U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Biopower Technical Strategy Workshop

Summary Report

December 2-3, 2009
Denver, Colorado

December 2010

Preface

The U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (DOE/EERE) invests in a diverse portfolio of energy technologies to achieve a stronger economy, a cleaner environment, and a secure energy future for America.

The Biomass Program is an integral component of DOE/EERE's efforts to diversify our energy supply. The program works with industrial partners, national laboratories, and other stakeholders to develop the technologies and systems needed to cost-effectively turn our abundant, domestic biomass resources into clean, affordable bioenergy.

This report summarizes the results of a workshop sponsored by the DOE/EERE Biomass Program in Denver, Colorado, on December 2–3, 2009. The workshop was convened to identify and discuss challenges to the expanded use of biopower and the possible solutions, including technology research, development, and demonstration (RD&D) as well as policies and other market transformation mechanisms.

This report underwent a formal public comment period during 2010. The comments that were received have been incorporated in this document in some form or addressed through other actions.

For more information, contact:

EERE Information Center
1-877-EERE-INFO (1-877-337-3463)
www.eere.energy.gov/informationcenter

Biomass Program
Energy Efficiency and Renewable Energy
U.S. Department of Energy
1000 Independence Ave., SW
Washington, DC 20585
www.eere.energy.gov/biomass

Cover Photos

Wood chips. Source: Verenium.
Industrial turbine. Source: Brand X Pictures, Steven Allen Photography.
Biomass gasifier at McNeil Station,Vermont. Source: NREL. Credit: Warren Gretz.
Power lines. Source: IStock.
Hybrid cottonwood tree farm. Source: NREL. Credit: Warren Gretz.

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EXECUTIVE SUMMARY

Biopower is electricity produced from a wide range of biomass (organic materials found in wood, plants, agricultural waste, and other materials). Biomass is a base load renewable energy source that is readily available across the United States, which makes it more reliable than wind and solar for electricity production. Biomass also offers a renewable energy solution in areas where other renewable sources are not as readily available.

Biopower is one means by which to meet national goals for the use of clean, renewable energy while promoting economic growth. A successful, sustainable biopower industry can provide clean, domestic, renewable power; revitalize rural economies; reduce impacts to the environment and climate; promote healthy forests; and create diverse job opportunities with agribusinesses, utility and power plant vendors, owners/operators, equipment suppliers, and small businesses.

Today more than half of all states have enacted legislation (renewable portfolio standards, or RPS) requiring some portion of electricity to be produced from renewable sources such as biomass by 2020. A federal standard is also currently under consideration. If enacted, such a standard will create additional demand for renewable energy sources such as biopower.

To explore opportunities for biopower in the United States, the U.S. Department of Energy (DOE), Office of Energy Efficiency and Renewable Energy Biomass Program conducted the *Biopower Technical Strategy Workshop* in Denver, Colorado, on December 2–3, 2009. The purpose of the workshop was to provide a forum for discussing technical and economic challenges; research, development, and demonstration (RD&D) priorities; and issues related to feedstocks, sustainability, and market transformation. The workshop was attended by a wide spectrum of experts from industry, academia, national laboratories, and government, and it generated a wealth of information and ideas.

This report presents the results of the workshop, organized by the five topic areas shown in Figure E.1. The DOE Biomass Program expects to use the results of the workshop to inform planning and help map future research and development priorities in sustainable biopower.

FIGURE E.1
WORKSHOP TOPICS

- Pretreatment and Conversion Technologies: Pretreatment to improve combustibility and other characteristics (e.g., torrefaction, bio coal briquetting, and densification), and conversion (e.g., pyrolysis and gasification).
- Large-Scale Systems: Biomass systems integrated with utility-scale power generation, such as large-scale cofiring with coal or natural gas, gasification, or direct combustion.
- Smaller-Scale Systems: Systems that range from ~1–50+ megawatts (10–15 megawatts are typically small scale; however, larger non-utility systems are included here), including industrial, community, and institutional systems; repurposed pulp and paper mills; and others; with a focus on combined heat and power.
- Feedstocks for Biopower: Integration of biomass handling systems with power plants, use of opportunity fuels, sustainability, super-high-yield energy crops, and other issues.
- Market Transformation: Policy, legislation and regulation, land use issues, renewable portfolio standards, tax and investment credits, permitting, markets, loan guarantees, and other elements.

Biopower Overview

Today, other than hydroelectricity, biopower is the largest source of renewable electricity in the world and accounts for more power generation than wind and solar combined. Globally, most biopower today is generated from solid biomass (e.g., wood) with smaller amounts from biogas, municipal solid waste (MSW), and biofuels (IEA 2007). In 2008, the net summer capacity of the U.S. biopower industry, which contributes about $10 billion to the economy annually, was approximately 11,050 megawatts (MW), including wood, landfill gas, MSW, and other waste biomass (EIA 2010). Most of today's biopower plants are direct-fired systems producing 50 MW or less of electricity. Plants are owned and operated by a wide range of stakeholders, from industrial users (e.g., pulp and paper mills and lumber companies), to utilities, independent power producers, and small-scale community users (e.g., institutional users). Independent power producers and industrial combined heat and power (CHP) facilities account for about 83% of net biomass summer generating capacity.

Biopower is a fairly mature technology with hundreds of successful commercial-scale operations. Many technologies are potentially available to transform raw biomass material directly or indirectly into electricity, including direct firing, cofiring of biomass with coal or natural gas, gasification, pyrolysis, torrefaction, pelletization, and anaerobic digestion. These technologies are in various stages of development and use. Over 50% of biopower facilities are utilizing higher-efficiency CHP systems to provide both heat and power.

Despite the benefits of biopower and the compelling economic and environmental drivers, there are still significant barriers to the realization of a widespread, sustainable U.S. biopower industry. Some of the major challenges today include ensuring the availability of a sustainable biomass supply, improving the efficiency and cost of conversion technologies, exploring more cost-effective ways to utilize biomass (e.g., advanced pretreatment), and addressing the economic and other ramifications of an uncertain policy and regulatory climate (e.g., carbon, environment, permitting, and RPS).

Major Challenges and Priorities for RD&D

The major technical challenges facing the biopower industry are summarized below. To address these challenges, a number of priority RD&D areas were identified, as illustrated in Figure E.2.

Pretreatment and Conversion—There is currently a shortage of large (over 10 tons) pilot projects that would provide some experience with new pretreatment technologies, including torrefaction and others. A lack of online sampling tools and analysis limits better understanding of technology performance. The removal of non-ferrous metals from fuel particles is also a barrier to improving the quality and consistency of the fuel. A better understanding of torrefaction is needed to determine technology status and commercial viability, particularly cost-effectiveness. Life cycle analysis (LCA) is also needed to determine the value and future prospects of each pretreatment and conversion technology in relation to biopower applications.

Large-Scale Systems—Feedstock supply and sourcing is a crucial issue, particularly the stability and maturity of fuel sourcing. The lack of uniform, well-characterized feedstocks also creates risk, as it is not well understood how the diversity of biomass fuels will perform and ultimately affect boiler and other system operations. One key concern is the ability to convert biomass into a form that is cost-effective and reliable for use in retrofit power plants with minimal impact on system integrity (e.g., corrosion). In addition to concerns about deposit formation and corrosion, the use of biomass may impede the sale and utilization of fly ash for cement production when cofiring with coal in pulverized coal burners.

The ability to successfully scale technologies from pilot- to large-scale (e.g., achieving the same equipment performance and reliability at larger scales) can be an issue for advanced technologies.

Smaller-Scale Systems—The most critical barrier is the difficulty in finding users for cogenerated heat in close proximity to the source. While gasification has significant potential, new, scalable designs will be needed to integrate the unique requirements of small-scale power. Another priority challenge is the need for cost-effective air emission controls, particularly for new systems (e.g., gasification). The high cost of pollution abatement and controls and the need to meet increasingly stringent (and potentially uncertain) standards makes it more difficult to justify investment in small-scale power. The lack of continuously operating demonstration plants for new technologies in the United States, especially for smaller-scale systems, increases the technical risk of new systems.

Feedstocks for Biopower—To ensure that large amounts of biomass fuel can be produced cost-effectively, much higher yields must be achieved (i.e., 10–20 dry tons/acre/year rather than today's yields of 2–6 dry tons/acre/year). The environmental and sustainability aspects of biomass must be measured both qualitatively and quantitatively to better understand the impacts. There will be significant variability in the type of studies needed based on feedstock, current land use, water requirements, soil type, growing region, and other parameters. Feedstock movement, storage, and quality are other key issues. Improvements are needed in harvesting (optimal timing and impacts on ash and moisture), transport (cost), and storage (spontaneous combustion, decomposition, quality, and impacts on ash and moisture).

FIGURE E.2

Priority RD&D and Analysis for Biopower

Pretreatment & Conversion	Cost-effective Biomass Pretreatment and Conversion Technologies	Characterization of Biomass Intermediates and Products from Pretreatment	Theoretical Analysis of Biomass Pretreatment and Conversion Processes	Proof of Concept and Scale-up Pretreatment	Feasibility Studies for Large Scale, Cost-effective Torrefaction	Clearinghouse for Techno-economic , Life Cycle, Assessment, and Systems Analysis
Large-Scale Systems	Low-Temperature Gasification Technology and Hot Gas Cleanup	High-Temperature Materials Research Related to Combustion of Biomass	Cost-effective, Combustion of Bio-oil for Biopower Applications	Demonstrations—Re-powering Boilers, Cofiring and Advanced Bipoower; Characterize Options/Benefits of Re-powering	Catalogue And Correlation of Biomass Fuel Properties With Downstream Processing	Techno-economic Analysis to Coordinate Technologies With Feedstocks
Smaller-Scale Systems	Synthesis Gas Cleanup For Small-scale Gasification	Micro-scale Biomass-based Combined Heat and Power	Demonstration of Integrated , Advanced Small Scale Systems	Cost-effective Emissions Control Technology for Small Scale Systems	Analysis for Small Scale System Applications , Including Market Assessment)	
Feedstocks for Biopower	High -Yield Feedstocks	Optimized Feedstock Production and Transport Supply Chain	Multi-region, Large-scale Environmental Monitoring of Energy Crops and Residue Removal	Techno-economic Models for Optimized Feedstock Supply/Use	Sustainability Indicators for Feedstocks And Energy Production	Standardized Analytical and Data Collection Methods For Biomass

Cross-cutting Themes

- Techno-economic Analysis—Understanding of economic feasibility to inform decision making for both RD&D and projects on the path to commercialization.
- Life Cycle Analysis—Life cycle analysis to evaluate biopower comparative to other options, as well as for justifying the carbon mitigation aspects of biopower.
- Feedstock Availability And Quality—Addressing uncertainties about the availability of reliable, consistent quality feedstock supplies all year round and in sufficient volumes for users.
- Impact of Feedstocks on Power System Performance and Operability—Better technologies for characterization and monitoring of physical and chemical feedstock properties to improve certainty and promote acceptance of biomass for biopower.
- Sustainability—Ensuring the development of *sustainable* biopower and feedstocks (environment, climate, societal).

Challenges and Priorities for Market Transformation

Widespread deployment of biopower faces a number of market barriers at the local, state, and federal levels. Chief among these are high capital and operating costs for early generation systems, feedstock cost and supply uncertainties, varying policies and incentives, inconsistent or inadequate codes and standards, high investment risks, and lack of understanding of the performance and benefits of biopower and sustainable biomass feedstock supply in real-world operations. The lack of a federal RPS was noted, as were the market uncertainties created by the lack of comprehensive and well-understood carbon legislation and energy policy. Figure E.3 illustrates actions that were identified to address some of these barriers.

FIGURE E.3

Priorities for Market Transformation

Multi-Year Planning	"Biopower Build-out Vision" to Guide Multi-Year Planning	
Technical Assistance & Demonstration	Technical Assistance for Deployment of Biopower	Demonstrations of Advanced Biopower Technologies are Needed
Coordination & Collaboration	Collaborative Efforts to Promote Biopower Best Practices	
Analysis for Decision Making	Techno-economic, Life Cycle, and Sustainability Analysis	Comparative Energy and Environmental Analysis
Education and Award Programs	Bio-Cities Program Similar to DOE Clean Cities	"Advancing Biomass Utilization Award" for All Sectors
Informing End Users & Other Stakeholders	Online Biopower Library for Enhanced Information Dissemination	Decision-making Tools, Resources, and Continuous Communication

Cross-cutting Themes

Renewable Portfolio Standard (RPS)—The need for a national RPS was universally identified as an urgent need. A federal RPS would include an expansive definition for biomass, provide nationally consistent incentives (e.g., tax parity) for biopower, and support a more certain policy environment for investors.

Carbon Legislation—Impending carbon legislation and associated regulatory impacts are currently creating market uncertainties. A cap and trade/market-based approach will require a harmonious carbon equivalent market; an equitable basis for taxation will be needed for command and control , should that be the approach.

1 INTRODUCTION

Biopower is electricity produced from a wide range of biomass (organic materials found in wood, plants, agricultural waste and other materials). Biomass is a base load renewable energy source with high availability, which makes it potentially more reliable and not intermittent like wind and solar power for electricity production.

The use of biopower is one way to help meet national goals for the use of clean, renewable energy. More than half of all states have enacted renewable portfolio standards (RPS) requiring some portion of electricity to be produced from renewable sources, such as biomass, by 2020. A federal standard is currently under consideration, and if enacted, will create additional demand for renewable energy.

The potential benefits of a successful, sustainable biopower industry are numerous:

- Diversify energy supply by providing a clean, domestic, renewable, source of power.
- Generate baseload power that can potentially be integrated with other renewable sources such as wind or solar.
- Revitalize rural economies.
- Reduce impacts to the environment and climate (can be carbon-neutral and emit less sulfur dioxide than coal).
- Promote healthy forests and use of waste, with little competition for crop lands.
- Create diverse job opportunities with agribusinesses, utility and power plant vendors, owners/operators, equipment suppliers, and small business.

Photo Courtesy of NREL.

Today, biopower is the largest source of renewable electricity in the world other than hydroelectricity, and it accounts for more power generation than wind and solar combined. Globally, most biopower today is generated from solid biomass (e.g., wood) with smaller amounts from biogas, biofuels, and municipal waste (IEA 2007). In the United States, biopower net summer generating capacity was about 11,050 megawatts (MW) in 2008 (EIA 2010).

Despite the benefits of biopower and the compelling economic and environmental drivers, there are still significant barriers to the realization of a widespread, sustainable U.S. biopower industry. Some of the major challenges today include ensuring the availability of a sustainable biomass supply, improving the efficiency and cost of conversion technologies, exploring more cost-effective ways to utilize biomass (e.g., advanced pretreatment), and addressing the economic and other attendant ramifications of policy and regulatory issues (e.g., carbon, environment, permitting, and RPS).

1.1 *Purpose/Objectives*

To explore opportunities for biopower in the United States, the DOE Office of Energy Efficiency and Renewable Energy (DOE/EERE) Biomass Program conducted the *Biopower Technical Strategy Workshop* in Denver, Colorado, in December 2009. The purpose of the workshop was to provide a forum for discussing the challenges to expanded use of biopower and the possible solutions, including technology research, development, and demonstration (RD&D), as well as policies and other market transformation mechanisms.

The workshop was attended by a wide spectrum of experts from industry, academia, national laboratories, and government, and generated a wealth of information and ideas (see the list of contributors in Appendix A; an agenda is included in Appendix B). The DOE/EERE Biomass Program expects to use the results of the workshop, which are presented in this report, to inform multi-year planning and help map future research and development priorities in sustainable biopower.

1.2 *Genesis of the Report*

The workshop covered a wide range of technologies and systems for the use of biopower, including direct combustion, gasification, pyrolysis, mass burn, torrefaction, cofiring, combined heat and power (CHP), repurposed pulp and paper plants, and others. Potential feedstocks of interest included wood (e.g., woody crops; wood byproducts; wood residues, such as forestry thinnings; pulp mill wastes; wood pellets; and wood from sorted municipal solid waste (MSW), such as wood pallets), high-yielding energy crops, other suitable bio-derived MSW streams, and agricultural residues. Sustainability was considered an important element throughout the workshop.

FIGURE 1.2.1
WORKSHOP TOPICS

- Pretreatment and Conversion Technologies: Pretreatment to improve combustibility and other characteristics (e.g., torrefaction, bio coal briquetting, and densification), and conversion (e.g., pyrolysis and gasification).
- Large-Scale Systems: Biomass systems integrated with utility-scale power generation, such as large-scale cofiring with coal or natural gas, gasification, or direct combustion.
- Smaller-Scale Systems: Systems that range from ~1–50 megawatts (10–15 megawatts is typically small scale; however, larger-scale non-utility systems are included here), including industrial, community, and institutional systems; repurposed pulp and paper mills; and others, with a focus on combined heat and power.
- Feedstocks for Biopower: Integration of biomass handling systems with power plants, use of opportunity fuels, sustainability, super high-yield energy crops, and other issues.
- Market Transformation: Policy, legislation and regulation, land use issues, RPS, tax and investment credits, permitting, markets, loan guarantees, and other elements.

Workshop discussions and results have been organized in this report around the five topics shown in Figure 1.2.1. Summary information is provided on the current status of the industry, technical and non-technical constraints, critical technologies and critical needs for technology RD&D, and policies and measures that could impact market transformation. Additional appendices include a list of source documents (Appendix C), acronyms (Appendix D), and a listing of state-level power incentives (Appendix E).

The results presented here are not intended to be all-inclusive of the biopower industry. Rather, they represent a snapshot of the expert opinions voiced at the workshop, as well as currently available information in the public domain.

2 CURRENT STATE OF THE BIOPOWER INDUSTRY

2.1 *Generating Capacity and Feedstocks*

2.1.1 Generating Capacity

Biopower facilities have been in operation in the United States since the early 1900s at pulp and paper mills, where wood residues or byproducts are burned to produce power for processing (Thorpe 2010). In 2008, the net summer capacity[1] of the U.S. biopower industry, which contributes about $10 billion to the economy annually, was approximately 11,050 MW, including wood, landfill gas, MSW, and other waste biomass (EIA 2010). Most of today's biopower plants are direct-fired systems producing 50 MW or less of electricity. Plants are owned and operated by a wide range of stakeholders, from industrial users (e.g., pulp and paper mills and lumber companies), to utilities, independent power producers, and small-scale community users (e.g., institutional users). Data collected for a significant portion of biopower facilities (140 plants) in 2006 showed the bulk of plant capacity was distributed evenly in the range of 10–20 MW, 20–30 MW, and greater than 30 MW; only about 13% of capacity was less than 10 MW (ORNL 2009).

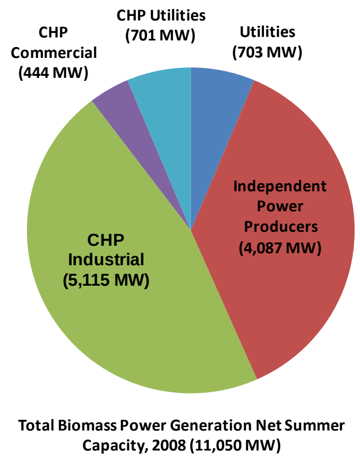


FIGURE 2.1.1 U.S. BIOPOWER NET SUMMER CAPACITY, 2008

As shown in Figure 2.1.1, independent power producers and industrial CHP facilities together account for about 83% of net summer biomass generating capacity today. Utilities (both CHP and traditional biopower) account for a smaller share, about 13%. Systems for commercial buildings account for a small share (4%). Most of these are CHP systems used in municipalities or large institutions, such as hospitals or schools. Cogeneration of heat and power provides greater thermal efficiencies and enables facilities to cost-effectively provide heat for processing and other uses.

Overall, biomass in various forms makes up about 16% of the total renewable electricity generation in the United States; the remainder is provided by hydropower, wind, solar, and geothermal energy (EIA 2009a). Figure 2.1.2 illustrates the net electric power generation by type of biomass (EIA 2009a). Wood and fuels derived from wood and/or wood processing comprise the largest share of biomass used for power generation today. Biomass from MSW and landfill gas (primarily methane) comprises a significant and growing share.

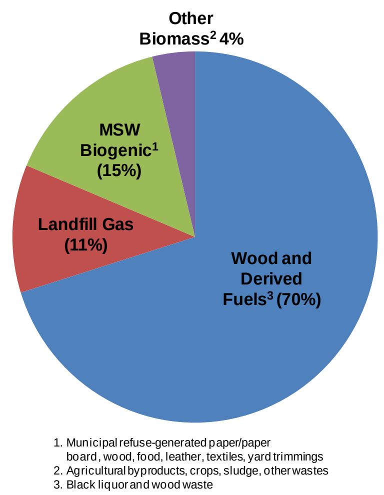
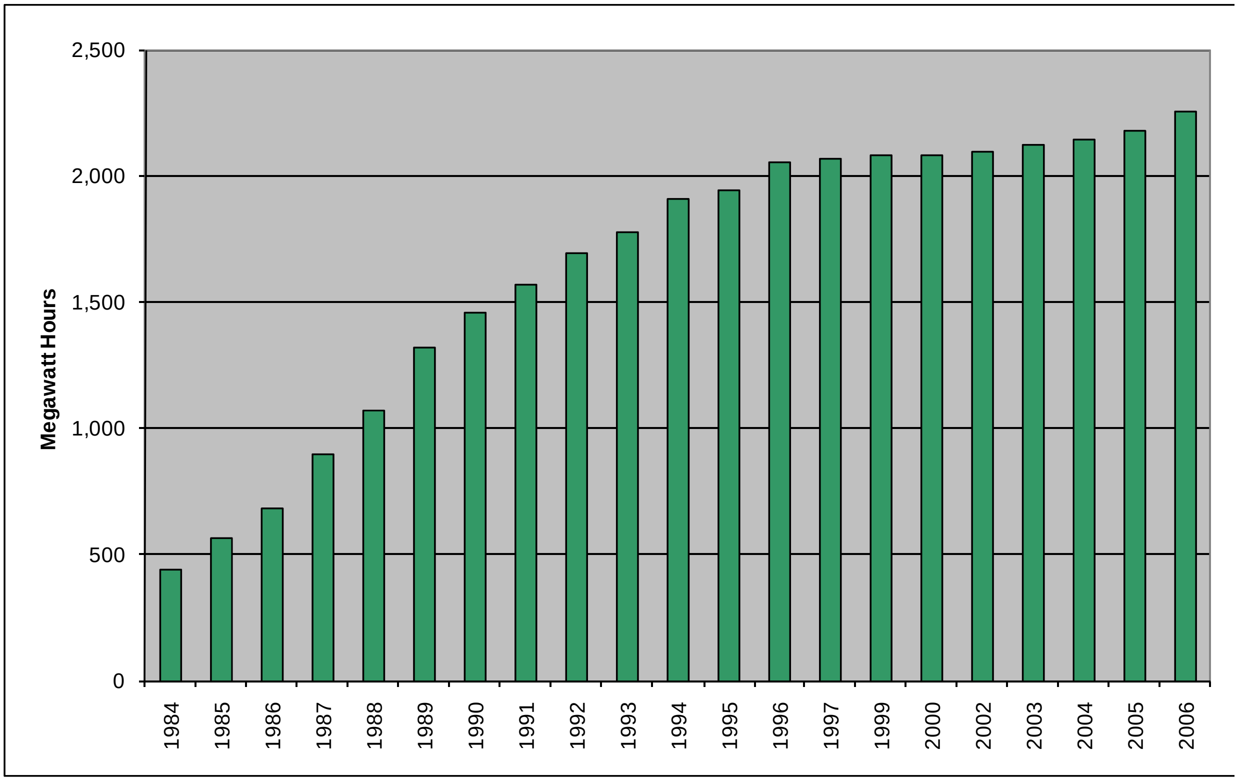


FIGURE 2.1.2 NET ELECTRIC POWER GENERATION BY BIOMASS TYPE, 2007

New dedicated biomass power plant generation grew sharply from the early 1980s through the early 1990s, as shown in Figure 2.1.3 (ORNL 2009), and has remained relatively steady over the last decade. Even though the

[1] The maximum output, commonly expressed in megawatts (MW), that generating equipment can supply to a system load, as demonstrated by a multi-hour test, adjusted to ambient weather conditions for summer peak demand (from June 1 through September 30).



