Biomass Feedstocks for Biopower: Background and Selected Issues

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October 6, 2010

Congressional Research Service
7-5700
www.crs.gov
R41440

CRS Report for Congress
Prepared for Members and Committees of Congress

Summary

Biopower—a form of renewable energy—is the generation of electric power from biomass feedstocks. Biopower, which comprised about 1% of electricity generation in 2008, may reduce greenhouse gas emissions, provide energy security, and promote economic development. A large range of feedstocks can be used, from woody and herbaceous biomass to agricultural residues. Each feedstock has technical and economic advantages and challenges compared to fossil fuels.

Unlike wind or solar energy, a biopower plant is considered to be a baseload power source because some biomass feedstocks can be used for continuous power production. However, ensuring a sustainable supply of biomass feedstocks is a major challenge. Although there are multiple biopower technologies, few of them except combustion have been deployed at commercial scale nationwide.

Federal policymakers are supporting biopower through feedstock supply analysis and biopower technology assessments. However, there is limited comprehensive data about the type and amount of biomass feedstock available to meet U.S. biopower needs at a national level. If the use of dedicated biomass feedstocks to generate biopower were to develop into a sizeable industry, concerns would likely include the effect of the industry on land use (i.e., how much land would it take to grow the crops needed to fuel or co-fuel power plants) and the effect on the broader economy, including farm income and food prices. To date, these have not been issues: most existing biomass feedstocks have been waste products generated by the forest products industry or by farms, or municipal solid waste for which combustion served as both a disposal method and a source of energy.

Growing crops for use as a power source would be different from using waste. Under generally accepted assumptions regarding crop yields and energy content, approximately 31 million acres—roughly the amount of land in farms in Iowa—would be needed to supply enough biomass feedstock to satisfy 6% of total 2008 U.S. electricity retail sales. When added to the amount of land needed to meet the requirements of the Renewable Fuel Standard (RFS), a federally mandated transportation fuel requirement, the potential impacts could be significant: the RFS already consumes 35% of the nation's corn crop, and its requirements will triple between 2010 and 2022 (although much of this fuel will come from feedstocks other than corn).

Beyond land use and economic impacts, others are concerned that the use of biomass feedstocks to generate biopower, particularly through combustion, could add to greenhouse gas (GHG) emission levels and exacerbate climate change concerns. They fear that certain areas may be unsustainably harvested to meet biomass feedstock demand, or that less biomass may be left for other purposes (e.g., wood and paper products). The concerns exist partly because biomass used for biopower does not face the same constraints as biomass used for liquid transportation fuels under the RFS. In addition, the idea that biomass combustion is carbon-neutral is under scrutiny. The Environmental Protection Agency has not exempted biomass combustion emissions from the Prevention of Significant Deterioration and Title V Greenhouse Gas Tailoring Rule. The rule sets thresholds for GHG emissions that define when permits are required for new and existing industrial facilities. It is unclear what the rule would mean for biomass combustion plants, since determinations of the best available control technologies (BACT)—a pollution control standard mandated by the Clean Air Act—will be provided in another rulemaking. Those who consider biomass combustion emissions to be biogenic (produced by living organisms), and thus carbon-neutral over time, argue that these emissions should be exempted from the rule.

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Introduction

The production of bioenergy—renewable energy derived from biomass—could potentially increase national energy security, reduce greenhouse gas emissions, and contribute to rural economic growth. Legislative, research, and industrial attention have focused on the production of bioenergy in the form of liquid transportation fuels (e.g., corn-based ethanol).[1] Biopower—the production of electricity from biomass feedstocks—may require new national policies or incentives if Congress decides to encourage its development.

Biopower, or biomass power, comprised about 1% of electricity generation in 2008.[2] It was the third-largest renewable energy source for electricity generation in that year, after conventional hydroelectric power and wind.[3] The Department of Energy's (DOE's) Energy Information Administration (EIA) projects that electricity generation from biomass will grow from 0.9% of total generation in 2008 to 5.5% in 2035.[4] The DOE reference case for this projection assumes extension of federal tax credits, state requirements for renewable electricity generation, and the loan guarantee program in the Energy Policy Act of 2005 (EPAct05; P.L. 109-58) and the American Recovery and Reinvestment Act of 2009 (ARRA; P.L. 111-5).

Current concerns for accelerating biopower growth include the need for a continuously available feedstock supply, a commercial-scale facility to generate the biopower, and market certainty for investors and purchasers alike. Improved feedstock availability, technological advancements, and new forms of economic support could increase the relative contribution of biopower to meeting U.S. energy demand.

One reason for the projected growth of biopower is the fuel's ability to be used in a baseload power plant. Baseload power is the minimum amount of electric power delivered or required over a given period of time at a steady rate. If a plant operates as a baseload plant, the plant can run continually except for maintenance and outages. With sufficient feedstock supplies, a biopower plant could provide "firm" power for baseload needs (and long-term contracts would reduce risk). In contrast, wind and solar energy require either a form of power storage, such as batteries, or a backup power source, such as natural gas turbines, in order to provide firm power.

Power generation from biomass is not limited to a specific feedstock and therefore is relatively flexible in terms of fuel suppliers. Each region of the country can pursue biomass feedstocks that are native and readily available (e.g., corn stover in the Midwest, hybrid poplar in the Northwest, switchgrass in the Southeast). The economic climate for biopower dictates that biopower plants

[1] The Renewable Fuel Standard, a mandate to ensure that domestic transportation fuel contains a specified volume of biofuels, is one reason most legislative and administrative efforts have focused on development of biofuels for transportation. For more information, see CRS Report R40155, *Renewable Fuel Standard (RFS): Overview and Issues*, by Randy Schnepf and Brent D. Yacobucci.

[2] U.S. Energy Information Administration, *Annual Energy Review 2009*, DOE/EIA-0384(2009), August 2010, http://www.eia.doe.gov/aer/elect.html.

[3] U.S. Energy Information Administration, *Renewable Energy Annual 2008 Edition*, August 2010, http://www.eia.doe.gov/cneaf/solar.renewables/page/rea_data/rea_sum.html. Biopower constituted roughly 14.4% of electricity generation from renewable energy sources in 2008, preceded by conventional hydroelectric power and wind, which constituted roughly 67% and 14.5%, respectively.

[4] U.S. Energy Information Administration, *Annual Energy Outlook 2010*, DOE/EIA-0383(2010), Washington, DC, April 2010, http://www.eia.doe.gov/oiaf/aeo/. The bulk of this increase is expected to come from growth in co-firing operations. Co-firing is the combustion of a supplementary fuel (e.g., biomass) and coal concurrently.

should be located in close proximity to feedstocks to reduce transportation costs, which can be significant.[5] Furthermore, existing combustion plants can be retrofitted for biopower production; power from these plants could use existing transmission infrastructure. Financing and siting of new transmission infrastructure could add uncertainty to a proposed project.

The availability and cost of biomass feedstocks determine the amount of biopower that can be produced nationally. An overarching concern is maintaining a sustainable biomass feedstock supply.[6] If feedstocks are collected without regard to replenishment, or in an otherwise unsustainable manner, biopower enterprises may lead to natural resource deterioration such as soil erosion or the depletion of forested land. The Renewable Fuel Standard (RFS), expanded under the Energy Independence and Security Act of 2007 (EISA; P.L. 110-140), mandates a minimum volume of biofuels to be used in the national transportation fuel supply each year. Under the RFS, biomass used for renewable fuel for transportation purposes cannot be removed from federal lands, and the law excludes crops from forested lands.[7] Thus far, biomass used for biopower is not subject to the same constraints as biomass used for liquid transportation fuels under the RFS. Additionally, feedstock diversity is a formidable challenge to biopower growth, because cultivation, harvest, storage, and transport vary according to the feedstock type. Another challenge is accounting for the amount of feedstock available for biopower production due to market fluctuations and weather variability.

In considering congressional action to broaden legislative authorities for sustainable biopower production, an understanding of the various biomass feedstocks and challenges to biopower production could be useful to policymakers. This report provides analyses of commonly discussed biomass feedstocks and their relative potential for power generation. Additional biopower issues—feedstock accessibility, the biomass power plant carbon-neutrality debate, and unintended consequences of legislative activities to promote bioenergy—are also discussed.

What Kind of Biomass Is Available for Biopower?

The type, amount, and costs of biomass feedstocks available for biopower will largely determine whether biopower can thrive as a major renewable energy alternative. There is limited comprehensive data on the amount of biomass feedstocks available to meet current and future biopower needs at a national level. The supply data available is generally evaluated in terms of meeting biofuel demand. Some may argue that feedstock assessments for biofuels are adequate for biopower purposes, as the same feedstock may be used to meet both biofuel and biopower demands. Information that identifies which feedstocks exhibit the most potential for power

[5] Pew Center on Global Climate Change , *Biopower*, December 2009, http://www.pewclimate.org/docUploads/Biopower%20final%2011%2009.pdf. Certain analysis indicates that feedstock supply should be located within a 50-mile radius to avoid excessive transportation costs: Marie E. Walsh, Robert L. Perlack, and Anthony Turhollow et al., *Biomass Feedstock Availability in the United States: 1999 State Level Analysis*, Oak Ridge National Laboratory, January 2000, http://bioenergy.ornl.gov/resourcedata/index.html.

