3. Biomass Resources

Detailed and specific information about local biomass resources available for fueling a project are essential before seriously considering a biomass power installation. For example, typical moisture content (including the effects of storage options), typical yield, seasonality of the resource, proximity to the power generation site, issues that could affect future availability, fuel quality, and weather are all factors to consider when selecting a biomass fuel and determining the feasibility of a project.

For background and use in narrowing the range of options, this chapter provides an overview of typical characteristics of the most common biomass fuels. In this report, feedstocks are classified into two general categories: rural resources and urban resources. Within these categories, the following biomass feedstocks are discussed:

Rural Resources:

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

Urban Resources:

- Urban wood waste
- LFG
- Wastewater treatment biogas
- Food processing residue

The following sections provide descriptions of these biomass feedstocks in the United States, including information about the resource base, current utilization, potential availability, typical energy content (in British thermal units [Btu]), typical cost, and the advantages and disadvantages of utilizing the feedstock. All resource availability figures in this analysis are defined as resources not currently destined for other productive uses.[14]

3.1 Rural Resources

3.1.1 Forest Residues and Wood Wastes

Forest residues and wood wastes represent a large potential resource for energy production and include forest residues, forest thinnings, and primary mill residues. Even though the costs for these fuels are usually greater than coal, they reduce fuel price risk by diversifying the fuel supply; result in significantly lower greenhouse gas, sulfur dioxide (SO_2), and nitrogen oxide (NO_X) emissions than coal; and can easily be cofired.[15]

Forest Residues

Forest residues are defined as the biomass material remaining in forests that have been harvested for timber, and are almost identical in composition to forest thinnings. Because only timber of a certain quality can be used in lumber mills and other processing facilities, biomass material—forest residue—is left in forests by harvesting operations. Forestry residues include logging residues, excess small pole trees, and rough or rotten dead wood. These residues could be collected after a timber harvest and used for energy purposes. Typically, forest residues are either left in the forest or disposed of via open burning through forest management programs. The primary advantage of using forest residues for power generation is that an existing collection infrastructure is already set up to harvest wood in many areas. Companies that harvest wood already own equipment and transportation options that could be extended to gathering forest residues. A report evaluating forest residues in the eastern United States estimated that

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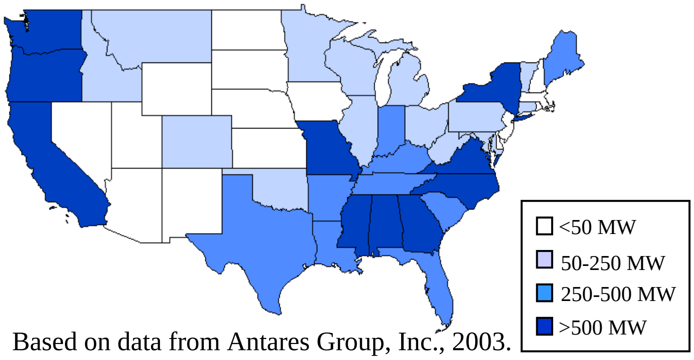
[14] The resource analysis in this section is based on previous work done by Oak Ridge National Laboratory, Antares Group, Inc., the U. S. Department of Agriculture (USDA), and Energy and Environmental Analysis (EEA), as noted.

[15] DOE, 2004; Robinson, et al., 2003.

2.3 tons are available for every 1,000 cubic feet of harvested timber.[16] **Figure 3-1** shows the potential capacity for power generation fueled by forest residues in each state. Potential capacity is concentrated in the western and southeastern regions of the United States.

Figure 3-1. Forest Residue Potential



Based on data from Antares Group, Inc., 2003.

Forest residues typically have an energy content of 5,140 Btu/pound (lb) (wet) and 8,570 Btu/lb (dry). The cost items for obtaining recoverable forest wood residues include collecting, harvesting, chipping, loading, transportation, and unloading; a stumpage fee; and a return for profit and risk. The cost of forest residue can be as low as \$15 to \$25 per ton, or between \$1.46 and \$2.43/million Btu (MMBtu); however, the average price in most parts of the country is roughly \$30/ton, or \$2.92/MMBtu.[17,18]