Source: Biomass Energy Data Book http://cta.ornl.gov/bedb/biopower.shtml

FIGURE 2.1.3 ANNUAL BIOMASS POWER PLANT INCREASES

growth of new facilities has slowed somewhat, increases in capacity are expected in 2010 and well into the future.

In its baseline case for energy projections, the Energy Information Administration (EIA) predicts an 8.6% annual growth in electric power generation from biomass from 2007 to 2030 (EIA 2009c). Growth is predicted for both dedicated biomass power plants and those cofiring with fossil fuels (5.9% and 12.9%, respectively). By 2030, 231 billion kilowatt-hours (kWh) of biomass power is expected to be generated annually, comprising 22% of the total marketed renewable energy (EIA 2009a).

Cofiring of biomass with coal is gaining increased attention from both utilities and regulatory stakeholders. It offers a way to incorporate renewable generation capacity with relatively low capital costs and is potentially a viable strategy for reducing emissions of carbon dioxide.

Figure 2.1.4 illustrates the extent of biomass-coal cofiring capacity in the United States as reported in 2007, the latest year for which comprehensive data is available (EIA 2009b). Note that this data is based on biomass-coal cofiring capacity, and does not reflect how much of that capacity is currently used or how much biomass is input to these systems. In addition, the data may double-count systems that are dual-fired (i.e., that can independently fire either fossil fuel or biomass in the same boiler, but not necessarily in combination). The data indicates that industry is the largest source of biomass-coal cofiring capacity, followed by utilities, power cooperatives, and independent power

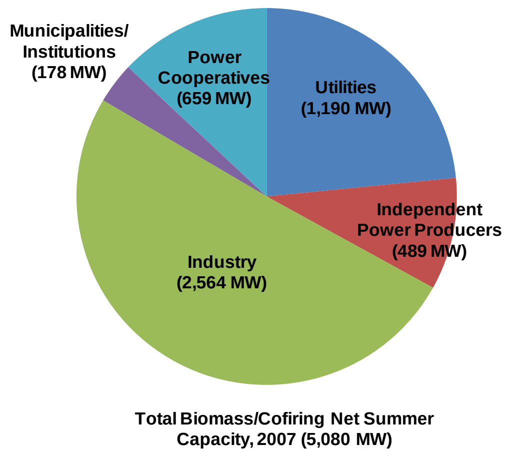


FIGURE 2.1.4 U.S. BIOMASS/COFIRING NET SUMMER CAPACITY, 2007

producers. Some of the largest capacity for cofiring is located in the south (Virginia Electric & Power Company and East Kentucky Power Cooperative), although cofiring plants are found across the country.

Biopower facilities are generally situated in proximity to readily available sources of biomass. In 2006, California and Maine led in installed biopower capacity in the United States, with significant generation in Florida, New Hampshire, Michigan, Minnesota, Washington State, and Wisconsin (ORNL 2009). These states and the surrounding regions have significant biomass resources for power, notably forestry residues, mill and urban wood wastes, and agricultural residues.

2.1.2 Feedstocks

Biomass feedstocks, the fuel for biopower and other bioenergy systems, can originate from various biological sources. The primary sources of biomass feedstocks include the following:

- Wood residues (e.g., wood processing, urban wood residues, and in-forest residues)
- Agricultural residues
- Energy crops (perennial grasses, energy cane, biomass sorghum, and short-rotation trees)
- Landfill gas
- Industrial and municipal wastes
- Animal wastes

Photo Courtesy of NREL. Willow biomass research plots, SUNY College of Environmental Science and Forestry Genetics Field Station, Tully, New York.

Biomass is sometimes classified as closed loop or open loop. Closed-loop biomass is defined as any organic material from a plant which has been planted exclusively for bioenergy use. Open-loop biomass is everything else, and makes up the vast majority of biomass used to generate biopower today.

Closed-loop biomass utilizes high-yielding feedstocks, such as switchgrass and high-biomass sorghum, which yield on average 10 to 15 dry tons per acre per year. Closed-loop feedstocks can be a resource to enable a large-scale bioenergy industry. Closed-loop biomass is only planted and developed once there is a firm demand from an end user, both the quantity and quality, as well as the price, of the feedstock supply is reliable.

Various studies have estimated that the amount of biomass available for power and other energy uses is substantial. However, the relative costs and availability of these resources vary widely across the country (USDA/DOE 2005; EPA 2007).

The availability and, to an extent, utilization of these feedstocks parallels variations in the presence and distribution of industries creating the feedstocks. For example, mill residues were a large portion of California biomass supplies through the 1980s, but have since declined, due in part to the declining lumber industry. However, nationwide, the dominant solid biomass fuel still originates from wood-processing residues.

In California, biomass energy generation aids in the disposal of 7.6 million tons per year of solid waste, 120,000 bone-dry equivalents per year of manure, and 26.5 billion cubic feet (ft^3) per year of landfill gas (PI 2008).

Woody biomass represents one of the most readily accessible domestic sources for biopower. Abundant wood fuel is currently available within the United States for sustainable utilization in many regions of the country (DOE/USDA 2005).

Wood residue feedstocks are usually generated from several major activities: primary mill activities, such as black liquor and other pulp and papermaking wastes; processing of trees into lumber products; wood residues from urban activities; and residues from forest overgrowth clearing or harvesting of timber. Black liquor, a byproduct of pulp processing, is a primary source of energy for pulp and paper mills today (both heat and power). At a primary sawmill, almost 50% of the total biomass content of a typical saw log becomes residue. While some products are generated from this waste, approximately 15%–20% cannot be used for product generation and must be disposed of. Biopower provides a potentially economical and environmentally acceptable method of disposal while producing electricity.

Urban wood waste comprises yard trimmings, wood construction and demolition waste, pallets, wood packaging, furniture, and other miscellaneous wood wastes. Urban wood waste can be cost-effective as a source because its use usually offsets disposal costs from otherwise being sent to landfills. Today urban waste wood accounts for a significant portion of the material typically directed to landfills in the United States. In California, separable wood waste accounts for approximately 15%–20% by weight of incoming municipal landfill material (PI 2008). One drawback is that this waste can contain high levels of impurities from chemical treatments to increase the wood's life, which can create emission problems when burned.

In-forest residues include waste from tree harvesting (i.e., slash) and forest management (e.g., clearing of overgrowth material). Slash includes tree tops, limbs, bark, and trees unsuitable for commercial wood products. Mechanically collected slash can be used in nearby biopower applications. Some states limit cheaper alternatives to mechanical slash collection, such as leaving the slash in place—which delays forest regrowth. Mechanical biomass removal is also used during forest overgrowth management. While environmentally preferred over prescribed burning, mechanical thinning of overgrowth material is expensive and usually only performed when the biomass can be used in high-value applications.

Photo Courtesy of NREL. Corn stover.

Large amounts of **agricultural residues** are produced in the country's agricultural regions, such as California, where agriculture is a multi-billion dollar industry. However, only a portion of agricultural residues meet the criteria for biopower feedstocks. Other disadvantages are crop seasonality and competing uses for the residues, such as feed, compost, or animal bedding.

Agricultural residues suitable for biopower include material from food processing such as pits, shells, and hulls; plants from orchard and vineyard pruning and removals; and corn or other field stalks. Currently, orchard and vineyard removals are the most cost-effective biomass feedstock in California (PI 2008).

Energy crops grown specifically for use as biomass feedstock are not currently in widespread use for biopower in the United States. Current research activities to hybridize species, such as switchgrass, sorghum, miscanthus, and poplar trees, for example, focus on improving the harvested mass per acre, growth time, and growth on lands not suitable for food production. These crops could provide advantages in terms of moisture content, heat content, and processing characteristics, but they are likely to be more costly than fossil fuels on a $/British thermal unit (Btu) basis.

Municipal landfills generate a **landfill gas** comprising 50%–60% methane (CH_4), 40%–50% carbon dioxide (CO_2), and varying percentages of volatile organic compounds (VOCs). Most VOCs have a global warming potential similar to or larger than CH_4, present serious odor issues and contribute to ground-level ozone formation. As greenhouse gas (GHG) production comes under increasing scrutiny and regulation, addressing landfill gas production could include abatement systems or energy generation systems.

Large quantities of **animal waste** are produced daily and are the source of growing environmental concerns with respect to GHG emissions and potential nutrient loading of surface and groundwater. As a result, biopower generated from animal wastes may become an increasingly attractive option. Currently, stabilization of manure typically occurs in open lagoons and produces a gas comprising approximately 60% CH_4 and 40% CO_2. Enclosed lagoons could facilitate the collection of biogas for energy production from combustion or for additional processing and incorporation into natural gas transmission lines.

2.2 *Trends and Drivers*

Along with technology improvements, current and future regulations, policies, and financial incentives will drive the growth of the U.S. biopower industry. Some of the key drivers for the biopower industry today are outlined below.

Policies related to climate change—Pending climate legislation for cap and trade or command and control approaches to carbon mitigation and emissions reduction could motivate industry expansion. A dollar price for carbon emissions will have significant (but uncertain) impacts. A clear price signal will permit electric producers to determine their production costs or any need for changes to production. A clear policy direction on climate issues or the cost of emitting carbon will add some certainty for electricity producers and may lead them to consider biopower as a power generation option. Modest penalties per kWh (for coal) and/or incentives (for biomass) could also lead to increased use of biomass for power production.

Renewable portfolio standards—A federal RPS that mandates the use of renewable energy for power generation could drive expansion on a national level. A number of states have already implemented RPS and other power incentives (see Appendix E) that could drive expansion of biopower at local levels, although there is varied treatment of biopower in these standards. In California, the governor approved an aggressive RPS (20% by 2010 and 33% by 2020). California has also issued Executive Order S0606, which sets in-state bioenergy production and use targets, and it has produced a Bioenergy Action Plan. Other states are providing similar incentives and direction.

Other federal policies and strategies—Policies and strategies from numerous federal agencies and organizations, including the Environmental Protection Agency, Federal Energy Regulatory Commission, and the Nuclear Regulatory Commission impact the biopower industry in different ways. The biopower industry currently receives fewer production tax credits than other renewable industries (e.g., coal, wind, solar, etc.).

Environmental regulations—Environmental regulations call for emission reductions, especially of sulfur oxides (SO_x), nitrogen oxides (NO_x), and CO_2. Replacing some or all of the coal used for electricity generation with biomass or other renewable fuels has potential to achieve these reductions.

Cost drivers—Costs will drive implementation in various ways. The type of biomass used and its form (e.g., torrefied, pellets), transport and handling equipment, yields, and the need for fuel feed modifications will all have an impact on cost.

Dispatchable generation—Energy generation sources used intermittently by grid operators to respond to demand fluctuations are considered “dispatchable.” Unlike wind and solar renewable energy sources, biomass is arguably one of the few dispatchable sources of renewable energy in that it can be used to generate at any time, and requires no supporting ambient conditions. Power producers’ interest or concern with using biomass for power generation often relates to the nearby availability of the feedstock supply, because sizable transportation costs can increase the cost of opting for biomass. Biomass generation choices are largely based on feedstock availability and proximity, reliability, durability, scalability, and most importantly, cost of generation.

Improving forest health and reducing wildfires—In the western United States, wildfires are a key issue. Forest thinnings can help reduce wildfires, and thinnings can be used by the biopower industry. The mutual benefits may provide a driver for increased gathering of these forest residues as an energy resource. Today, only a small amount of thinnings are used for this purpose.

Federal opportunities for use of biopower—The federal government is the largest single purchaser of power in the United States. If power producers can provide energy generated by biomass at competitive prices, federal facilities could be a large customer. The U.S. Department of Defense (DoD) wants every military base in the nation to function as an energy island, independent from the grid. DoD is aggressively pursuing the feasibility of locating renewable energy power plants at their facilities, and biopower could offer a huge opportunity.

International activities in biopower—There are many opportunities for the United States to build on and learn from the biopower advances of other nations. Canada and Mexico, along with many European nations, especially Scandinavian countries, have a relatively long history in the use of biomass for energy generation, including advanced infrastructure, established markets, and government regulations. Finland, for example, has a well-developed use of biomass for energy due to the country's indigenous biomass supply. The United States should capitalize on lessons learned by global partners and collaborate on international projects.

Production tax credit (PTC)—Currently, open-loop biomass cofiring receives no PTC, which could defray costs and encourage market expansion at larger scales.

2.3 *State of Technology*

Biopower is a fairly mature technology with hundreds of successful commercial-scale operations. There are many technologies in various stages of development and use that are potentially available to transform raw biomass material directly or indirectly into electricity, including direct firing, cofiring of biomass with coal or natural gas, gasification, pyrolysis, torrefaction, and anaerobic digestion. Table 2.3.1 identifies the commercialization status of the major biomass conversion technologies and associated prime movers (adapted from Table 1-1, EPA 2007).

Table 2.3.1
Commercialization Status for Biomass Power Technologies

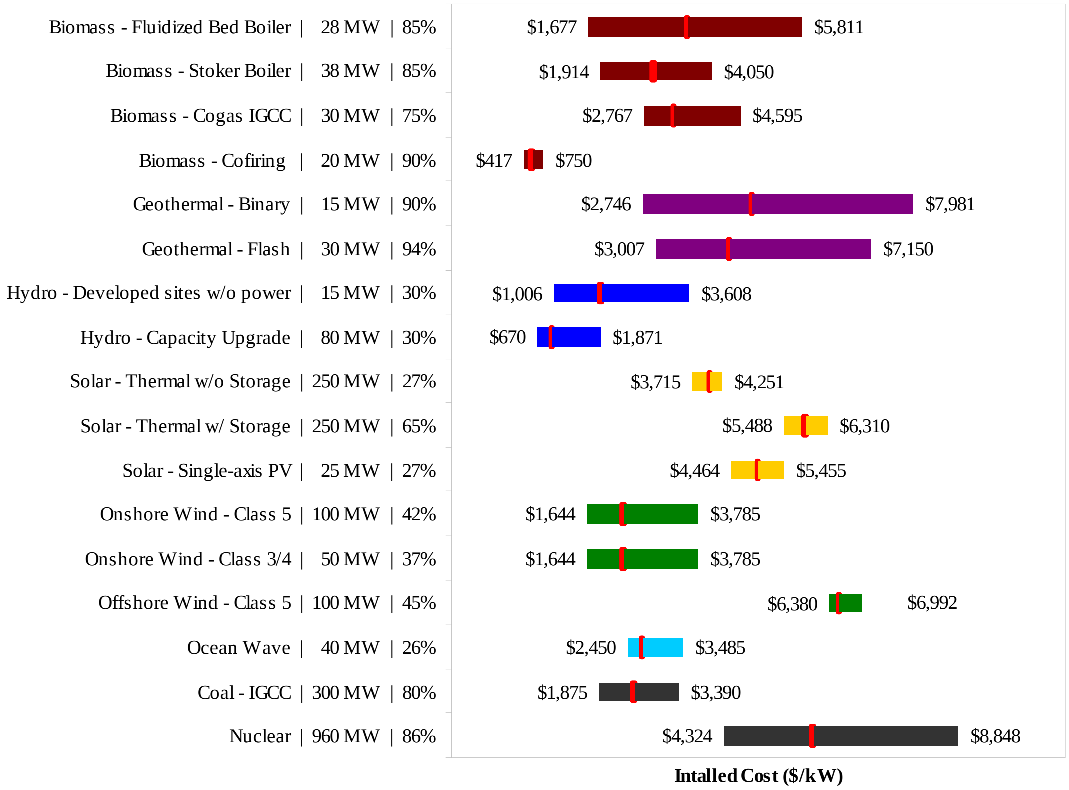
<table>
<tr><th>Energy Conversion Technology</th><th>Conversion Technology Commercialization Status</th><th>Integrated Prime Mover (commercial unless noted)</th></tr>
<tr><td colspan="3">Anaerobic Digestion</td></tr>
<tr><td rowspan="5">Anaerobic digester (from animal feeding operations or wastewater treatment)</td><td rowspan="5">Commercial technology</td><td>Internal combustion engine</td></tr>
<tr><td>Microturbine</td></tr>
<tr><td>Gas turbine</td></tr>
<tr><td>Fuel cell (commercial introduction)</td></tr>
<tr><td>Stirling engine (emerging)</td></tr>
<tr><td colspan="3">Direct Combustion—Boilers</td></tr>
<tr><td>Fixed bed boilers (stoker)</td><td>Commercial technology—Stoker boilers have long been a standard technology for biomass as well as coal, and are offered by a number of manufacturers.</td><td rowspan="3">Steam turbine</td></tr>
<tr><td>Fluidized bed boilers</td><td>Commercial technology—Until recently fluidized bed boiler use has been more widespread in Europe than the United States. Fluidized bed boilers are a newer technology, but are commercially available through a number of manufacturers, many of whom are European-based.</td></tr>
<tr><td>Cofiring</td><td>Commercial technology—Cofiring biomass with coal has been successful in a wide range of boiler types including cyclone, stoker, pulverized coal, and bubbling and circulating fluidized bed boilers.</td></tr>
<tr><td rowspan="4">Modular* direct combustion Technology</td><td rowspan="4">Commercial technology—Small boiler Systems commercially available for space heating. A small number of demonstration projects in CHP configuration</td><td>Small steam turbine</td></tr>
<tr><td>Organic Rankine cycle (emerging)</td></tr>
<tr><td>“Entropic” cycle (R&D stage)</td></tr>
<tr><td>Hot air turbine (R&D stage)</td></tr>
<tr><td colspan="3">Gasification</td></tr>
<tr><td>Fixed bed gasifiers</td><td rowspan="2">Now in limited use—The actual number of biomass gasification systems in operation worldwide is unknown, but is estimated to be about 37.

A review of gasifier manufacturers in Europe, the United States, and Canada identified 50 manufacturers offering commercial gasification plants from which 75% of the designs were fixed bed; 20% of the designs were fluidized bed systems.</td><td rowspan="2">Gas turbines—simple cycle and combined cycle; and large internal combustion (IC) engines—simple cycle and combined cycle (not commercial due to small number in operation; no commercial gasifiers are currently supplying a gas turbine—demonstrations with biogas are needed)</td></tr>
<tr><td>Fluidized bed gasifiers</td></tr>
<tr><td rowspan="3">Modular* gasification technology</td><td rowspan="3">Emerging technology—Small number of demonstration projects supported with research, design, and development funding.</td><td>IC engine and Microturbines (demonstrations with biogas needed)</td></tr>
<tr><td>Fuel cell (emerging)</td></tr>
<tr><td>Stirling engine (emerging)</td></tr>
<tr><td>Modular* hybrid gasification/ combustion</td><td>Emerging technology—Limited commercial demonstration</td><td>Small steam turbine</td></tr>
</table>

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

The relative installed cost range for biomass power and other renewables is shown in Figure 2.3.1, based on a recent study comparing various scenarios for production of power (KEMA/CEC 2009). As the data shows, biomass power options in many cases are highly cost-competitive with other renewables as well as fossil and nuclear. In some cases, such as biomass cofiring, the installed cost range for the biomass technology is substantially lower.

FIGURE 2.3.1 INSTALLED COST RANGE FOR UTILITY-SCALE TECHNOLOGIES (KEMA/CEC 2009)



2.3.1 Direct Firing

Direct firing involves the combustion of biomass feedstocks to produce steam, which is then used with a turbine and generator to produce electricity. While direct-firing systems are used in most of the biopower plants operating today, the energy efficiency can be limited (in the low 20% range). Biomass power plants (typically 20–50 MW) are much smaller than coal-fired power plants (100–1,500 MW).

Direct firing is the most common method used to produce electricity from agriculture and forest materials. Wood chips are common choices for biomass feedstocks in these systems. The biomass characteristics, regulated emissions levels, and required power output determine the combustion technology. Two technologies, stoker boilers and fluidized beds, are more feasibly adapted to fuels other than coal. In general, stoker boilers have lower capital and operational costs than fluidized beds. However, they have lower tolerance for variations in biomass moisture. Fluidized beds operate at lower temperatures, which minimize slagging and fouling and allow the use of low-quality biomass fuels such as urban wood waste. Improvements are being made in fluidized bed boiler designs to offset the higher cost. Steam cycle design plays a larger role in net plant heat rates than combustion technology. Improvements in advanced technologies for direct-fired biopower generation for the small-scale would improve the economics of biopower systems.

2.3.2 Combined Heat and Power

Combined heat and power, or cogeneration, is the process where heat and electricity are produced simultaneously from a single fuel source. Combined heat and power systems provide advantages such as the distributed generation of electrical and/or mechanical power and waste heat recovery for heating, cooling, or other applications. System efficiencies can be as high as 60%–80% in some cases, although those operating with biomass are lower (45%–65%) due to the moisture content of the fuel. Combined heat and power is not a singular biopower technology, but an integrated energy system that can be relatively flexible depending on the user and requirements. For CHP to be effective, the application that uses the heat it produces needs to be in relatively close proximity to the system (e.g., building and manufacturing process).

The industrial sector uses biomass to produce both steam or hot water and electricity in CHP facilities in the pulp and paper, wood products, and food processing industries. The largest industrial user of cogeneration from biomass is the forest products industry, which consumes about 85% of all the wood waste used for energy in the United States (EPA 2007). Most of the electricity and heat produced by industrial cogenerators is used onsite. Excess electricity—when generated—can in some cases be sold to the local grid.

CHP is also gaining interest as a distributed source of energy for buildings and community systems. Applications include hospitals, universities, municipalities, and sometimes a collection of facilities where there is a significant need for both heat and power.

2.3.3 Cofiring

In general, cofired systems replace a portion of nonrenewable fuel with biomass. In a coal-fired power plant, cofiring biomass reduces the amount of coal needed, resulting in lowered emissions such as sulfur dioxide. Even though approximately half of U.S. electricity is generated by coal, not all of these power plants are suitable for cofiring without significant modifications to the boiler.