[6] Executive Order 13514 defines sustainability as the creation and maintenance of conditions that allow humans and animals to exist in productive harmony, and that permit fulfilling the social, economic, and other requirements of present and future generations. For more information, see CRS Report R40974, *Executive Order 13514: Sustainability and Greenhouse Gas Emissions Reduction* , by Richard J. Campbell and Anthony Andrews.

[7] For more information on biomass definitions, see CRS Report R40529, *Biomass: Comparison of Definitions in Legislation*, by Kelsi Bracmort and Ross W. Gorte.

generation in the near and long term is also scarce.[8] Furthermore, ideal or feasible locations where feedstocks may be grown are not well assessed. The potential inclusion of genetically modified dedicated energy crops or selective breeding for bioenergy purposes may alter the amount of biomass feedstock available for biopower production (and may alter land use).

Additional legislative action concerning financial support of biopower may depend on better data to estimate the economic viability of biopower plants nationwide.[9] Costs associated with biomass storage and transportation to a biopower plant, as well as other economic and environmental considerations, are among the factors assessed in individual biopower plant feasibility studies. These factors are key to determining which biomass feedstocks can be used.

In addition to economics, biological characteristics play a large role in determining the suitability of any type of biomass. Biomass is organic matter that can be converted into energy. Plants use photosynthesis to store energy (carbon-based molecules) within cell walls, and that energy is released when the biomass undergoes a biological process such as anaerobic digestion, or a chemical process such as combustion. Biomass can include land- and water-based vegetation (e.g., trees, algae), as well as other organic wastes (see **Table 1**).

Table 1. General Classification of Biomass

Biomass groups	Biomass sub-groups, varieties and species
Wood and woody biomass	Coniferous or deciduous (gymnosperm or angiosperm); stems, branches, foliage, bark, chips, lumps, pellets, briquettes, sawdust, sawmill and other wastes from various woody species
Herbaceous and agricultural biomass	Annual or perennial and field-based or process-based such as: —grasses and flowers (alfalfa, arundo, bamboo, bana, brassica, cane, miscanthus, switchgrass, timothy, others); —straws (barley, bean, flax, corn, mint, oat, rape, rice, rye, sesame, sunflower, wheat, others); —other residues (fruits, shells, husks, hulls, pits, pips, grains, seeds, coir, stalks, cobs, kernels, bagasse, food, fodder, pulps, cakes, others)
Aquatic biomass	Marine or freshwater algae and microalgae; macroalgae (blue, green, blue-green, brown, red); seaweed, kelp, lake weed, water hyacinth, others
Animal and human biomass wastes	Bones, meat-bone meal, chicken litter, various manures, others
Contaminated biomass and industrial biomass wastes (semi-biomass)	Municipal solid waste, demolition wood, refuse-derived fuel, sewage sludge, hospital waste, paper-pulp sludge and liquors, waste papers, paperboard waste, chipboard, fibreboard, plywood, wood pallets and boxes, railway sleepers, tannery waste, others
Biomass mixtures	Blends from the above varieties

Source: Stanislav V. Vassilev, David Baxter, and Lars K. Andersen, et al., "An Overview of the Chemical Composition of Biomass," *Fuel*, vol. 89 (2010), pp. 913-933. Adapted by CRS.

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[8] Some of this information may be provided in a forthcoming update to the frequently cited DOE/USDA Billion-Ton Study, *Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply*, April 2005, http://www1.eere.energy.gov/biomass/pdfs/final_billionton_vision_report2.pdf.

[9] In September 2010 the National Renewable Energy Laboratory released a comprehensive mapping application that may provide better data to compare biomass feedstock and biopower by location. National Renewable Energy Laboratory, "NREL Releases BioEnergy Atlas—A Comprehensive Biomass Mapping Application," press release, September 28, 2010, http://www.nrel.gov/news/press/2010/891.html

Several types of feedstocks can be used as a fuel source for electric power generation. Primary biomass feedstocks are materials harvested or collected directly where they are grown (e.g., grains). Secondary biomass feedstocks are by-products of the processing of primary feedstocks (e.g., corn stover). Tertiary biomass feedstocks include post-consumer residues and wastes (e.g., construction and demolition waste). **Appendix A** shows the energy value, crop yield, advantages, disadvantages, and general comments for selected biomass feedstocks and fossil fuels for comparison.

Biomass would have to be grown in enormous quantities if it is to be used as a power source to satisfy a significant portion of national energy demand. For example, approximately 31 million acres—roughly the amount of land in farms in Iowa—of managed crops with a yield of 6 dry tons per acre per year would be needed to supply enough biomass feedstock to satisfy 6% of total 2008 U.S. electricity retail sales.[10] Quintessential biomass crops grown specifically for energy generation (i.e., dedicated energy crops) are being considered to meet energy demand. Dedicated energy crops may possess several desirable characteristics: high yield, low energy input to produce, low cost, low nutrient requirements, low contaminant level, pest resistance, and low fertilizer input.[11]

From Biomass to Biopower

Biomass can be converted to biopower via thermo-chemical and bio-chemical conversion processes. These processes include combustion (or firing), pyrolysis, gasification, and anaerobic digestion (see box, below, and **Figure 1**). The technologies are at varying stages of maturity (see **Figure 2**). The choice of conversion technique selected for a specific biomass feedstock results in differing amounts of useful energy recovered and forms for that energy.[12] The systems can range substantially in scale. Small-scale systems (or modular units) may be an optimal choice for rural areas with limited electricity demand. Large-scale systems may be more economically suitable in more urbanized areas or near grid connections if feedstocks are ample.

The volume of biomass feedstock supply necessary to run a biopower plant depends on the feedstock's energy content—the less the energy value, the more volume is needed. The growing area needed to produce the biomass that will supply a biopower plant is contingent not only on the energy value of the feedstock, but also on the power plant capacity, the power plant efficiency, and the feedstock yield (see **Table 2**). Power plant capacity is the maximum output of power, commonly expressed in millions of watts (megawatts, MW), that generating equipment can supply over a certain time period. Power plant efficiency is the amount of electric energy produced per unit of feedstock input. In general, the higher the yield of the biomass feedstock, the less growing area is required to produce a MW of power. Also, less biomass is needed to support power plants with high efficiency rates.

[10] CRS calculations based on 2008 total U.S. retail electricity sales available at http://www.eia.doe.gov/electricity/esr/esr_sum.html. Power plant capacity factor was assumed to be 80% with 988 growing acres required per megawatt; see http://bioenergy.ornl.gov/resourcedata/powerandwood.html. The yield, six dry tons/acre, is similar to what may be achieved by switchgrass. Land in farms data for Iowa obtained from the 2007 Census of Agriculture, available at http://www.agcensus.usda.gov/Publications/2007/Online_Highlights/County_Profiles/Iowa/cp99019.pdf.

[11] Peter McKendry, "Energy Production from Biomass (Part 1): Overview of Biomass," *Bioresource Technology*, vol. 83 (2002), pp. 37-46.

[12] Peter McKendry, "Energy Production from Biomass (Part 1): Overview of Biomass," *Bioresource Technology*, vol. 83 (2002), pp. 37-46.

Selected Biopower Conversion Processes Defined

A. **Combustion** is the burning of biomass in a power plant. The biomass is burned to heat a boiler and create steam. The steam powers a turbine, which is connected to a generator to produce electricity. Existing plant efficiencies are in the low 20% range, although methods are available to advance efficiency to upwards of 40%. ("Efficiency" describes which percentage of the feedstock processed is actually converted to electricity.) Approximately 180 combustion units for biomass are in operation using wood and agricultural residues as the feedstock.

Co-firing, the simultaneous firing of biomass with coal in an existing power plant, is the most cost-effective biopower technology. Co-firing with biomass using existing equipment is less expensive than constructing a new biopower plant. The existing plant does require retrofitting to accept the biomass entering the plant. Certain air particulates associated with coal combustion are reduced with co-firing, as less coal is being burned. Co-firing has a generation efficiency in the 33%-37% range; coal-fired plants have efficiencies in the 33%-45% range. Approximately 78 co-firing units for biomass are in operation using wood and agricultural residues as the feedstock.