Forest Thinnings

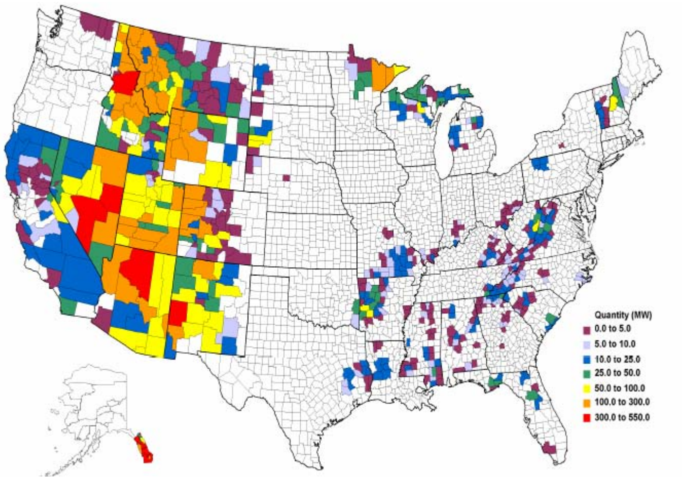
Forest thinnings are defined as underbrush and saplings smaller than 2 inches in diameter, as well as fallen or dead trees. These substances are sometimes known as "ladder fuels" because they can accelerate a forest fire's vertical spread. Large volumes of forest biomass should be available from implementation of U.S. Department of the Interior, the U.S. Department of Agriculture (USDA)/U.S. Forest Service, and Bureau of Land Management joint initiatives to reduce fire risk in national forests; however, the actual business of harvesting, collecting, processing, and transporting loose forest thinnings is costly and presents an economic barrier to their recovery and utilization for energy. Typically, the wood waste from forest thinnings is disposed of through controlled burning due to the expense of transporting it to a power generation facility. In areas that are not already used for wood harvesting, there is no existing infrastructure to extract forest thinnings. A study for the Colorado Office of Energy Management and Conservation found that the delivered cost of forest thinnings was nearly \$100 per dry ton, making it hard to compete with other fuels at a cost of \$5.83 to \$9.73/MMBtu.[19]

Forest thinnings typically have an energy content of 5,140 Btu/lb (wet) and 8,570 Btu/lb (dry). The use of forest thinnings for power generation is concentrated in the western United States. **Figure 3-2** shows that Nevada, Arizona, Idaho, and New Mexico have the greatest potential to generate power from forest thinnings.

Primary Mill Residues

Primary mill residues are waste wood from manufacturing operations that would otherwise be sent to a landfill.

Figure 3-2. Forest Thinning Generation Potential From National Forests and Bureau of Land Management Property



Source: Antares Group, Inc., 2003.

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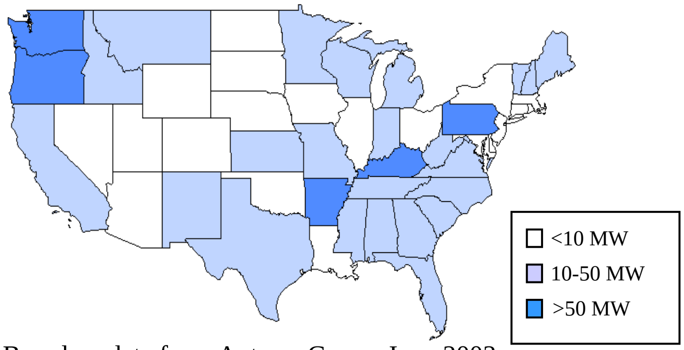
[16] C.T. Donovan Associates, 1994.
[17] Walsh, et al., 1999.
[18] Curtis, et al, 2003.
[19] Colorado Governor's Energy Office, n.d.

Manufacturing operations that produce mill residues usually include sawmills, pulp and paper companies, and other millwork companies involved in producing lumber, pulp, veneers, and other composite wood fiber materials. Primary mill residues are usually in the form of bark, chips, sander dust, edgings, sawdust, or slabs. Due to the fact that primary mill residues are relatively homogeneous and concentrated at one source, nearly 98 percent of all residues generated in the United States are currently used as fuel or to produce other fiber products. Of the 21.6 million dry tons of bark produced in the United States, 76.6 percent is used for fuel and 20.6 percent is used for other purposes such as mulch, bedding, and charcoal. Overall, USDA estimates that 2 to 3 percent of primary mill residues are available as an additional fuel resource because they are not being used for other purposes. **Figure 3-3** shows that the largest concentrations of primary mill residues are in the western and southeastern regions of the United States.

