GRID-CONNECTED RENEWABLE ENERGY:

BIOMASS POWER
Slide 1

Grid-Connected Renewable Energy: Biomass Power
• Biomass Resources & Technologies
• Global Status
• Biomass Promotion & Policies
• Biomass Economics
• Issues & Solutions
• Best Practices
• Success Stories
Slide 2

Presentation Contents

This module provides information on grid-connected biomass power generation systems, including direct combustion and biogas combustion technologies.

Section One – The first section of this presentation discusses the biomass resource and the different conversion and generating technologies used to convert biomass into electricity.

Section Two – This section reports on the global status of biomass generation.

Section Three – The third section discusses biomass promotion laws and policies.

Section Four – The fourth section covers the economics of electricity production from biomass generating plants.

Section Five – This section discusses barriers and solutions to the deployment of large biomass generating systems.

Section Six – Section six includes sample project development flow and best practices for enabling the development of large, grid-connected biomass generating plants.

Section Seven – The final section provides some examples of successful biomass projects in several countries.

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Organic material from:

- Agricultural and livestock waste, crop and forest byproducts & residues
- Dedicated crops
- Municipal solid waste
- Methane recovery

Kudzu field, Mississippi, US
Biomass Resources

Virtually anything that burns can be used as a feedstock for biomass electricity generation projects. These feedstocks come from a wide variety of sources and are broadly divided into four general categories, detailed below. The terms open-loop and closed-loop biomass are used in the United States but are becoming more widely used elsewhere as well. Depending upon a country’s biomass resources and interests, the distinction between closed- and open-loop biomass feedstocks is used for policy purposes to focus strategies on encouraging the use of waste products (open-loop) or to encourage the production of dedicated energy crops (closed-loop). In some regions policymakers might want to encourage both types of biomass, while in others they may prefer one over the other depending upon the local situation.

**Methane** – methane gas is recovered from a landfill, or through anaerobic digestion (e.g., from sewage treatment plants) and then used to produce electricity either directly on-site or the methane is put into a gas pipeline for use at another site.

**Open-loop biomass** – includes livestock waste (e.g., manure), agricultural crop by-products and residues, forest-related by-products and residues, and non-hazardous solid-wood waste as the feedstocks for electricity production.

**Closed-loop biomass** – includes any organic material that is planted exclusively for purposes of being used to produce electricity.

**Municipal solid waste (MSW)** – often is distinguished from other biomass feedstocks used for producing electricity because policies and programs that encourage the use of MSW tend to be quite different from those used to promote other biomass use. Specifically, the MSW waste stream generally is collected and controlled by a governmental entity (usually a municipal government) rather than a farmer or private-sector entity, so the design, siting, and economics of plants using MSW are distinct from other forms of biomass generation.

In most developing nations there is competition over the use of the biomass feedstocks: e.g., charcoal producers may covet wood waste; farmers may prefer to burn agricultural waste in the fields, while using organic waste for cooking and domestic heating; and other parties may seek to promote the use of some feedstocks for the production of biofuels for transportation rather than for power production. Currently, dedicated crops (e.g., corn, sugarcane, etc.) rather than organic waste have been the preferred feedstocks for biofuels.

In some developed countries there are also conflicts about the use of municipal solid waste for power production without first recycling as much of the waste stream as possible. However, aggressive recycling can result in making some waste-to-energy projects uneconomic due to insufficient combustible feedstock remaining in the waste stream. Economics are the prime motivator for how a particular feedstock is ultimately used, aided, or hampered by government and regulatory policies.

This competition for resources, especially in developing nations, has led to major problems in the biopower industry in the ability to plan for and secure adequate feedstocks over the 30-40 year planned lifetimes of biopower projects. Added to this uncertainty is the temporary nature of many government policies, which can change abruptly due to economics and politics. Because of this uncertainty, developers increasingly incorporate flexibility into their contracts and their plant designs to accommodate a wide variety of closed- or open-loop feedstocks, with the goal of ensuring the project’s economic viability over its lifetime.
Photo credit: Wikimedia Commons
BIOMASS TECHNOLOGIES

BIOMASS

DRY

Thermochemical Processes

Combustion

Hot Gas

Steam Heat Electricity

Gasification

Producer Gas Synthesis Gas

Gas Steam Heat Electricity

Pyrolysis

Liquid hydrocarbons

Fuels Electricity

Pyrolysis

Biochemical Processes

Fermentation

Ethanol

Biodiesel

Anaerobic Processes

Trans-esterification

Methane
Understanding the challenges facing the biomass industry first requires a basic understanding of the technologies involved in various types of biomass energy production. Biomass is a very complex area since there are multiple biomass feedstocks and multiple types of technologies used to convert those feedstocks into electricity. In general, bioenergy is created from biomass through either a thermochemical or a biochemical process, each utilizing three different conversion technologies. Thermochemical processes include direct combustion, gasification and pyrolysis, the latter two using heat and low or no oxygen to create gaseous and liquid fuels. Biochemical processes include three conversion technologies that use biological and chemical additives to create ethanol, methane or biodiesel. Of the six types of biomass conversion technologies used under these two general processes, four are commonly used today to transform feedstocks into electric power:

**Direct combustion** – Direct combustion plants were the first type of biomass plant used, and are still the most plentiful. They directly burn organic material in a boiler, creating steam for power. When direct combustion plants are used in a cogeneration mode the steam can also be used for commercial processes. In general, the feedstock is moved to the boiler on a conveyor belt (grate feeder). The only change to this technology in the last 50 years has been in emissions controls. A typical plant may use several different types of organic material, such as crop residues and construction waste. Biomass feedstocks can also be used for **Co-firing** – a term used when a biomass feedstock is mixed with a fossil fuel, such as coal. These are often very efficient power plants, though the total biomass fuel portion seldom is more than 10 percent. Co-firing with more than 10% or 15% biomass fuel is technically feasible, but requires significant alterations to the boiler that are not yet sufficiently economic for widespread use.