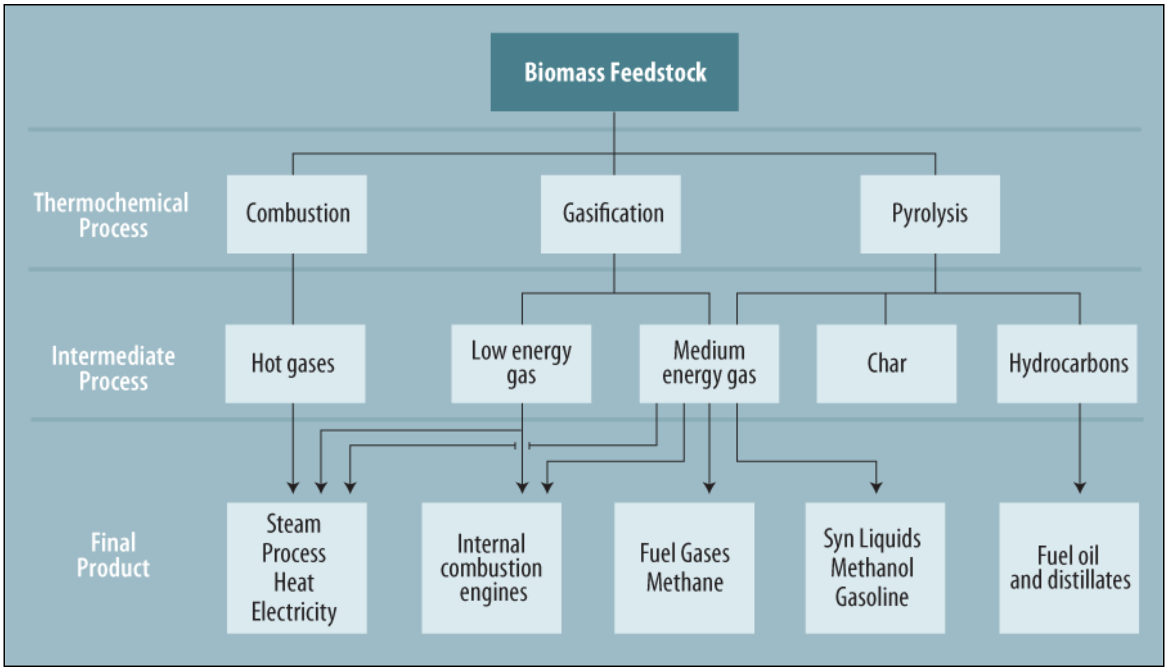
B. **Gasification** is the heating of biomass into synthesis gas (syngas, a mixture of hydrogen and carbon monoxide) in an environment with limited oxygen. The flammable syngas can be used in a combined gas and steam turbine to generate electricity. Generation efficiencies range from 40% to 50%. One challenge for gasification is feedstock logistics (e.g., cost to ship or transport the feedstock to the power plant). A wide variety of feedstocks could undergo gasification, including wood chips, sawdust, bark, agricultural residues, and waste. There are currently no gasification systems for biomass at any scale.

C. **Pyrolysis** is the chemical breakdown of a substance under extremely high temperatures (400°C -500°C) in the absence of oxygen. There are fast and slow pyrolysis technologies. Fast pyrolysis technologies could be used to generate electricity. Fast pyrolysis of biomass produces a liquid product, pyrolysis oil or bio-oil, that can be readily stored and transported. The bio-oils produced from these technologies would be suitable for use in boilers for electricity generation. One of the challenges with pyrolysis is that the bio-oil produced tends to be low-quality relative to what is needed for power production. Commonly used feedstock types for pyrolysis include a variety of wood and agricultural resources. There are currently no commercial-scale pyrolysis facilities for biomass.

D. **Anaerobic digestion** (not shown in **Figure 1**) is a biological conversion process that breaks down a feedstock (e.g., manure, landfill waste) in the absence of oxygen to produce methane, among other outputs, that can be captured and used as an energy source to generate electricity. Anaerobic digestion systems have historically been used for comparatively smaller-scale energy generation in rural areas. Feedstocks suitable for digestion include brewery waste, cheese whey, manure, grass clippings, restaurant wastes, and the organic fraction of municipal solid waste, among others. Generation efficiency is roughly 20%-30%. Approximately 150 anaerobic digesters are in operation using manure as the feedstock.

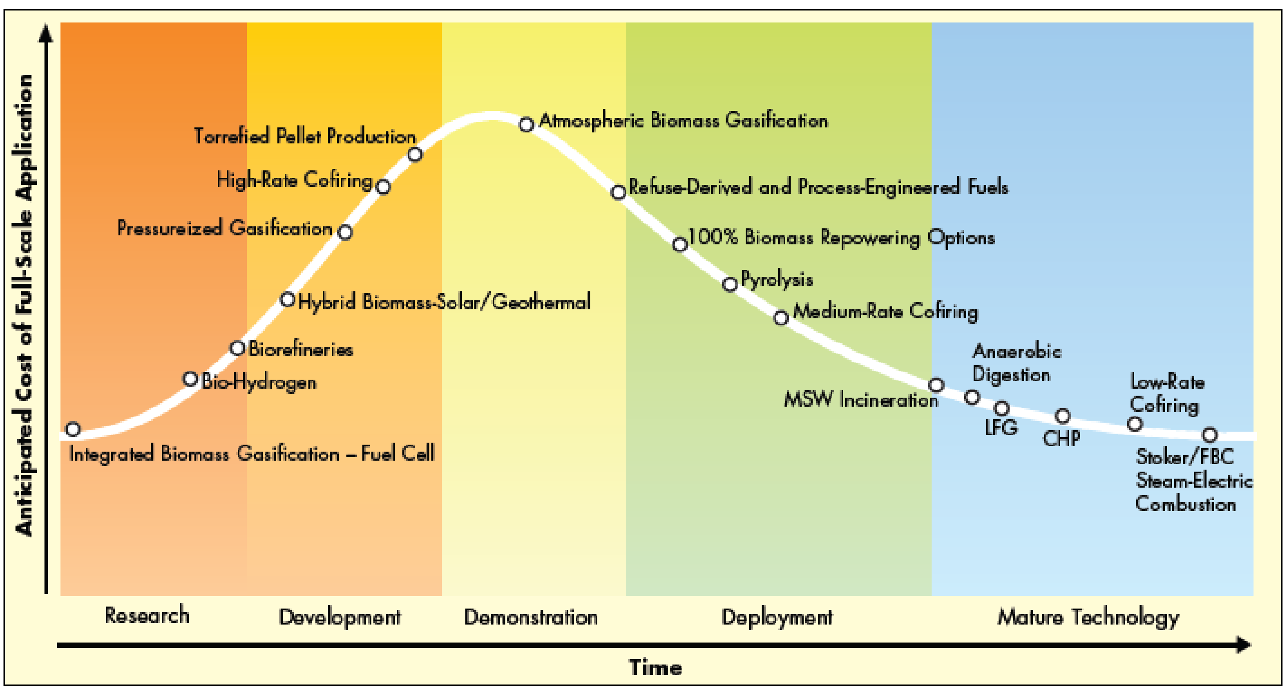
Sources: Oak Ridge National Laboratory, *Biomass Energy Data Book: Edition 2*, ORNL/Tm-2009/098, December 2009, http://cta.ornl.gov/bedb/pdf/BEDB2_Full_Doc.pdf. International Energy Agency, *Biomass for Power Generation and CHP*, ETE03, January 2007, http://www.iea.org/techno/essentials3.pdf. National Association of State Foresters, *A Strategy for Increasing the Use of Woody Biomass for Energy*, Portland, ME, September 2008, http://www.stateforesters.org/files/NASF-biomass-strategy-FULL-REPORT-2009.pdf. Sally Brown, "Putting the Landfill Energy Myth to Rest," *BioCycle*, May 2010. John Balsam and Dave Ryan, *Anaerobic Digestion of Animal Wastes: Factors to Consider*, ATTRA—National Sustainable Agriculture Information Service, IP219, 2006, http://attra.ncat.org/attra-pub/anaerobic.html. Jennifer Beddoes, Kelsi Bracmort, and Robert Burns et al., *An Analysis of Energy Production Costs from Anaerobic Digestion Systems on U.S. Livestock Production Facilities*, USDA Natural Resources Conservation Service, October 2007. Personal communication with Robert Baldwin, National Renewable Energy Laboratory, 2010. Personal communication with Lynn Wright, biomass consultant working with Oak Ridge National Laboratory. For more information on anaerobic digestion, see CRS Report R40667, *Anaerobic Digestion: Greenhouse Gas Emission Reduction and Energy Generation*, by Kelsi Bracmort.

Figure 1. Biopower Conversion Processes



Source: Peter McKendry, "Energy Production from Biomass (Part 2): Conversion Technologies," *Bioresource Technology*, vol. 83 (2002), pp. 47-54. Adapted by CRS.

Figure 2. Biopower and Biofuel Technology Pipeline



Source: Electric Power Research Institute, Biopower Generation: Biomass Issues, Fuels, Technologies, and Research, Development, Demonstration, and Deployment Opportunities, February 2010.

Table 2. Biomass Feedstock Growing Area Required to Produce Biopower

Power plant capacity factor (%)	**80**	**80**	**80**	**80**	**90**	**90**	**90**	**90**
Power plant efficiency (%)	**25**	**30**	**35**	**40**	**25**	**30**	**35**	**40**
Crop yield (dry tons/acre/year) (see Appendix A)	**Growing Acres Required per MW**							
1	5930	4941	4235	3706	6671	5559	4765	4169
2	2965	2471	2118	1853	3335	2780	2382	2085
3	1977	1647	1412	1235	2224	1853	1588	1390
4	1482	1235	1059	927	1668	1390	1191	1042
5	1186	988	847	741	1334	1112	953	834
6	988	824	706	618	1112	927	794	695
7	847	706	605	529	953	794	681	596
8	741	618	529	463	834	695	596	521
9	659	549	471	412	741	618	529	463
10	593	494	424	371	667	556	476	417

Source: Department of Energy, Relationship Between Power Plant Efficiency and Capacity and Tons Biomass Required and Acres Required, Lynn Wright, http://bioenergy.ornl.gov/resourcedata/powerandwood.html.

Notes (from original source): Raw numbers have been used in the above table. Calculations assume dry biomass at 8500 btu/lb = 19.75 Gj/MG and 3413 btu/kWH = 0.0036 Gj/kWh.

Rule of thumb relationship of 1000 acres and 5000 dry tons per MW is based on 80% capacity, 30% efficiency, and 5 dry ton/acre/year yield. A program goal would be to have a relationship of 500 acres and 4200 dry tons per MW at 90% capacity, 40% efficiency, and 8 dry ton/acre/year yield.