Figure 3-3. Primary Mill Residue Potential



Based on data from Antares Group, Inc., 2003.

Because most primary mill residues are fairly dry after they have been through a manufacturing process, they fall at the upper level of the energy content range for wood (8,570 Btu/lb). Producing power from primary mill residues is highly advantageous in the wood products industries because they have a "free" (i.e., no additional cost) source of fuel with no transportation costs and a secure supply that they control. The cost of these residues is actually negative to most wood products industries because if the residues are not used on site, companies have to pay for disposal. When purchasing mill residues, the price can vary considerably from $8 to $50 per oven dry ton, corresponding to a cost of $0.46 to $2.92/MMBtu.[20] This high variability occurs on a site by site basis depending on whether the site is already using the residues.

3.1.2 Crop Residues

Agriculture is a major economic activity in the United States with approximately 302 million acres of harvested cropland currently being used for agricultural production.[21] According to the most recent USDA Census (2004), the most frequently planted crops (in terms of average total acres planted) are corn, wheat, soybeans, hay, cotton, grain sorghum, barley, oats, and rice.[21] Following the harvest of many traditional agricultural crops such as corn and wheat, residues such as crop stalks, leaves, and cobs, referred to as corn stover and wheat straw, are left in the field. A segment of these residues could potentially be collected and combusted to produce energy. Only slightly more than one-fifth of the more than 100 million tons of agricultural waste generated in the United States is currently used each year.[22]

Corn stover[23] and wheat straw are the primary agricultural residues used in energy production. **Figures 3-4** and **3-5** show the location and MW potential for corn stover and wheat straw that can be delivered at less than $50/dry ton. Although more states produce wheat than corn, the country's total MW-generation potential is significantly less from wheat straw than from corn stover because wheat straw has a lower energy content than corn stover and fewer tons of wheat straw can be collected per acre

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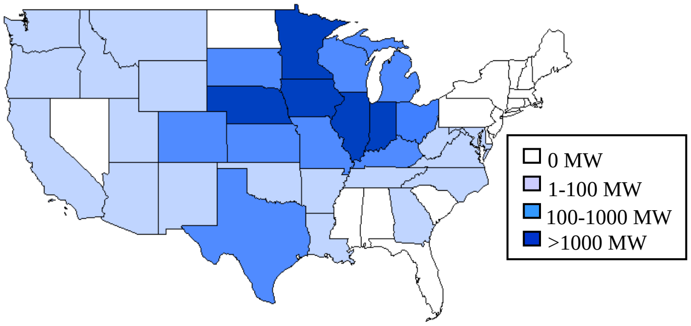
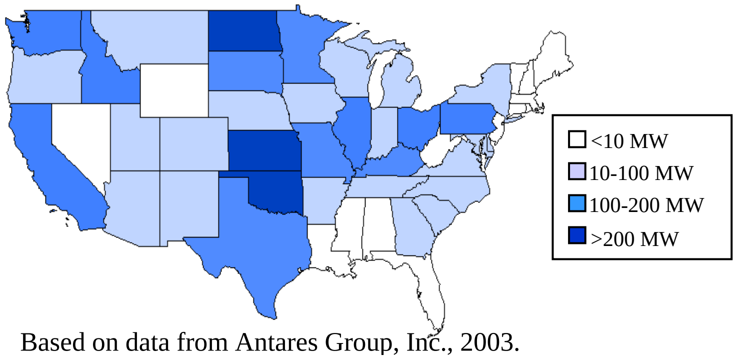
[20] Walsh, et al., 1999.
[21] USDA, 2004.
[22] DOE/USDA, 2005.
[23] Corn stover is the stalks, leaves, and cobs that are left in the field after harvesting.

Figure 3-4. Available Corn Stover Residues at Less Than $50/Dry Ton



Based on data from Antares Group, Inc., 2003.

Figure 3-5. Available Wheat Straw Residues at Less Than $50/Dry Ton



Based on data from Antares Group, Inc., 2003.

than corn stover. Corn stover has an energy content of 5,290 Btu/lb (wet) and 7,560 Btu/lb (dry). Wheat straw has an energy content of 5,470 Btu/lb (wet) and 6,840 Btu/lb (dry).