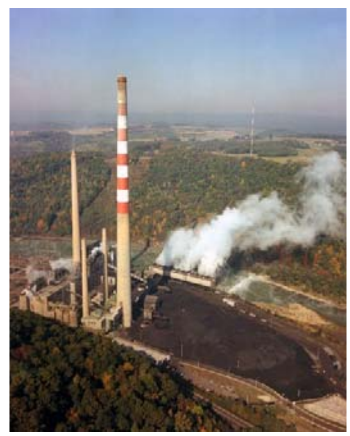


Photo Courtesy of NREL. Shawville Station biomass cofiring plant.

Plants must address complex technical, logistic, economic, and environmental issues prior to introducing a secondary biomass fuel. Utilizing existing boiler configuration and size must be technically and economically feasible to create a cofired system. A steady supply of biomass feedstock, with reliable characteristics, must be secured to ensure continued operation. Although biomass characteristics vary, biomass has a much lower bulk density than coal (about one-fifth), has a significant moisture content, is hydrophilic, and has about half the heating value of coal. Diverse wood fuel resources such as logging residue, wood chips, pellets, and urban wood residues are available for cofiring. Fluidized bed and grate boilers are more permissive than pulverized fuel boilers in the type of wood fuels permitted. Differences in biomass characteristics may cause problems such as fouling, slagging, selective catalytic reduction catalyst-accelerated deactivation, and bed agglomeration, as well as issues with electrostatic precipitators and fly ash sales.

In many states and European countries today, these cofired systems qualify for renewable energy credits and count toward meeting RPS goals. Even though existing coal-fired power plants can be converted into cofired systems, it is not a simple endeavor and various issues must be addressed, such as tailoring boilers to the different physical and chemical characteristics of the biomass feedstock, obtaining permits and financing, and securing a source of biomass feedstock. However, it is considered the most cost-effective technology for implementing new biopower generation in the near term because the costs of retrofitting an existing plant are significantly less than building a new facility. The main attraction of this technology is that it utilizes existing assets and infrastructure and turns a homogenous fuel-based power plant into a flexible energy conversion facility.


Photo Courtesy of NREL. McNeil Generating Station, Burlington, VT.

When compared to other renewables, installed costs for utility-scale biomass cofiring with coal may be, under some conditions, lower than those for geothermal, wind, solar, and hydropower (see Figure 2.3.1). General reluctance by operators to use new fuels in coal-fired boilers, uncertainties about feedstock availability, and limited commercial applications have constrained growth of this technology in the United States. Despite constraints, EIA predicts a 13% growth from 2007 to 2030 in cofiring biomass consumption for electricity generation (EIA 2009a). Over 60 plants in the United States have cofired coal and biomass capabilities, with operations ranging from several hours to several years. The International Energy Agency has compiled a database with an overview of global cofiring experience and demonstrates the remarkably rapid progress that has been made in this technology over the last decade (IEA 2009).

2.3.4 Gasification

Gasification, a thermochemical process, is used to convert biomass feedstock into an intermediate product amenable to a wider range of utilization options. In general, lignocellulosic biomass is thermally decomposed with limited or no oxygen, then oxidized to yield a raw syngas, which is a mixture of hydrogen and carbon monoxide. The quality and composition of the raw syngas depends on the biomass feedstock properties, amount of moisture, gasification reactor type, temperature, pressure, and other technical specifications. Torrefied biomass is thought to be a superior feedstock for gasification processes, although more research is required.

The raw syngas is cleaned up to remove contaminants that are undesirable in a final gas product. The cleanup process varies depending on the intended final use, but usually includes the removal or reforming of tars, ammonia, alkali metals, and particulates. If necessary, the gas may be conditioned to lower sulfur levels and adjust the hydrogen to carbon monoxide ratio. The heating value of biomass syngas can range from 100–500 Btu/ft^3, which is 10%–50% of the heating value of natural gas. Syngas cleanup and conditioning have the greatest impact on the cost of syngas and remain a major barrier to the commercialization of this technology. There is currently no commercial gasifier supplying a gas turbine.

The gasification process may be coupled with power generation applications, such as cofiring, or as a precursor to biofuel or bioproduct production. Because the final syngas product is compatible with current infrastructure, biomass gasification processes can be integrated with existing power generating facilities. The high efficiency of gas turbines can be increased by operating a combined cycle, where exhaust gases are used for additional steam generation. By recovering turbine exhaust heat, the system efficiency can reach 45%–50%. At very high pressures, gasification is further optimized. However, research and development is needed to make high-pressure feed systems commercially viable. In the future, gasification systems may be coupled with fuel cell systems.

With respect to power generation, biomass gasification has seen less commercial demonstration than other systems such as direct-fired biomass systems. There are some demonstration facilities in the United States at present, but few if any sustained commercial operations. Several benefits of biomass gasification make it attractive:

- Syngas can be used in a wider variety of machinery (boilers, turbines, process heaters, etc.) and transportation infrastructure (pipelines, mixed with natural gas, etc.).
- A greater range of biomass feedstocks can be used, including woody biomass and waste material.
- Contaminants (including heavy metals) which may otherwise be released as emissions in direct-fire systems, are removed via gas cleanup systems.

2.3.5 Pyrolysis

Like gasification, biomass pyrolysis processes transform solid biomass feedstocks into a form suitable for biopower systems. While using the same process of heating biomass in the absence of oxygen, the main product of the pyrolysis process is a liquid known as pyrolysis oil, resembling No. 4 fuel oil. Reaction temperatures of pyrolysis (450°–600°C) are lower than gasification (700°–1,300°C). While gas and charcoal are also produced during this pyrolysis process, the main objective is to maximize the pyrolysis oil product. Variations in the pyrolysis method, biomass characteristics, and reaction specifications will vary the percentages of the three products. Several technologies and methodologies can be used to extract the desired product,

Courtesy of NREL. Pyrolysis oil and wood chips.

such as circulating fluid beds, entrained flow reactors, multiple hearth reactors, or vortex reactors.

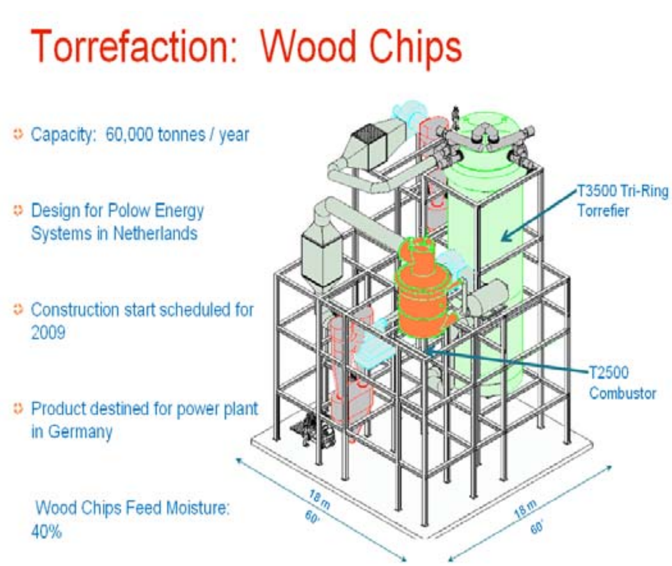
Pyrolysis oil can be a fuel as such or further processed to produce liquid fuels, various materials, and chemicals. The chemical properties of pyrolysis oil depend on the original biomass feedstock and processing conditions, but it typically contains significant water (15%–30% by weight), has a higher density than conventional fuel oils, and a low pH (2–4). The higher heating value of pyrolysis oil is approximately half that of conventional fuel oils, due in part to high oxygen and water contents.

Converting solid biomass to liquid fuel for biopower has several advantages, including ease of storage and longer temporal stability if alkali species are removed. Pyrolysis oil also has a bulk density and energy density three to four times that of wood chips.

Use of pyrolysis oil for biopower has not been commercialized in the United States. Research and development efforts are underway to improve pyrolysis processes for both power generation applications and pyrolysis oil optimization for subsequent products. Fast pyrolysis is being commercially developed by several organizations, with some sites in the United States. To improve commercial viability, new methods are needed to control the pyrolytic pathways of bio-oil intermediates in order to increase product yields. There are also approaches for injecting pyrolysis oil along with biochar for use in power production.

2.3.6 Torrefaction

Compared to the processes mentioned above, torrefaction is a lower-temperature biomass pretreatment process that increases the fuel quality for combustion and gasification applications. Similar to gasification and pyrolysis, the biomass is heated in the absence of oxygen, only at lower temperatures (200°–300°C) and near atmospheric pressure. Decomposition reactions at the torrefaction temperatures produce a stable, hydrophobic product, with increased energy density and without the fibrous structure of the original biomass. Thus, the torrefied biomass is more amenable to use in applications such as cofiring with coal, where the coal and torrefied biomass are co-milled.



Courtesy of KEMA. Design by Polow Energy

The benefits gained from torrefaction are attractive for combustion and gasification applications and aid with storage and transport issues, especially when combined with pelletization. After the torrefaction process, the product can be further compacted to produce energy-dense biomass-derived fuel pellets (750–850 kilograms per cubic meter [kg/m^3]). In addition, torrefaction produces biochars, which could enhance soil productivity for both food and bio-crop production.

While torrefaction can bring many benefits to biopower systems, the technology still needs additional research and development to reach full commercial potential in the biomass industry. Improvements in system efficiency and process parameters are necessary to increase its cost effectiveness.

2.3.7 Anaerobic Digestion

In anaerobic digestion, organic matter is biologically converted in an environment without oxygen to a biogas and stabilized slurry. The resulting biogas, which is approximately 60% CH_4 and 40% CO_2 by volume, can be harvested and processed for use in biopower systems. The raw biogas also contains trace impurities, such as moisture, hydrogen sulfide (a gas that poses human health hazards and mechanical concerns), and other sulfur-containing species. The slurry can be separated into solids and a nutrient-rich liquid, both of which may be valuable byproducts in the agriculture industry, for example.

Anaerobic digesters usually work in two temperature ranges: 90°–110°F and 120°–140°F. The first temperature range is optimal for mesophilic bacteria and the second for thermophilic bacteria. Due to the higher temperatures, thermophilic digestion kills more pathogenic bacteria and has higher operating costs. Below 60°F or 70°F, anaerobic digestion slows or stops completely (NSAIS 2006).

Anaerobic digestion is widely employed in manmade constructs, such as digester tanks at wastewater treatment plants (WWTP) or agricultural operations, or is a natural occurrence in settings such as an MSW landfill. Municipal solid waste landfills, WWTP, and agricultural operations are the three most common domestic uses, with over 850, 540, and 120 digester systems in use, respectively. Municipal solid waste landfills effectively work as anaerobic digesters, decomposing organic matter such as food scraps and yard trimmings. The biogas could be collected via a system of wells placed throughout the landfill. At WWTPs, dedicated tanks are placed in the process stream for anaerobic digestion of waste sludge, which contains a significant percentage of organic solids. The majority of agricultural applications occur at dairy farms (78%), processing a manure slurry rich in organic solids. Other system configurations or feedstocks are emerging, including co-digestion of higher energy content material (e.g., food waste or cheese whey) with the lower energy content feedstocks (e.g., manure and WWTP waste sludge) to increase gas production and centralized systems that process waste from multiple farms.

Benefits of anaerobic digestion include reductions in odor, water pollution, and GHG emissions which, depending on the industry, may be regulatory requirements. Recently, the U.S. Department of Agriculture (USDA) and U.S. dairy producers signed a memorandum of understanding to achieve a 25% reduction of greenhouse gas emissions by 2020 through the increased use of anaerobic digesters (USDA 2009). A typical dairy operation could produce enough electricity for an average of 200 homes. Of the farms where anaerobic digesters would be cost effective, only 2% have implemented the technology, producing an estimated 290 million kWh equivalent of useable energy in 2008. Even though recent improvements in digester design have increased their use in farm settings, anaerobic digesters may only be cost-effective for approximately 7,000 farms (EPA 2009). In addition to generating electricity, some operations use the gas as a boiler fuel, upgrade the gas for injection into the natural gas pipeline, flare the gas for odor control, or capture waste heat for farm uses (EPA 2009).

3 PRETREATMENT AND CONVERSION TECHNOLOGIES

Courtesy NREL. Biomass gasifier operating on wood chips.

When appropriate, pretreatment and conversion technologies are used to improve various biomass qualities and characteristics prior to transforming raw biomass into value-added intermediates and products. The technologies used encompass a broad range of physical and chemical processes to alter the raw biomass as needed for downstream processes. The pretreatment and conversion of biomass can occur at different points in the supply chain (e.g., in the field, prior to storage, after transport, or at the plant) and is often important in pathways that include storage of biomass.

Not all biopower generation scenarios require biomass that has undergone pretreatment and conversion. Many installations are specifically designed for the fuels available and do not use fuel pretreatment, as it increases costs. However, the traditional business case for power generation requires standardization and consistency of fuel inputs and operating parameters that may not always be easily achieved using raw biomass feedstocks. A significant amount of biomass power is generated today with little to no pretreatment. However, by utilizing various pretreatment and conversion processes, the biomass can be altered so that it is optimized for use in certain downstream processes.

The pretreatment and conversion (see Figure 3.1.1 for definitions) of raw biomass into higher-value products results in additional costs that impact the final delivered cost of biomass feedstocks and overall project economics. To enable successful widespread development and implementation of biopower generation, advanced RD&D is necessary to achieve robust, efficient, least-cost, and omnivorous pretreatment and conversion pathways and processes.

FIGURE 3.1.1
DEFINITIONS

- Biomass Pretreatment—The physical and chemical manipulation of raw biomass feedstocks in a manner intended to improve its inherent qualities and characteristics prior to its use in biopower generation processes.
- Biomass Conversion—The chemical conversion of raw or pretreated biomass into other material forms for the production of energy. Conversion can take place as the final step in the power generation pathway or earlier in the supply chain to produce syngas for injection into pipeline infrastructure or pyrolysis oil for storage and later use.

This section outlines the key challenges and priority RD&D and analysis needed in the area of feedstock pretreatment and conversion. Areas of interest include a wide range of technologies, such as pretreatment to improve combustibility and other characteristics (e.g., torrefaction, densification, pelletization, and others) and conversion to gas or bio-oil (e.g., gasification and pyrolysis).

3.1 *Challenges and Constraints*

3.1.1 Technical Challenges

The technical barriers that were identified are ranked and listed in Table 3.1.2. The major challenges include those related to torrefaction, moisture analysis, online sampling and analysis, non-ferrous metals, and life cycle analyses (LCAs).

Torrefaction—A better understanding of torrefaction is needed to determine technology status and commercial viability, particularly cost-effectiveness. Limited information is publicly available on existing demonstrations for proof-of-concept and performance. Densification of torrefied material is not easy, and more research is required to perfect the process. Safe handling of dried/terrified residual “dust” will become critically important. Minimal Ignition Energies (MIE) should be investigated and recommendations made for proper handling.

Sampling and Analysis—The lack of online sampling and analysis is a barrier to better understanding the technology performance. Better sampling systems would enable data collection and analysis of feedstock, intermediates, and final products with regard to process optimization and environmental impacts. If publicly accessible, this data could also be used to inform design decisions on selecting the best pretreatment and conversion processes based on feedstock type.

Non-ferrous Metals Removal—The removal of non-ferrous metals from fuel particles is a barrier to improving the quality and consistency of the fuel. Some biomass contains rocks, debris, metals, and other contaminants when it arrives at the plant and cannot be fed directly into conversion systems. Non-ferrous metal separators and magnetic separators and screening processes must be used to prepare the biomass.

LCA—Analyses are needed to determine the value and future prospects of each pretreatment and conversion technology in relation to biopower applications. Complete LCA from soil to transmission, including carbon, is needed.

Technology Development/Demonstration—Current needs include more large (over 10 tons) pilot projects to provide experience with new pretreatment technologies; additional experimental trials of pretreatment technologies on a variety of biomass types; and new technologies for increasing energy density.

TABLE 3.1.2
TECHNICAL BARRIERS AND CHALLENGES FOR PRETREATMENT AND CONVERSION

Torrefaction	
High Priority	• Insufficient understanding of extent of technology utilization, state of technology, commercial availability, technology performance, and demonstrations • Relatively high processing cost
Medium Priority	• Uncertain role for federal government
Sampling and Analysis	
High Priority	• Scarcity of methods to understand and control moisture • Absence of online sampling and analysis to centralize knowledge of existing pretreatment and conversion technologies
Medium Priority	• Need to determine biomass sources that may be best suited for end-use processes
Non-ferrous Metals	
High Priority	• Metal removal methods need to be improved for quality and consistency
Medium Priority	• Increased number of feedstock lot inspections may be necessary to protect biomass pretreatment equipment from damage due to non-ferrous metal entering the feedstock preparation stream
Lower Priority	• More than 24 hours' worth of feedstock material storage may be needed to minimize outage risks associated with non-ferrous metal detection
Life Cycle Analysis	
High Priority	• Incomplete understanding of the value of pretreatment and conversion processes to biopower costs and operation
Medium Priority	• Need for full LCAs of biomass pretreatment and conversion processes • Potential environmental impacts associated with potential processes are currently unknown
Technology Development	
High Priority	• Shortage of large (over 10 tons) pilot projects
Medium Priority	• Insufficient experimental trials of pretreatment technologies on a variety of biomass types • Shortage of technology to increase energy density (Btu/ft^3)
Lower Priority	• Absence of small-scale modular mobile pretreatment densification units • Lack of pelletization technology that is low-cost, rapid, scalable, and produces high net energy fuel

3.1.2 Non-Technical Challenges

Some of the highest-priority non-technical challenges for pretreatment and conversion include the cost of biomass, value proposition, and support for technology development.

Cost—The high cost of pretreatment technologies is a critical barrier that currently hinders the competitiveness and commercialization of biopower. Advanced pretreatment or conditioning technologies are needed to reduce the cost of feedstock per ton or per Btu delivered and to raise the quality and consistency of fuel.

Value Proposition—The value of the "depot" concept in the supply chain is not completely proven, which creates uncertainty about the overall economics. Further, each step in feedstock handling must have a corresponding value increase in the product. It is also difficult to place value on different pretreatment processes without an existing marketplace where that value can be effectively determined.

3.2 *Priorities for Research and Development and Analysis*

There are many technologies in various stages of development that could prove to be of critical importance to the pretreatment and conversion of biomass. These technologies are listed in Table 3.2.1.

Table 3.2.1 Critical Technologies for Pretreatment and Conversion

- *Torrefied biomass and pellets*. Torrefaction is a thermochemical treatment of biomass to increase its energy content. Torrified wood can be used directly or can be further densified by pelletizing the material for uniform product requirements.
- *Advanced combustion to heat*. This involves achieving a highly efficient combustion and using its heat for another purpose.
- *Densification compaction*. This technology compacts biomass into pellet or briquette form to increase density and improve energy use, transportability, and storability.
- *Pyrolysis oil injection with char*. Pyrolysis oil is produced through the chemical process of heating biomass at a high temperature to produce a liquid. Char is charcoal created through the pyrolysis of biomass and is a solid that is rich in carbon. The injection of char or other carbon-rich materials (e.g., coal fines) into the pyrolysis oil can increase heating and performance values.
- *Size reduction*. This step makes the biomass easier to handle and makes the fuel production process more efficient.
- *Anaerobic digestion*. In this process, microorganisms break down biomass in an environment without oxygen to produce a gas rich in methane and carbon dioxide (CO_2).
- *Fermentation*. This is the process of energy production in a cell under anaerobic conditions (without oxygen).
- *Flash carbonization*. This process uses heat and pressure to turn green waste into charcoal that can be used as a cleaner-burning alternative to coal.
- *Hydrolysis*. This is a form of hydration, a chemical reaction where water molecules are split into hydrogen and hydroxide anions. The catalytic action can include the use of an enzyme, acid, or alkali.
- *Low-temperature gasification*. Gasification is a partial oxidation process that can break biomass down into carbon monoxide, hydrogen, CO_2, and hydrocarbons. Higher-level hydrocarbons are produced with low-temperature gasification, making the product a better source of energy. Low-temperature gasification can also be done in the absence of oxygen, through steam reforming and/or indirect heating.
- *Hydrothermal pretreatment*. Water as liquid, vapor, or both is used to heat and pretreat biomass to enhance fuel production.
- *Leaching*. Leaching or other processing can be used to remove alkali metals, chorine, and/or other problematic elements in the biomass.
- *Chemical looping combustion*. This is a low-temperature oxidizing process with two fluidized beds. A metal oxide is used as the first bed to provide oxygen for combustion, whereby the product is transferred to the second bed. Steam is used to oxidize the metal, and the deoxidized hot air is put back through a turbine.
- *Syngas injection*. This thermochemical process transforms biomass into a synthetic gas (mainly hydrogen and carbon monoxide) that can be mixed with a fossil fuel for use.
- *Wet gasification*. This is the gasification of wet biomass feedstocks with a high moisture content in order to achieve higher conversions and reduce processing waste.
- *Solvent extraction*. This is the process of using a solvent to separate material of different chemical types.
- *Catalysis*. A chemical process that uses a catalyst to augment the rate of a chemical reaction and can be applied to biomass through gasification.

A broad discussion of RD&D and analysis needed to address barriers to pretreatment and conversion technologies, including some of those shown in Table 3.2.1, resulted in the identification of six priority topic areas. These topics are described below and in more detail in Figures 3.2.1 through 3.2.6.

3.2.1 RD&D Priorities

The highest priorities for RD&D were identified as development of a wide range of cost-effective pretreatment and conversion technologies, better understanding of biomass and intermediates and co-products, and proof-of-concept through demonstrations and scale-up projects.

Cost-effective Biomass Pretreatment and Conversion Technologies—Research and development on biomass pretreatment and conversion technologies is needed to drive down the capital and operating costs and support a sound business case for biopower. There are many potential approaches, including novel concepts for densification, homogenization, and pelletization, as well as more cost-effective conversion.

Characterization of Biomass Intermediates and Products from Pretreatment—Real-time, qualitative characterization of biomass, intermediate products, and co-products is needed to provide detailed design data for downstream processing and improve information for analysis and system optimization. A physical and chemical characterization database is needed in order to determine the top biomass sources for pretreatment. A meta-level collection of all existing and available analysis on pretreatment technologies is needed.

Theoretical Analysis of Biomass Pretreatment and Conversion Processes—Thermodynamic, kinetic, and computational fluid dynamic modeling are needed for pretreatment and conversion process. This should include model verification and validation analysis. These modeling and analysis efforts will improve the fundamental understanding of biomass leading to new and novel technologies while also improving the operation of existing technologies.

Proof of Concept and Scale-up for Pretreatment—Bench, pilot, and demonstration projects are needed for proof-of-concept and scale-up of pretreatment technologies, including both homogenous and heterogeneous biomass types.