Yields of 1-2 dry ton/acre/year are common for natural forests but could also represent residue levels available from high yield plantations. Yields of 3-4 dry ton/acre/year are common for pulpwood pine plantations. Yields of 4-7 dry ton/acre/year are being observed in woody crop and herbaceous crop plantings without irrigation, 5dt/ac/yr still best average estimate. Yields of 7-10 dry ton/acre/year are being observed in some energy crop plantings with best clones or varieties and/or with irrigation or high water tables.

Total planted area or growing area required to supply a biomass facility should be used rather than area actually being harvested in any given year. While these are the same for a herbaceous crop harvested annually, they differ significantly for a woody crop harvested once every few years. Calculation of the annual harvested area for a wood crop requires knowing both the yield (dry ton/acre/year) and the harvest age of the woody crop. This varies from project to project.

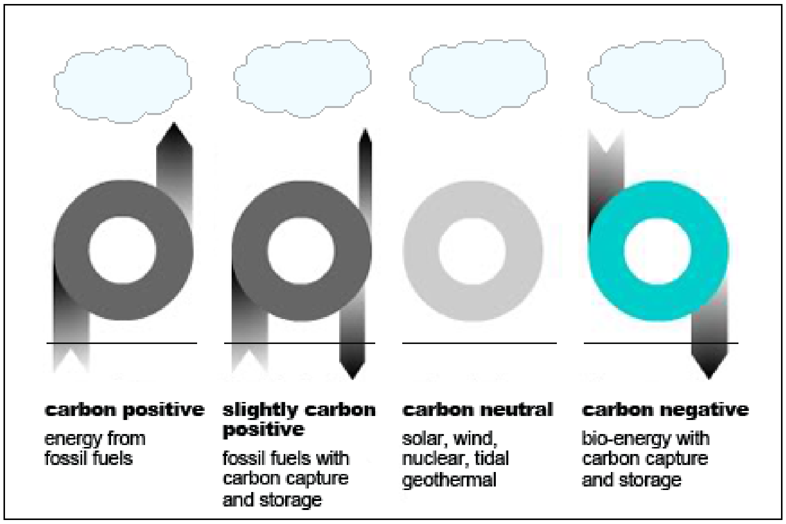
Carbon Balance

Certain sources of biomass (e.g., forestry products, dedicated energy crops) are deemed by some to be carbon-neutral because they absorb enough CO_2 during their growth period to balance the release of CO_2 when they are burned for energy (see **Figure 3**). The term *carbon-neutral* is defined as the combustion or oxidation of matter which causes no net increase in GHG emissions on a lifecycle basis.[13] One controversial aspect of the carbon neutrality debate, and what requires

[13] Section 201 of the Energy Independence and Security Act of 2007 (EISA; P.L. 110-140) defines lifecycle emissions as follows: "(H) LIFECYCLE GREENHOUSE GAS EMISSIONS.—The term 'lifecycle greenhouse gas emissions' means the aggregate quantity of greenhouse gas emissions (including direct emissions and significant indirect (continued...)

further study, is the magnitude in which these plant-derived feedstocks will be used for energy production and thus whether the feedstock supply can be sustained (or replenished) without environmental impairment. Some examples of environmental impairment involve disrupting forest ecosystems by cutting down large amounts of trees, or affecting the climate by not capturing GHGs emitted during bioenergy production. If the feedstocks are not replenished so that they can absorb CO_2, or GHG emissions are not captured from a biopower plant, the resulting GHG releases can be akin to that of carbon-positive fossil fuels.

Figure 3. Carbon Balance of Energy



Source: John A. Matthews, "Carbon-Negative Biofuels," *Energy Policy*, vol. 36 (2008), pp. 940-945; Biopact, "The Strange World of Carbon-Negative Bioenergy: The More You Drive Your Car, the More You Tackle Climate Change," 2007, http://news.mongabay.com/bioenergy/2007/10/strange-world-of-carbon-negative.html. Adapted by CRS.

Notes: Carbon-positive fuels are burned, releasing CO_2 into the atmosphere. Carbon-neutral fuels absorb CO_2 as they grow and release the same carbon back into the atmosphere when burnt. Carbon-negative fuels absorb CO_2 as they grow and release less than this amount into the atmosphere when used as fuel, either through directing part of the biomass as biochar back into the soil or through carbon capture and sequestration.

The designation of biomass combustion as carbon-neutral has come under scrutiny recently due to the Prevention of Significant Deterioration and Title V Greenhouse Gas Tailoring Rule (Tailoring Rule) finalized in May 2010 by the U.S. Environmental Protection Agency (EPA). The Tailoring Rule does not exempt emissions from biomass combustion.[14] The rule grants exemptions not based on source category (e.g., fossil fuels, biomass), but on carbon tonnage

(...continued)

emissions such as significant emissions from land use changes), as determined by the Administrator, related to the full fuel lifecycle, including all stages of fuel and feedstock production and distribution, from feedstock generation or extraction through the distribution and delivery and use of the finished fuel to the ultimate consumer, where the mass values for all greenhouse gases are adjusted to account for their relative global warming potential." 42 U.S.C. §7545(o)(1). For more information on lifecycle emissions, see CRS Report R40460, *Calculation of Lifecycle Greenhouse Gas Emissions for the Renewable Fuel Standard (RFS)*, by Brent D. Yacobucci and Kelsi Bracmort.

[14] EPA's decision on biomass combustion and biogenic activities is described in further detail on pages 419-422 of the final rule, available at http://www.epa.gov/nsr/documents/20100413final.pdf. For more information on the final rule, see CRS Report R41212, *EPA Regulation of Greenhouse Gases: Congressional Responses and Options*, by James E. McCarthy and Larry Parker.

emitted from a facility. Beginning in January 2011, the first phase of the rule applies to any project that emits at least 75,000 tons per year of carbon dioxide equivalent (CO_2e). One reason EPA did not exempt the biomass industry from the Tailoring Rule requirements is lack of information demonstrating the costs and administrative burdens the biopower industry would face if subject to the permitting requirements.[15] EPA issued a call for information in July 2010 to request comment on possible accounting approaches for biogenic emissions under the Tailoring Rule.[16] It is unclear what the Tailoring Rule would mean for biomass combustion plants, since the best available control technologies (BACT)—a pollution control standard mandated by the Clean Air Act—are determined by individual states with EPA guidance on a case-by-case basis.[17]

State perspectives on the inclusion of emissions from biomass combustion in the Tailoring Rule are divided.[18] Some states contend that the inclusion of biomass combustion will jeopardize renewable energy development due to excessive permitting requirements and fees, while other states argue that not including biomass combustion will aggravate climate change over time.

Advocates of not exempting biomass combustion from the Tailoring Rule assert that not all biomass is carbon-neutral.[19] They point out that some types of biomass, particularly biomass coming from waste streams, settle closer to the carbon-neutral and carbon-negative side of the scale. However, cutting down trees from a forest to burn in a power plant without regard to replenishing the tree stand is carbon-positive. Moreover, these advocates argue, fossil fuels are still used to farm, harvest, and transport the biomass for biopower purposes, potentially negating the carbon neutrality over the lifecycle.

Advocates of a complete biomass combustion exemption from the Tailoring Rule contend that biopower plant emissions add no new carbon to the atmosphere because only residuals, byproducts, and thinnings, or waste materials that would decay, are used.[20] Furthermore, they argue that CO_2 released during biomass combustion is neutral because it is re-absorbed by growing biomass. Thus, measuring the emissions released during biomass combustion does not capture the entire biomass emission portfolio. The American Forest & Paper Association asserts that not exempting biomass combustion from the Tailoring Rule "jeopardizes public and private investment in biomass-based renewable energy, which is fundamental to existing and future green jobs in rural communities hit hard by the economic downturn."[21]

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[15] Environmental Protection Agency, "Prevention of Significant Deterioration," 75 *Federal Register* 31590, June 3, 2010.

[16] U.S. Environmental Protection Agency, *Call for Information on Greenhouse Gas Emissions Associated with Bioenergy and Other Biogenic Sources*, July 9, 2010, http://www.epa.gov/climatechange/emissions/biogenic_emissions.html.

[17] BACT is an emissions limitation which is based on the maximum degree of control that can be achieved. It is a case-by-case decision that considers energy, environmental, and economic impact. BACT can be add-on control equipment or modification of the production processes or methods. BACT may be a design, equipment, work practice, or operational standard if imposition of an emissions standard is infeasible.

[18] Energy Washington, *States Split on Whether Biomass Should Be Exempt from GHG Permits*, September 22, 2010.

[19] Nathanael Greene, *Scientists to Congress & Obama: Count the Carbon in Biomass*, Natural Resources Defense Council, May 24, 2010, http://switchboard.nrdc.org/blogs/ngreene/scientists_to_congress_obama_c.html.

[20] Personal communication with Bob Cleaves, CEO, Biomass Power Association, October 1, 2010.

[21] American Forest & Paper Association, "EPA'S Tailoring Rule Undermines Renewable Energy From Biomass, Harms Rural Communities and Puts American Jobs at Risk," press release, May 14, 2010, http://www.afandpa.org/pressreleases.aspx?id=1364.