The estimated prices of corn stover and wheat straw include the cost of collecting the residues, the premium paid to farmers for participation in a collection program, and transportation costs. The cost of corn stover ranges from $20 to $40 per ton and the cost of wheat straw is approximately $50 per ton. Consequently, corn stover typically costs between $1.89 to $3.78/MMBtu, and wheat straw costs approximately $4.57/MMBtu.[24,25]

The primary drivers for converting agricultural residues into electricity are avoided fossil fuel purchases and the environmental improvements due to avoided decomposition and open burning practices. The disadvantages to using these residues are crop seasonality, which creates an unsteady and unreliable fuel supply, and competing uses for the residue. For example, corn stover is normally used for animal feed or compost, and wheat straw is used for feed or animal bedding—all of which are established markets.

3.1.3 Energy Crops

Energy crops are perennial grasses and trees grown through traditional agricultural practices that are produced primarily to be used as feedstocks for energy generation. The Bioenergy Feedstock Development Program at Oak Ridge National Laboratory (ORNL) has identified hybrid poplars, hybrid willows, and switchgrass as having the greatest potential for dedicated energy use over a wide geographic range. Currently, energy crops are not being grown commercially in the United States, but this situation could change if they could be sold at prices that ensure producers a profit that is comparable to using the land for alternate purposes. Demonstration programs are underway with Department of Energy (DOE) funding in Iowa and New York, but DOE assumes that energy crops will not become commercially available until 2010 or beyond. DOE estimates that about 190 million acres of land in the United States could be used to produce energy crops.[26]

Table 3-1 presents the energy content and typical costs for common energy crops. Harvesting costs for switchgrass are similar to most forage crops because switchgrass can be cut and baled with conventional mowers and balers, which make this energy crop the easiest and cheapest to harvest.

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[24] Hag, 2002.
[25] Curtis, et al, 2003.
[26] Antares, 2003.

Table 3-1. Energy and Cost Characteristics of Energy Crops

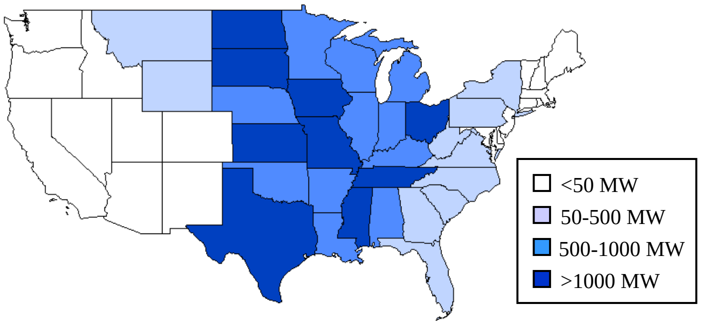
Energy Crop	Energy Content Wet (Btu/lb)	Energy Content Dry (Btu/lb)	Cost Range (per ton)	Cost/MMBtu
Hybrid Poplar	4,100	8,200	\$39 to \$60	\$4.76 to \$7.32
Hybrid Willow	4,100	8,200	\$39 to \$60	\$4.76 to \$7.32
Switchgrass	6,060	8,670	\$35 to \$50	\$2.89 to \$4.13

Source: State of Oregon, n.d.; Walsh et al., 1999

As an example of energy crop generation potential, **Figure 3-6** shows the amount of generation capacity that could be achieved by using switchgrass. Several states throughout the Midwest and South could provide more than 1,000 MW of power fueled by switchgrass.

If developed, energy crops could represent significant additional farm income. The advantages of using crops specifically grown for energy production is consistency in moisture content, heat content, and processing characteristics. Disadvantages include relatively higher overall costs than many fossil fuels, higher-value alternative land uses that further drive up costs, added expenses associated with harvesting and processing, and farmers' and power plant owners' unfamiliarity with energy crops.

Figure 3-6. Available Switchgrass at Less Than \$50/Dry Ton



Based on data from Antares Group, Inc., 2003.

3.1.4 Manure Biogas

Manure digester biogas is produced at animal production operations when manure decomposes anaerobically (without oxygen) in a digester. Animal production operations use anaerobic digestion to reduce odor and pathogens and to effectively separate the solid and liquid portions of the sludge for application to cropland as fertilizer or irrigation water, respectively. Energy-recovery digesters are specially designed digesters that optimize the production of biogas from the decomposition of manure. Biogas from a manure digester typically contains 60 to 80 percent methane, depending on the type of animal and the manure collection system, resulting in an energy content of approximately 600 to 800 Btu per standard cubic foot (scf). The balance of the biogas is composed of CO_2 and trace amounts of hydrogen sulfide.