Feasibility Studies for Large-Scale, Cost-Effective Biomass Torrefaction—Cost and feedstock analysis on region/area-specific biomass is needed to demonstrate the feasibility of torrefying biomass material for cofiring with coal in baseload electric generation facilities. Research and development will explore applied thermochemical and thermodynamic methods needed to achieve the compositional requirements to combust torrefied materials in large-scale applications. Due to existing industry requirements, torrefied biomass will need to meet specific material properties, characteristics, and standards. Opportunities also exist for torrefied biomass to serve as a substitute for coal and may enable emission reduction opportunities based on fuel mix if feasibility is demonstrated.

3.2.2 Priorities for Analysis

The top priorities for analysis involve collecting data and conducting analysis to better understand costs, life cycle impacts, and integration of pretreatment and conversion with power systems.

Clearinghouse for Techno-economic, Life Cycle, and Systems Analyses—The objective is to develop a centralized clearinghouse of techno-economic analysis, life cycle analysis, and systems analysis to answer key questions for decision making on biopower RD&D and investments. The clearinghouse will disseminate publicly available results of analysis, research and development, demonstration, pilot-scale, and deployment projects.

FIGURE 3.2.1

Cost-effective Biomass Pretreatment and Conversion Technologies

RD&D PRIORITY

Objective

Conduct research and development on pretreatment and conversion technologies to drive down capital and operating costs

Key Technical Targets

- Cost-effective technology that supports a sound business case for biopower
- Establishment of a regional commodity structure for biomass feedstocks
- Include advanced technologies and improvements to existing technologies (see Table 3.2.1)
- Understand additives and/or boiler modifications needed to burn high alkali and silica biomass.

Major Barriers

- Issues of feedstock quality and consistency
- Challenges of scaling up

Applications

- Commoditization at a regional level to increase competitiveness and ease of use of feedstocks for biopower

Benefits

	Low High
Energy	■■■■■■
Environment	■■■■■
Carbon Reduction	■■■■■■
Economic Growth	■■■■■
Other	—

Relative Risk

	Low High
Technical *Much exists, but further development is needed*	■■
Commercial	■■■■■■

Stakeholders & Roles

Industry	Input on practicality
Agricultural/Forestry Community	Provide fuel
Government	Project support
Research Institutes National Laboratories Universities	R&D assistance

Timeframe and Activities

Near-Term (by 2012)	Mid-Term (2012–2015)	Long-Term (2015+)
Develop pretreatment and conditioning technologies to improve delivered feedstock quality and consistency	Develop pretreatment and conditioning technologies to drive down capital and operating costs	Establish operating regional commodity structure

FIGURE 3.2.2
Characterization of Biomass Intermediates and Co-products

RD&D PRIORITY

Objective

Develop detailed design data on intermediates and co-products from conversion and downstream processing, to improve information for evaluation of overall system performance and economic viability

Key Technical Targets

- Technologies and procedures to conduct real-time qualitative characterizations on biomass and intermediate products and co-products
- Physical and chemical characterization database

Major Barriers

- Insufficient detailed design data for downstream processing
- Inadequate information for analysis

Applications

- Improved evaluation of biopower systems through more universally acknowledged product characterization

Benefits

	Low — High
Energy	■■■■■■
Environment	■■■■■
Carbon Reduction	■■
Economic Growth	■■■■■
Other	—

Relative Risk

	Low — High
Technical *Necessary, but not high risk*	■■
Commercial	■■

Stakeholders & Roles

Government	Project support
Research Institutes National Laboratories Universities	R&D
Industry	Implementation , use, and refinement of developed capabilities

Timeframe and Activities

Near-Term (by 2012)	Mid-Term (2012–2015)	Long-Term (2015+)
Develop a physical and chemical characterization database	Develop real time biomass and intermediate characterization capability	Refine real time biomass and intermediate characterization capabilities with industry leadership

FIGURE 3.2.3

Theoretical Analysis of Biomass Pretreatment and Conversion Processes

RD&D PRIORITY

Objective

Theoretical analysis (including models and simulations) to improve fundamental understanding of biomass, leading to new and innovative pretreatment conversion technologies and improved operation of existing systems

Key Technical Targets

- Research and development of thermodynamic, kinetic, and CFD modeling of pretreatment and conversion processes
- Model verification and validation

Major Barriers

- There are knowledge gaps that exist regarding the pretreatment and conversion of biomass.
- Thermodynamic, kinetic, and computation fluid dynamic modeling improvements are needed to guide engineering and pretreatment and conversion process development.

Applications

- Underpins all pretreatment and conversion processes

Benefits

	Low — High
Energy	■■■■■■
Environment	■■■■■
Carbon Reduction	■■■
Economic Growth	■■■■■
Other	—

Relative Risk

	Low — High
Technical *Analysis only*	■■
Commercial	■■

Stakeholders & Roles

Government	Project support
Research Institutes National Laboratories Universities	R&D
Industry	Implementation

Timeframe and Activities

Near-Term (by 2012)	Mid-Term (2012–2015)	Long-Term (2015+)
Thermodynamic, kinetic, and CFD modeling of pretreatment and conversion processes	Model verification and validation	Integration of new feedstocks and systems into models

FIGURE 3.2.4
Proof of Concept and Scale-up for Pretreatment

RD&D PRIORITY

Objective

Conduct bench research, pilot testing, and demonstration of pretreatment technologies (e.g., densification) for proof-of-concept and to aid in technology scale-up.

Key Technical Targets

- Investigation of pretreatment technologies on various types of homogeneous and heterogeneous biomass
- Densification using an ag-fiber feedstock
- Small-scale, modular, mobile pretreatment and densification units

Major Barriers

- Issues relating to the scaling-up from pilot-scale processes and equipment to large-scale systems
- Permitting requirements for new systems
- Technical Risks—limited information exists on these processes, their scale-up, and operational attributes, which impacts financing and adoption.

Applications

- Streamlines pathway from development and demonstration stages to commercialization
- Maximizing feedstock uniformity to reduce user's capital costs through simplified material handling and streamlined safeguards

Benefits

	Low — High
Energy	■■■■■■
Environment	■■■■■
Carbon Reduction	■■■■■
Economic Growth	■■■■■■
Other	—

Relative Risk

	Low — High
Technical	■■
Mature sector in some cases; scale up may be needed	
Commercial	■■■■■■
Will market pay premium for pelletized feedstock?	

Stakeholders & Roles

Industry	Input on practicality
Agricultural/Forestry Community	Provide fuel material
Government	Project support
Research Institutes National Laboratories Universities	R&D

Timeframe and Activities

Near-Term (by 2012)	Mid-Term (2012–2015)	Long-Term (2015+)
Investigate pretreatment technologies for various types of homogeneous and heterogeneous biomass; identify candidates for ag-fiber feedstocks for densification; assess fragility, durability, binders	R&D of appropriately scaled and modular pretreatment and densification units	Demonstration of appropriately scaled and modular pretreatment and densification units

FIGURE 3.2.5

Large-scale, Cost-effective Biomass Torrefaction Capabilities

RD&D PRIORITY

Objective

Conduct analysis on region/area-specific biomass, and develop the necessary parameters to optimize the preparation of feedstocks (density, particle size, stability, moisture content), thermochemical and thermodynamic requirements to achieve torrefaction results, and the compositional requirements needed to meet desired material properties, characteristics, and standards.

Key Technical Targets

- Develop "recipes" for torrefying biomass based on feedstock analysis and industry need
- Use "torrefaction recipes" to produce sufficient materials and confirm plant performance using torrefied biomass fuels
- Optimize systems and deploy production facilities to enable biomass utilization if cost-effective strategies emerge
- Evaluation of the combustion and gasification properties of torrefied biomass, with a focus on potential new applications
- Innovative processing such as low-cost fine milling

Major Barriers

- There is a lack of information pertaining to torrefaction , and whether it can achieve large-scale, cost-effective means of producing a bio-coal substitute.
- Densification is difficult—more research needed
- Development of cost-effective production processes.
- Garnering interest and involvement of stakeholders

Applications

- Value-added processing of feedstocks (stable storage medium; high energy density)
- Larger-scale biopower applications
- Cofiring of biomass in coal boilers and base-load electric generation plants
- Provides substitute or replacement opportunities for biomass versus coal and enables fuel mix based emission reduction opportunities

Benefits

	Low – High
Energy	■■■■
Environment	■■■■■■
Carbon Reduction	■■■■■■
Economic Growth	■■■■■■
Other	—

Relative Risk

	Low – High
Technical Already developed in Europe	■■
Commercial *Scale qualification*	■■■■■■

Stakeholders & Roles

Industry	Coal industry, harvesters, manufacturers
Agricultural Community	Growers
Government	USFS, USDA
National Laboratories	Idaho National Lab
Universities	UT, ND, MS, OR, WA

Timeframe and Activities

Near-Term (by 2012)	Mid-Term (2012–2015)	Long-Term (2015+)
Gather feedstock-specific data affecting methods and recipes for preparing and processing materials	Test methods and recipes for preparing and processing torrefied biomass materials. Prepare 200 Ton samples of recipe materials to test plant performance using torrefied biomass fuel runs.	If proven cost effective, deploy torrefied biomass production facilities to enable increased biomass utilization in base-load electric generation facilities.

FIGURE 3.2.6

Techno-economic Analysis, Life Cycle Assessment, and Systems Analysis

RD&D PRIORITY

Objective

Identify and organize existing analyses within a central clearinghouse to advance understanding of overall system design and integration

Key Technical Targets

- Understanding of completed analyses
- Organization and development of a central clearinghouse for available information

Major Barriers

- Overall process costs, benefits and other techno-economic information are not available and assessable by stakeholders
- Quantification of environmental impacts and attributes are not well understood

Applications

- Access to a large array of analysis to assist in decision making by entities interested in producing biopower

Benefits

	Low – High
Energy	■■■■■
Environment	■■■■
Carbon Reduction	■■■■
Economic Growth	■■■■■■
Other	—

Relative Risk

	Low – High
Technical *Analysis is not high risk*	■■
Commercial	■■

Stakeholders & Roles

Industry	Provide examples for analysis
Research Institutes	Research
Government	Project support
National Laboratories	Analysis and assessment
Universities	Develop systems and assessment

Timeframe and Activities

Near-Term (by 2012)	Mid-Term (2012–2015)	Long-Term (2015+)
Meta analysis and development of clearinghouse for research and commercialization	Guide and respond to R&D (fundamental through pilot)	Provide supporting analysis as necessary to quantify, understand, and communicate technical and economic benefits and other attributes

4 LARGE-SCALE SYSTEMS

Spurred by RPS, impending carbon legislation, and public concerns about the environment, utilities across the United States are considering how they might lower emissions and incorporate more renewable energy into their electricity generation mix. While wind, solar, and other types of renewable energy plants are viable options in some cases, utilities may find biomass more attractive because it is less intermittent and widely available. If a utility already burns coal, it may be economical for the utility to convert some of the coal-burning plants to biomass plants or to plants that cofire biomass with coal.

The definition of large-scale power is open to some debate, but it is often described as "utility scale." Designation can also be established in terms of power output. Some define large-scale power production as production higher than 10 MW, while others define it as production higher than 20 MW. In California, "utility scale" is defined as power production above 5 MW. In practice, there are utility providers that produce less than 10 MW and industrial facilities with power plants that produce greater than 10 MW. Due to this variability, for the purposes of this report, the definition of large-scale power is open to interpretation and takes into account all possible scenarios.

Decision making for large-scale biopower projects is often complicated by a number of factors: technologies are often unproven at large scale; up-front capital investment is typically much greater; and there is a lack of confidence in feedstock supply, infrastructure needs, and consumer demand. Dedicated long-term financial support and improved understanding of biomass characterization and integration capabilities, including demonstrations, will be necessary to overcome these and other barriers.

This section outlines the key challenges and priority RD&D and analysis needed in the large-scale biopower area. The topics of interest are diverse and include large-scale cofiring with coal or natural gas, gasification, dedicated direct combustion of biomass, other advanced technologies, and integration of biomass with large-scale or utility power generation systems.

4.1 *Challenges and Constraints*

4.1.1 Technical Challenges

The identified technical challenges to the increased deployment of large-scale biopower are ranked and listed in Table 4.1.1. The top-priority technology challenges emerged in the areas of feedstock sourcing, biomass conversion and performance, and effective technology scale-up.

Feedstock Supply—The subject of feedstock supply, sourcing, and competition is crucial, particularly the stability and maturity of fuel sourcing. Techniques to expand the radius of the supply basket are needed. The lack of uniform, well-characterized feedstocks also creates risk because it is not well understood how these fuels will perform and ultimately affect boiler and other system operations. The uncertainty of long-term, large-volume feedstock availability and cost is also a critical barrier. Issues contributing to the issue of feedstock availability include ensuring an adequate supply at a large scale and development of the associated supply infrastructure.

Biomass Conversion and Performance Issues—One key concern is the ability to convert or pretreat biomass if needed to ensure that it is cost effective and reliable for use in retrofit power plants. The pretreatment or conversion needs to be efficient at large scales in order to justify the retrofit. An added concern with the introduction of biomass fuel is the presence of inorganic constituents in some biomass (chlorine, potassium, and salts such as potassium chloride). Release of these components may lead to heavy deposition on heat transfer surfaces, resulting in reduced heat transfer and enhanced corrosion rates. In addition to concerns about deposit formation and corrosion, the use of biomass may impede the sale and utilization of fly ash for cement production when cofiring with coal in pulverized coal burners. Boiler capacity de-rating, reduced efficiency, and reliability could also result from combining lower grade biomass directly with coal.

Technology Scale-Up—Participants expressed concern over the ability to successfully scale technologies from pilot to large scale (e.g., achieving the same performance and reliability of equipment at larger scales).

TABLE 4.1.1
TECHNICAL BARRIERS AND CHALLENGES FOR LARGE-SCALE SYSTEMS

Feedstock Supply	
High Priority	• Uncertainty of long-term, large-volume feedstock supply availability and costs o Issues of scale o Competition o Biomass supply infrastructure • Undeveloped and unstable fuel sourcing • Lack of uniform, well-characterized feedstock
Medium Priority	• Problems with feedstock transportation at scale
Lower Priority	• Lack of transmission infrastructure • Mismatch between consumer demand and technology deployment • Increased supply risk with large bio-refineries
Technology Issues	
High Priority	• Technology scale-up issues from pilot- to large-scale (e.g., mixing equipment and entrained flow gasification) • Lack of optimal and efficient conversion of biomass to a form for use in retrofitted existing power plants
Lower Priority	• Difficulty of industry standardization with the diversity of site-specific requirements • Acceptable methods for utilization or disposal of ash and other wastes • Optimization of thermal efficiencies needs to approach pulverized coal-fired plants • Lack of environmental data for new technologies

4.1.2 Non-Technical Challenges

The highest-priority non-technical challenges for large-scale biopower include financial risks, an uncertain policy climate, and issues associated with permitting and regulation.

Financial Risk—When participants were asked to consider barriers to past government-supported biopower efforts, they identified the lack of sustained investment as a critical barrier. The financial value proposition for biopower projects is generally a constraint; the cost of converting a plant to biopower, which will affect the cost of the electricity produced, is a deterrent. A large financial investment is required for commercial development, which is challenging when the financial landscape is uncertain, longer-term federal funding support is unlikely, and the commercial success of large biopower projects is not well-demonstrated. This is especially true when considering regional competition with fossil fuels and hydropower. For the investment funds that are available, there is no clear list of prioritized topics for investment.

Policy—The lack of clearly written, stable policy hinders biopower deployment. The lack of a federal RPS and inconsistent tax credits all contribute to policy uncertainties. There is also a lack of national policy incentives to allow for profitable commercialization (e.g., costs of CO_2 emissions to compete with fossil fuel and market incentives for large investments).

Environmental/Regulatory Risk—The permitting process, described as “arduous and complex,” was identified as a barrier. Uncertainty in air permitting, especially for modifying existing plants, is a concern for many utilities interested in pursuing biopower. Changes to the operating conditions of power plants will require re-permitting (Title V and New Source Review). The compatibility of a biomass fuel with existing emission control technology needs further proof.

Institutional Risk—Without clear market signals, there is a lack of buy-in from the utility community for cofiring and repowering projects.

4.2 *Priorities for Research and Development and Analysis*

A broad discussion of RD&D and analysis needed to address barriers to large-scale biopower resulted in seven priority topic areas. A complete set of RD&D topics are described below and in more detail in Figures 4.2.1 through 4.2.7.

4.2.1 RD&D Priorities

The highest priorities for RD&D emphasize the need for better technical and economic understanding of biopower technologies and feedstocks and the impact of biomass feedstock on existing systems and performance.

Low-Temperature Gasification and Hot Gas Cleanup—Improvements to low-temperature gasification and hot gas cleanup capabilities will facilitate the use of this technology in advanced conversion devices such as gas turbines, fuel cells, and high-efficiency combustion boilers.

High-Temperature Materials Research Related to Combustion of Biomass—High-temperature materials research is needed to aid in understanding the mechanisms of ash slagging, metals corrosion, and refractory degradation in boilers and gasifiers used for 100% biomass as well as cofiring of biomass with coal. These can be significant problems due to the inorganic components of some biomass resources.

Cost-Effective Combustion of Bio-oil for Biopower Applications—An efficient, cost-effective approach is needed for combusting partially upgraded bio-oil in turbines and boilers.

Funded Demonstrations: Repowering Boilers, Cofiring, and Other Advanced Biopower Applications—Demonstrations of advanced or improved concepts for repowering are a high priority, important to answering remaining questions of system performance and integrity. It was suggested that funded demonstrations are needed at both pilot scale and commercial scale, for modernizing pulp mills and for repowering existing power plants, and for hybrid and cofired systems.

Characterize Options and Benefits of Repowering Existing Plants and Pulp Mills—A characterization study (i.e., a design case demonstration) is needed to compare and evaluate multiple biopower repowering technology options. The objectives are to characterize performance, benefits, and costs for each option.

Catalogue and Correlation of Biomass Fuel Properties with Downstream Processing—There is a need for an expanded catalogue of biomass fuel properties. The existing DOE database should be expanded to include chemical (both organic and inorganic—ash, in particular), physical, and thermal properties and correlated to downstream operation, emissions, and products. To complete this characterization catalogue, standards for biomass analysis (chemical and physical) are necessary.

4.2.2 Priorities for Analysis

Techno-economic Analysis to Correlate Technologies with Feedstocks—Techno-economic analysis is a priority analysis need and will aid in understanding how to best correlate the most cost-effective and efficient biopower conversion processes and technologies with regionally available feedstocks. The goals are to establish technology benchmarks, identify and fill data gaps, and produce regionally specific feasibility analyses.

FIGURE 4.2.1
Low Temperature Gasification and Hot Gas Clean-up

RD&D PRIORITY

Objective

Improvement of low temperature gasification (less than 1000 ºC approximately) is needed in order to utilize the technology in advanced conversion devices, such as gas turbines, fuel cells, and high efficiency combustion boilers. Hot gas clean-up is a key component.

Key Technical Targets

- Provide a state-of-technology summary, including various low temperature gasifier operating parameters and gas clean up parameters
- Compare oxygen flow, air flow, and atmospheric conditions
- Improved syngas/product gas clean up capability (alkalki and heavy metals for boilers, and sulfur, nitrogen, and tar for fuel cells/gas turbines); catalyst development is needed

Major Barriers

- Syngas/product gas contaminants (inorganic and organic) are detrimental to end use equipment
- Lack of long-term demonstration with documented cost, environmental and performance data
- Lack of proven use of hot gas filters
- Oxygen production (e.g. via air separation) is not cost effective, especially at the relatively small scale necessary for biomass gasification

Applications

- Production of biopower via single cycle and combined cycle plants
- Low temperature gasification as an alternative to direct combustion to reduce slagging and fouling problems

Benefits

	Low — High
Energy	■■■■■■
Environment	■■■■■■
Carbon Reduction	■■■■■■
Economic Growth	■■■■■
Other	—

Relative Risk

	Low — High
Technical & Commercial	
Single Cycle Plant	■■
Combined Cycle Plant	■■■■

Complex system. Depends on catalyst development and hot gas clean-up

Stakeholders & Roles

Industry	Host
Agricultural Community	Feedstock supply
Research Institutes, National Laboratories	Advanced technology host, pilot host, cost share
Government	Funding and regulations, public acceptance
Universities	Grad student, demonstration host, fundamental data

Timeframe and Activities

Near-Term (by 2012)	Mid- to Long-Term (2012+)
Complete state-of-technology summary and lessons learned. Initiate research. Develop boiler applications	Develop gas turbine, combined cycle, and fuel cell applications

FIGURE 4.2.2

High Temperature Materials Research Related to Combustion Impacts

RD&D PRIORITY

Objective

Conduct high-temperature materials RD&D to better understand the mechanisms for ash slagging, metals corrosion, and refractory degradation in boilers and gasifiers used for 100% biomass and for cofiring of biomass and coal.

Key Technical Targets

- Correlations between bio-ash properties and constituents and high temperature durability of metals and refractories
- Correlations between biomass ash content, its constituents, and their chemical and thermal properties
- Guidelines for boiler and gasifier materials selection

Major Barriers

- Defining the scope of feed materials to be considered
- Defining and implementing a matrix of tests and conditions
- Establishing and implementing a cooperative consortium of industry and government stakeholders

Applications

- High efficiency boilers with either 100% biomass feed or cofired biomass and coal
- Pyrolyzers and high- and low-temperature gasifiers

Benefits

	Low – High
Energy	■■■■■■
Environment	■■■■
Carbon Reduction	■■■■■
Economic Growth	■■■■■
Other	—

Relative Risk

	Low – High
Technical	■■■■
Commercial	■■

Stakeholders & Roles

Industry	Demonstration, validation of technology
Research Institutes, National Laboratories, Government	Generate basic data

Timeframe and Activities

Near-Term (by 2012)	Mid-Term (2012–2015)	Long-Term (2015+)
Define and award materials research program by 2012	Complete design correlations and materials selection guidelines per program deliverables	—

FIGURE 4.2.3
Cost Effective Combustion of Bio-oil for Biopower Applications

RD&D PRIORITY

Objective

Develop an efficient approach for combusting partially-upgraded bio-oil in applications such as turbines and boilers. Application to be cost efficient, energy efficient, and chemically efficient (atomic scale).

Key Technical Targets

- Demonstrate increased number of hours with bio-oil combustors for boilers and turbines (100, 1000, 5000, 20,000 hrs)
- Develop benchmarks for varying bio-oil blends for each end use
- Analyze materials, emissions, and performance impacts; develop necessary alloys and pacified surfaces

Major Barriers

- Compatibility with materials of construction and lifecycle operation (turbine combustor and boiler combustor); durability
- Lack of understanding of the liquid impact on stack emissions
- Lack of understanding of the level of upgrade needed for storage and handling

Applications

- Bio-oil steam boilers (near-term)
- Bio-oil turbines (mid-term)
- Bio-oil gasification gas turbines and fuel cells for power or CHP

Benefits

	Low – High
Energy	■■■■■
Environment	■■■■■
Carbon Reduction	■■■■■
Economic Growth	■■■■■■
Other	—

Relative Risk

Technical & Commercial	Low – High
Boiler	■■
Turbine	■■■■■■

Turbine is more complex. Specifications needed for various bio-oil upgrade levels. Need standards.