Looking forward, these competing parties may be concerned with the designation of biomass combustion as carbon-neutral because of congressional discussion and proposals to expand the biomass definition in energy legislation. Expanding the biomass definition could increase the amount of land eligible for biomass removal. The biomass definition in the Energy Independence and Security Act of 2007 (EISA; P.L. 110-140) for the Renewable Fuel Standard (RFS) excludes biomass removal from federal lands, and crops from forested lands are excluded as a biofuel feedstock.[22] However, the Food, Conservation, and Energy Act of 2008 (2008 farm bill, P.L. 110-246) includes biomass from federal lands as a biofuel feedstock. The RFS addresses the carbon balance issue of liquid transportation biofuels by requiring advanced biofuels to have lower lifecycle emissions relative to petroleum products. EPA was responsible for determining how the lifecycle emissions analysis would be carried out. The debate about how EPA should address the lifecycle emissions analysis, especially the land use component, was controversial.[23] While the RFS focuses on liquid transportation fuels, legislation has been introduced to create a renewable electricity standard (RES).[24] Many of the same biomass concerns, and thus carbon neutrality concerns, expressed for the RFS are applicable to an RES.

There are other aspects associated with the designation of biomass energy as carbon-neutral, many of which are beyond the scope of this report.

Implications for Legislation

Biopower straddles at least three legislative areas: agriculture, energy, and environment. The main benefits that agricultural legislation could provide, as argued by proponents for biopower, are to ensure an adequate feedstock supply, maintain productive field conditions during biomass growth and harvest, and assist farmers who participate in the bioenergy market. Energy objectives, as stated by supporters, involve establishing a robust biopower technology platform and providing financial and technical assistance for biopower technology pioneers. Protecting the environment throughout the biomass-to-biopower conversion is the major environmental objective, including monitoring GHG emissions released during energy production.

As a candidate for large-scale energy use, the biopower industry may challenge Congress to address its evolving needs on a frequent basis until biopower is a seasoned energy alternative. One frequent topic of discussion for renewable energy is the "uneven" playing field for certain feedstocks. Supporters of pre-selected feedstocks for biopower production argue that resources can be targeted to that handful of feedstocks that display the most potential for bioenergy production. Opponents contend that pre-selecting certain feedstocks makes it difficult for other feedstocks to obtain the support needed to show their competitiveness as a biopower source.

Congress currently supports biopower with the Renewable Energy Production Tax Credit (PTC) and the Investment Tax Credit (ITC). The PTC is an incentive to business developers of

[22] The Renewable Fuel Standard (RFS) is a provision established by the Energy Policy Act of 2005 requiring gasoline to contain a minimum amount of fuel produced from renewable biomass. For more information on the RFS, see CRS Report R40155, *Renewable Fuel Standard (RFS): Overview and Issues*, by Randy Schnepf and Brent D. Yacobucci.

[23] For more information, see CRS Report R40460, *Calculation of Lifecycle Greenhouse Gas Emissions for the Renewable Fuel Standard (RFS)*, by Brent D. Yacobucci and Kelsi Bracmort.

[24] For more information on the renewable electricity standard debate, see CRS Report R40565, *Biomass Resources: The Southeastern United States and the Renewable Electricity Standard Debate*, by Richard J. Campbell.

renewable energy projects producing electricity, whereby a developer can apply for a credit against taxes for each kilowatt-hour of renewable energy produced.[25] The ITC is an incentive for domestic investment in renewable energy plants and equipment.[26] Moving forward, there may be unintended consequences of legislation that supports biopower. For example, initial USDA regulations for implementing the Biomass Crop Assistance Program (BCAP) led to shifting sawmill residues from products (especially particleboard) to energy rather than increasing utilization of forest waste or planting biomass feedstocks for bioenergy.[27]

Legislative efforts are under way to further support the biopower industry. One relevant legislative effort is the creation of a renewable electricity standard (RES) to encourage renewable energy use, and thus production of renewable energy such as biopower. One bill that includes a federal RES is the American Clean Energy Leadership Act of 2009 (ACELA, S. 1462), an energy policy bill reported out of the Senate Committee on Energy and Natural Resources on July 16, 2009.[28] The RES would require utilities that sell electricity to consumers to obtain a percentage of their annual electricity supply from renewable energy sources or energy efficiency, starting at 3% in 2011 and rising incrementally to 15% by 2021. S. 1462 identifies biomass as an eligible renewable source. H.R. 890, S. 433, and S. 3021 are other bills that would create a federal RES. Additionally, H.R. 2454, the American Clean Energy and Security Act, also contains provisions that would support biopower, such as transmission planning and net metering, along with an RES.[29]

Conclusion

While there remain significant challenges to its future development, biopower production could increase in the coming years to satisfy U.S. renewable energy demand (e.g., state renewable portfolio standards). Generation of electricity from biopower plants has advantages over other renewable sources such as wind and solar. Biopower plants are considered baseload plants. Also, multiple biomass feedstocks can be used to generate electricity. Some disadvantages of using biomass for electricity generation include the cost to transport the biomass to the biopower plant, less biomass to be used for other purposes, and environmental tensions such as whether biomass combustion is carbon-neutral. A sustainable supply of biomass feedstocks could be favorable to biopower growth.

Questions remain about how to encourage biopower production and simultaneously address technological, environmental, and agricultural concerns. Because market uncertainties exist for biopower, the agricultural community may hesitate to grow the amount of biomass feedstocks needed to support large-scale biopower production. Moreover, most biopower technologies, with the exception of combustion and co-firing systems, have yet to reach commercial status.

[25] 26 U.S.C. § 45.

[26] 26 U.S.C. § 48.

[27] For more information on BCAP, see CRS Report R41296, *Biomass Crop Assistance Program (BCAP): Status and Issues*, by Megan Stubbs. BCAP provides financial assistance to producers or entities that deliver eligible biomass material to designated biomass conversion facilities for use as heat, power, biobased products, or biofuels.

[28] For more information on the proposed RES in S. 1462, see CRS Report R40837, *Summary and Analysis of S. 1462: American Clean Energy Leadership Act of 2009, As Reported*, coordinated by Mark Holt and Gene Whitney.

[29] For more information, see CRS Report R40890, *Summary and Analysis of S. 1733 and Comparison with H.R. 2454: Electric Power and Natural Gas*, by Stan Mark Kaplan.

Improvements to the remaining biopower conversion technologies may arise when there is a solid market for biopower. There is no federal mandate requiring the production of biopower, although more than 25 states have implemented state renewable portfolio standards or goals that include biopower. Furthermore, legislative uncertainty has contributed to the reluctance to develop biopower. Additional assurances of federal support, whether technical, economic, or through renewable mandates, could spur commitments by investors, the technology community, and others.

Appendix A. Biomass Feedstock Characteristics for Biopower Generation

Feedstock Type	Energy Value Btu/lb (dry)[a]	Feedstock Yield[b]	Selected Advantages	Selected Disadvantages	Comments[c]
Woody Biomass					
Willow (example of a wood crop grown as a bush type or "coppice" crop in high density plantings as dedicated bioenergy crop)	7,983-8,497	4-8 dry tons/acre/year harvested on 2-4 year cycle	• High yield potential • Grown for several cycles before replanting • Select varieties easily replicated by cloning • Easy to automate planting and harvest as a row crop • Short harvest cycle for wood • Farmers can grow and harvest • Low ash content	• Requires specialized harvesting equipment • High density plantings are costly to establish • U.S. experience and varieties of willow currently limited to Northeast • Must be harvested in winter to obtain regrowth for several cycles • Agricultural site preparation needed for successful establishment • Susceptibility of some willow varieties to insects and diseases may require occasional chemical applications	• Very high future yield potential with genetic selection • Innovative harvest equipment is available • Many woody hardwood crops can be grown as bush type crops • Economic yields obtained on marginal to good cropland • Less fertilization required than agricultural crops
Hybrid poplar (example of a fast growing hardwood grown as a row crop for bioenergy or multiple purposes)	8,183-8,491	3-7 dry tons/acre/year; harvested on 5-15 year cycles	• High yield potential • Select varieties easily replicated by cloning • Easy to automate planting and harvest as a row crop • Can be stored on stump until needed • Relatively low-	• No immediate return on investment • Susceptibility of some hybrid poplar varieties to insects and diseases may require occasional chemical applications • Agriculture-type site preparation needed for successful establishment • Regrowth after harvest is possible but replanting	• Very high future yield potential with genetic selection • Innovative harvest equipment is under development • Economic yields obtained on marginal to good cropland

Feedstock Type	Energy Value Btu/lb (dry)[a]	Feedstock Yield[b]	Selected Advantages	Selected Disadvantages	Comments[c]
			maintenance crop • Improvements for bioenergy will also likely benefit the pulp and paper industry	with superior clones is recommend	
Loblolly pine (example of fast-growing softwood grown as a row crop for bioenergy or multiple purposes)	8,000-9,120	3-7 dry tons/acre/year; harvested every 20-40 years	• 30 million acres of southern pines already are being managed in southern U.S. • Somewhat higher energy value than poplars and willows • Grows better than poplars and other hardwoods on marginal coastal plains and flatwoods soils • Valuable to landowners as a low-intensity crop with multiple markets	• Pines cannot currently be cloned; standard breeding and family selection techniques must be used to improve yield • Pines are mostly hand planted, since planted as rooted seedlings; Limited automation is possible • Agricultural type site preparation needed for rapid early growth	• Well suited for thermal technologies to generate electricity and ethanol • Conversion to liquid fuels is possible with acid hydrolysis and as a co-product of pulp fiber production • Less fertilization required than for agricultural crops
Pine chips (example of forest residues from timber and fiber harvests)	8,000-9,120	10-20 dry tons/acre of on-site residues following logging; harvested every 20-40 years	• Relatively inexpensive if chips produced at the roadside as a by-product of wood processing • Infrastructure to handle forest residues exists	• High retrieval cost when tops and branches collected in forest due to labor-intensive collection and transportation • Tops and branches may not be accessible or environmentally sustainable to remove for chipping, depending on location and soil type	• An expanded ethanol industry using wood can also be an additional source of biopower as a co-product