The use of manure biogas to produce energy is limited to farms that have the animals and manure management to accommodate anaerobic digestion. Farms that produce electricity from biogas might sell the electricity back to the grid, making this energy available to consumers outside of the farm. Selling electricity back to the grid, however, has not typically been an economically viable option for these operations. Furthermore, animal operations with anaerobic digesters currently represent a small fraction of the total number of animal operations. The USDA 2002 Census of Agriculture data showed a total of 91,989 dairy operations and 78,895 swine operations in the United States.[27] Out of these operations, only 65 dairy operations and 40 swine operations used anaerobic digesters.

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[27] USDA, 2004

The EPA AgSTAR Program has identified the most viable candidates for anaerobic digestion as dairy operations with greater than 500 head and swine operations with more than 2,000 head. Also, the potential for generating biogas from manure is greatest for manure management systems that collect and store manure as a liquid, slurry, or semi-solid (lagoon, liquid/slurry, or deep pit). Considering these parameters, approximately 2,290 dairy operations and 6,440 swine operations are potential candidates for anaerobic digestion and manure biogas production.[28]

Assuming an anaerobic digester is in place, there are no additional costs associated with obtaining the biogas. Therefore, manure biogas for energy use is considered an opportunity—or free—fuel. Capital costs, operation and maintenance (O&M) costs, and costs associated with collection and gas treatment will be a factor, however, in evaluating the suitability for a biogas power project. These costs are discussed in Chapter 4.

3.2 Urban Resources

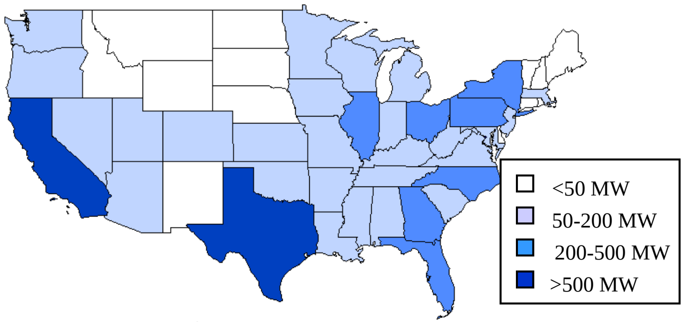
3.2.1 Urban Wood Waste

Urban wood wastes include yard trimmings; wood construction and demolition (C&D) waste; site clearing wastes; and pallets, wood packaging, furniture, and other miscellaneous commercial and household wood wastes that are generally disposed at MSW landfills or C&D landfills. Urban wood wastes are available across the United States, but they are mainly concentrated in populous areas.

Woody yard trimmings are an abundant source of wood sent to landfills. In 1996, yard trimmings were the second largest component of the MSW stream at 29.3 million tons.[29] Yard trimmings can be generated from residential landscaping and right-of-way trimming near roads, railways, and utility systems such as power lines. Yard trimmings comprise about 14 percent of the MSW stream; because approximately 36 percent of yard trimmings are recoverable, roughly 5 percent of the total MSW stream for each state is available yard trimming residue.

C&D waste is woody material generated from C&D activity. Wood debris makes up around 26 percent of the total C&D stream, or approximately 35.1 million tons.[30] Approximately 30 percent of that debris, about 10.5 million tons/year, is uncontaminated by chemical treatment and available for recovery.[31]

Figure 3-7. Urban Wood Waste Potential Including Yard Trimmings, C&D Waste, and Other Wood Wastes



Based on data from Antares Group, Inc., 2003.

Other wood wastes include discarded consumer wood products and wood residues from non-primary mill manufacturers, such as discarded wooden furniture, cabinets, pallets and containers, and scrap lumber. Approximately 7 percent of the entire MSW stream is other wood residue; of this, 44 percent is generally available. **Figure 3-7** shows the states with the highest concentrations and potential capacity for generating

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[28] Additional information about manure biogas and anaerobic digester potential at animal production operations is available at <www.epa.gov/agstar>.
[29] McKeever, 1998.
[30] Sandler, 2003.
[31] Antares Group, Inc., 2003.

power from urban wood wastes.