Stakeholders & Roles

Industry	Pilot, demonstration, channel to market
Agricultural Community	Homogeneous feedstock and use of biochar
Research Institutes, National Laboratories	Advancement of technology
Government	Program funding, regulations
Universities	Fundamental data collection and experimentation

Timeframe and Activities

Near-Term (by 2012)	Mid-Term (2012–2015)	Long-Term (2015+)
Laboratory and bench scale work	Work on boiler combustor (pilot) Work on turbines (pilot)	Demonstration of optimal technology

FIGURE 4.2.4
Funded Demonstrations—Repowering Boilers, Cofiring, and Other Advanced Biopower Technologies

RD&D PRIORITY

Objective

Co-fund and document results from biomass co-firing for feedstock/technology combinations that are not well understood, and from re-powering existing boilers from fossil fuel to 100% biomass. Also demonstrate advanced technologies including gasification, hybrid systems, and pyrolysis oils.

Key Technical Targets

- Improve economics, efficiency, reliability, and performance for large new biopower applications and document results
- Pilot-scale and plant-scale demonstrations and demonstrate advanced technologies including gasification, and fuel cells
- Large-scale demonstrations of closed-loop co-firing
- Understand infrastructure requirements for delivering biomass to coal facilities and mixed feedstock issues
- Focus first on utilizing existing technology and equipment when possible and avoid high-capital customization

Major Barriers

- Lack of documentation and demonstration of the impacts of biofuels on existing equipment
- Lack of demonstrated near-term technologies and pre-commercial and/or commercial scale technologies
- Lack of documented environmental impacts and sustainability of feedstock supply systems

Applications

- Utilizing existing infrastructure to rapidly deploy biopower at commercial scale
- Application of emissions control equipment
- Application of feedstock handling and supply systems
- Cogasification of biomass with coal

Benefits

	Low — High
Energy	■■■■
Environment	■■■■■
Carbon Reduction	■■■■■■
Economic Growth	■■■■■■
Other	—

Relative Risk

	Low — High
Technical	■■
Commercial	■■

Technical: *Technically feasible but untested at commercial scale for sufficient durations*

Commercial: *Feedstock supply can pose a risk for large projects; available incentives may not be sufficient*

Stakeholders & Roles

Industry	Host and plan demonstrations
Agricultural Community	Supply feedstock
Research Institutes, National Laboratories	Cost-share/organize stakeholder participation and priorities, e.g., EPRI
National Laboratories	Fundamental research data and models, characterize sustainability impacts, leverage pilot-scale facilities
Government	Cost-share, coordinate agency assistance

Timeframe and Activities

Near-Term (by 2012)	Mid-Term (2012–2015)	Long-Term (2015+)
Detailed scoping study and stakeholder feedback process leading to and RFP process	Develop and release RFP, co-fund projects, and document results	Continue process for advanced or emerging technologies, applications, or processes

FIGURE 4.2.5

Catalogue and Correlation of Biomass Fuel Properties (Including Ash Analysis)

RD&D PRIORITY

Objective

Develop catalogue of biomass fuels, documenting chemical, physical and thermal properties for each fuel. Correlate fuel properties to downstream operation, emissions and products (i.e., coordination with NIST).

Key Technical Targets

- Establish standard operating procedures and standards (physical and thermal) for the elemental analysis of biomass components
- Correlate fuel properties to downstream operation, emissions and products
- Standardize sampling of heterogeneous biomass
- Establish a work-in-progress database in an agreed format with end users (define important descriptors)

Major Barriers

- Nature of biomass: heterogeneous, diverse feedstocks/fuels (physically, regionally, seasonally)
- Lack of correlation between feedstocks/fuel components, operations, emissions, and downstream products
- Lack of thorough analysis and current description of elements analyzed and methods used (e.g., inorganic analysis of materials)

Applications

- Design of biomass power systems
- Feedback loop to growers and researchers of biomass

Benefits

	Low — High
Energy	■■■■■■
Environment	■■■■■
Carbon Reduction	■■■■■
Economic Growth	■■■■■■
Other	—

Relative Risk

	Low — High
Technical	■■
Commercial	■■

Stakeholders & Roles

Industry, Agricultural Community	Stakeholder, user
Research Institutes, National Laboratories, Universities	Enable analysis, populate database
Government	Enable analysis and development of standards, funding

Timeframe and Activities

Near-Term (by 2012)	Mid-Term (2012–2015)	Long-Term (2015+)
Establish sampling Establish analysis standards	Establish and evolve database	—

FIGURE 4.2.6

Techno-economic Analysis (TEA) to Correlate Technologies with Feedstocks

ANALYSIS PRIORITY

Objective

Identify the most cost-effective and technically-efficient processes and technologies and develop a model to regionally correlate these to appropriate feedstocks.

Key Technical Targets

- Regionally-based analysis
- Establishment of technology benchmarks
- Develop open architecture, assumptions, and calculations in the design and implementation of TEA
- The TEA should be available for public use and public input on key assumptions
- Hold workshop to gain consensus on methodology and assumptions
- Incorporation of exergy analysis of biopower systems as complement to techno-economic analysis

Major Barriers

- Existing data gaps, data quality, and benchmarks
- Lack of understanding of biomass feedstock characteristics
- Lack of understanding of the most cost-effective, efficient applications/use of biomass
- Building consensus

Applications

- Biopower industry and feedstock suppliers
- Optimization for states and regions (feedstock supply and technology application); regional studies aggregated for national use
- Improved public education, including development of policy maker knowledge

Benefits

	Low → High
Energy	■■■■■
Environment	■■■■■
Carbon Reduction	■■■■■
Economic Growth	■■■■■■
Other	—

Relative Risk

	Low → High
Technical	■■■■
Commercial	■■

No barriers to implementation except personnel time and funding to do the project; risk of developing an inaccurate model is high

Stakeholders & Roles

Industry	Inputs, critical stakeholder, validate assumptions, user of model
Agricultural Community	Provide data, validate assumptions
Research Institutes	Developing standard methods
National Laboratories, Universities	Development partners
Government	Funding, stakeholder, implementer, model host

Timeframe and Activities

Near-Term (by 2012)	Mid-Term (2012–2015)	Long-Term (2015+)
Establish benchmarks, hold workshops, identify partners, secure funds, work scope, literature review	Create framework and working model	Deploy for use by stakeholders

FIGURE 4.2.7

Characterize Options and Benefits of Re-powering Existing Power Plants and Pulp Mills

RD&D PRIORITY

Objective

Develop a characterization report (i.e., design case demonstration) comparing multiple biopower repowering technology options. Characterize performance, benefits, and costs for each option.

Key Technical Targets

- Documented plant and system efficiency improvements
- Documented reduction in GHG emissions
- Determination of equivalent cost of electricity
- Development of characterization report that leads to demonstration projects

Major Barriers

- Limited demonstration of biomass power technologies and efficient use of biomass
- Limited biopower funding opportunities (characterization report and subsequent demonstrations will provide cost-share opportunity)

Applications

- Small, existing coal boilers/gasifiers <175 MW
- Shuttered pulp mills
- Currently operating pulp mills

Benefits

	Low → High
Energy	■■
Environment	■■■■
Carbon Reduction	■■■■■■
Economic Growth	■■■■■■
Other	■■■■■■

Relative Risk

	Low → High
Technical	■■
Commercial *Only a study*	■■

Stakeholders & Roles

Industry	Facility host
Agricultural/Forest Community	Fuel supply
Research Institutes, National Laboratories	Study authors
Government	Funding
Universities	Study authors
Utilities	Power off-takers

Timeframe and Activities

Near-Term (by 2012)	Mid-Term (2012–2015)	Long-Term (2015+)
Study completed Complete FEED (front end engineering and design)	Identify project partners, develop and release solicitation to co-fund project	Replicate based on favorable results

5 SMALLER-SCALE SYSTEMS

Courtesy of NREL. Small-scale gasification pilot unit.

A variety of industries are turning to alternative and renewable fuels as the United States nears implementation of formal carbon legislation, with many focusing on CHP applications. These applications are commonly used in large-scale systems, but are also available in small-scale systems (smaller than 80 MW, per the definition in the Public Utility Regulatory Policies Act of 1978). A key challenge for CHP systems, which are more thermally efficient, is finding uses for the generated heat and effectively adapting these systems for use at small scales.

Smaller-scale systems, for the purposes of this report, generally range from 1–50+ MW with an emphasis on non-utility applications. While 10–15 MW is typically considered small-scale, this report also includes larger-scale, non-utility systems from 50 to 100 MW. Smaller-scale systems are in use across the United States, but greater adoption is hampered by a number of technical and non-technical challenges. Small-scale biopower technologies are likely to have reduced capital requirements, thus creating an early impact on biopower market penetration and paving the way for larger biopower systems.

The section outlines the key challenges and priority RD&D and analysis needed for smaller-scale biopower systems, particularly those that cogenerate heat and power. Of particular interest are industrial and community systems, mass burn of biomass wastes, and institutional or commercial building applications.

5.1 *Challenges and Constraints*

5.1.1 Technical Challenges

Technical challenges and barriers to developing and deploying small-scale biotechnology systems are shown in Table 5.1.2. The top priorities were identified as fuel and feedstock quality, cost, and availability, finding users for cogenerated waste heat, and the lack of demonstrated, cost-effective small-scale gasifiers.

Waste Heat Utilization (Combined Heat and Power)—The most critical barrier is the difficulty in finding users for cogenerated heat in the vicinity of the source of fuel. Finding a use for waste heat with more efficient CHP systems increases the viability of small-scale biopower systems. The infrastructure for utilizing (transporting) heat may also be lacking, and it may be difficult to integrate waste heat with existing systems.

Fuel Quality and Handling—The high cost and availability of biomass is challenging for small-scale and large-scale users. There is still significant uncertainty about how to handle biomass feedstocks (preprocess, store, convey), and how to ensure that a consistent quality of supply can be maintained year-round. However, small-scale systems can use economical, locally sourced wood drawn from within a 100-mile radius, which alleviates much of the trucking costs.

Small-Scale Gasification—While this technology has significant potential, new scalable designs will be needed to integrate with the unique requirements of small-scale power. Emissions data for operating biomass gasifiers is lacking, which is an issue for environmental compliance and permitting. In addition, current synthesis gas cleanup technologies are insufficient, particularly with regard to organics, which limits prediction of system performance and operation and may also impact emissions. The current high cost of gasifiers would be reduced by mass production of the technology.

Environmental Controls—There is a priority need for cost-effective air emission controls to meet ever-increasing regulatory emission limits, particularly for new systems (e.g., gasification). The high cost of pollution abatement and controls and the need to meet increasingly stringent (and potentially uncertain) standards make it more difficult to justify investment in small-scale power.

TABLE 5.1.2
TECHNICAL BARRIERS AND CHALLENGES FOR SMALLER-SCALE SYSTEMS

Waste Heat Utilization (Combined Heat and Power)	
High Priority	• Lack of a customer for waste heat generated by CHP in close proximity to the source
Medium Priority	• Difficult integration of adsorption/absorption chillers with CHP
Lower Priority	• Lack of infrastructure for using heat from CHP
Fuel Quality and Handling	
High Priority	• High cost and availability of biomass feedstock
Medium Priority	• Feedstock handling (conditioning, preprocessing, collection, conveyance to boiler)
Lower Priority	• Inconsistent quality of fuel supply • Ability to identify/understand fuel type and treatment needed (wet/dry, or chips/grinding) • Lack of feedstock standardization
Small-Scale Biomass Gasification	
High Priority	• Lack of cost-effective small biomass gasifiers
Medium Priority	• Lack of good emissions data for gasification systems • Inefficient gasification cleanup, particularly for organics
Lower Priority	• Concerns over impact of syngas quality on internal combustion engines, boilers, and pipelines • Lack of reliable, cost-effective system for syngas cleanup • Difficulty and high cost of scaling down tar and particulate control technologies
Technology Development/Demonstration at Small Scale	
High Priority	• Lack of cost effective biomass-fired hot air turbine system[2]
Medium Priority	• Lack of continuously operating demonstration plants for new technologies in the United States • Ash and aerosol issues, including slagging and fouling • Lack of data on the life and effectiveness of biomass-fired primary air heaters for hot air turbines
Lower Priority	• Uncertainty of overall system availability and impact on profitability • Need for new "clean" high-efficiency technologies for CHP applications (e.g., low NO_x and SO_x, pre-vaporized liquid biofuel combustion) • Lack of cost-effective downstream unit operations for anaerobic digestion • Lack of cost-effective, scaled-down reactor designs
Fuel Flexibility	
Lower Priority	• Lack of technological flexibility to adjust to natural fuel quality • Insufficient data/understanding of combusting, gasifying, and feeding lignin residuals from ethanol facilities and the difference from raw biomass (e.g., particle size increase contaminants)
Water Use and Discharge	
Medium Priority	• Reduction of water usage and wastewater discharge • Excessive water use with low-cost generating options
Lower Priority	• Handling effluent remediation (e.g., to a WWTP for reuse)
Environmental Controls	
High Priority	• Economic air emission controls to meet ever-increasing regulatory emission limits
Lower Priority	• Lack of emission controls to meet requirements in non-attainment areas

[2] High priority added by post-workshop reviewers

Technology Development/Demonstration at Small Scale—The lack of continuously operating demonstration plants for new technologies in the United States, especially for smaller-scale systems, increases the technical risk of new systems. Limited understanding of ash content and production of aerosols that cause corrosion is another technical issue.

Waste Use and Discharge—Reducing water usage and wastewater discharge is a challenge for small-scale biopower systems. In addition, lower-cost generating options use comparatively high amounts of water. Strategies are needed for water reuse and overall reduction in water requirements.

5.1.2 Non-Technical Challenges

Non-technical barriers were identified in the areas of policy, risk management, and economics.

Policy—Policy issues generally relate to a lack of uniform legislation to support the deployment of small-scale biomass power plants. For example, the shortage of consistent regulations for small-scale biomass systems is one key barrier that must be addressed. Other key issues include uncertainty related to carbon legislation and production incentives such as renewable energy credits, which are not currently given for the thermal portion of combined heat and power applications. Large regulatory risks when combined with financial risk can stifle innovation as well as investment.

Risk Management—Making the business case for small-scale systems and financial hurdles creates high risk and makes investment in these systems a challenge. Business models, a long-term outlook, and market data for biopower systems, particularly at a small scale, are inadequate, which reduces the attractiveness of small-scale systems as an investment. Market assessment and definition is a critical need. Adequate price supports for "green" electricity, which could reduce risk, are lacking. A contributing factor is the lack of investors who understand and appreciate the benefits of CHP for small-scale use. The return on investment for an energy project is often viewed differently than other projects (e.g., higher risk factors) and may be harder to justify, especially if energy prices are low.

System Economics—The limiting and high-cost structure for small-scale systems was identified as one of the most important barriers. In most utility markets, small-scale CHP may be less cost-effective than using large utilities, and capital expenses and operating costs may also be higher per megawatt.

Scalability—A biopower generation technology which can be introduced at the 1–100 kW range and can be scaled up to 50+ MW that can be developed and commercialized in a more cost effective manner than a technology which is only suited for lower applications (10+ MW). Gasifiers, turbines, and oxygen plants do not scale well to low kilowatt capacity and therefore do not have robust small-scale markets or a capital-efficient market entry point.

5.2 *Priorities for Research and Development and Analysis*

5.2.1 RD&D Priorities

Five topics for priority RD&D and analysis were identified as critical to addressing barriers to the use of small-scale systems. These are shown below and described in more detail in Figures 5.2.1 through 5.2.5.

Synthesis Gas Cleanup for Small-Scale Biomass Gasification—The objectives are to develop and test syngas cleaning and conditioning technologies for small-scale systems (including those smaller than 1 MW) and to enable reliable production of clean, usable syngas. The system would cost-effectively remove contaminants specific to the feedstock of use and be readily integrated with affordable conversion to electricity.

Micro-scale Biomass-based Combined Heat and Power—Creation of micro-scale (smaller than 5 MW) biomass-based CHP applications and boiler/chiller or boiler/power applications that are easy to use and quickly implementable (i.e., plug and play). Emphasis is on single-stage modular biomass technology with internal combustion and waste heat recovery and includes a variety of technologies, ranging from organic Rankine cycle to anaerobic digestion.

Demonstration of Integrated Small-Scale Systems—A general consensus was that more technologies would be adopted if additional technology demonstrations were conducted. Demonstrations would include syngas-related technologies (gasification, integrated combined cycle, catalytic tar destruction, and syngas cleanup) and other integrated systems. Demonstrations would provide performance and economic data that could be made publicly available and used to qualify for financing.

Cost-effective Emissions Control Technology for Small-Scale Systems—The objective is to conduct short-term pilot testing of unit operations within integrated systems to develop publicly available data that will enable improved, environmentally sound equipment designs and processes.

5.2.2 Priorities for Analysis

Analysis for Small-Scale System Applications—Analytic activities would explore and begin to address a wide range of small-scale issues through development of an applications matrix that connects small-scale systems with potential resources, users, and stakeholder organizations.

FIGURE 5.2.1
Synthesis Gas Cleanup for Small-Scale Gasification

RD&D PRIORITY

Objective

Develop and test syngas cleaning and conditioning technologies for small scale systems (including those smaller than 1 MW) that can cost-effectively remove contaminants specific to the feedstock of use, and integrate with economic conversion to electricity

Key Technical Targets

- Improved tar reforming catalyst durability and long-term conversion efficiency
- Improved separation efficiencies and long-term operation of particulate separation technologies
- Removal of ammonia
- Cost-effective, efficient sulfur removal technologies

Major Barriers

- Lack of accelerated durability testing for every unit of the conversion process
- Difficulty capturing cleanup costs as advances are made (1st of kind vs. nth plant)
- Continuous adoption of state-of-the art to foster innovation
- Finding cost-effective solutions for small scale

Applications

- All prime movers, with cleanup requirements from high to low, as shown. While emphasis is on small-scale, concepts could be applied to large scale.

High	Fuel Cell
	Gas Turbine
↕	IC Engine
	EC Engine
Low	Boiler

- Dynamic and interactive strategic business decision-making

Benefits

	Low – High
Energy	■■■■■
Environment	■■■■■■
Carbon Reduction	■■■■
Economic Growth	■■■■■
Other	—

Relative Risk

	Low – High
Technical *Prime mover functionality is highly dependent*	■■■■■■
Commercial *Current techniques are cost prohibitive due to the novel nature of the technologies*	■■■■■■

Stakeholders & Roles

Industry	Technology validation
Agricultural/Forestry Community	Demonstration/feedstock provider
Research Institutes National Laboratories Universities	R&D (F&A)
Government	Incentives

Timeframe and Activities

Near-Term (by 2012)	Mid-Term (2012–2015)	Long-Term (2015+)
Establish sampling, analysis standards; technology development and testing	Establish and evolve database; technology demonstration and improvement	Continued development as new feedstocks emerge

FIGURE 5.2.2

Micro-scale Biomass-based Combined Heat and Power (CHP)

RD&D PRIORITY

Objective

Develop small-scale modular CHP systems, particularly a single-stage modular biomass gasification with internal combustion and waste heat recovery system

Key Technical Targets

- Packaged, small-scale (1-5 MW) CHP systems for wood waste
- Single stage modular gasifier
- Direct Combustion (DC) Organic Rankine Cycle (ORC) or hot air turbine with waste heat recovery
- Anaerobic digester, with real time process controls
- CHP based on municipal solid waste using anaerobic digestion to produce power and heat
- Packaged, small-scale systems which feed heat to a high temperature gasifier and then to a gas turbine
- Systems suitable for distributed generation applications
- Small, modular, and highly flexible biopower in range of 100 kW up to 3 MW

Major Barriers

- Low fuel quality/Btu content
- Engine warranty/run time required
- Identifying effective CHP co-location and client load
- Adequate facility scale
- Inconsistent incentives that favor solar and wind generation
- Lack of modular biomass demonstration and deployment limit commercial development and its finance

Applications

- Institutions
- Commercial buildings

Benefits

	Low — High
Energy	■■■■
Environment	■■■■
Carbon Reduction	■■■■■
Economic Growth	■■
Other	—

Relative Risk

	Low — High
Technical *Components exist and need integration*	■■
Commercial *Engine warranty for commercial products*	■■■■■■
Other *Finance performance guarantee*	■■■■■■

Stakeholders & Roles

Industry	OEM engine suppliers and client applications
Government	DOE, permits
National Laboratories Universities	System development and application

Timeframe and Activities

Near-Term (by 2012)	Mid-Term (2012–2015)	Long-Term (2015+)
Engine testing on surrogate gas, co-firing natural gas, upgrading of Btu content and fuel quality, selection and field testing of components	Demonstration, warranty acceptance, and modular fabrication	Development/deployment of modular woody biomass CHP systems

FIGURE 5.2.3
Demonstration of Integrated Advanced Small-scale Systems

RD&D PRIORITY

Objective

Support for demonstration-scale runs of integrated, advanced, small-scale systems to obtain performance and economic data that will be publicly available and can be used to qualify for financing

Key Technical Targets

- Performance and economics data from lab, pilot, and demonstration scales
- Emissions and reliability data and catalyst degradation data
- Cost-effective technologies that meet policy objectives
- Identification of unit operations that have technical challenges or are the most costly and would benefit from further R&D
- Demonstration of technology treatment of municipal solid waste by anaerobic digestion
- Optimization of feedstocks for specific conversion processes and applications
- Improve efficiency via intercooling and recuperation or high efficiency heat exchangers

Major Barriers

- Lack of real world data
- Lack of a well-supported business case
- Cost effectiveness issues
- Issues related to life cycle assessment
- Policy uncertainties and changes
- Cost and adequacy of emissions control and abatement systems

Applications

- Integrated systems
- All types of biopower systems, including gasification, combustion, fuel cells, and anaerobic digestion

Benefits

	Low — High
Energy	■■■■■
Environment	■■■■■
Carbon Reduction	■■■■■■
Economic Growth	■■■■■
Other *Lack of information on similar technology*	■■■■■■

Relative Risk

	Low — High
Technical	
IGCC	■■■■■■
Combustion	■■
IGCC high due to syngas cleanup; combustion low—commercially available	
Commercial *Policy- and location-sensitive*	■■■■■■
Other *Expensive emission controls*	■■■■■■

Stakeholders & Roles

Industry	Demonstration partners
Agricultural/Forestry Community	Feedstock provider
Research Institutes National Laboratories Universities	House pilot studies, demonstrations
Government	Long-term program/project support

Timeframe and Activities

Near-Term (by 2012)	Mid-Term (2012–2015)	Long-Term (2015+)
Pilot and demonstration projects using different pathways	Continued support for most viable projects, and dissemination of results	Realignment of focus based on progress and new developments

FIGURE 5.2.4
Cost-effective Emissions Control Technology for Small Scale Systems

RD&D PRIORITY

Objective

Provide support for short-term pilot testing of unit operations within integrated systems to develop publicly-available data for improved, environmentally sound equipment design and processes (e.g., meet near-zero emissions targets for NOx, SOx, and hazardous air pollutants [HAPS]).