Feedstock Type	Energy Value Btu/lb (dry)[a]	Feedstock Yield[b]	Selected Advantages	Selected Disadvantages	Comments[c]
Mill residue (from both sawmills and pulp mills)	7,000-10,000	Highly variable depending on operating size of the mill	• Easily available and accessible • Inexpensive • Infrastructure to handle feedstock exists	• Nearly all mill residues are currently being used in wood products such as particleboard and paper, as fuel for heat or biopower, or to make mulch	• Most mill residues will continue to be used at or near the site where wood is processed though at higher energy costs, more might shift to on-site bioenergy production
Herbaceous Biomass					
Miscanthus (highly productive grass in Europe)	7,781-8,417	4-7 dry tons/acre/year current U.S. average 4-12 dry tons/acre/year has been observed for delayed harvest yields in Europe	• Once established, can be harvested annually for 15-20 years before having to replant • Low fertilizer requirements • Drought-tolerant • Very high yield potential with adequate water • Long growth season in mid-U.S. • Giant miscanthus is sterile, thus not invasive	• No immediate harvest; takes one to three years to be established • Not a native species • Testing as a bioenergy feedstock limited to the last 10 years (most research conducted in Europe) • Thick-stem and moisture content of 30 to 50% in late fall requires specialized harvesting equipment • Planting of rhizomes requires specialized equipment	• Perennial grass • Established vegetatively by planting divided rhizome pieces • Higher yields are likely to occur on well-drained soils suitable for annual row crops • Suitable for thermochemical conversion processes, such as combustion, if harvest is delayed until late winter
Switchgrass (example of several possible perennial warm-season grasses)	7,754-8,233	4-9 dry tons/acre/year range in research trials	• Suitable for growth on marginal land • Relatively high, reliable productivity across a wide geographical range	• No immediate harvest; takes two to three years to be established • May require annual fertilization to optimize yields, but at relatively low levels	• Native perennial grass • Can be used for gasification, combustion or pyrolysis technologies to

Feedstock Type	Energy Value Btu/lb (dry)[a]	Feedstock Yield[b]	Selected Advantages	Selected Disadvantages	Comments[c]
			• Low water and nutrient requirements • Provides wildlife cover and erosion control • Can be grown and harvested with existing farm equipment • Planted by seeding • Low moisture content if harvested in late fall (15% to 20%) • Few major insect or disease pests	• Annual harvest must occur over a relatively short window of time each fall • Year-round storage is needed if switchgrass is only feedstock for a bioenergy facility • Energy content diminishes over year if not kept dry • Ash content can be high	generate electricity or for biochemical conversion to ethanol • Research for bioenergy feedstock began in the 1980s
Sorghum—varieties selected for biomass production (similar to a tall thin stalked forage sorghum crop)	7,476-8,184	4-10 dry tons/acre/year Higher yields observed	• Suitable for warm and dry growing regions • Seed production delayed, thus produces more biomass • Annual crop, thus immediate return on investment • Grows across most of eastern and central U.S., not frost limited	• Yields more variable than switchgrass, with rainfall differences • Requires > 20 inches of rainfall annually • Annual crop, thus more expense and work to replant each year	• Sweet, grain, and silage sorghums are more suitable for ethanol production with higher sugar content • Susceptibility to anthracnose disease of some genotypes
Sugarcane/Energycane	7,450-8,349	Yields exceeding 10 dry tons/acre common	• Takes approximately one year to become	• Planting locations limited to a few states in the South and Hawaii	• Literature mostly centers on its use for ethanol

Feedstock Type	Energy Value Btu/lb (dry)[a]	Feedstock Yield[b]	Selected Advantages	Selected Disadvantages	Comments[c]
			established • Has very high yield potential in tropical, semi-tropical and subtropical regions of world • A multi-purpose crop-producing sugar (or ethanol) and biopower feedstock • Drought-adapted	• Must be replanted every 4 to 5 years • Planting is vegetative (stalks are laid down) rather than by seed • Vulnerable to bacterial, fungal, viral, and insect pests • Crop must be harvested green and dewatered or stored like silage	• The bagasse (residue once juice is extracted from the sugarcane) may be used for biopower e.g., frequently used in Brazil • Research ongoing to hybridize to achieve cold tolerance
Aquatic Biomass					
Algae	8,000-10,000 for algal mass; 16,000 for algal oil and lipids	Estimates not available for biopower	• Cultivation strategies can minimize or avoid competition with arable land and nutrients used for conventional agriculture • Can use waste water, produced water, and saline water, reducing competition for limited freshwater supplies • Can recycle carbon from CO_2-rich flue emissions from stationary sources including power plants and other industrial emitters	• Relatively little R&D investment regarding feedstock, biopower conversion, and infrastructure	• Considered a third-generation bioenergy source • Mainly considered for biofuel purposes; however, some scientists are studying its biopower potential, both directly or via methane production[d]

Feedstock Type	Energy Value Btu/lb (dry)[a]	Feedstock Yield[b]	Selected Advantages	Selected Disadvantages	Comments[c]
Agricultural Biomass and Animal Wastes					
Corn stover	7,587-7,967	Stover amounts could range from 3-4.5 dry tons/acre/year in fields producing 100-150 bushels of grain/acre	• Cultivation techniques are established • Using a resource that has previously gone unused • Stover conversion process could be added to grain-to-ethanol facilities	• Harvesting and transportation infrastructure not yet established • Excessive removal may lead to soil erosion and nutrient runoff • Requires high level of nutrients and fertile soils	• Corn grain and stover use has reinvigorated the food-fuel debate • Can be used for gasification, combustion, or pyrolysis technologies for electricity or biochemical processes for biofuels
Wheat straw	6,964-8,148	2.6 tons dry tons/acre	• Cultivation techniques are established • Using a resource that has previously gone unused	• Harvesting and transportation infrastructure not yet established • Excessive removal may lead to soil erosion and nutrient runoff	• Can be used for gasification, combustion or pyrolysis technologies to generate electricity or biochemical processes to biofuels
Sugarcane bagasse (residue once juice is extracted from the sugar cane; see above for sugarcane)	7,450-8,349	14%-30% of total sugarcane yield	• Sugarcane takes approximately one year to become established • Bagasse is collected as part of the main crop	• Bagasse availability limited to a few states in the South and Hawaii • Ash content can be high	• Literature mostly centers on its use for ethanol • The bagasse is used to power sugarcane mills in many parts of the world.
Cattle manure	8,500	Based on manure excretion rate of cow	• Using a resource that is generally regarded as a waste product with little to no value	• Technology to convert manure to electricity is expensive • Difficult for some	• Well suited for anaerobic digestion to generate electricity

Feedstock Type	Energy Value Btu/lb (dry)[a]	Feedstock Yield[b]	Selected Advantages	Selected Disadvantages	Comments[c]
			• Using a resource that has undesirable environmental impacts if improperly managed • Collection systems established for dairy manure • Water and air quality improvement	agricultural producers to sell power to utilities due to economics and utility company collaboration	
Industrial Biomass					
Municipal solid waste (MSW)	5,100 (on an as arrived basis)	1,643 lbs/person/year	• A resource available in abundant supply • Diverts MSW from landfill disposal • Well-commercialized technology (waste-to-energy plants)	• Could serve as a disincentive to separate and recycle certain waste • Air emissions are strictly regulated to control the release of toxic materials often in MSW; toxins removed from air emissions will be transferred to waste ash, which may require disposal as hazardous waste • Costs are substantially higher than landfill in most areas	• Not considered by some as a renewable energy feedstock because some of the waste materials are made using fossil fuels • Well suited for combustion (waste to energy plants), gasification, pyrolysis, or anaerobic digestion technologies to generate electricity
Fossil Fuels					
Coal (low rank; lignite/sub-bituminous)	6,437-8,154	Not applicable	• Established infrastructure • Reliable	• Limited resource • Major source of mercury, SO_2, and NOx emissions	

Feedstock Type	Energy Value Btu/lb (dry)[a]	Feedstock Yield[b]	Selected Advantages	Selected Disadvantages	Comments[c]
			• Relatively inexpensive	• Main source of U.S. greenhouse gas emissions • Generates a tremendous amount of waste ash that likely contains a host of hazardous constituents	
Coal (high rank; bituminous)	11,587-12,875	Not applicable	• Established infrastructure • Reliable • Relatively inexpensive	• Limited resource • Major source of mercury, SO_2 and NOx emissions • Main source of U.S. greenhouse gas emissions • Generates a tremendous amount of waste ash that likely contains a host of hazardous constituents	
Oil (typical distillate)	18,025-19,313	Not applicable	• Established infrastructure • Reliable	• Limited resource • Major source of SO_2 and NOx emissions • Purchased in large quantities from foreign sources	

Source: Compiled from various sources by CRS and Lynn Wright, biomass consultant working with Oak Ridge National Laboratory.