Wood waste costs can be lower than other forms of biomass because wood waste that is burned for energy generation purposes is usually offsetting disposal costs from otherwise being landfilled. Therefore, some urban wood wastes can actually be collected at a negative cost. Typically, urban wood waste costs range from $3 to $24/ton. The energy content of urban wood waste is 4,600 Btu/lb (wet) and 6,150 Btu/lb (dry), or between $0.33 and $2.61/MMBtu.[32, 33]

One drawback to using urban wood waste for energy generation is that wood used for construction and consumer wooden goods can contain high levels of impurities caused by chemical treatments to extend the wood's useful life. These impurities can cause emission problems when burned and might require wood waste boilers to have extra filtration and control equipment to curb contaminants or would require effective separation of the contaminated items prior to burning.

3.2.2 Landfill Gas

LFG is generated through the decomposition of organic waste in anaerobic (oxygen-deprived) conditions at MSW disposal facilities, commonly known as landfills. Of all anthropogenic sources of methane emissions in the United States, landfills are estimated to account for the most generation from a single source category—25 percent of the total in 2004.[34] The amount of methane generated by a landfill over its lifetime is dependent on the composition of the waste, the quantity and moisture content of the waste, and the design and management practices of the facility. Landfills with more waste deposited in them typically produce more gas over time than those with less waste. Other factors aside, landfills in drier regions do not produce as much gas as those in areas that receive greater precipitation, as moisture is a necessary component in decomposition. The gas generation potential of a landfill is a function of the facility's size (waste in place), the climate in which it is located, and other site-specific attributes. Significant generation of LFG generally begins about one to two years after disposal of a mass of waste and continues evolving from that mass at an exponentially declining rate for 10 to 60 years, depending on landfill conditions.

On a dry basis, LFG is basically composed of 50 percent methane and 50 percent CO_2, resulting in a heating value of approximately 500 Btu/scf. Minute amounts of nitrogen, oxygen, and hydrogen, and trace amounts of inorganic compounds such as hydrogen sulfide (which has a strong odor), are also found in LFG.[35] Due to varying compositions of LFG at different sites (primarily variations in the relative amounts of methane and CO_2), measured heating values can range from 350 to 600 Btu/scf.[36]

The EPA Landfill Methane Outreach Program (LMOP) estimates that, in addition to the approximately 410 landfills already collecting LFG for energy recovery, 570 additional landfills are good candidates for LFG energy recovery. The majority of these landfills have more than 1 million tons of waste in place and either are still accepting waste or have been closed for five or fewer years.[37] These candidate landfills have the potential to generate approximately 1,370 MW of electricity. **Figure 3-8** shows the number of landfill energy recovery systems currently in place in each state as well as the number of candidate landfills.[38]

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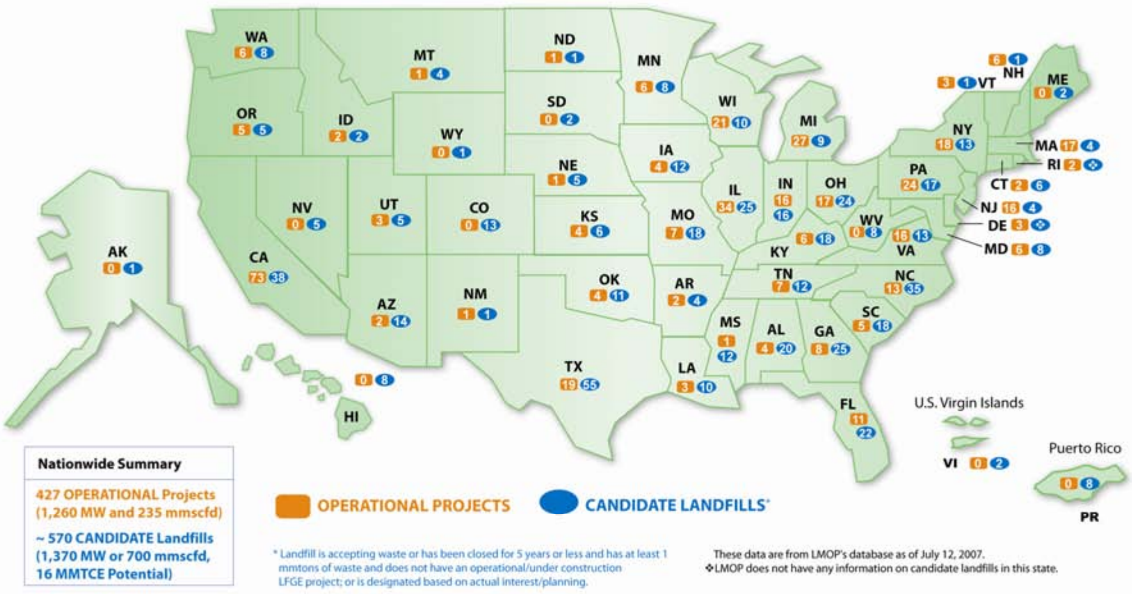
[32] Antares Group, Inc., 2003.
[33] Walsh, et al., 1999.
[34] EPA, 2006a.
[35] EPA, 2006b.
[36] Perry, 1963.
[37] EPA, 2006c.
[38] Additional information about LFG and the feasibility of collecting it at landfills across the United States is available at <www.epa.gov/lmop>.

