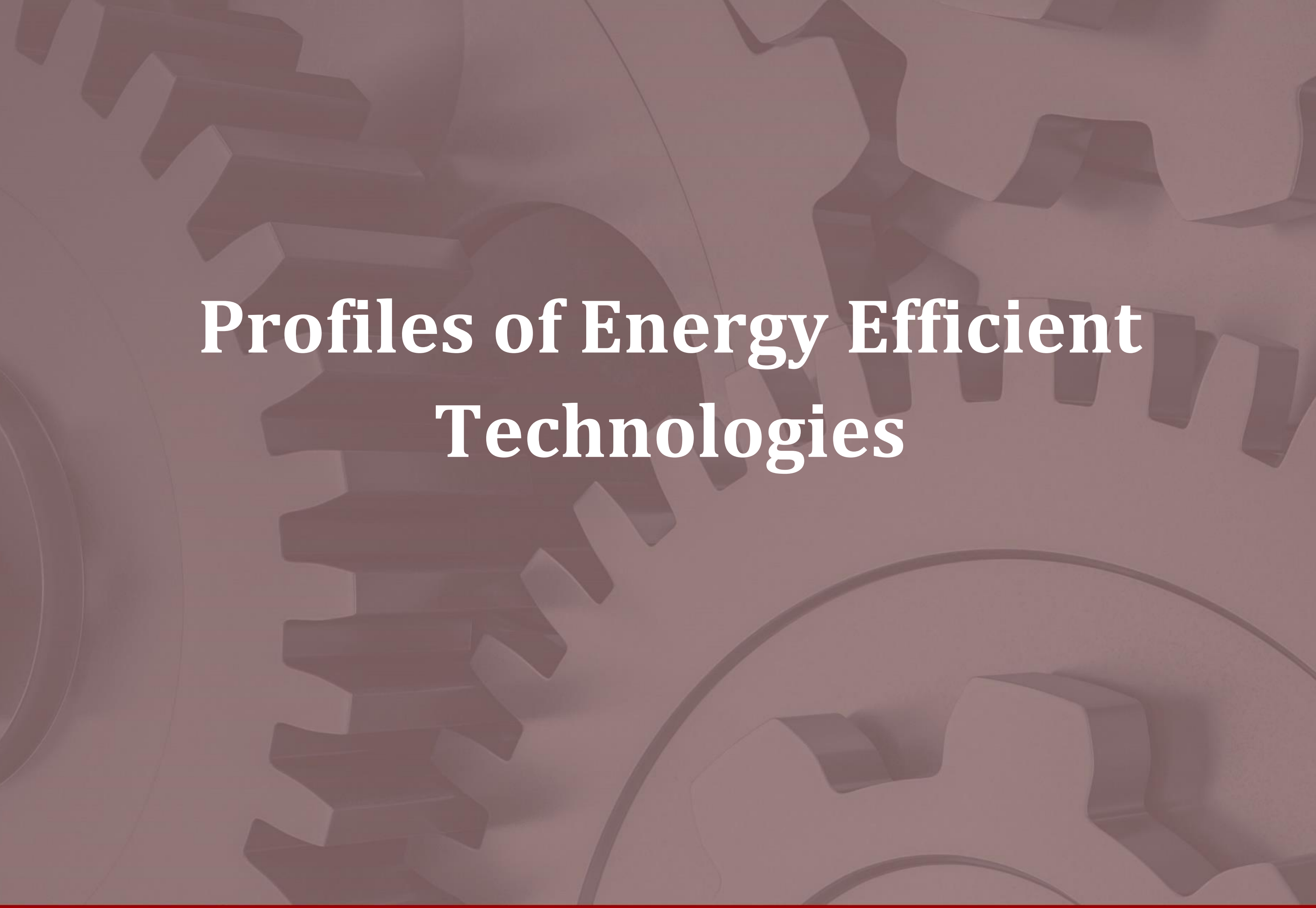

Profiles of Energy Efficient Technologies

An Online Continuing Education Course for Engineers

Course Number: R-4012

Credit: 4 Hours / 4 PDH / 4 CPD

Profiles of Energy Efficient Technologies

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Introduction

This course profiles several technologies that are likely to play prominent roles in reducing greenhouse gases in the future. This material provides a brief overview of each technology and the status of the research and commercialization efforts for the technology. Most of the technologies are related to the generation of electric power, but a few of the technologies concern the energy efficiency of buildings and building systems.

The technologies profiled in the course include biopower, geothermal, concentrating solar power, photovoltaics, wind energy, hydrogen, advanced hydropower, building technologies, reciprocating engines, microturbines, fuel cells, batteries, advanced energy storage, super-conducting power technology, and thermally activated technologies.