**Pyrolysis/Gasification** – Pyrolysis and gasification are the newest types of biomass conversion technologies. Pyrolysis uses heat and pressure to create various forms of biogas from wood and other forms of cellulosic waste. Pyrolysis has also been used for decades to create charcoal. The latest generation of gasification plants shows promise to produce biogas that can be used in gas turbines or internal combustion engines (ICE) in place of or mixed with natural gas. These conversion technologies can use any type of waste or plant material to produce natural gas-compatible fuel for electric power generation, or they can produce biofuels for transportation. Some of these types of plants also produce byproducts that can by used as soil amendments and livestock feed. The latest generation pyrolysis plants create bio-oils from rapid pyrolysis or hydro-thermal cracking that can produce combustible liquids that are similar to diesel fuel and can be used for electric power generation, or produce biofuels for transportation.

**Methane gas plants** – Two general types of power systems use methane as their primary fuel: (1) Those in which the methane is recovered directly, e.g. from landfills, and then burned to produce electricity; and (2) plants that first create methane through anaerobic digestion by adding bacteria to organic material, such as sewage or animal waste, then burn the methane to produce electricity. Landfill plants require a completely different delivery system than digestion systems. Landfill gas recovery systems can be relatively expensive to retrofit to an existing landfill, but have much lower capital costs when designed into a landfill before it is constructed, as is common practice in most developed nations for newly constructed landfills. Landfill gas also needs some additional treatment to remove moisture before it can be mixed with natural gas or burned directly. Anaerobic digestion plants are widely used around the world, and range from relatively crude and rudimentary systems to highly sophisticated systems using methane piped in from multiple sources.

**Biofuels** – Biofuels have been the most active area of biomass development in recent years. Hundreds of companies
around the world are trying to develop new and better ways to make biomass-derived fuels to power everything from cars to jets. Transportation biofuel production competes with the biopower industry for land for dedicated crops and may in the future compete for other biomass feedstocks. Biodiesel can be used to replace regular diesel in diesel generation sets, but currently tends to be used in smaller generators for on-site power generation and therefore will not be discussed in this presentation.

Though the term “biofuels” has in the past referred specifically to fuels used for transportation, the term today also is used for any liquid or gaseous fuel produced from pyrolysis or methane recovery conversion systems, both of which produce fuels that can be used to produce electricity. Combined systems providing biogas for power production and residential cooking and heating are becoming increasingly popular in India and China.

Many biomass experts now predict that a combined conversion technology will become the low-cost option for biomass-derived power and transportation fuels. These combined systems would have two stages of production. The first stage would involve a series of small facilities scattered over a broad region with significant biomass resources. These smaller facilities would use pyrolysis conversion technologies to produce bio-oil, which has the densest energy content of any biomass-derived fuel to date. The concentrated nature of bio-oil allows economic transport of the product to large, centralized facilities. In the second stage, such facilities would refine the bio-oil into many different types of fuels for both transportation and power production. These types of projects already are in the demonstration stage in Germany, and early data reveal that when sized properly, such systems can be more economical than any present conversion technology.

**Graphic credit:** Pat DeLaquil, originally published in BioEnergy Technical Overview – Nov. 19, 2001, used by permission
DIRECT COMBUSTION TECHNOLOGIES

- Similar to conventional coal or natural gas plants
- Can burn variety of materials in single plant
- Easily integrated to the grid
- Emissions controls and offsets add a major expense
Direct Combustion Technologies

Direct combustion plants are the simplest and most plentiful type of biopower plant in the world, both in developed and developing nations. Other than the source of fuel, and how it is fed into the boiler, they are almost identical to other boiler-based power plants fueled by coal or natural gas. Development of direct combustion biomass plants essentially began in North America during the 1980s following legislation allowing the plants to sell renewable power to local utilities at favorable rates, as well as to self-generate the power and process heat (steam) needed for on-site use.

Photo credit: Black & Veatch

References

- 83. Bioenergy Primer – UN Development Programme
DIRECT COMBUSTION TECHNOLOGIES: MOVING THE FUEL

• Most plants are grate stokers

• Fluidized bed combustors (FBC) increasingly used
  – Lower NO\textsubscript{x} and sulfur emissions
  – Use different fuels, including co-fired coal and biomass
  – Grate plants can be converted easily to FBC
  – Advanced FBC boilers promise increased efficiency and fuel flexibility
Direct Combustion Technologies: Moving the Fuel

Grate Stokers – Most direct combustion plants use simple conveyor belts to move the feedstock into the combustor, located at the base of a boiler that produces steam from the burned biomass. These plants are called “grate stokers” and look very much like coal-fired boilers.