Figure 3-8. Operational LFG Energy Projects and Candidate Landfills



Source: EPA, 2006d.

A LFG energy recovery project developer typically pays between $1.00 and $3.00/MMBtu for raw LFG.[39] In addition to these royalties paid for raw LFG, there are often costs associated with gas collection and treatment, which are discussed in Chapter 4. In certain cases, a landfill will already have a gas collection system in place to comply with regulations but is burning the gas in a flare. A number of federal and state financial incentives and programs, including tax credits and state renewable portfolio standards, are available to help make LFG energy projects economically feasible. Appendix B provides information about an online funding guide that tracks LFG-related programs and incentives.

3.2.3 Wastewater Treatment Biogas

Wastewater treatment biogas is produced from the anaerobic digestion of domestic/industrial wastewater sludge. During the wastewater treatment process, solids from primary and secondary treatment are collected and further processed, via digestion, to stabilize and reduce the volume of the sludge. The digestion is performed either aerobically (in the presence of oxygen) or anaerobically (without oxygen) to produce biogas. Anaerobic digestion and wastewater treatment take place in a closed or covered tank to exclude air or oxygen from the waste. Anaerobic treatment has been historically used to biologically stabilize high-strength wastes at a low cost. In many cases, the biogas has not been used as an energy resource but has been burned in a flare and discharged to the atmosphere. Biogas is also generated from other anaerobic wastewater treatment processes, including anaerobic lagoons and facultative lagoons.

Wastewater treatment biogas consists of approximately 55 to 65 percent methane, 30 percent CO_2, and other inert gases such as nitrogen. This composition results in a heating value of approximately

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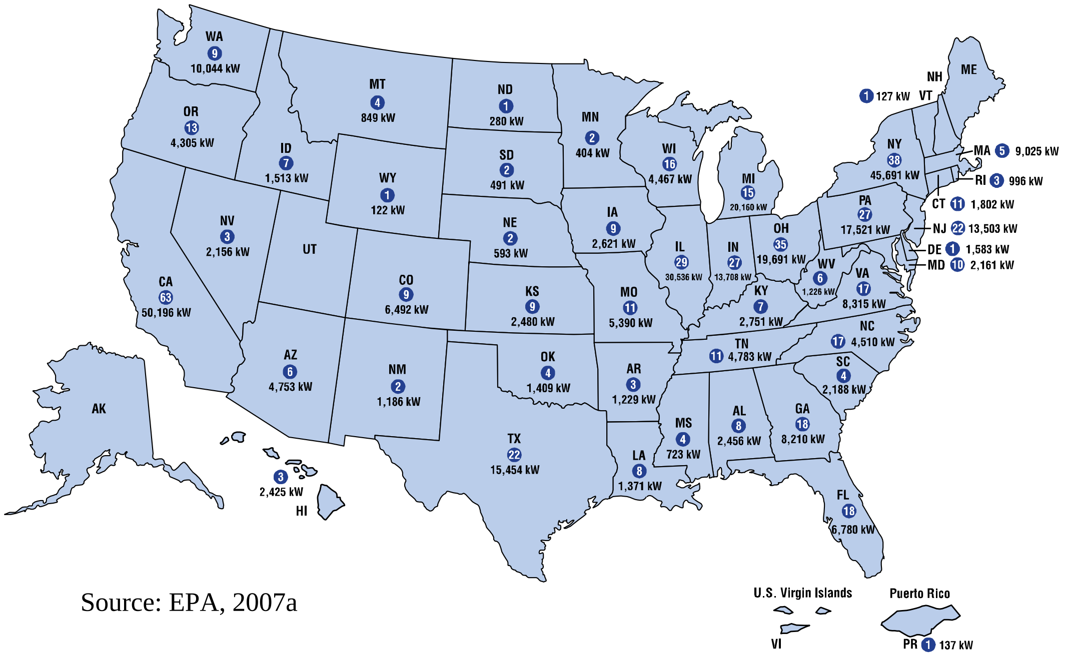
[39] Brian Guzzone, Landfill Methane Outreach Program (August 29, 2007).