Notes: The information provided in this table are estimates for general use. Multiple factors including location, economics, and technical parameters will influence the data on a case-by-case basis. Lynn Wright, biomass consultant working with Oak Ridge National Laboratory, provided the following comments: The infrastructure to handle woody resources (both forest residues and plantation grown wood) already exists in the pulp and paper industry and can be easily used for the bioenergy industry. Most woody biomass resources (whether forest residues or plantation grown wood) will be delivered as chips similar to current pulp and paper industry practices. However, new equipment and harvest techniques may allow delivery as bundles or whole trees in some situations. Wood resources such as chipped pine (softwoods) and hardwoods and urban wood residues are already being used to generate electricity using direct combustion technologies, all woody feedstocks are well suited for all thermal conversion technologies including combustion, gasification and pryolysis to generate electricity. Biopower can also be produced from the black liquor by-product of both pulp and ethanol production. Clean wood chips from willow, hybrid poplar, and other hardwoods are also very suitable for conversion to liquid fuels using biochemical conversion technologies.

a. Energy values for the following feedstocks were obtained from Oak Ridge National Laboratory, Biomass Energy Data Book: Edition 2, ORNL/Tm-2009/098, December 2009, http://cta.ornl.gov/bedb/pdf/BEDB2_Full_Doc.pdf; Table A.2 "Heat Content Ranges for Various Biomass Fuels"; willow, hybrid poplar, pine = Forest Residues - softwoods, switchgrass, miscanthus (converted from kj/kg to Btu/lb) corn stover, sugarcane bagasse and wheat straw. Energy values for fossil fuels were obtained by converting the heating values (GJ/t) provided in Jonathan Scurlock, *Bioenergy Feedstock Characteristics*, Oak Ridge National Laboratory, 2002, http://bioenergy.ornl.gov/papers/misc/biochar_factsheet.html to an energy value (Btu/lb). The energy value for sawmill residue was obtained from Nathan McClure, Georgia Forestry Commission, "Forest Biomass as a Feedstock for Energy Production," oral presentation for Georgia Bioenergy Conference, August 2, 2006, http://www.gabioenergy.org/ppt/McClure—Forest%20Biomass%20as%20a%20Feedstock%20for%20Energy%20Production.pdf. The energy value for algae was obtained from Oilgae, "Answers to some Algae Oil FAQs—Heating Value, Yield ...," February 2007, http://www.oilgae.com/blog/2007/02/answers-to-some-algae-oil-faqs-heating.html. The energy value of manure on a dry ash-free basis was obtained from Texas Cooperative Extension, *Manure to Energy: Understanding Processes, Principles and Jargon*, E-428, 2006, http://tammi.tamu.edu/ManurtoEnrgyE428.pdf. The manure heating value may be reduced by the ash and moisture content of the manure given certain conditions. The energy value of municipal solid waste was obtained from C. Valkenburg, C.W. Walton, and B.L. Thompson, et al., *Municipal Solid Waste (MSW) to Liquid Fuels Synthesis, Volume 1: Availability of Feedstock and Technology*, Pacific Northwest National Laboratory, PNNL-18144, December 2008, http://www.pnl.gov/main/publications/external/technical_reports/PNNL-18144.pdf. The energy value for sorghum was obtained using a value for sudan grass, a closely related crop, from the European PHYLLIS database http://www.ecn.nl/phyllis/dataTable.asp.

b. The harvest frequency is on an annual basis unless stated otherwise. Energy yield ranges for willows, poplars, pines, switchgrass, miscanthus, sugarcane, sugarcane bagasse and sorghum were provided by Lynn Wright, biomass consultant working with Oak Ridge National Laboratory. Energy yields for miscanthus. and switchgrass were also discussed with Jeffrey Steiner (USDA), August 2010. Energy yields for hybrid poplar were also obtained from Minnesota Department of Agriculture, *Minnesota Energy from Biomass*, http://www.mda.state.mn.us/renewable/renewablefuels/biomass.aspx; Energy yield for pine chips (forest residues) was obtained from calculations from data in David A. Hartman et al., *Conversion Factors for the Pacific Northwest Forest Industry* (Seattle, WA; Univ. of Washington, Institute of Forest Products, no date), pp. 6, 47. Energy yield for corn stover was obtained from R.L Nielsen, *Questions Relative to Harvesting & Storing Corn Stover*, Purdue University, AGRY-95-09, September 1995, http://www.agry.purdue.edu/ext/corn/pubs/agry9509.htm. Energy yield for wheat straw was obtained from Jim Morrison, Emerson Nafziger, and Lyle Paul, *Predicting Wheat Straw Yields in Northern Illinois*, University of Illinois at Urbana-Champaign, 2007, http://cropsci.illinois.edu/research/rdc/dekalb/publications/2007/PredictingWheatStrawYieldsFinalReportToExtensionMay2007.pdf; In general, it is assumed a dairy cow excretes 150lbs of manure/day based on the American Society of Agricultural and Biological Engineers (ASABE) Manure Production and Characteristics Standard D384.2, March 2005. Energy yield for municipal solid waste was calculated based on data from U.S. Environmental Protection Agency Office of Solid Waste http://www.epa.gov/osw/basic-solid.htm (In 2008, U.S. residents, businesses, and institutions produced about 250 million tons of MSW, which is approximately 4.5 pounds of waste per person per day). Energy yield for miscanthus in Europe was obtained from Clifton-Brown, J.C., Stampfl, P.A., and Jones, M.B., *Miscanthus Biomass Production for Energy in Europe and Its Potential Contribution to Decreasing Fossil Fuel Carbon Emissions*. Global Change Biology, 10, (2004) pp. 509-518; Energy yield for siwtchgrass was obtained from McLaughlin, S.B., and Kszos, L.A., "Development of Switchgrass (panicum virgatum) as a bioenergy feedstock in the United States." Biomass and Bioenergy 28 (2005) pp. 515-535. Energy yield for sorghum was obtained from W.L. Rooney, et al, "Designing Sorghum as a Dedicated Bioenergy Feedstock." *Biofuels, Bioproducts, and Biorefining*. 1, (2007) pp.147-157; Energy yield for sugarcane/energycane obtained from http://www.ars.usda.gov/research/publications/publications.htm?seq_no_115=251543&pf=1 (a web-published abstract of a book chapter written by Bransby et. al. and submitted for publication in February 2010); Energy yield for sugarcane baggase was obtained from http://www.ars.usda.gov/research/publications/publications.htm?seq_no_115=254594&pf=1 (an abstract of a book chapter prepared by R. Viator, P. White, and E. Richard, and entitled " Sustainable Production of Energycane for Bio-energy in the Southeastern U.S." submitted for publication by the Sugarcane Research Unit in Houma, LA in August 2010).

c. For more information on the state of combustion, pyrolysis, gasification, and anaerobic digestion technologies, see the shaded text box on page 5.

d. For more information, see Stanford University, "Stanford Researchers Find Electrical Current Stemming from Plants," press release, April 13, 2010, http://news.stanford.edu/news/2010/april/electric-current-plants-041310.html; and John Ferrell and Valerie Sarisky-Reed, *National Algal Biofuels Technology Roadmap*, U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Office of the Biomass Program, May 2010, http://www1.eere.energy.gov/biomass/pdfs/algal_biofuels_roadmap.pdf.

Appendix B. Biopower R&D Authorizations

R&D Authorizations

Congress has enacted numerous provisions that authorize the Departments of Energy (DOE) and Agriculture (USDA) to conduct biopower research, development, and demonstration projects (RD&D) and to support biopower commercial application efforts.[30] At least eight public laws contain one or more biopower provisions:

- P.L. 95-620, Powerplants and Industrial Fuel Use Act of 1978
- P.L. 96-294, Energy Security Act of 1980
- P.L. 106-224, Biomass Research and Development Act of 2000
- P.L. 107-171, Farm Security and Rural Investment Act of 2002
- P.L. 108-148, Healthy Forest Restoration Act of 2003
- P.L. 109-58, Energy Policy Act of 2005
- P.L. 110-140, Energy Independence and Security Act of 2007
- P.L. 110-246, Food, Conservation, and Energy Act of 2008

The public laws discussed in this section are summaries of provisions at the time of enactment to illustrate the evolution of bioenergy policy. Some provisions may have been amended since enactment. A comprehensive legislative history of current law is beyond the scope of this report.

1978-1980: Biopower Legislative Origin

Both the Powerplant and Industrial Fuel Use Act of 1978 (P.L. 95-620) and the Energy Security Act of 1980 (P.L. 96-294) introduced the concept of biopower to the legislative arena. However, the enacted legislation emphasized the use of biomass as a liquid fuel to reduce dependence on imported petroleum and natural gas. Biomass used to generate electricity appears to have received less legislative support compared to biomass use as a liquid fuel, based on the report language and authorizations.

Powerplant and Industrial Fuel Use Act of 1978 (P.L. 95-620)

The legislative origin of biopower stems from the Powerplant and Industrial Fuel Use Act of 1978. The act aimed to restrict the use of oil and natural gas as fuel in an attempt to mitigate the oil crisis of the mid-1970s by encouraging industries and utilities to reduce oil use. It required new power plants to operate using coal or alternate fuel sources. Otherwise, the act did not provide explicit support for biopower RD&D and commercial application.

[30] National Renewable Energy Laboratory, *Power Technologies Energy Data Book*, NREL/TP-620-39728, August 2006, http://www.nrel.gov/analysis/power_databook/docs/pdf/39728_complete.pdf.