Key Technical Targets

- Meet and exceed best available control technology (BACT) levels with lower operating and capital costs
- Sulfur-tolerant, robust technology
- Low-temperature solutions for environmental controls (e.g., selective catalytic reduction for NOx)

Major Barriers

- Cost effectiveness of available and proposed technologies
- Assurance of environmental compliance and related issues
- Compliance with permitting requirements

Applications

- End-use emissions control for a variety of biopower systems

Benefits

	Low → High
Energy	■■
Environment	■■■■■■
Carbon Reduction	—
Economic Growth	■■■■■
Other	■■■

Relative Risk

	Low → High
Technical *Complex problem due to different targets, fuel inputs*	■■■■■■
Commercial *Long-term durability and viability*	■■■■■■
Other *Patchwork of emission targets*	■■■■■■

Stakeholders & Roles

Industry	Supply, product development
Government	Permit, establish reasonable (low) emissions targets; reward success
National Laboratories	Evaluate technologies, disseminate results to suppliers, integrate
Universities	Develop new technologies and conduct long-term R&D

Timeframe and Activities

Near-Term (by 2012)	Mid-Term (2012–2015)	Long-Term (2015+)
Develop inexpensive catalytic technologies for NOx, particulate matter (PM)	Examine long-term durability and performance of systems	Reduce additional pollutants (e.g., trace contaminants)

FIGURE 5.2.5
Analysis for Small Scale System Applications, Including Market Assessment

ANALYSIS PRIORITY

Objective

Explore and begin to address a diversity of small-scale issues through analysis and development of an applications matrix that connects systems with potential resources, users, and stakeholder organizations.

Key Analysis Targets

- Applications matrix that connects systems with municipalities, industry, other users, and biopower organizations
- Market assessment and definition
- Understanding of county-level biomass resources
- Update on lessons learned from small-scale system deployment and operation
- Publically-available study and data

Major Barriers

- Inconsistent or missing data
- Understanding of key technical issues (lack of demonstrations)
- Understanding local and regional characteristics (biomass resources, power needs)

Applications

- All small-scale biopower systems
- Diverse end users (institutions, commercial buildings, industry, municipalities, others)

Benefits

	Low → High
Energy	■■■
Environment	■■■
Carbon Reduction	■■■
Economic Growth	■■■
Other	—

Relative Risk

	Low → High
Technical	■
Commercial	■

Stakeholders & Roles

Industry	Feedback on results
Government	Support for analysis and matrix development
National Laboratories	Evaluate systems, conduct analysis
Universities	Conduct analysis

Timeframe and Activities

Near-Term (by 2012)	Mid-Term (2012–2015)	Long-Term (2015+)
Systems and stakeholder analysis; development of applications matrix	—	—

6 FEEDSTOCKS FOR BIOPOWER

Photo Courtesy MS Online.

Many types of biomass feedstocks can potentially provide input to biopower systems. Historically, wood industry wastes, such as pulp and paper processing wastes, black liquor, sawdust, and lumber byproducts, have been the major sources of biomass feedstocks for biopower generation. In the future, as the use of biopower expands, a wider range of biomass feedstocks will likely be required to satisfy fuel demands.

One of the unique and attractive aspects of many biopower technologies is that they are fuel-flexible, meaning that they can operate using a wide variety of feedstock types. Therefore, many biopower systems can potentially be supplied with a mix of feedstocks or can change feedstocks due to seasonal availability or other issues. However, a number of technical issues must be addressed to effectively utilize either single or mixed biomass feedstocks for power generation.

Effectively adapting the biomass feed handling system and the conversion technology to the biomass feedstock(s) is a key technical requirement for biopower systems. In addition, biomass feedstocks typically have lower energy and weight densities than their counterpart fossil fuels. As a result, retrofitting an existing system or cofiring with fossil fuels may require altering the generation system to accommodate these characteristics. Supplying and storing large volumes of feedstocks is also challenging.

This section outlines the key challenges and priority RD&D and analysis needed in the feedstock area. Areas of interest include super-high-yield energy crops and other issues related to an expanded, reliable, and sustainable feedstock supply for biopower.

6.1 *Challenges and Constraints*

6.1.1 Technical Challenges

Technical challenges for feedstocks are ranked and listed in Table 6.1.1. The top-priority challenges include a sustainable and economic feedstock supply, feedstock movement and storage, and quality and monitoring.

Sustainable and Economic Feedstock Supply—Creating a biomass market large enough to serve the energy needs of the nation will require an intense use of existing natural resources and agricultural residuals. The sustainability aspects of biomass must be measured both qualitatively and quantitatively—this is a crucial issue for expansion of the industry. How this will be performed is not yet completely understood. There will be significant variability in the type of studies needed based on feedstock, current land use, water requirements, soil type, growing region, and other parameters.

The economic costs associated with the growing of a dedicated sustainable energy crop are high, and the parameters that affect these costs (and impacts on sustainability) need to be well understood. Solutions will most likely be regionalized, i.e., specific to certain regions of North America, primarily due to feedstock availability and energy costs. While dedicated energy feedstocks are a potential solution in some regions, they face challenges.

Feedstock Movement and Storage—Depending on the type of feedstock, there will need to be significant improvements in the way it is grown, harvested, collected, and stored. Harvesting systems are in need of significant additional development. For example, there is no easy, cost-effective method of removing slash from logging operations and transporting it to a biopower plant. In addition, most biomass has neither the required bulk density nor energy density to make large-scale movement of the product cost-effective when compared to a fossil fuel resource like coal.

Biopower facilities will need access to a consistent quantity of resources to provide energy over the long term and between harvests. Long-term storage of feedstocks will create instability issues associated with material moisture mold. The cost of collection and transportation of biomass from the field to the power plant increases with distance from the power plant and may create an upper bound on the biopower plant economic size. Storage availability will also be a problem as large quantities of biomass are stockpiled. Increasing the flow ability of the feedstock at the point of processing can also be problematic. With a variety of both the quality and type of feedstock that may arrive at a biopower plant, the feedstock supply system must be capable of self-adjustment to accommodate for changing conditions.

Quality and Monitoring—Developing methods and techniques to provide for an adequate supply of quality-controlled feedstock will be a continuing challenge. Parameters for measuring the quality of the feedstock through all phases of the supply chain are currently needed, and standards should eventually be developed. The quality of field test methods and monitoring tools must be improved.

Supply Chain Analysis—Biomass utilization will require a number of stages of transport, processing, and storage. Sizing and location of these facilities will be critical to the economics of biomass utilization. Supply chain analysis is lacking to identify the optimal sizing and location of facilities within the entire, integrated supply chain for biomass. This could include, for example, considering whether initial biomass compaction is done in the field, at a nearby depot, or after the initial processing step, and determining the optimal size and location of a torrefaction facility.

TABLE 6.1.1
TECHNICAL BARRIERS AND CHALLENGES FOR BIOPOWER FEEDSTOCKS

Sustainable and Economic Feedstock Supply	
High Priority	• Qualitative and quantitative measurement tools for environmental sustainability • High costs for dedicated, sustainable feedstock crops
Medium Priority	• Biomass production sustainability issues, such as soil compaction, nutrient loss, and soil carbon
Lower Priority	• No clear path for decision making about land-use changes brought about by feedstock demand
Movement & Storage	
High Priority	• Inadequate harvesting systems • Difficulty moving biomass through conventional systems (e.g., hoppers and screws)
Lower Priority	• Problematic long-term (greater than 1 year) storage of biomass due to moisture (water-assisted breakdown) and format (loose bulk, piled, or bailed/bundled) • Terrain-induced barriers to forest feedstock harvest (raises cost and lowers efficiencies)
Quality & Monitoring	
High Priority	• Unpredictable feedstock supply and quality • Inconsistent parameters at point of harvest (e.g., particle size, bulk density, moisture content, and energy density)
Medium Priority	• Variability in biomass properties and lack of commodity status • Lack of lower-cost, field-based analytical methods
Lower Priority	• Inadequate monitoring methods for harvesting, nutrient replacement, and crop genetics
Fundamental Data	
Lower Priority	• Insufficient data on scale-up (e.g., water issues) for production of 5 dry tons/acre-year to >15 dry tons/acre-year • Detailed chemistry of biomass feedstocks not compiled or readily available (e.g., provide authoritative information and knowledge on materials and processes, materials chemistry through ASM International, other venues) • Lack of data sharing

6.1.2 Non-Technical Challenges

Some of the highest priority non-technical challenges for feedstocks include market issues, and policy and legislation.

Policy and Legislative Drivers— Clear policies and mandates (e.g., carbon policies, federal RPS) may positively impact feedstock supply by aligning feedstock availability with the market and accelerating the use of these feedstocks, impacting both near- and long-term feedstock supply costs. There are also few or no policy incentives for power utilities to utilize waste materials such as landfill gas, wastewater, and animal manure.

Market Issues—Currently, there is a need to recognize the importance of energy markets for wastes produced from higher-value products. These include urban sources such as wood waste products from residential construction or commercial sources (e.g., paper production). Supply chain partners for these waste streams need to be aligned with feedstock sources. Currently, dialogue between the relevant stakeholders is lacking, which hinders the integration and use of these potential waste streams for energy production. Permitting for new uses is also an impediment.

Expanding the growth of closed-loop energy crops will be difficult but necessary as the need for a reliable and scalable supply source increases. As the expansion of biopower continues, a critical challenge is the need to increase landowner participation in growing high-value energy crops and to provide effective incentives to produce the best feedstock choice.

Current regional barriers for feedstock harvesting must be removed. In the South, there is too much competition for biomass, but the West has the opposite problem—higher capital investment costs generate little market pull.

6.2 *Priorities for Research and Development and Analysis*

A broad discussion of RD&D and analysis needed to overcome feedstock challenges resulted in six priority topic areas in research and development and analysis, shown below.

6.2.1 RD&D Priorities

The highest research and development priorities were identified as increased feedstock yields, optimization of the feedstock production and transport supply chain, and environmental impacts and the sustainability of feedstock (see Figures 6.2.1 through 6.2.3).

High-Yield Feedstocks—Continuous development is needed to increase feedstock yields through various pathways; these include cultivating high-yield, low-input (i.e., water and fertilizer) energy crops that fit into existing farm structures; conducting maximum-yield field trials for a series of feedstocks; developing drought-resistant plants, and other innovative approaches.

Optimized Feedstock Production and Transport Supply Chain—Research is needed to develop optimized methods and technologies for harvesting, collecting, storing, transporting, and preprocessing a range of feedstocks (woody crops, grassy crops, agriculture/forestry residuals, animal wastes, landfill, other industrial wastes, etc.).

Multi-region, Large-Scale Environmental Monitoring of Energy Crops and Residue Removal—Documenting the environmental consequences of energy crop production at a watershed scale will improve our ability to compare the various options, demonstrate feasibility, and develop advanced production systems that enhance sustainability.

6.2.2 Priorities for Analysis

Analysis is needed to better understand techno-economic costs and develop supporting models and data for understanding the sustainability of feedstock and technology options (see Figures 6.2.4 and 6.2.5).

Techno-economic Model for Optimized Feedstock Supply and Use—Development of a techno-economic cost curve analysis is needed to help optimize feedstock procurement and use cost elements (e.g., capital expenditures, operations and maintenance) and evaluate the highest-value use of each feedstock.

Sustainability Indicators for Feedstock and Energy Production—A set of indicators of sustainability is needed to enable the evaluation and comparison of various biomass and fossil energy power systems, from feedstock production through power generation. These will support consistent LCAs of individual feedstock systems across the value chain and show that improving yields can provide substantial benefit.

Standardized Analytical and Data Collection Methods for Biomass—Standard analytical and data collection methods for biomass are needed to compare feedstock specifications versus applications and to aid in creating a standard analysis methods handbook. Such methods could also be applied to collection of fundamental data, including physical and chemical properties.

FIGURE 6.2.1
High-yield Feedstocks

RD&D PRIORITY

Objective

Achieve high yields from land-based crops (i.e., achieve high energy content per acre, which depends on the combination of fuel yield (BTU/dry ton) and crop yield (dry tons/acre). Accomplish this through various pathways including dedicated crop systems, genetic breeding, better agro/forestry systems, and innovative feedstocks.

Key Technical Targets

- Data to represent crops/yields
- High yield, high energy-density, low input (water, fertilizers) energy crops suitable for existing farm structures
- Concept ual designs of energy producing systems, seed production, seed specifications
- Genetic engineering and genetic-guided breeding (e.g., clonal material for specific feedstocks); especially for dedicated energy crops (perennial grasses, energy cane, and biomass sorghum
- Enhanced knowledge of agro/forestry systems (e.g., maximized photosynthetic capacity)

Major Barriers

- Concerns about genetically modified organisms and containment (input requirements, minimizing cost and impact)
- Increased water and nutrient use
- Perception of competition with food, feed or other uses
- High cost

Applications

- Cost-effective biopower supply
- Co-products to reduce front-end energy costs
- Integrated cropping systems

Benefits

	Low — High
Energy	■■■■■■
Environment	—
Carbon Reduction	■■■■■■
Economic Growth	—
Other	■■■■

Relative Risk

	Low — High
Technical	■■
Commercial	■■■■■■
Other *Genetically-modified organisms*	■■

Stakeholders & Roles

Industry	Biotech, power generation, processing equipment, harvesting equipment testers
Agricultural Community	Farmers, forestry products
Research Institutes	Microbiology, agriculture and forest products, power industry, EPRI
Government	DOD, USDA
National Laboratories	NREL

Timeframe and Activities

Near-Term (by 2012)	Mid-Term (2012–2020)	Long-Term (2020+)
Data sets out to stakeholders, farmer; enhanced agronomic practices	Biological design, large scale plantings in several regions, work on low input /drought resistant crops	Genetic-guided breeding and field trials, algae-wood mixed fuels

FIGURE 6.2.2
Optimized Feedstock Production and Transport Supply Chain

RD&D PRIORITY

Objective

Optimize harvesting, collection, storage, and transport of a wide range of biomass to maximize efficiency along the path from biomass feedstock to kWh.

Key Technical Targets

- Optimized methods and technologies for harvesting, collection, storage, transport, and materials handling, for a range of feedstocks (woody crops, grassy crops, agriculture/forestry residuals, animal wastes, landfill, other industrial wastes, etc.)
- In-woods or in-field feedstock processing

Major Barriers

- Costs of transportation (bulk density), and handling
- Storage (spontaneous combustion, decomposition of biomass, quality over time)
- Harvesting (optimal timing, impacts of different practices on ash and moisture)
- Handling of mixed feedstocks

Applications

- Power production from biomass feedstocks
- Other bioenergy systems (biofuels, bioproducts)
- Waste feedstocks

Benefits

	Low ... High
Energy	■■■■■
Environment	■■■
Carbon Reduction	■■■■■
Economic Growth	■■■■■■
Other	■■■

Relative Risk

	Low ... High
Technical	■■
Commercial	■■

Stakeholders & Roles

Industry	Farm machinery; power producers
Agricultural Community	Farmers
Research Institutes Government National Laboratories	Project support
Universities	Agricultural engineering; land grant schools

Timeframe and Activities

Near-Term (by 2012)	Mid-Term (2012–2020)	Long-Term (2020+)
Design and build prototypes for feedstock-specific equipment; design biomass storage systems	Field test improvements to handling and transport, combustion performance, emissions, operability, byproduct streams	Large-scale deployment

FIGURE 6.2.3

Multi-region, Large-scale Environmental Monitoring of Energy Crops and Residue Removal

RD&D PRIORITY

Objective

Monitor, understand and verify the environmental consequences of energy crop production and residue removal at a watershed scale.

Key Technical Targets

- Field plantings of sufficient size to characterize the environmental parameters of interest at multiple locations and production options (e.g., nutrient removal, water use, erosion, soil fertility, emissions, fertilizer inputs, pesticide leaching, biodiversity)
- Robust measurements of sufficient frequency to quantify environmental consequences
- Production management to allow cross-site comparisons that are representative of commercial production

Major Barriers

- Limited quantitative understanding of energy crop environmental features; and ability to compare sustainability of different energy crops/ production practices
- Limited ability to conduct life cycle analysis incorporating all key metrics
- Public concern that energy crop production is environmentally non-sustainable

Applications

- Design of more effective commercial production of biomass in the field
- Farming credits for environmental benefits
- Quantification of attributes with future economic value, e.g., sequestered carbon or water quality
- Reliability of feedstock supplies

Benefits

	Low → High
Energy	■■
Environment	■■■■■■
Carbon Reduction	■■■■■■
Economic Growth	■■■■
Other	—

Relative Risk

	Low → High
Technical *Coordination of multiple partners and navigating weather conditions will be challenging*	■■■■■■
Commercial	■■
Other	■■■■■■

Stakeholders & Roles

Industry	Harvest technology; seed source
Agricultural Community	Land and labor
Research Institutes National Laboratories Universities	Design, measurement, & analysis
Government	Extension efforts
Non-governmental Organizations	Participation

Timeframe and Activities

Near-Term (by 2012)	Mid-Term (2012–2020)	Long-Term (2020+)
Approach and partnerships in place for creating multiple multi-year large field trials across the country	Implement trials and collect data and synthesize information	Expand and/or replace trials as new crops and/or management strategies emerge

FIGURE 6.2.4
Techno-economic Cost Model for Optimized Feedstock Supply and Use

ANALYSIS PRIORITY

Objective
Build a biomass power generation cost model and analytical tool for a range of feedstocks that predicts cost in $/MWH and optimizes feedstock procurement and combustion cost ratios (capital expenditures and operation and maintenance).

Key Technical Targets
- Feedstock supply model ($/ton) that includes growth, harvest, and preparation
- Integration of feedstock module with a power generation cost model (capital, O&M, environmental, ash, etc.)
- Detailed explanation of module components (agricultural and harvest cost, transportation, and processing)
- Ability to analyze the highest value use of feedstocks

Major Barriers
- Completing feedstock supply module for all biomass types (insufficient data on feedstocks and systems)
- Seamlessly integrating feedstock modules into power generation cost model

Applications
- Power generation industry (PC, BFA, Stoker)
- Support for decision-making (agricultural, forestry, municipalities, industry, others)

Benefits

	Low — High
Energy	■■■■■■
Environment	■■■■■■
Carbon Reduction	■■■■
Economic Growth	■■
Other	—

Relative Risk

	Low — High
Technical *Models already exist*	■■
Commercial *Models have variable accuracy*	■■■■

Stakeholders & Roles

Industry	Power cost model
Agricultural Community	Input costs
Research Institutes	Specific feedstock information
Government	Support for modeling
National Laboratories	Build and integrate models
Universities	Consulting

Timeframe and Activities

Near-Term (by 2012)	Mid-Term (2012–2020)	Long-Term (2020+)
Techno-economic cost curves and integration into power generation cost model	Refinement of models based on new/improved data	Additions to models based on advanced, innovative feedstocks

FIGURE 6.2.5

Sustainability Indicators for Feedstock and Energy Production

ANALYSIS PRIORITY

Objective

A set of indicators of environmental sustainability that can be used to evaluate alternative biomass and fossil energy power systems, from feedstock production through power generation.

Key Technical Targets

- Consensus set of sustainability indicators
- Life cycle analysis incorporating indicators
- Methodology to weigh or value environmental impacts of alternative energy sources (e.g., fossil vs. biomass)

Major Barriers

- Lack of consensus indicators for economic and social measures of sustainability
- Significant data needs for life cycle analysis and complexity of necessary data sets
- Lack of methods for weighing/evaluating indicators

Applications

- Evaluating cost of alternative fossil and biomass-driven systems
- Evaluating alternative systems for feedstock sourcing and conversion relative to environmental sustainability

Benefits

	Low High
Energy	■■■■■■
Environment	■■■■■■
Carbon Reduction	■■■■
Economic Growth	■■■■
Other	—

Relative Risk

	Low High
Technical	■■
Commercial	■■
Other	■■■■

(Building consensus)

Stakeholders & Roles

Industry, Agricultural Community	Develop data sets
Research Institutes, National Laboratories	Develop data sets & methodologies to support the analysis
Government	Provide financial support for data set development and analysis; test methodologies.

Timeframe and Activities

Near-Term (by 2012)	Mid-Term (2012–2020)	Long-Term (2020+)
Develop consensus indicators	Develop life cycle analysis of each indicator and methodology to weight or value environmental impacts	Refine methodology and apply to evaluation of feedstock sources; add economic and social indicators to analytic framework

FIGURE 6.2.6
Standardized Analytical and Data Collection Methods for Biomass

ANALYSIS PRIORITY

Objective

Develop standard analytical and data collection methods for biomass to enable comparison of feedstock specifications versus applications, and to aid in creating a standard analysis methods handbook. Such methods could also be applied to collection of fundamental data, including physical and chemical properties.

Key Technical Targets

- Analytical methods for biomass in the United States that match global requirements
- Established targets that are consistent with research on fuel crops
- Standard units of measure and data protocols for biomass

Major Barriers

- Acceptance of standard units of measure
- Perceptions and acceptance of biomass fuel as an energy commodity

Applications

- Broad—supports long-term contracts for biomass fuels for biopower and other bioenergy applications
- Consistent biomass data collection and publication

Benefits

	Low	High
Energy	■■■■■■	
Environment	■■■■■■	
Carbon Reduction	■■■■■■	
Economic Growth	■■■■■■	
Other	—	

Relative Risk

	Low	High
Technical *Procedures exist—but consistency is needed*	■■	
Commercial *Data gathering is low risk*	■■	

Stakeholders & Roles

Stakeholders	Roles
Industry Agricultural Community	Endorsing standards
Research Institutes Government National Laboratories Universities	Developing standard analytical methods

Timeframe and Activities

Near-Term (by 2012)	Mid-Term (2012–2020)	Long-Term (2020+)
Review global analytical methods and data requirements, solicit desired biomass fuel properties from equipment vendors	Round robin analytical testing, prepare biomass samples to specs and confirm performance in equipment	Methods refinement for new feedstocks

7 MARKET TRANSFORMATION AND OTHER ACTIONS

Photo Courtesy of MS Online

Market transformation activities focus on eliminating non-technical and market barriers and increasing opportunities for the market expansion of biopower technologies. This includes stakeholder outreach and communication; demonstrations, data gathering, and analysis to support informed decision making; financial and other incentives; supportive and consistent regulations, codes, and standards; and strategic partnerships. These activities are important across the supply chain and at each stage of development—from research and development through commercial deployment. The ultimate goal of market transformation is to facilitate the commercialization of biopower by supporting early adoption and building the knowledge base, communication tools, incentives, and partnerships needed to support a sustainable, competitive market for biopower facilities.