Fluidized Bed Combustors (FBCs) – Increasingly, plants are using a more advanced boiler called a fluidized-bed combustor (FBC). These boilers use finely ground fuel suspended in a stream of air blown into the combustor, usually from below, to create an area of high turbulence that resembles a fluid in its operation. This “fluidized bed” provides a comparatively efficient transfer of heat into the boiler water jacket. This efficient heat transfer allows lower temperature combustion, which significantly reduces emissions.

The first FBC boiler was put to use in Germany in the 1950s, and that country still leads the world in FBC research and development. The latest generation of FBCs now offers even greater efficiency gains and the ability to use several different types of fuels while operating. Many were designed specifically to use dozens of different types of biomass, since obtaining fuels from different sources is often necessary to secure a sufficient feedstock stream. Changing fuel types in older boilers often required at least a day as operators compensated for the changing heat value of the fuel. Modern FBC plants have the ability to switch back and forth between several different fuel sources, without affecting power operations.

Photo credit: Black & Veatch

References

- 317. Conversion of Stocker Fired Boilers
Plant heat rates range from 11,000 to 20,000 BTU/kWh
  – Modern FBC and gasification combined-cycle plants most efficient

Fixed cost ranges from $1,700 to $3,500/kW

Variable costs 1-12 ¢/kWh depending on technology and scale:
  – Lower costs for large co-fired plants
  – Higher costs for small solid biomass

Cogeneration attractive economically and technically
  – Process steam for industry
  – Centralized heat and power
**Heat Rates** – Even the most efficient biomass-fed FBC boiler is still less efficient than modern gas-fired power plants as indicated by the BTU/kWh heat rate – the lower the heat rate, the more efficient the plant. Gas-fired power plants have heat rates as low as 8,500 BTU/kWh. Newer coal plants can operate as low as 9,000 BTU/kWh, and even new simple-cycle gas turbines can operate under 10,000 BTU/kWh. Biopower plants have heat rates that range from 11,000 to 20,000 BTU/kWh.

Older plants have no added features such as economizers and reheaters and thus have higher heat rates. Economizers recover some of the heat in the steam exhausted from the turbine by preheating the feed water as it comes into the boiler. Reheaters route some of the exhausted steam back into the boiler where it is reheated into superheated steam.

Heat rates of biomass plants also vary greatly depending upon the fuel used. The net energy available in biomass ranges from about 8 mega-joules per kilogram (MJ/kg) for green wood, to 20 MJ/kg for oven-dried plant matter, to 55 MJ/kg for methane; by comparison, the range for coal is about 23-30 MJ/kg. Fuel choice is often a balance of heat content versus the fuel cost. Design, transportation, and drying costs also are factors in fuel selection. The choice of feedstock has a big impact on the amount of energy a plant can produce and, accordingly, the amount of revenue it can earn.

**Fixed Construction Costs** – Along with heat rate, construction costs also vary greatly depending upon the design and technologies used in the plant. Simple direct-burn plants with no emission controls are relatively cheap, but are not allowed to operate today in most countries due to air pollution standards. Modern FBC boiler plants with advanced emissions controls can cost almost triple that of a comparable natural gas plant. (See further cost discussions Slide #27)

**Variable Costs** – Variable costs also fluctuate greatly, depending upon the type and size of the plant and its ability to obtain cheap or free fuel. Large plants have the advantage of economies of scale, but fuel availability and the need to transport that fuel over long distances generally limits biomass plants to ~50 MW maximum.

**Biomass-fired Cogeneration** – One method to increase the efficiency of biomass plants is to use cogeneration, which generally involves producing steam for power generation and for other purposes, such as for district heating or process steam at lumber mills. This is also called combined heat and power (CHP). Some CHP plants emphasize power production as the main priority, while others base their operations solely on thermal production, usually for district heating or industrial process heating, with power operations considered secondary. Those that place priority on power operations can “over-fire” the boilers to make sure enough thermal energy always is available for power operations, and use any excess for heating or other purposes. Conversely, plants with a priority on thermal applications will focus on supplying internal loads, and supply power to the grid only when sufficient excess heat is available.

**References**

Anaerobic digesters

- Sewage (wastewater) treatment plants
- Animal-handling facilities
  - Dairies
  - Feedlots
- Landfill gas recovery
- Municipal solid waste

500 m³ anaerobic digester treating wastewater and producing power for a 10,000-pig farm in Hangzhou, China
## Slide 8

### Technology: Methane Recovery

#### Anaerobic Digesters

Anaerobic digestion involves fermentation of biodegradable materials such as manure, sewage, green waste, and energy crops. The digesters are simple containers in which bacteria is added to the waste to create methane gas that can be burned to produce electric power (or burned as cooking or heating fuel). Methane is the main component of natural gas, and the relatively clean methane from anaerobic digesters can be mixed with natural gas at the end use (district heating boilers, for instance) to augment natural gas supplies. Direct injection of biogas into most natural gas systems, a tactic employed in Sweden, requires removing the CO₂ and H₂S from the biogas, increasing costs. Recent research is exploring ways to reduce the biogas “upgrade” costs, as well as the optimum mixture and upgrading needed to meet an acceptable standard at reduced costs.