- § 103(a)(6) - defines alternate fuel, in part, as electricity or any fuel, other than natural gas or petroleum, from sources such as biomass, municipal, industrial or agricultural wastes, wood, and renewable and geothermal energy sources.

Energy Security Act of 1980 (P.L. 96-294)

- § 203(4)(B) - defines biomass energy, in part, as energy or steam derived from the direct combustion of biomass for the generation of electricity, mechanical power, or industrial process heat.
- § 203(5)(B) - defines biomass energy project, in part, as any facility (or portion of a facility) located in the United States which is primarily for the combustion of biomass for generating industrial process heat, mechanical power, or electricity, including cogeneration.
- § 203(19) - defines a small-scale biomass energy project as a biomass energy project with an anticipated annual production capacity of not more than 1 million gallons of ethanol per year, or its energy equivalent of other forms of biomass energy.
- § 211(a) - requires DOE and USDA to collaborate on a biomass energy production and use plan and on providing financial assistance for biomass energy projects.
- § 251(a) - indirect reference to biopower; stipulates the establishment of demonstration biomass energy facilities by the Secretary of Agriculture to exhibit the most advanced technology available for producing biomass energy.
- § 252 - indirect reference to biopower; modifies § 1419 of the National Agricultural Research, Extension, and Teaching Policy Act of 1977 (P.L. 95-113) to better address biomass energy for RD&D purposes; authorizes the Secretary of Agriculture to award grants for research related to, in part, the development of the most economical and commercially feasible means of producing, collecting, and transporting agricultural crops, wastes, residues, and byproducts for use as feedstocks for the production of alcohol and other forms of biomass energy.
- § 255(a) - indirect reference to biopower; adds a Biomass Energy Educational and Technical Assistance Program to Subtitle B of P.L. 95-113 to provide technical assistance to producers for efficient use of biomass energy and disseminate research results to producers about biomass energy, among other things.

1981-1999: Biopower Legislation and Technology

Congress did not significantly address biopower during most of the 1980s and 1990s partially due to stable conventional energy prices and supplies. Some biopower technologies emerged during this time period with low success rates due to poor design and inadequate management (e.g., anaerobic digestion systems). Other reliable biopower technologies were developed during this time period (e.g., biomass co-firing), but these could not compete economically with other energy sources.

2000-Present: Biopower Legislative Action

Described below are a variety of biopower provisions contained in public laws since 2000. Although many of the provisions focus primarily on the use of biomass for liquid transportation fuel, there is also legislative support for biopower. Both DOE and USDA have the authority to conduct RD&D and support commercial application efforts for biopower. However, project summaries and financial allotments indicate the majority of resources in recent years were directed toward liquid fuels for transportation.[31]

Biomass Research and Development Act of 2000 (P.L. 106-224)

The Biomass Research and Development Act[32] established a partnership between the USDA and DOE for RD&D on the production of biobased industrial products. (This act was amended by the Energy Policy Act of 2005, P.L. 109-58.) The original provisions included:

- § 303(2) - defines biobased industrial products to include fuels, chemicals, building materials, or electric power or heat produced from biomass.
- § 305 - implicit reference to biopower; establishes the Biomass Research and Development Board to coordinate research and development activities relating to biobased industrial products; Board membership includes a representative from DOE, USDA, Department of the Interior, the U.S. Environmental Protection Agency, the National Science Foundation, and the Office of Science and Technology Policy.
- § 306 - implicit reference to biopower; establishes the Biomass Research and Development Technical Advisory Committee to, in part, advise the Biomass Research and Development Board concerning the technical focus and direction of requests for proposals issued under the Biomass Research and Development Initiative
- § 307 - implicit reference to biopower; authorizes the Secretaries of Agriculture and of Energy to, in part, competitively award grants, contracts, and financial assistance to eligible entities that can perform research on biobased industrial products. For example, grants may be rendered to an entity conducting research on advanced biomass gasification and combustion to produce electricity (§ 307(d)(2)(e)); related research in advanced turbine and stationary fuel cell technology for production of electricity from biomass (§ 307(d)(2)(f)); biomass gasification and combustion to produce electricity (§ 307(d)(3)(A)(v)); and any research and development in technologies or processes determined by the Secretaries, acting through their respective points of contact and in consultation with the Biomass Research and Development Board (§ 307(d)(4)).

[31] For information on biomass energy incentives, see CRS Report R40913, *Renewable Energy and Energy Efficiency Incentives: A Summary of Federal Programs*, by Richard J. Campbell, Lynn J. Cunningham, and Beth A. Roberts

[32] The Biomass Research and Development Act is Title III of the Agricultural Risk Protection Act of 2000 (P.L. 106-224).

Farm Security and Rural Investment Act of 2002 (P.L. 107-171)

- § 9003 - authorizes the Secretary of Agriculture to award grants to assist in paying the development and construction costs of biorefineries in order to carry out projects that demonstrate their commercial viability for converting biomass to fuels or chemicals.
- § 9003(b)(2) - defines biorefinery as equipment and processes that convert biomass into fuels and chemicals; and may produce electricity.

Healthy Forest Restoration Act of 2003 (P.L. 108-148)

- § 203 - establishes the Biomass Commercial Utilization Grant Program; authorizes the Secretary of Agriculture to make grants to the owner or operator of a facility that uses biomass as a raw material to produce one or more of several outputs, including electric energy.

Energy Policy Act of 2005 (EPAct05; P.L. 109-58)

- § 931(f) - authorizes the Secretary of Energy, in consultation with the Secretary of Agriculture, to implement rural demonstration projects that use renewable energy technologies to assist in delivering electricity to rural and remote locations from biomass.
- § 932 (b)(1) - authorizes the Secretary of Energy to conduct a program of RD&D, and commercial application for bioenergy including biopower energy systems.
- § 932 (d)(B)(iv) - authorizes the Secretary of Energy to demonstrate the commercial application of integrated biorefineries from the commercial application of biomass technologies for energy in the form of electricity or useful heat.
- § 941(a) - amends the definition for biobased product in P.L. 106-224 to mean an industrial product (including chemicals, materials, and polymers) produced from biomass, or a commercial or industrial product (including animal feed and electric power) derived in connection with the conversion of biomass to fuel.
- § 941(d)(1) - modifies membership of the Biomass Research and Development Technical Advisory Committee (P.L. 106-224 § 306); replaces an individual affiliated with the biobased industrial products industry with an individual affiliated with the biofuels industry; adds an individual affiliated with the biobased industrial and commercial products industry; requires committee members as described in P.L. 106-224, § 306(b)(1)(C), (D), (G), and (I) to have expertise in 'fuels and biobased products' whereas previously members were to have expertise in 'biobased industrial products'.
- § 941(e)(1) - modifies the Biomass Research and Development Initiative (P.L. 106-224, § 307(a)) to focus on "research on, and development and demonstration of, biobased fuels and biobased products, and the methods, practices and technologies, for their production." Previously the initiative focus was on "research on biobased industrial products."

- § 941(e)(2) - adds to the Biomass Research and Development Initiative (P.L. 106-224, § 307) an objectives section and a technical areas section, in addition to other sections, that specify biobased fuels as a priority. For example, the initiative is to support "product diversification through technologies relevant to production of a range of biobased products (including chemicals, animal feeds, and cogenerated power) that eventually can increase the feasibility of fuel production in a biorefinery."

Energy Independence and Security Act of 2007 (EISA; P.L. 110-140)

- § 231(1) - modifies EPAct05 § 931(b) by adding an authorization of $963 million for FY2010. Section 931 of the EPAct05 authorizes the Secretary of Energy to conduct programs of renewable energy RD&D, and commercial application.
- § 231(2) - modifies EPAct05 § 931(c)(2) to increase authorized funding for FY2008 from $251 million to $377 million; Also modifies EPAct05 § 931(c)(3) to increase authorized funding for FY2009 from $274 million to $398 million.

The Food, Conservation, and Energy Act of 2008 (2008 Farm Bill, P.L. 110-246)

- § 7526 - reauthorizes the Sun Grant program, which requires USDA to coordinate with DOE and land-grant colleges and universities to provide grants to the Sun Grant centers to enhance the efficiency of bioenergy and biomass research and development programs.
- § 9001 - defines biorefinery as a facility that converts renewable biomass into biofuels and biobased products; and may produce electricity.
- § 9008 - defines biobased product as an industrial product (including chemicals, materials, and polymers) produced from biomass, or a commercial or industrial product (including animal feed and electric power) derived in connection with the conversion of biomass to fuel.
- § 9011 - establishes the Biomass Crop Assistance Program which provides financial assistance to producers or entities that deliver eligible biomass material to designated biomass conversion facilities for use as heat, power, biobased products or biofuels.
- § 9012 - authorizes the Secretary of Agriculture, acting through the Forest Service, to conduct a competitive R&D program to encourage use of forest biomass for energy.
- § 9013(a)(2) - defines a community wood energy system as an energy system that primarily services public facilities owned or operated by state or local governments, including schools, town halls, libraries, and other public buildings; and uses woody biomass as the primary fuel. The term includes single facility central heating, district heating, combined heat and energy systems, and other related biomass energy systems.
- § 9013(b) - establishes the Community Wood Energy Program and authorizes the Secretary of Agriculture, acting through the Forest Service, to provide grants of up to $50,000 for up to 50% of the cost for communities to plan and install wood energy systems in public buildings.

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