The first chapter covers biopower, which is the generation of electric power from biomass resources.

Chapter 1: Biopower Technology

Biopower, or biomass power, is the generation of electric power from biomass resources such as waste wood, crop, and forest residues. In the future, crops may be 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 re-growing biomass can result in very low CO_2 emissions compared to fossil energy without carbon sequestration, such as coal, oil or natural gas.

Biomass products must be processed into a suitable form to be used as a fuel for electric power generation. Three of the most common feedstock conversion technologies include homogenization, gasification, and anaerobic digestion. *Homogenization* is a process by which feedstock is made physically uniform for further processing or for combustion and includes chopping, grinding, baling, cubing, and pelletizing. *Gasification,* from 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.

Once the feedstock is converted into a suitable fuel, the fuel can be converted to power and heat by either direct combustion or as a chemical fuel in a fuel cell. Direct combustion systems burn biomass fuel in a boiler to produce steam that is expanded in a Rankine Cycle prime mover to produce power. *Co-firing* substitutes biomass for coal and allows either or both fuels to be used in existing coal-fired boilers. Biomass or biomass-derived fuels, such as ethanol or biodiesel, can also be burned in combustion turbines or engines to produce power. When further processed, biomass-derived fuels can be used by fuels cells to produce electricity.

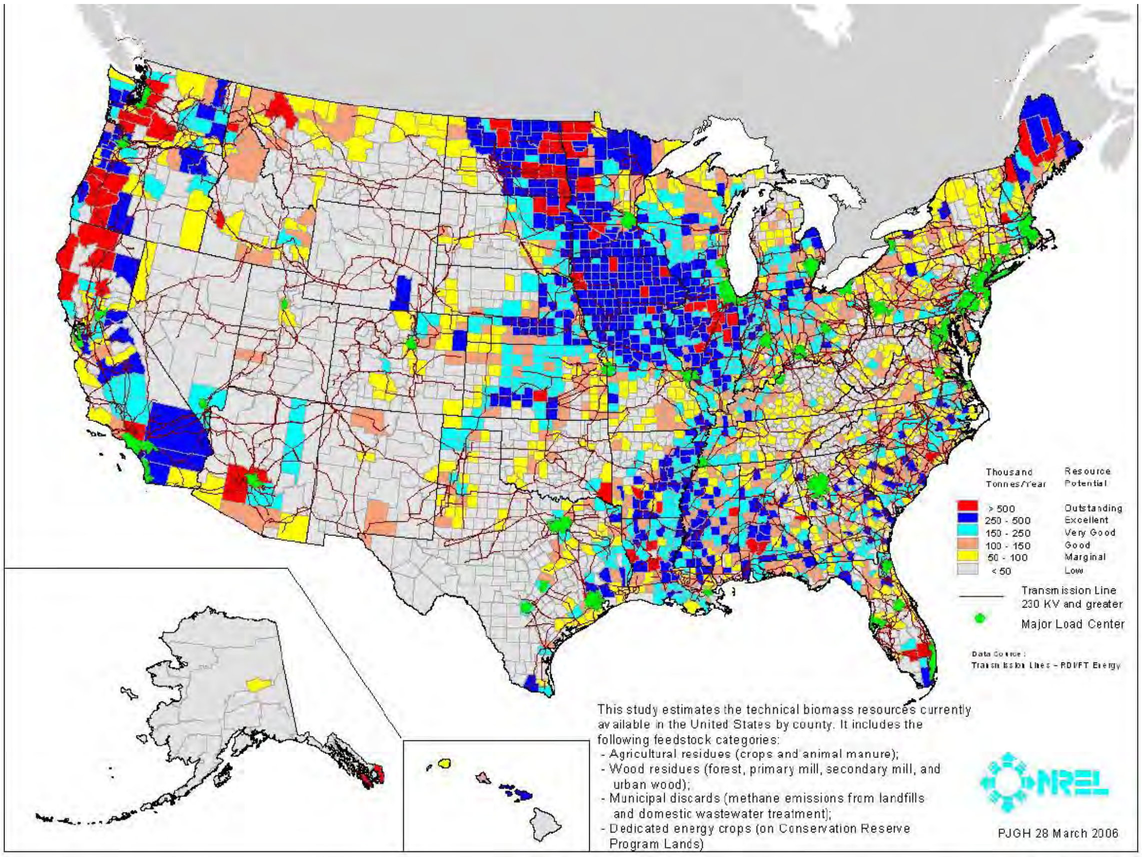
Biopower is generally used in combined heat and power (CHP) systems where the system not only generates electricity, but also recovers heat for steam and/or hot water.

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 boiler, turbine, condenser, and pump.