Digesters can range from small, household-sized units to units capable of processing the sewage of a million people. Anaerobic digestion has the added benefit of greatly reducing the volume of the solid waste prior to its ultimate disposal. Sometimes the solid waste can be converted to valuable byproducts such as animal feed and bedding or a soil amendment. (See the next slide for a diagram of the anaerobic digestion process.) On the cutting edge are custom-designed (genetically engineered) bacteria that can digest almost any type of waste material and directly create biogas and biofuels of various types.

### Methane Recovery from Municipal Solid Waste

The anaerobic digestion process also occurs in landfills, where natural bacteria break down the organic waste portion of the garbage. Landfills must be specifically designed to recover this gas when the landfill is created, thereby resulting in higher initial capital costs for the landfill developer. Most landfill gas facilities use the methane produced on-site for power production, simplifying the fuel delivery process. Unlike methane obtained from the anaerobic digestion plants described above, methane gas recovered from a landfill is relatively low quality and requires scrubbers to clean it if, rather than using the methane on-site, it is mixed with natural gas in a pipeline. Still, landfill gas recovery offers perhaps the lowest initial capital cost of all biopower projects, ranging from $1,200 to $1,500/kW (see slide 24).

The organic portion of municipal solid waste can be separated and placed in anaerobic digesters, where additional bacteria are added to aid fermentation. This may be an appropriate strategy where there is aggressive recycling of the waste stream that can extract the organic material.

**Photo credit:** Hangzhou Energy & Environment Co via Purdue University

### References

- 186. IEA – Bioenergy, 2004 Annual Report, Task 37, Energy from Biogas and Landfill Gas
- 321. DOE – Joint Energy Institute
- 328. Methane Production through Anaerobic Digestion of Various Energy Crops Grown in Sustainable Crop
Rotations
TECHNOLOGY: ANAEROBIC DIGESTION

Biogas plant digester at a rural school in Bangladesh

Poultry litter-fired power plant, Moerdijk, The Netherlands
Methane or biogas production using anaerobic digestion is one of the fastest growing segments of the biopower industry. These systems can range from small, crude-but-effective farm-based facilities that supply biogas for heat, light and small internal combustion engine-based power production, to very large and sophisticated systems taking manure from cattle feedlots or municipal sewage treatment systems to fuel large gas turbine power plants.

A typical system takes manure or human waste into a vessel or pit where it is mixed with a solution containing bacteria before being fed into a digester. Digesters range from simple concrete tanks to very complex vessels. The biogas is scrubbed of contaminants and sent to a turbine or internal combustion engine (depicted here) for power production. The size and sophistication of the digester generally tends to be proportional to the amount of waste it can process in a given time period. Induced blanket reactors (IBR), which converts the organic waste to a methane-rich biogas, can process the waste much faster than more conventional digesters, making them suitable for large plants.

The leftover solid material from the digestion process is a nutrient rich, sterilized mass that can be dried and used for fertilizer. The moisture extracted from the mass can be treated and used for irrigation.

**Photo credit:**
- NREL – Biogas plant digester
- BMC Moerdijk BV – Poultry litter-fired power plant, Moerdijk, The Netherlands

**References**
- 186. IEA – Bioenergy, 2004 Annual Report, Task 37, Energy from Biogas and Landfill Gas
- 257. Inland Empire Utilities Agency – Facilities

**Further Reading**
• Nearly automated systems for livestock facilities and wastewater treatment plants
  – capital costs $2,300 - $3,800 kWh

• Centralized power plants take feedstock via pipeline from multiple sources
  – Often mixed with natural gas
  – capital costs $2,100 - $4,000 kWh

Wastewater treatment plant wet scrubber for cleaning biogas – Kings County, WA,
Using Methane Recovered from Anaerobic Digestion

Nearly Automated Systems for Livestock Facilities – Lack of maintenance has hampered many digester gas plants, especially at animal handling facilities that seldom have employees with the background or training needed to maintain the equipment. To address this problem, companies have developed nearly automated systems that require little daily maintenance for operation. These plants generally require construction of dedicated buildings with slotted floors, allowing the manure to fall through onto a sloped lower floor, where water periodically washes the waste into a digester at the end of the building. Automated controls burn the methane for power and heat as it is produced. System controls direct the use of methane-fueled power when available, and grid power when methane is not available. Cost for these systems range from about $2,300 to $3,800/kWh in capital costs, depending on the complexity of the system.

Power Systems for Wastewater Treatment Plants (WWTP) – Similar systems are available for wastewater (sewage) treatment plants. The power produced can provide up to 100% of the facility’s electric needs, and in some cases can produce excess power for delivery into the grid. WWTP aerobic power facilities have become increasingly popular, being sized to at least power the pumps and other equipment at the treatment plant. Larger facilities are able to sell power into the grid as well. Costs for digester systems for wastewater treatment are similar to those for livestock facilities.

Centralized Biogas Plants – Some of the most successful biogas generation facilities are centralized plants that take methane via pipeline from multiple nearby facilities, such as dairies and WWTP, and mix it with natural gas to allow larger generating capacities and therefore more attractive economies of scale. Costs of these systems range from $2,100 to $4,000/kWh, depending on wide variety of factors, including the degree to which the methane must be treated prior to being mixed with natural gas.