Market transformation activities encourage interest in biopower and its early adoption, deployment, and use; build understanding of how these technologies perform in real-world service; and educate policymakers and the general public about the availability and benefits of these technologies. By moving the technology from the laboratory to the real world, the potential benefits to the nation are transformed into realized, quantifiable benefits, with tangible results that will help establish the business case for future installations. Early applications will also exercise and expand the manufacturing and supply chain for biomass feedstocks and biopower equipment, which will help to build economies of scale and reduce costs.

7.1 *Market and Other Non-technical Barriers*

Widespread deployment of biopower faces a number of market barriers at the local, state, and federal levels. Chief among these are high capital and operating costs for early generation systems, feedstock cost and supply uncertainty, varying policies and incentives, inconsistent or inadequate codes and standards, high investment risks, and lack of understanding of the performance and benefits of biopower and sustainable biomass feedstock supply in real-world operations. Key market barriers are summarized below.

Feedstock Cost and Supply—As noted in Section 6, the uncertainty of a sustainable supply chain for biomass feedstock and the associated risk are major barriers to start-up biopower operations. Investors lack confidence about the availability and cost of feedstock over multiple years. Market transformation could require large capital investments, and industry commitments will be needed to develop the infrastructure to deliver cost-competitive biomass feedstocks in large volumes.

Utility Policies—In general, electric utility companies are conservative operations that favor the use of well-known technologies. They may be reluctant to integrate biopower into their operations because of their lack of familiarity with the technology and concern over risks inherent in adopting unfamiliar technology. Most are not interested in pursuing biopower or distributed generation and can actively resist policies that encourage new generation options. For example, restrictions involving standby rates and power wheeling rules can in some cases discourage new generation. Biopower has to be connected to the grid in order to be sold elsewhere.

Government Policies and Regulations—Legislative and policy uncertainties create an unclear environment for future investments. For example, it is not clear if federal priorities will be on carbon reduction, fossil displacement, or another direction. Impacts need to be evaluated to help clearly guide policy, e.g., the comparative impacts on carbon achieved via the different policy directions.

According to the Biomass Power Association, biopower also lacks parity with other renewables in terms of energy production tax credits (see Table 7.1.1). Biomass, for example, has only one-half the production tax credit available to wind and geothermal. The lack of one, single federal standard for bioenergy (versus different state RPS) and a federal Renewable Fuel Standard (RFS) is also a barrier, as is the lack of a national GHG or carbon sequestration policy.

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TABLE 7.1.1 COMPARISON OF SELECTED ENERGY PRODUCTION TAX CREDITS (JCT/CLEAVES 2009)

	Statutory Credit	Credit Amount*
Cellulosic Ethanol	$1.01 per gallon	$13.29
Biodiesel	$1.00 per gallon	$8.45
Wind	2.1 cents per kwh	$6.15
Geothermal	2.1 cents per kwh	$6.15
Ethanol	$0.45 per gallon	$5.92
Advanced Nuclear Power	1.8 cents per kwh	$5.28
Open Loop Biomass	1 cent per kwh	$2.93

* Credit amount stated in dollars per million British thermal units (Btus) of heat energy

Risks and Costs of Biopower Investments—Costs of biopower are typically higher than conventional, fossil-fueled power plants. In most U.S. markets, the incentives are not sufficient to make biopower economical. Higher project costs and risks revolve around lengthy permitting processes, lack of a framework to monetize and reward external benefits, and lack of information on real-world technology performance and life cycle costs and benefits. Long lead times are required to secure financing and negotiate contracts, due in part to lack of standard permitting guidelines or model contracts.

Information on Life Cycle Costs, Performance, and Reliability—Current techno-economic and LCAs do not fully address all questions associated with biopower, including sustainable biomass feedstock production and associated issues, such as direct and indirect impacts. This information is needed for both industry and government decision makers, as well as for building support for biopower from the general public. Real-world data on current biopower technology and feedstock supply operations is also needed to establish a business case for biopower, including how well the technologies perform, how long they will last, and what they will cost. The presence of competing uses for biomass and alternative "green power" technologies also requires an understanding of the relative value of biopower in achieving national energy goals such as reducing GHG emissions.

Public Awareness and Perceptions—There is a lack of credible, targeted information that clearly describes the costs and benefits of biopower in terms that can help users make informed decisions regarding energy. Public education programs are needed to convey the potential for carbon-negative biopower applications to help the United States reduce its GHG emissions.

7.2 *Lessons Learned*

The generation of electric power from biomass has been practiced in the United States for decades, as a result of favorable policies created under the Public Utilities Regulatory Policies Act (PURPA) in the 1990s, and within the forest products industry, which generates large amounts of biopower from paper manufacturing and forestry residues. A number of lessons have been learned from this experience, which should inform market transformation activities going forward (Figure 7.2.1).

FIGURE 7.2.1
LESSONS LEARNED FROM PREVIOUS BIOPOWER EXPERIENCE

- Policies designed to stimulate biopower development vary.
- End user interest in biopower development is often place-based.
- All stakeholders need to be involved.
- There are a number of uses for the feedstocks; varying policies can shift the direction toward different uses.
- Avoid the fallacy of "cheap, plentiful" biomass supplies. Increasing use of biomass will increase its price and possibly stress a sustainable production and delivery system. Feedstock supply was a limiting factor in California, where a lot of biopower plants were built under the Public Utilities Regulatory Policies Act, but there was insufficient, cost-competitive supply to support them.
- Don't reinvent the wheel: many studies have already been done that have useful and relevant information
- The permitting process can be quite lengthy and lead to big front-end project costs—it is best to get all environmental questions asked and answered before applying for permits.
- Education is critical and should be accomplished at all levels (grade school, high school, and college).

7.3 *Critical Strategies and Priorities for Market Transformation*

There are a number of critical biopower market transformation actions and strategies, which can be grouped into the seven categories described below. The top-priority actions in each of these categories are summarized below and in Figures 7.3 1 through 7.3.9.

- Multi-year Planning and Guidance:
  - "Biopower build-out vision" to guide planning
- Technical/Financial Assistance and Demonstrations:
  - Technical assistance for deployment of biopower
  - Public support for biopower demonstrations
- Coordination and Collaboration:
  - Collaborative efforts to promote biopower best practices
- Analysis to Support Informed Policy and Decision Making
  - Techno-economic, life cycle, and sustainability analyses
  - Comparative energy and environmental analysis
- Education and Award Programs:
  - Bio-cities program
  - "Advancing biomass utilization awards"
- Informing End Users and Other Stakeholders:
  - Online biopower library for enhanced information dissemination
  - Decision making tools and resources

Multi-year Planning and Guidance

Biopower may be one of a suite of technologies used to address the nation's energy and environmental goals. Effective planning and top-down policy guidance is needed to help guide market transformation efforts, show how and where the technology can contribute, and ensure that all environmental and land use concerns have been addressed.

A suggested priority is the development of a "biopower vision" document that would answer the question of what a biopower build-out might look like at various penetration rates over the next twenty years (2010 to 2030), for example at 5%, 10%, or 15% of national electric supply. The report should be non-prescriptive and address issues like price sensitivity, substitution effects, direct and indirect impacts, and sustainability. The report should also address the current and projected performance of technology (including technical performance, life cycle environmental and energy impacts, employment impacts, and costs). Modeled deployment scenarios, informed by accurate biomass feedstock supply and demand constraints, should be presented along with clearly stated, transparent assumptions. The report and deployment scenarios, including all major assumptions, should be reviewed with stakeholder groups to help build support and agreement on the results. The deployment scenarios might also consider how different policy priorities would impact biopower deployment; for example, the effect of focusing primarily on GHG reduction or on imported oil reduction.

Demonstrations and Technical Assistance

Demonstrations of advanced and innovative biopower and feedstock supply systems with representative users who will collect and report on their experiences will provide historical experience on reliability and help mitigate resistance to new technologies, providing end users and investors with a level of familiarity and confidence in the technologies. Demonstrations will also provide critical data needed to support environmental assessments, permitting, regulations, codes and standards development, and financing and insurance transactions.

Government cost sharing of these advanced technology demonstrations could reduce the cost and risk to investors and make certain that relevant data is properly gathered and publicly shared. The availability of defensible real-world data for business and policy decisions will help transform the biopower market. Data from prior demonstrations should also be collected and disseminated.

Demonstration efforts should include large- and small-scale biopower systems using a variety of feedstocks, as well as collaborative efforts with utilities to initiate and promote successfully demonstrated advanced biopower into existing power generation systems. In addition, advanced feedstock production, harvesting, and supply systems should also be demonstrated, including mobile units to densify or stabilize biomass in the field.

Technical assistance programs

Technical assistance to support interested biopower developers is needed. These subject matter experts could provide technical and financial analysis assistance and troubleshooting for small- and medium-scale project developers or for consultation by other project stakeholders, including investors and safety and code officials. The eight DOE Regional Application Centers established by DOE to promote CHP technologies and practices were mentioned as potentially analogous to technical assistance programs.

Coordination and Collaboration

Effective partnerships, coordination, and strategic alliances indirectly support market transformation by providing opportunities to link the necessary nodes in the biomass-to-biopower supply chain, leverage a broad base of expertise, and jointly solve biopower-related issues. Because biopower, and the biomass feedstock on which it relies, is very "place-based," it is important to establish and maintain community-based and regional biopower partnership networks that include landowners, state and local governments, rural electric co-ops, municipal power, and public power groups. Financial support for these organizations would help to ensure their effective operation and continuity. It is also critical to develop partnerships and strategic alliances among the different biomass energy interest groups, so that there is discussion and coordination on the projected supply and demand of biomass resources for biofuels, bioproducts, and biopower. The USDA Agricultural Extension Service (and other rural outreach programs) could also be used to build and support these partnerships.

One high-priority area for coordination and collaboration, especially among U.S. and European organizations, is identifying and establishing best practices for incentivizing biopower and for sustainable biomass feedstock production and supply. A DOE-European forum should be established to document the policies, regulations, and practices that have worked best and publish a best practices database. There are also opportunities to collaborate with the Canadian government and their counterpart organizations involved in biomass research and development.

Utilities are also major stakeholders in the biopower arena, and a working group of utility companies and trade associations (e.g., Electric Power Research Institute) should be established to meet regularly to discuss and address issues of common interest.

Collaboration and coordination among domestic and international regulatory agencies is also necessary to harmonize the requirements of regulations, codes, and standards and to identify opportunities to streamline permitting and regulatory requirements. Collaboration is also needed within DOE programs such as the Biomass Program, the Fossil Energy Program, and the Industrial Technologies Program and with federal agencies, local and state governments, and universities to help increase awareness, deployment, and adoption of these technologies and to stay abreast of current activities. Reaching out to the Federal Energy Management Program and DoD could help identify new opportunities for biopower. One suggested approach was to maintain an advisory committee of biomass experts.

Analysis to Support Informed Decision Making

One of the top-priority needs is for credible, unbiased analysis and information that will support biopower investments and policy decisions. Underlying techno-economic and sustainability analysis is needed to inform business and government decision makers about the technical and environmental performance, costs, and sustainability of biopower and feedstock supply systems. These studies must include detailed LCAs that investigate direct and indirect impacts of biopower use, including a systematic evaluation of the impact of expanded biomass feedstock production and use on the environment and food supply for humans and animals. Analytical tools are also needed to compare the impacts, costs, and benefits of various renewable energy alternatives, including existing and proposed public incentives. These tools will enable consistent evaluation of the energy, economic, GHG, and other environmental impacts of all potential biomass feedstock production and conversion technologies, as well as comparisons with other renewable alternatives. This information could potentially be useful in developing and justifying beneficial national policies and incentives, such as a single federal RPS, expanded tax credits and carbon credits, a flexible feed-in tariff, and a broad, standard definition of biomass and qualifying biopower facilities. Peer-reviewed articles suitable for both mass media and scientific journals should be developed to validate assumptions.

Informing End Users and Other Stakeholders

It is essential to provide the general public, industry, and regional, state, and local organizations with factual, easy-to-use information that will facilitate biopower use. This includes making sure that accurate, credible technical information is made available to the research, technology development, and project development communities. A large amount of work was done on biopower during the late 1980s and 1990s, as a result of the market incentives provided under PURPA; much of this work is still relevant today and should not be lost or “reinvented.” As a first step, DOE is encouraged to develop an online biopower library to include all credible information resources relevant to biopower and identify those that need to be updated. Fact sheets, guidebooks, and other products designed to inform end users and stakeholders should be included in this database.

The online library could distribute needed decision making tools and resources, such as best practices for sustainable feedstock production, case studies of successful biopower installations that provide good business models, and a state-by-state incentives and tax guide. Fact sheets can be used to highlight issues affecting biopower, such as utility standby rates, buy-back rates, thermal credits, and wheeling rules. Guidelines for facility permitting, incentive offerings, and power contracts would also be useful. Finally, a biopower resource handbook that helps developers understand the major steps, processes and options for getting power to the grid would help to clarify the process and considerations involved in developing a biopower facility.

Education, Outreach, and Award Programs

Public education and outreach is critical to building understanding and support for biopower technologies. Efforts should be directed at making biopower visible to people in their daily lives. This could be done by partnering with DOE's Clean Cities program to include "bio-cities" initiatives as part of their efforts. Award programs are also good ways to raise visibility. For end user organizations, a national award program would provide public recognition for early adopters. One example might be a program similar to ENERGY STAR® that recognizes biopower users for their contributions to a carbon-negative technology. Competitions in schools and universities with substantial cash- or tuition-based rewards would help to foster innovation and stimulate interest among students, and focused classroom lesson plans are needed to help teachers educate their K–12 students. "Advancing biomass utilization awards" could be established for universities, companies, and other parties.

FIGURE 7.3.1
"Biopower Build-out Vision" to Guide Strategic Planning

MARKET TRANSFORMATION PRIORITY

Objective

Produce a "biopower build-out vision" report depicting the impacts of biopower at various penetration rates over the years 2010–2030 at 5%,10%,and 15% of national electric supply.

Major Targets

Government decision-makers who need strategic information on issues like price sensitivity, substitution effects, direct and indirect impacts, sustainability, etc., including:

- Congress and other policymakers
- Agencies implementing major legislation (e.g., USDA Biomass Crop Assistance Program, DOE Integrated Biorefineries Program)
- Other key decision-makers

Major Barriers

- Lack of information on pros and cons of biopower as a major contributor to national electric supply, which is needed by policymakers to develop policies and incentives ssnd a single Federal RPS

Timeframe and Activities

Near-Term	Mid-Term	Long-Term
Conduct analysis for and complete report in 6 months to 1 year	—	—

Possible Resources: Update characterization studies; life cycle Opportunities for Agriculture in Carolina: An Economic Analy Standard," Univ. of Tennessee; L As, Association bioenergy strategy and siting studies, New York State bioenergy roadmap, SAFER Alliance Southern Bioenergy Roadmap, World Resources Institute "Local Clean Power" report for the Southeastern U.S.

FIGURE 7.3.2
Technical Assistance for Deployment of Biopower

MARKET TRANSFORMATION PRIORITY

Objective

Provide deployment support (analysts and subject matter experts) to provide advice, technical assistance, and troubleshooting for biopower project implementation.

Major Targets

- Effective and useful technical support for small- to medium-scale project developers
- Accessible network of technical assistance experts in different regions of the country

Major Barriers

- Potential project developers often lack technical expertise necessary for all aspects of project planning and implementation
- Complex permitting and financing processes inhibit potential project developers, particularly small- and medium-sized projects

Action Plan Elements

- Identify and set up DOE Regional Application Centers (RAC) to lead program
- Expand scope to address the full range of biopower technologies and systems

Benefits

- Provides nationwide network of technical information and resources to improve chances for project success
- Accelerates project implementation

Timeframe and Activities

Near-Term	Mid-Term	Long-Term
Identify/coordinate technical resources for select technologies; establish regional assistance centers	Expand reach of program	Sustain and refine assistance centers

Stakeholders

DOE RACs
National Labs
Universities
Government (federal, state, local)
Industry

FIGURE 7.3.3

Public Support for Advanced Biopower Technology Demonstrations

MARKET TRANSFORMATION PRIORITY

Objective

Support and communicate the results of advanced biopower technology demonstrations to the general public, industry, investment community, and other stakeholders.

Major Targets

- Increased public awareness and understanding of advanced biopower technologies
- Cost and performance data for new, innovative technologies to reduce risk and inform the investment community and project decision-making

Major Barriers

- Lack of real-world data on emissions from state-of-the-art biopower facilities (update EPA factors)
- Lack of real-world data on state-of-the-art and advanced biopower operations (including feedstock delivery/supply) to support project financing
- High cost of building biopower plants and need for government cost-sharing
- Not-in-my-backyard concerns about local impacts

Action Plan Elements

- Promote demonstrations that will integrate advanced biopower into existing systems
- Provide financial support for pilots and demonstrations of infrastructure technologies
- Promote use of mobile technologies for biomass feedstock densification and stabilization
- Projects should include robust data tracking, validation, and reporting

Benefits

- Provides needed commercialization assistance (large- and small-scale)
- Generates validated, real-world performance and cost data
- Reduces risks (technical and financial)

Timeframe and Activities

Near-Term	Mid-Term	Long-Term
Initiate support for start of multi-year demonstration projects; communicate interim results	Continue project demonstrations and communicate lessons learned	—

Stakeholders

Emerging technology developers

Utilities

Government (DOE, USDA)

FIGURE 7.3.4

Collaborative Efforts to Promote Biopower Best Practices and Information Sharing

MARKET TRANSFORMATION PRIORITY

Objective

Identify and communicate best practices, promote cooperation, and facilitate technical information sharing and database development among national and international organizations; provide continuous source of information for stakeholders.

Major Targets

- Leverage the efforts of all interested parties to advance opportunities and applications for biopower
- Coordination and centralization of information on best practices and technical information relevant to biopower
- Better understanding of carbon-negative options and role of biopower

Major Barriers

- Lack of consensus-based best management practices for sustainable feedstock production
- Many different federal agencies and organizations impact biopower development and efforts are not always coordinated or aligned
- Insufficient attention to the need for carbon-negative options and the role biopower could play

Action Plan Elements

- Coordinate with European Union, United States government (DOE, USDA, EPA, etc.), technical societies, trade associations, task forces, state and local government (energy offices, rural and economic development offices, etc.), DOE Regional Application Centers (RAC) , etc., to develop a framework for action and coordination on biopower and feedstock development
- Make concerted efforts to promote awareness of carbon-negative bioenergy technologies
- Investigate and document what policies and practices have worked to support development of a best practices database (review policies, practices and regulations from EU successes, e.g., in Sweden)

Benefits

- Better information about biopower options and practices
- Increased understanding/awareness of best practices for sustainability and carbon-negative operations
- Increased stakeholder communication; better aligned and leveraged actions and policies

Timeframe and Activities

coordinating efforts on national level	Refine and expand framework for collaboration; incorporate lessons learned	

Stakeholders

Government (federal, state, local)

DOE RACs

International governments and interest groups/trade groups

Technical societies

Trade associations

Interagency task forces and working groups

FIGURE 7.3.5
Techno-economic, Life Cycle and Sustainability Analysis

MARKET TRANSFORMATION PRIORITY

Objective

Perform underlying techno-economic and sustainability analysis for all technology options.

Major Targets

- Credible, unbiased data to support:
  - Government R&D priorities and portfolio development
  - Environmental impact assessments
  - Congressional decision-making
  - Improved public understanding and awareness
- Information sets that are specifically targeted to scientific and business audiences

Major Barriers

- Lack of information to address uncertainties and concerns surrounding competing land use issues (including direct and indirect impacts) and the sustainability of feedstock supply
- Lack of detailed, in-depth, credible life cycle analysis to support informed decision-making and build public support

Action Plan Elements

- Conduct techno-economic life cycle analysis, including efficiencies of all technology options
- Assess direct and indirect impacts

Benefits

- Improved scientific, business, and public perceptions of biopower
- Credible data to support policy and investment decisions

Timeframe and Activities

Near-Term	Mid-Term	Long-Term
Initiate analysis; publish interim results	Continue to refine with new feedstocks and technologies; publish interim results	Expand and publish interim and continuing results

Stakeholders

National Labs
Universities
Non-governmental organizations
Industry research organizations (EPRI, GTI, etc.)
Utility reviewers
EPA, DOE (EE and SC), USDA, NOAA, NSF
International organizations

FIGURE 7.3.6
Comparative Energy and Environmental Analysis

MARKET TRANSFORMATION PRIORITY

Objective

Analyze biomass relative to other renewables in terms of environmental impacts, GHGs, and carbon footprint.

Major Targets

Credible, unbiased data to support:

- Government R&D priorities and portfolio development
- Environmental impact assessments
- Congressional decision-making
- Improved public understanding and awareness

Major Barriers

- No clear understanding of the relative value of biopower in reducing carbon footprint
- Limited understanding of alternative technologies and approaches for biomass

Action Plan Elements

- Conduct analysis and publish in peer-reviewed literature (e.g., *Science, Nature*)
- Analysis should support development of value-based incentives for green power sources
- Identify and incorporate unbiased, credible sources
- Host and include results of public debates

Benefits

- Provide solid justification for program decision-making
- Evaluation and communication of potential for reduced carbon footprint, rural economic development, soil improvement, and other benefits

Timeframe and Activities

Near-Term	Mid-Term	Long-Term
Identify and focus on highest priority elements of analysis	Incorporate new data and feedstocks	Refine and maintain

Stakeholders

National Labs
Universities
Non-governmental organizations
Industry research organizations (EPRI, GTI, etc.)
Utility reviewers
EPA, DOE (EE and SC), USDA, NOAA, NSF
International organizations

FIGURE 7.3.7
Bio Cities Program Similar to DOE Clean Cities

MARKET TRANSFORMATION PRIORITY

Objective
Establish a "Bio-Cities" program similar to DOE's Clean Cities program.

Major Targets
- Demonstrate the long-term, sustainable benefits of biopower to the general population
- Create an image for biopower as a "real" technology with popular appeal; target younger segments of the popoulation that may be more open to new technologies

Major Barriers
- Negative public impression associated with burning fuels using biomass for energy
- Lack of public understanding of benefits of biopower to environment and the economy

Action Plan Elements
- Select and fund "bio-city" projects
- Incorporate college and high school competitions

Benefits
- More enlightened population
- Mechanism for engaging municipal partners in deploying biopower

Timeframe and Activities

Near-Term	Mid-Term	Long-Term
Initiate efforts over 2–5 years	Sustain and expand program as needed	—

Stakeholders
Groups involved with "Clean Cities" Program
States and regional groups
Consumers

FIGURE 7.3.8
Online Biopower Library for Enhanced Information Dissemination

MARKET TRANSFORMATION PRIORITY

Objective

Rebuild and refresh the biopower on-line library and expand it to include modern communication and networking capabilities.