550 to 650 Btu/scf.[40] Today, most wastewater treatment plants that employ anaerobic digestion collect and use their biogas on site. If used on site, the biogas created during the anaerobic digestion process is typically collected and used, often without pretreatment, in boilers that generate steam for space and digester heating and in reciprocating engines that drive air compressors and/or electric generators. Any excess biogas that cannot be used on site is generally flared.

According to the 2004 Clean Watersheds Needs Survey,[41] there are more than 16,000 municipal wastewater treatment facilities operating in the United States. An analysis completed by the CHP Partnership found that if all 544 wastewater treatment facilities with influent flow rates greater than 5 million gallons per day that operate anaerobic digesters were to install CHP, approximately 340 MW of electricity could be generated.[42] **Figure 3-9** shows the number of wastewater treatment facilities in each state greater than 5 million gallons per day, and the potential electric capacity estimated by the EPA CHP Partnership.

Figure 3-9. Wastewater Treatment Facilities Greater Than 5 Million Gallons Per Day and Electric Generating Potential



Source: EPA, 2007a

Like manure biogas and LFG, wastewater treatment biogas is an opportunity fuel, meaning there is no cost associated with generating the gas if the anaerobic digester used to produce the gas is already in place. Despite being an opportunity fuel, there are costs associated with collection, gas treatment, and O&M, which are discussed in Chapter 4. The cost of the collection system piping and the blower for moving the gas through the piping is relatively insignificant in comparison to the cost of the gas utilization systems discussed in subsequent sections.

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[40] Metcalf and Eddy, 2003.
[41] EPA, 2004a
[42] EPA, 2007a

3.2.4 Food Processing Waste

Food processing wastes are being used throughout the country as biomass feedstocks for energy generation. These wastes include:

Nut shells
Fruit pits
Rice hulls
Cotton gin trash
Meat processing residues
Cheese whey

Food processing wastes can be difficult to utilize as a fuel source due to the varying characteristics and properties of different waste streams. As such, most food wastes are currently disposed of as industrial wastewater and discharged to a local treatment plant. Work is underway in the food processing industry, however, to evaluate the energy resource these wastes represent, and to develop collection and processing methods that would allow for more effective utilization of this biomass resource. For example, dry solids production of shells, pits, hulls, and cotton gin trash exceeds 1 million dry tons per year in California, with at least three of these feedstocks currently being used for power generation in a few applications—almond shells, walnut shells, and rice hulls.[43]

In addition, utilities are taking advantage of these low-cost fuel sources. For example, peanut processors must dispose of large amounts of peanut hulls every month that cannot be used for such things as mulch, cat litter, or fire logs. Georgia Power has worked with firms to cofire peanut hulls with a mixture of coal at the Plant Mitchell Generating Station. Georgia Power estimates that every truckload of peanut hulls fired saves the company approximately $400 in fuel costs.[44] In southwest Louisiana, electric power generated from rice hulls powers a rice processing plant. Most of the power is used to operate the rice mill from which the hulls come, while any extra power is sold to Entergy, the regional electrical utility.

Researchers at the University of Georgia have done considerable research into the costs of using food processing wastes in power production. They have found that every bale of ginned cotton produces 200 pounds of gin trash,[45] which can be sold at prices ranging from $10 to $12 per ginned bale (i.e., per 200 pounds of gin trash).[46] Some resources indicate that large peanut and pecan shellers offer the hulls of these nuts at no cost if picked up and transported off their properties. Food processing wastes can produce a high-quality and clean-burning fuel that is cost competitive with coal on a Btu basis ($1.25 to $2.50/MMBtu) when sold as a solid. Potential waste sources are hard to generalize, however, and must be evaluated on a case-by-case basis.

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[43] California Energy Commission, 2004.
[44] National Food and Energy Council, n.d.
[45] Gin trash is a light material that cattle farmers currently utilize as a supplemental feed source.
[46] Curtis, 2003.