Photo credit: Kings County, WA – WWTP Wet Scrubber for cleaning biogas

References

- 186. IEA – Bioenergy, 2004 Annual Report, Task 37, Energy from Biogas and Landfill Gas
- 187. Harvesting Manure For Energy, Nutrients & More
- 188. NW Community Website – Inland Empire Project
- 189. Inland Empire Dairy Manure To Energy Program
- 318. Wind and Biopower Resource Assessment-Mark Loeser
Highly advanced pyrolysis and gasification processes on the horizon

- Can use virtually any biomass source
- Create multiple types of fuels
- Relatively high cost hampers development
Pyrolysis and gasification are not new technologies, but are being applied now in very advanced applications. The basic process involves exposing biomass or petroleum-based waste to high heat in the absence of oxygen (pyrolysis) or with partial oxidation (gasification), creating a synthetic gas (syngas) composed of methane, hydrogen, and carbon monoxide. The syngas can be burned directly for heat and power, or mixed with natural gas at the end use to augment fuel supplies, though its high CO₂ content requires significant upgrading prior to direct injection into the natural gas system. The process is particularly effective with wood waste, leaving only charcoal as a byproduct.

Advanced systems now entering commercialization also can create other fuels in addition to or instead of syngas, including biodiesel, bio-oil and bio-jet fuel. There are several experimental plants around the world using bio-oil mixed with fuel oil for power generation. Bio-oil has the greatest energy density of all the biofuels and has the most carbon reduction potential. It is produced in a partial pyrolysis process that creates a biochar that is almost 90% inactive carbon and can be used as a fertilizer (it won't break down and release the carbon, in contrast to composting). Some experts think this will be the technology choice of the future since bio-oil can be further refined to produce other types of fuels, including biogas for power production. However, high initial cost, complexity and the need for specialized skills has, to date, hampered development of this technology, especially in developing nations.

The primary focus in biopower production is to lower total costs (including feedstock and capital costs) from the present average of around 9 ¢/kWh, which is the break-even cost for the developer, over the assumed lifetime of the plant. Current trends in the latest available technology show costs could fall to about 4.5 ¢/kWh, using advanced FBC boilers, co-firing, advanced pyrolysis, and gasification. Even relatively low-cost upgrades in boiler and steam turbine technologies have shown the ability to greatly increase efficiency in existing biomass plants, such as plants that burn bagasse as fuel.

Graphic credit: P.H.S Japan Co Ltd. – Waste tire pyrolysis cycle

References

- Emergy Evaluation of Bio-Oil Production Using Sugarcane Biomass Residues at fast Pyrolysis Pilot Plant in Brazil
- 317. Conversion of Stocker Fired Boilers
Advantages:

• May solve waste disposal problems
• Provides reliable baseload power
• Can reduce overall carbon emissions
• Rural economic development

Mesquite Lake Plant, California, US
Used 900 tons/day of manure from adjacent feedlots; now being refurbished
Biomass – Advantages

**Can solve landfill and waste disposal problems** – Developed nations often have greater incentives to develop biomass facilities because these facilities can resolve or mitigate other problems, such as lack of land availability, inadequate waste disposal facilities, water pollution and odor problems at animal feedlots and dairies, and air pollution from open burning of crop residues. Though controversial, harvesting dead and diseased trees from forests for biopower production is also becoming a viable method to reduce fire danger.

**Provides baseload power** – Unlike many other types of renewable energy, biopower plants can provide reliable baseload power. These facilities are generally designed in a manner similar to coal-fired plants, often requiring long start-up times and slow ramping rates, making them somewhat less flexible and useful to system dispatchers. But when warmed up and on-line they can provide constant power at or near maximum-rated levels, for as long as there is sufficient feedstock. This makes them especially useful for self-generating facilities at factories working two or three shifts per day, such as pulp mills or food processing plants. Because of their proven reliability, biopower facilities require no backup reserves to compensate for any variability, allowing seamless integration into the grid.

**Can reduce carbon emissions** – If designed as part of a comprehensive program, biomass generation plants have considerable potential to reduce carbon levels in the atmosphere by replacing fossil fuels. Biomass essentially consists of carbon absorbed from the atmosphere in plant form, and when converted to fuel often results in a significant net reduction over what would otherwise be emitted if the material was left to decompose naturally or was burned in the open. Verification of carbon savings is vital to the industry’s success in any carbon market or program. The UNFCC and various volunteer carbon markets have developed methodologies for estimating and verifying carbon credits from biopower projects, including UNFCC’s “Consolidated Methodology for Electricity Generation from Biomass Residues” (ACM0006), which has gone through seven rounds of revisions since its inception and is now well accepted among participants in the UNFCC’s Clean Development Mechanism (CDM) process.

Companies are working on a wide range of technologies to take advantage of a future carbon market, such as sequestering the carbon from power plant emissions by removing (scrubbing) the CO₂ and bubbling it through algae ponds, and then using the algae as fuel.

**Can support the agricultural sector and rural economic development** – To the extent that biomass feedstocks come from the agricultural sector, either as waste material or as dedicated crops, the use of these feedstocks may provide alternative revenue to the farmer and an alternative source of economic development in rural areas. One key economic factor for biopower plants is to have sufficient feedstock supply within a 50-mile radius of the plant. Because large-scale food processing typically requires electricity and often is performed in close proximity to food production areas, the use of biofuels to produce that electricity can be a natural and economic complement.