Major Targets

- Enhanced capabilities using modern tools (e.g., social media) for on-line information sharing and collaboration
- Centralized information resource to meet the needs of various stakeholders from the general public to research to technology user and regulatory groups

Major Barriers

- Lack of central repository for clear, accessible, validated information to address information needs of various user groups
- Relevant information from past biopower demonstration/operation efforts is not accessible
- Ability to communicate a compelling value proposition for biopower

Action Plan Elements

- Rebuild biopower library
- Add updated capabilities to promote use

Benefits

- Up-to-date list of information that provides a go-to resource for credible data and analysis
- Cost-effective leveraging of already-developed data, analysis, and resources
- Enhanced use of increasingly popular social media tools (networking sites, blogs and discussion groups)

Timeframe and Activities

Near-Term	Mid-Term	Long-Term
Initiate over 2–5 years	Sustain and expand as needed	—

Stakeholders

Originators of the documents
General public
Government/private sector
Technical/research community
Growers, producers, users of technology and feedstocks
Investors/project developers
Codes and standards organizations
Environmental assessment communities

FIGURE 7.3.9
Decision-making Tools and Resources

MARKET TRANSFORMATION PRIORITY

Objective

Prepare and present fact sheets, issue guides, and develop model legislation on policies that affect biopower, including state and federal stand-by rates, buy-back rates, transmission wheeling rates, and thermal credits.

Major Targets

- State legislators, state regulators and staff, stakeholders that work with these parties at state level (including non-profits and trade associations)
- Enhanced public sector knowledge

Major Barriers

- Utility rules or rate structures that damage the economic viability of biopower projects, and lack of information to dispute rules in rate cases
- Lack of publicly available case studies and fact sheets on project deployment, policy successes, and articulation of the biopower business case

Action Plan Elements

- Develop biopower best practices fact sheets, guides, and model legislation for state adoption
- Produce case studies of successful biopower installations (that identify good business models) and publicize as virtual tours, showcases
- Produce factsheets for the general public

Benefits

- Adoption of model legislation
- Real market transformation that boosts public sector knowledge and capabilities to be on par with that of the utilities and raises awareness of the issues

Timeframe and Activities

Near-Term	Mid-Term	Long-Term
Address over two years with roll-out of one item every three months	Refine and expand resources	—

Stakeholders

DOE-OBP, FERC
DOE RACs
NARUC
NASEO
CHP trade associations
State-level renewable energy advisory groups

8 CROSS-CUTTING THEMES

A number of cross-cutting themes were identified with broad implications for the expansion of biopower. These are summarized below.

8.1 *Technical and Analytical*

Techno-economic Analysis—Credible techno-economic analysis of existing and new systems and a variety of technology options are critical needs for many reasons. Better understanding of the economic feasibility, particularly predicting where costs are still relatively high compared to other power options, will help inform decision making for both RD&D efforts and projects on the path to commercialization.

Life Cycle Analysis—LCAs are crucial to the evaluation of biopower compared to other options and to justifying the carbon mitigation aspects of biopower. Models, data collection, and validation efforts are needed to ensure that credible analyses are possible.

Feedstock Availability and Quality—This is a key issue for all biopower options at all scales and for all technologies. There is still significant uncertainty about the availability of reliable, consistent quality feedstock supplies year-round and in sufficient volumes for users. The handling, storage, and transport of biomass are challenges that still need to be resolved, particularly for feedstocks that are not currently used for biopower to any great extent. A better understanding of feedstock infrastructure needs (including water rights, rail spurs, other transport, and related issues) is required to support biopower deployment, especially at a large scale.

Impact of Feedstocks on Power System Performance and Operability—The characterization of feedstocks (e.g., chemical and physical properties) both before and during use in processing and power systems is seriously limited. This means users have a poor understanding of how different feedstocks will behave during equipment interactions (e.g., corrosive or other detrimental properties) or how they may impact performance and overall system efficiency. Better technologies for the characterization and monitoring of feedstock properties would provide more certainty and promote acceptance of biomass as an option for conversion technologies, repowered boilers, and new systems.

Sustainability—Ensuring the development of sustainable biopower and feedstocks was a repeating and important theme. Concerns ranged from the use of water resources to impacts on society and the environment. Developing and ensuring sustainable systems will require ongoing and continuous support for analysis, environmental monitoring and data collection, field trials, targeted research and development, and demonstrations for all important components. Concepts such as biochars and others could be explored as a means to improve soil quality and sustainability.

Economics and Scalability—For biopower to be successfully commercialized it must be economic. Policies such as RPS and other energy or climate regulations could alter the economics. The economics of collecting and transporting biomass may limit the ability to scale.

8.2 *Political and Societal*

Renewable Portfolio Standard (RPS)—The lack for a national RPS was identified as a key limitation to expanded biopower development. A federal RPS would provide an incentive for biopower, create a more consistent national approach, and support a more certain policy environment for investors. A federal standard should consider current mandates and incentives already in place at the state level across the country.

Regulatory and Policy Uncertainties—Impending carbon legislation and the associated regulatory impacts could place a value on carbon emissions and impact the investment climate for biopower. Until it is clear what the final form of legislation will be, the cost and demand for biomass power generation will be uncertain.

Federal and State Feedstock Policies—Policies can provide significant drivers for the increased use of biomass for power. These include, for example, federally guided and funded regional bioenergy programs that promote region- and biomass feedstock-specific solutions; or local incentives for power utilities to use feedstocks such as landfill gas, wastewater, and animal manure for biopower.

Potential Job Creation and Rural Revitalization—Jobs creation continues to be an important issue throughout the nation, with opportunities for green jobs coming from all areas of bioenergy, including biopower. Rural revitalization is an important aspect. Farming and rural communities could benefit both directly and indirectly from construction and operation of new power generation based on woodchips, agricultural residues, and other feedstocks.

Appendix A: LIST OF CONTRIBUTORS

Name	Affiliation
Feedstocks for Biopower	
Chris Clark	Energetics Incorporated
Steven Crow	Retired Professor
Michael Cunningham	ArborGen LLC
Rob Davis	BTEC
Pamela de los Reyes >	Energetics Incorporated
Mark Decot	DOE Biomass Program
Mark Downing‡	ORNL
Marvin Duncan	USDA
Robert Fireovid	USDA ARS
Robin Graham	ORNL
Evan Hughes	Biomass & Geothermal Energy
Joseph James	Agri-Tech Producers, LLC
James Leitheiser	Weyerhaeuser
Anelia Milbrandt	NREL
Edward Olthoff	Cedar Falls Utilities
Saritha Peruri	Ceres, Inc.
Doug Robertson	Sea2Sky Corporation
John Stipanovich	NETL
Bruce Summers	Greenwood Resources
James Warchol	Babcock & Wilcox Research
Chris Wright†	INL
Large-Scale Systems	
Sabine Brueske	Energetics Incorporated
Kevin Comer	Antares Group
Kevin Craig	DOE Golden Field Office
Keith Cummer	Black & Veatch
Stuart Daw	ORNL
Leo Eskin	LPP Combustion LLC
John Ferrell	DOE Biomass Program
Paul Grabowski‡	DOE Biomass Program
Scott Haase	NREL
Jake Jacobson	INL
Jonathan Male	DOE Biomass Program
Susan Maley	NETL
John Monacelli	Babcock & Wilcox
George Muntean	PNNL
Reyhaneh Shenassa	Metso Power
Larry Swanson	General Electric Energy
Valentino Tiangco	Sacramento Municipal Utility District
Michael Winter	Pratt & Whitney
Carl Wolf*	BCS, Incorporated

Name	Affiliation
Market Transformation	
John Bonitz	SACE
Christine Brinker	DOE Intermountain Clean Energy Center
Susan Ford	USDA States Forest Service
Thomas Foust	NREL
Shawn Garvey	The Grant Farm
Cindy Gerk >	NREL
Mike Husain	Arizona Chemical
Ron Larson	U.S. Biochar Initiative
Elliott Levine†‡	DOE Biomass Program
Christopher Lindsey	Antares Group
Ripudaman Malhotra	SRI International
Shawna McQueen^	Energetics Incorporated
James Newcomb	NREL
Sharon Shoemaker	CIFAR and Energy Institute, UC Davis
David Sjoding	Washington State University—NW CE-AC
Don Stevens	PNNL
Kevin Sullivan†	KEMA Inc
Pretreatment and Conversion Technologies	
Terry Ackman	LTI, Inc.
Doug Asbe	Kimberly Clark
Stewart Boyd	American Process
Timothy Brandvold	UOP, LLC
Vann Bush	Gas Technology Institute
Chris Cassidy	USDA
Mike Cleary	NREL
Harrison Cooper	Bountiful Applied Research Corp.
Craig Hustwit	NETL
Bryan Jenkins	University of California
Susanne Jones	PNNL
George Kervitsky^	BCS, Incorporated
Kelly Murphy	EUCI
Neil Rossmeissl‡	DOE Biomass Program
Debbie Sandor	NREL
Joseph Smith	INL
George Touchton	Zero Emissions Renewable Energy
Robert Wallace	Penn State University
Smaller-Scale Systems	
John Anderson	Clean Energy Solutions LLC
Richard Bain‡	NREL
Kenneth Banks	Hurst Boiler & Welding, Inc.
Lindsay Bixby ›	BCS, Incorporated
Steve Brooks	Verso Paper
Bill Carlson†	Carlson Small Power Consultants
Anthony Crooks	USDA Rural Development
Brian Duff	DOE Biomass Program

Name	Affiliation
Mark Knaebe	USDA Forest Service—Forest Products Lab
Tom Lepak	Casey Industrial, Inc.
Jim Patel	Carbona Corporation
Vicky Putsche	NREL
Michael Ramotowski	LPP Combustion LLC
John Scahill	DOE Golden Field Office
Alan Shedd	National Rural Electric Cooperative Association
David Specca	Rutgers University EcoComplex
John Tao	Weyerhaeuser
Roy Tiley^	BCS, Incorporated
Frederick Tornatore	TSS Consultants
Kathryn Valdez	Xcel Energy
Corinne Valkenburg	PNNL
Mark Yancey	NEAtech LLC
Other Attendees	
Robert Cleaves†	Biomass Power Association
Mark Mathis	Confluence Energy
Seema Patel*	BCS, Incorporated
Theodora Retsina	American Process
Garrett Shields ›	BCS, Incorporated
Tim Theiss	ORNL
Additional Contributors	
Ed Gray	Antares
Zia Haq	DOE
Joseph James	Agri-Tech Reducers, LLC
Thomas W. Johnson	Southern Company Services
Charlie Ker	Nexterra Systems Corp.
Stan Rosinski	Antares

Notes:

‡ Technical Chair
› Scribe
† Plenary Speaker
^ Facilitator
* Logistical POC

Organizational Acronyms:
BTEC = Biomass Thermal Energy Council
DOE = U.S. Department of Energy
ORNL = Oak Ridge National Laboratory
USDA = U.S. Department of Agriculture
USDA ARS = USDA Agriculture Research Service
NREL = National Renewable Energy Laboratory
NETL = National Energy Technology Laboratory
INL = Idaho National Laboratory
PNNL = Pacific Northwest National Laboratory
SACE = Southern Alliance for Clean Energy

Appendix B: Workshop Agenda

Time	Day 1
7:30 am	**Registration/Continental Breakfast**
8:30 am	**Welcome and Purpose** *Elliott Levine, U.S. Department of Energy* **Biomass Program Overview** *John Ferrell, U.S. Department of Energy*
8:45 am	**Plenary** • A Business Case for Biomass as a Prime Energy Resource *Kevin Sullivan, Senior Vice President - Power Generation Services, KEMA* • Status of Biopower and Market Potential *Bob Cleaves, President & CEO, Biomass Power Association* • Small-Scale Biopower Systems *Bill Carlson, Carlson Small Power Consultants* • Feedstocks for Today and Tomorrow *Chris Wright, Idaho National Laboratory* • Introduction to Breakouts *Elliott Levine, U.S. Department of Energy*
10:45 am	**Break**
11:00 am	***Moderated Group Discussion:*** Review of Workshop Objectives Moderated Topic Questions: What are the **Key Drivers** for Biopower today? What is the **Vision** for **Next Generation Technology**?
12:00 pm	**LUNCH**
1:00 pm	**Concurrent Topical Breakout Sessions (5 Tracks – see Attachment 1 following agenda for description and specific topic questions)** **Breakout Session 1:** What are the **Technical and Non-Technical Barriers and Challenges** to expanding use of Biopower, within the topic area? What are the **Top Priorities** in addressing these barriers, e.g., where are the showstoppers for biopower?
2:30 pm	**Break**
2:45 pm	**Breakout Session 2:** What **Technology R&D** is needed to accelerate use of Biopower? What **Critical Analysis** is needed to support sustainable technology development and deployment?
3:45 pm	**Move to Report Out Session**
4:00 pm	**Report Outs**
5:00 pm	**Adjourn for Day**

Time	Day 2
7:30 am	**Continental Breakfast**
8:30 am	**Concurrent Breakout Sessions Continue** **Breakout Session 2 continues:** What further **Technology R&D** is needed to accelerate use of Biopower? What other **Critical Analysis** is needed to support sustainable technology development and deployment? What are the **Priorities and Timing for R&D and Analysis** (near, mid, long)?
10:00 am	**Break**
10:30 am	**Breakout Session 3:** What **Critical Actions (other than R&D)** are needed to **Promote Commercialization and Deployment** of Biopower technologies?
11:15 am	**Small Group Activity: Top Priorities for R&D and Analysis** Small interactive group discussion to define the elements of the top priorities.
12:00 pm	**LUNCH**
1:00 pm	**Small Group Activity: Top Priorities for R&D and Analysis** Small interactive group discussion to define the elements of the top priorities.
2:30 pm	**Break**
2:45 pm	**Report Outs**
4:00 pm	**Final Comments and Next Steps**
4:30 pm	**Adjourn**

Time	Day 3: NREL Tour
8:00 am	Shuttle Bus leaves Grand Hyatt Denver for NREL
8:30 am – 9:00 am	**Arrive at NREL** (light breakfast to be provided)
9:00 am	**NREL Overview** (NREL mission and future vision) Room FTLB - 268 Dale Gardner, Associate Director for Renewable Fuels and Vehicle Systems NREL
9:15 am	**NREL Biopower** (past projects, current projects, and future projects) Room FTLB - 268 Richard Bain, PhD, Principal Research Engineer National Bioenergy Center, NREL
9:30 am	**Divide into Two groups** **Algae** (Group 1) Room FTLB 279 **Thermochemical Conversion** (Group 2) Room FTLB 268

Time	Day 3: NREL Tour
9:35 am	**Simultaneous Presentations** **Algae** (Group 1) Room FTLB 279: Phil Pienkos, PhD, Applied Biology NREL **Thermochemical Conversion** (Group 2) Room FTLB 268: Robert Baldwin, PhD, Principal Scientist and Group Manager Thermochemical Process R&D, NREL
9:55 am	**Simultaneous Laboratory Tours** **Algae Lab** – Eric Knoshaug (Group 1) **Thermochemical Conversion** TCPDU – Calvin Feik (Group 2)
10:15 am	----------------------------*GROUPS SWITCH*------------------------------- **Simultaneous Presentations** **Algae** (Group 2) Room FTLB 279: Phil Pienkos, PhD, Applied Biology, NREL **Thermochemical Conversion** (Group 1) Room FTLB 268: Robert Baldwin, PhD, Principal Scientist and Group Manager Thermochemical Process R&D, NREL
10:35 am	**Simultaneous Laboratory Tours** **Algae Lab** – Eric Knoshaug (Group 2) **Thermochemical Conversion** TCPDU – Calvin Feik (Group 1)
10:55 am	**Reconvene for brief wrap up with Richard Bain** Room FTLB 268

Appendix C: References

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Appendix D: Acronyms

ASM	ASM International, Materials Information Society
Btu	British thermal unit
CH_4	methane
CHP	combined heat and power
CO_2	carbon dioxide
DBFC	direct biomass fuel cell (fuel cell capable of producing electrical power directly from biomass without any intervening gasification or reforming steps
DCFC	direct carbon fuel cell
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
DOE/EERE	U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy
EFGT	externally fired gas turbine
EIA	Energy Information Administration
EPA	Environmental Protection Agency
FEMP	Federal Energy Management Program
FERC	Federal Energy Regulatory Commission
ft^3	cubic feet
GHG	greenhouse gas
kWh	kilowatt-hour
LCA	life cycle analysis
LTA-SOFC	liquid tin anode solid oxide fuel cell
MIE	minimal ignition energies (the minimum amount of energy required to ignite a combustible vapor, gas, or dust cloud, for example, due to an electrostatic discharge)
MSW	municipal solid waste
MW	megawatt
NERC	North American Electricity Regulatory Commission
NO_x	nitrogen oxides
NRC	Nuclear Regulatory Commission
NREL	National Renewable Energy Laboratory
PTC	Production Tax Credit
PURPA	Public Utilities Regulatory Policies Act
RAC	U.S. Department of Energy Regional Application Center
RD&D	research, development, and demonstration
RFS	renewable fuel standard
RPS	renewable portfolio standard
SO_x	sulfur oxides

USDA	U.S. Department of Agriculture
VOC	volatile organic compound
WWTP	wastewater treatment plant

Appendix E: STATE-level Power Incentives

ALABAMA

PI TVA - Generation Partners Program

ALASKA

PI Golden Valley Electric Association - Sustainable Natural Alternative Power (SNAP) Program

ARIZONA

RPS Renewable Energy Standard
GPP Scottsdale - Green Power Purchasing

CALIFORNIA

RPS Renewables Portfolio Standard
GPP San Diego - Green Power Purchasing
GPP San Francisco - Renewable Energy Purchasing
GPP Santa Monica - Green Power Purchasing
PI California Feed-In Tariff

COLORADO

RPS Fort Collins - Electric Energy Supply Policy
RPS Renewable Energy Standard
GPP Aspen - Green Power Purchasing
GPP Boulder - Green Power Purchasing
MGPO Mandatory Green Power Option for Large Municipal Utilities

CONNECTICUT

RPS Renewables Portfolio Standard
GPP Connecticut - Green Power Purchase Plan
GPP Connecticut Municipalities - SmartPower 20% by 2010 Campaign

DELAWARE

RPS Renewable Portfolio Standard
MGPO Delaware - Mandatory Utility Green Power Programs

DISTRICT OF COLUMBIA

RPS Renewables Portfolio Standard

FLORIDA

RPS JEA - Clean Power Program

GEORGIA

PI TVA - Generation Partners Program

GUAM

RPS Guam - Renewable Energy Portfolio Goal

HAWAII

RPS Renewable Portfolio Standard

ILLINOIS

RPS Renewable Portfolio Standard
GPP Illinois - Green Power Purchasing

INDIANA

GPP Indiana - Green Power Purchasing

IOWA

RPS Alternative Energy Law (AEL)
MGPO Mandatory Utility Green Power Option

KANSAS

RPS Renewables Portfolio Standard

KENTUCKY

PI TVA - Generation Partners Program

MAINE

RPS Renewables Portfolio Standard
GPP Maine - Green Power Purchasing
PI Community Based Renewable Energy Production Incentive (Pilot Program)

MARYLAND

RPS Renewable Energy Portfolio Standard
GPP Maryland - Clean Energy Procurement
GPP Montgomery County - Green Power Purchasing

MASSACHUSETTS

RPS Renewable Portfolio Standard
GPP Boston - Green Power Purchasing
GPP Massachusetts - Green Power Purchasing Commitment

MICHIGAN

RPS Lansing Board of Water and Light - Renewables Portfolio Goal
RPS Renewable Energy Standard
GPP Ann Arbor - Green Power Purchasing
GPP Grand Rapids - Green Power Purchasing Policy
GPP Lansing - Green Power Purchasing Policy

MINNESOTA

RPS Renewables Portfolio Standard
RPS Xcel Energy Wind and Biomass Generation Mandate
PI Minnesota - Renewable Energy Production Incentive

MISSISSIPPI

PI TVA - Generation Partners Program

MISSOURI

RPS Columbia - Renewables Portfolio Standard
RPS Renewable Electricity Standard

MONTANA

RPS Renewable Resource Standard
MGPO Mandatory Utility Green Power Option

NEVADA

RPS Energy Portfolio Standard

NEW HAMPSHIRE

RPS Renewables Portfolio Standard

NEW JERSEY

RPS Renewables Portfolio Standard
PI Grid-Connected Renewables Program

NEW MEXICO

RPS Renewables Portfolio Standard
MGPO Mandatory Utility Green Power Option

NEW YORK

RPS Long Island Power Authority - Renewable Electricity Goal
RPS Renewable Portfolio Standard
GPP New York - Renewable Power Procurement Policy
GPP Suffolk County - Green Power Purchasing Policy

NORTH CAROLINA

RPS Renewable Energy and Energy Efficiency Portfolio Standard
PI NC GreenPower Production Incentive
PI TVA - Generation Partners Program

NORTH DAKOTA

RPS Renewable and Recycled Energy Objective

OHIO

RPS Alternative Energy Resource Standard

OREGON

RPS Renewable Portfolio Standard
GPP Portland - Green Power Purchasing & Generation
MGPO Mandatory Utility Green Power Option

PENNSYLVANIA

RPS Alternative Energy Portfolio Standard
GPP Montgomery County - Wind Power Purchasing
GPP Pennsylvania - Green Power Purchasing

RHODE ISLAND

RPS Renewable Energy Standard

SOUTH CAROLINA

GPP South Carolina Municipalities - Green Power Purchasing
PI Biomass Energy Production Incentive

SOUTH DAKOTA

RPS Renewable, Recycled and Conserved Energy Objective

TENNESSEE

PI TVA - Generation Partners Program

PI Xcel Energy - Renewable Energy Buy-Back Rates

TEXAS

RPS Austin - Renewables Portfolio Standard
RPS Renewable Generation Requirement
RPS San Antonio City Public Service (CPS Energy) - Renewables Portfolio Goal
GPP Austin - Green Power Purchasing
GPP Dallas - Green Energy Purchasing
GPP Houston - Green Power Purchasing
PI Green Mountain Energy Renewable Rewards Buy-Back Program

UTAH

RPS Renewables Portfolio Goal
GPP Salt Lake City - Green Power Purchasing

VERMONT

RPS Sustainably Priced Energy Enterprise Development (SPEED) Goals
PI CVPS - Biomass Electricity Production Incentive
PI Vermont Standard Offer for Qualifying SPEED Resources

VIRGINIA

RPS Voluntary Renewable Energy Portfolio Goal
GPP Fairfax County - Green Power Purchase
MGPO Mandatory Utility Green Power Option
PI TVA - Generation Partners Program

WASHINGTON

RPS Renewable Energy Standard
GPP Clark County - Green Power Purchasing
MGPO Mandatory Utility Green Power Option
PI Chelan County PUD - Sustainable Natural Alternative Power Producers Program
PI Okanogan County PUD - Sustainable Natural Alternative Power Program
PI Washington Renewable Energy Production Incentives

WEST VIRGINIA

RPS Alternative Energy Standard

WISCONSIN

RPS Renewable Portfolio Standard
GPP Madison - Green Power Purchasing
GPP Wisconsin - Green Power Purchasing
PI We Energies - Biogas Buy-Back Rate
PI Wisconsin Power and Light (Alliant Energy) - Advanced Renewables Tariff

EERE Information Center
1-877-EERE-INFO (1-877-337-3463)
www.eere.energy.gov/informationcenter

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