For the near term, co-firing is the most cost-effective of the power-only technologies. Large coal steam plants have electric efficiencies near 33%. The highest levels of coal co-firing, 15% on a heat-input basis, require separate feed preparation and injection systems.

Biomass gasification combined-cycle plants promise comparable or higher electric efficiencies - greater than 40% - using only biomass, because they involve gas turbines, which are more efficient than Rankine cycles. Other technologies being developed include integrated gasification/fuel cell and bio-refinery concepts.

The following map shows the biomass resources in United States.



This study estimates the technical biomass resources currently available in the United States by county. It includes the following feedstock categories:

- Agricultural residues (crops and animal manure);
- Wood residues (forest, primary mill, secondary mill, and urban wood);
- Municipal discards (methane emissions from landfills and domestic wastewater treatment);
- Dedicated energy crops (on Conservation Reserve Program Lands)

The existing biopower sector – nearly 1,000 plants – is mainly comprised of direct-combustion plants, with an additional small amount of co-firing. Plant size averages 20 MW, and the biomass-to-electricity conversion efficiency is about 20%. Grid-connected electrical capacity has increased from less than 200 MW in 1978 to more than 15,000 MW in 2014. More than 70% 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. Municipal solid waste and landfill gas generating capacity is slightly less than 30% of the total biomass power.

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 co-firing with coal is the most near-term option for large-scale use of biomass for power-only electricity generation. Co-firing also reduces sulfur dioxide and nitrogen oxide emissions. When co-firing with crop and forest-product residues, greenhouse gas (GHG) emissions are reduced by a greater percentage. For example, a 15% co-firing can reduce GHG emissions by 23%.

Biomass gasification for large-scale (20-100MW) power production is being commercialized and it will be an important technology for cogeneration in the forest-products industries, as well as for new baseload capacity. Gasification also is important as a potential platform for a bio-refinery.

Approximately 20 million gallons of biodiesel are produced annually in the United States. Utility and industrial biopower generation is more than 90 billion kWh, representing about 75% of non-hydroelectric 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.

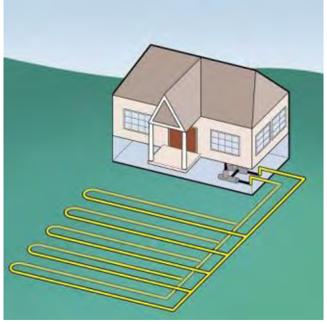
The levelized cost of electricity (in constant 2000 $/kWh) for biomass direct-fired and gasification configurations are projected to be:

Biopower electricity cost (cents/kwh)		
Type	**2000**	**2020**
Direct fired	8.1	6.2
Gasification	7.2	5.8

Future biopower technology improvements include the development of better ways to 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 co-firing up to 5% of natural gas combined-cycle capacity.

Chapter 2: Geothermal Energy

Geothermal energy is heat from within the Earth. Hot water or steam are used to produce electricity or applied directly for space heating and industrial processes. This energy can offset the emission of carbon dioxide from conventional fossil-powered electricity generation, industrial processes, building thermal systems, and other applications.



Geophysical, geochemical, and geological exploration is used to identify geothermal reservoirs and their fracture systems. Once identified, the sites are drilled, reservoirs are tested, and modeling is done to optimize production and predict useful lifetime. These sites include highly permeable hot reservoirs, shallow warm groundwater, hot impermeable rock masses, and highly pressured hot fluids. Well fields and distribution systems are designed to allow the hot fluids to move to the point of use, and afterward, back to the earth. The geothermal energy can either be used to drive steam turbines by using natural steam or hot water flashed to steam to produce electricity or binary conversion systems can produce electricity from water not hot enough to flash. Direct applications use the heat from geothermal fluids without conversion to electricity. Another form of geothermal energy is the use of geothermal heat pumps, which use the shallow earth as a heat source and heat sink for heating and cooling applications. The drawing on right shows a typical geothermal heat pump loop system.

With improved technology, the United States has a resource base capable of producing up to 100 GW of electricity. Hydrothermal reservoirs are being used to produce electricity with an online availability of up to 97% and advanced energy-conversion technologies are being implemented to improve plant thermal efficiency. Direct-use applications are successful throughout the western United States and provide heat for space heating, aquaculture, greenhouses, spas, and other applications. Geothermal heat pumps continue to penetrate both residential and commercial markets for heating/cooling (HVAC

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Hydrothermal reservoirs have an installed electrical capacity of about 3,800 MW in the United States and about 8,000 MW worldwide. Direct-use applications have an installed thermal capacity of about 600 MW in the United States.

Geothermal will continue production at existing plants with future construction potential of 100 GW by 2040. By 2020, an installed electricity capacity of 20 GW from hydrothermal plants and 20 GW from enhanced geothermal systems is projected.