**Photo credit:** GreenHunter Energy Inc
• High capital costs
• Difficulty in securing feedstock stream
• Uncertain policy framework in many countries
Biomass – Challenges

Perhaps the greatest hindrance to biopower development has been high initial capital costs, and the lack of certainty that investment would be recouped over the planned lifetime of the project. This uncertainty comes in many forms, including difficulty in securing adequate feedstocks over 20-30 years, and inconsistent government and utility policy concerning biopower projects. Capital costs of most biopower plants are in the mid-range of most other types of renewable power plants and are generally higher than those of conventional fossil fuel plants. But unlike all other renewable power technologies, the fuel for biopower projects is not free, and securing adequate feedstock over the life of the project is critical to recovering the relatively high initial capital costs.

In Kenya, for example, a newly constructed biomass plant intending to use local agricultural and construction waste never delivered a kilowatt-hour to the grid because not a single contracted fuel delivery was completed due to unexpected and often violent competition for the feedstock. This plant provided a valuable lesson about working with all aspects of the local community, both to accurately assess feedstock availability and competition, and also to gain trust and support from key community, industry, and government leaders.

Many factors can affect fuel availability over the 30-40 year planned lifetimes of waste-to-energy plants. These include the seasonality of agricultural waste; drought and other climate change effects that alter or even halt crop production in a given area; and alternative demand for the waste material. For example, in the 1980s in the timber-producing areas of North America, Europe, and Asia there was little use for sawdust and wood chips from lumber mills, other than to dump it or burn it as a fuel. Today, many manufactured products are sourcing wood waste, which may provide a superior revenue stream to the seller compared to the price he can get selling the waste to a power plant. In addition, the local economy can have a great effect on waste production, as municipal solid waste (garbage) and construction waste will ebb and flow with consumer spending and population growth (see slides #25-27 for project development details).

Combustion technologies for most types of biopower facilities are adapted from the coal and natural gas power plant industry, and therefore readily understood by the utility industry. Only the feedstock-to-fuel conversion technology is unique to the industry, and most of that technology in use today is relatively old and well-proven. Planned and under development biopower facilities generally are updating this technology, by using modern pyrolysis, fluidized-bed boilers, or gas-turbine technologies. But new technologies are on the horizon, and will require forward-thinking developers to take on more risk to achieve commercialization and market penetration for any newly commercialized technology.

References

- 83. Bioenergy Primer – UN Development Programme
- 103. Solid Biomass Barometer – EurObserv’ER
• Biomass Resources & Technologies
• **Global Status**
• Biomass Promotion & Policies
• Biomass Economics
• Issues & Solutions
• Best Practices
• Success Stories
Global Status
Biomass is a leading energy source in much of the world

- Up to 80% of energy requirements in African nations (charcoal and firewood)

- Demand for cooking fuel is in direct competition with biomass power production
Biomass Experience Worldwide

In many USAID countries, biomass is still the primary source of energy used in homes and businesses, and more than two billion people worldwide still cook over open fires. Even medium to large office buildings, hospitals, and factories in many parts of Africa and India still use charcoal as their main heating source, often because of the limited availability of other fuels. Residential cooking accounts for the largest use of biomass resources in most African nations, as well as several South Asian nations, and competition for that fuel source has hampered or even forced the closure of biopower facilities in those areas.

Alternative cooking fuels could help take pressure off of the biomass fuel streams needed for power plant development. Removing that pressure is considered vital to the future of biomass generation in many countries, and could help in reducing deforestation, soil depletion (depleted biochar is a very good soil amendment), and the time spent by women and girls collecting cooking fuel. Some recent efforts have focused on producing biogas for cooking, heating, and lighting, as well as power production, while others focus on increasing the efficiency of the conversion process, leaving more feedstock available for other uses.

**Photo credit:** Black & Veatch

**References**

- 13. Partnership For Clean Indoor Air
- 83. Bioenergy Primer – UN Development Programme
- 200. Summary of Biomass Power Generation in India
- 272. Institute for Biochar Initiative
GLOBAL BIOPOWER GENERATION

- Worldwide estimate 14 to 45 GW installed capacity
  - largest source of non-hydro renewable electricity
  - perhaps 30 – 50 GW by 2020

- 42% of US non-hydro renewable power

- Annual growth rate 3 - 4 %
Installed Capacity

Many biopower facilities are self-generating, serving only the facility producing the waste, making the amount of power produced difficult to calculate. Gathering statistics on biopower generation, therefore, is difficult because data on self-generation may not be kept and seldom is distributed, as no money changes hands. Estimates of worldwide biomass generating capacity vary significantly, and may not reflect the same criteria. The United Nations estimates that present global installed biomass generating capacity is around 14,000 MW, while the Organization for Economic Cooperation and Development (OECD) estimates worldwide biomass capacity at 40,000 MW and the REN 21 2007 Global Status Report estimates 45,000 MW.

The US biopower industry has experienced a 33% decline since the early 1990s (see slide #25) and though biomass facilities produce 42 percent of US non-hydro renewable power, its future is uncertain. The industry grew rapidly in the United States following passage in 1978 of the Public Utilities Regulatory Powers Act (PURPA), which resulted in favorable “avoided-cost” based tariffs that attracted investment capital. As power purchase tariffs became less favorable, and the supply of economic feedstock diminished due to overdevelopment and lack of planning, the industry essentially came to a halt in North America in the 1990s. Tighter emission controls and offset requirements increased capital costs, further squeezing plants' economic viability in California, especially, leading to nearly 20 years of stagnation of the North American biopower industry.

However, the biopower industry is growing in many developing countries, especially in areas of intense agricultural operations such as India, China, Indonesia, and Brazil. Biopower development is now also active in many parts of the EU, and new US biomass plants have been recently proposed in response to state and federal incentives, promising a possible comeback for the industry. Many analysts predict a very bright future for biopower, however, especially if global efforts to reduce carbon emissions intensify, and biopower proves effective at developing carbon credits. The International Energy Agency predicts biomass’s contribution to the electric power production sector could grow as high as 30% under effective carbon reduction policies, from its present level of about 12%. Key to its success will be the ability to prove to skeptics that biopower can result in significant carbon savings.

References

- 186. IEA – Bioenergy, 2004 Annual Report, Task 37, Energy from Biogas and Landfill Gas
BIOMASS RESOURCES WORLDWIDE

Source: DOE/USDA “Billion Ton” Report – Over 1,300 million dry tons possible annually

unit = million dry tons
Biomass Resources Available Worldwide

This table by USDOE/USDA indicates more than 1,300 million dry tons of biomass resource is available for as non-food crop biomass in the United States alone, beyond all biomass produced today, with relatively modest changes in land use, and in forestry and agricultural practices. A 2008 report by REN21 came up with 360 EJ/year – 70 EJ/y from residues and 290 from energy crops. The REN 21 report indicated that there is insufficient biomass to meet all of the estimated demand for energy uses: biofuels for transportation, biofuels and biomass for electricity production, and biomass for cooking and heating fuels.

References

LEADING BIOMASS POWER PRODUCING COUNTRIES IN 2005 (TWh)

Source: Observ'ER, 2006
Leading Biopower Producers

This graph shows the 10 top biopower-producing countries as of 2005. Brazil was the largest developing country producer. Other top biomass-producing, USAID-assisted countries include Russia, India, Mexico, Indonesia, Ukraine, South Africa, and Nigeria. More recent statistics show big gains in biopower development in Brazil and the EU, though gathering reliable worldwide data still remains a challenge. The industry enjoys robust competition, with literally hundreds of companies competing to develop biopower facilities and the carbon benefits they produce. Germany, Spain, and the United States lead in boiler technology development, but India and China alone have hundreds of companies working in the biopower industry.

References

- 103. Solid Biomass Barometer – EurObserv’ER
• Biomass Resources & Technologies
• Global Status
• **Biomass Promotion & Policies**
• Biomass Economics
• Issues & Solutions
• Best Practices
• Success Stories
Biomass Promotion & Policies
Prime obstacles:

- Poor or no effective government policy
- Difficult financing
- Overcoming negative issues and reputation

Willow grown for biomass fuel
Promoting Biopower

Government Policy

Under present policies in most countries, biopower cannot compete on a head-to-head basis with existing coal, natural gas, or diesel-fueled power generation. Nor can it compete against well-sited wind, hydro, and perhaps CSP projects on a busbar cost comparison basis. However, biopower can better compete with other forms of energy when all externalities are included in the calculation, including the negative impact from emissions and positive impacts of avoiding waste disposal or burning of crop residue. Biopower can naturally compliment the agricultural sector (e.g., by mitigating agricultural wastes and providing both a supplemental revenue stream and on-site power production). Biopower therefore tends to thrive in areas of intense agricultural or timber operations that have limited access to fossil fuels.

Financing

The financial industry is also reluctant to finance new biomass plants because of the past boom-and-bust history and unfavorable plant economics. Much of the current expansion of biopower is self-financed, where owners of existing power or industrial facilities have opportunities to take advantage of nearby biomass supplies and transmission access (India, Brazil). Due to the lack of clear and enduring policies that support renewables, including biopower, obtaining outside financing for biopower in almost all areas of the world was very difficult even before the 2008 economic downturn.

Past History

Also hampering the industry is a persistent public resistance to biopower plants in many areas of the world, where past real and perceived problems have given biopower a generally poor reputation (See slide #30). In areas reliant on biomass fuel for cooking, many people see biopower as a threat to their way of life. Effective public education, therefore, also is critical to biopower development success.

Photo credit: NREL

References

- 193. Investing in a Climate for Change; Engaging the Finance Sector, United Nations Environmental Programme (UNEP), 2008
- 194. Energy Privatisation and Reform in East Africa
- 319. OECD – African Economic Outlook 2004
• Policies to support deployment
  – Mandatory renewable targets: China, US
  – Feed-in tariffs: Brazil, India

• Efforts more successful when local manufacturing is included
  – India’s biopower industry associations
  – China’s technology transfer policies
Policies Promoting Biomass

Market policies, feed-in tariffs, and mandatory targets such as Renewable Portfolio Standards (RPS) have been enacted in recent years in countries around the world to support development of renewables in general, and in many areas biomass in particular. (For more detail on these policies, see Overview Module slides #18-20)

The countries that currently have the fastest-growing biomass sectors – India, Croatia, Finland, Iceland, Germany, and Brazil – have strong national policies promoting biomass development. These countries have enacted policies that promote the present industry, and that also promote the research and development necessary to increase the efficiency of biomass technologies, making them more competitive in the marketplace. India has a tariff system setting mandatory rates for renewable power of all types. Other places, such as China and 29 US states, have set mandatory renewable energy targets requiring utilities to purchase a portion of their power needs from renewable power generators. European countries have implemented both types of renewable promotion policies.

These policies have stimulated the use of landfill methane and the installation of anaerobic digesters at animal-handling facilities, and have also prompted the expansion of district heating schemes. In Scandinavia, for example, Denmark’s combined heat and power system utilizes straw, while systems in Sweden and Finland rely on wood residues. Work is under way in Austria to develop district heat and power using biomass pellets, and Slovenia is undertaking grid-connected CHP projects with financing from the Global Environmental Facility (GEF) revolving fund. The loan program promotes biomass energy in general, and all feedstocks are allowed, but it is meant to primarily promote use of woody biomass from forest residues and the wood-processing industries (wood-chips, sawdust, bark, pellets, etc.), which is very large in Slovenia.

China’s new Renewable Energy Law has sparked a small boom in profitable 20-50 MW biopower plants. These plants were created by a public/quasi-private joint effort of the central, provincial, and local governments and several government-owned corporations, using local project components whenever possible. A feed-in tariff in Brazil that set a favorable rate for biomass-generated electricity helped spark a boom in bagasse-based electricity generation at sugarcane processing facilities. India has a feed-in tariff for biomass-generated electricity that has encouraged expansion of biomass generating capacity there. The biomass industries in both Brazil and India appear mature enough now that they can compete more favorably with other sources of power generation, even without special tariffs, though penetration will be shallower than with more favorable incentives. (* see also Policy portion of the Overview Module)

Biopower also has dozens of industry organizations around the world actively promoting the industry. The organizations have been effective in helping correct certain problems of the past, such as lack of coordination between developers when planning projects that would compete for the same feedstocks.

Policies to Encourage Local Manufacturing

Though the advanced conversion, boiler, and gas-turbine technologies still come mostly from the EU, United States, and Japan, manufacturing of relatively low-tech conversion technology is thriving in many developing nations. India has long emphasized local manufacturing for all goods sold in the country, and biopower and conversion technology is no exception. State governments, in particular, have launched development efforts to promote local manufacturing of renewable power
technology, with some states favoring biopower and others solar power. This emphasis has helped create a thriving biopower industry in the country, and resultant formation of industry associations that have been very active and effective in working with local, regional, and national governments in promoting effective policies and projects. These include several projects that bring both biopower and biogas for cooking to villages in agricultural areas, as well as converting heating systems at large institutional buildings from firewood to biogas, all using domestically manufactured machinery.

China’s national and local governments also are strongly emphasizing technology transfer and local manufacturing in all of its Clean Development Mechanism (CDM) programs, and its national bank is also actively supporting companies that export biomass conversion technologies. Emphasis on local manufacturing came after studies showed that such policies not only created jobs and economic development, but also increased the reliability of CDM projects due to the ready availability of spare parts, as well as the training provided to local technicians. Technology transfer elements in all of these programs include:

- Partnership with local organizations
- Development of local equipment suppliers
- Involvement of local organizations in project design and operation, thus enabling project replication
- Training of local staff on project construction, operation and maintenance
- Replicability of the project activity
- Improvement of local manufacturing capacity through Joint ventures, establishment of local manufacturing plants, etc.
- Building of local know-how about the technology
- Building of local know-how and knowledge about the technology in use, correct management, CDM, etc.
- Feedback to the government regarding the operation of the project and relevant technologies

References


Further Reading

- Technology Transfer in the CDM, by Duan Maosheng, Tsinghua University, presentation to the Linking Climate Mitigation Policy and Modeling in China Workshop, Beijing, February 2006
Waste and carbon policies can drive biopower

- Waste disposal laws
  - help create feedstock supply

- Air and water pollution laws
  - limit open burning, thereby helping incentivize use of waste as feedstock

- Climate change and carbon finance policies
  - provide revenue stream
Other Policies Supporting Biomass

In addition to the main market policies used as the basis to a renewable promotion framework, there are a number of environmental and waste disposal policies that can significantly drive the biomass industry.

**Waste Disposal** – Many developing countries and emerging economies have garbage problems. Garbage thrown around a city or countryside not only poses health problems but is also an eyesore that can discourage tourism. Waste disposal laws, where they are enforced, address these two issues and can provide a source of fuel for power generation.

**Air and Water Pollution** – Air pollution laws targeted at improving air quality and reducing the negative health impacts of air pollution can be a strong ally of renewable energy promotion policies. Air pollution laws that limit open burning of garbage or crop residues, when combined with a positive renewable energy policy framework, can incentivize the use of these materials for power production. This combination of policies supports the perception that the open burning of biomass is like burning money.

Similarly, fully enforced water pollution laws can make it costly to have manure or other biomass wastes polluting ground and surface water supplies.

**Climate Change and CDM Policies** – As countries become more and more committed to greenhouse gas reductions, these climate change policies will help to support the efficient use of biomass resources. To the extent that a country implements supportive Clean Development Mechanism (CDM) policies, the incentives provided by these policies can provide an additional revenue stream for renewable energy projects. Biomass projects can actually benefit more than other renewables from CDM programs since there are carbon benefits that come from the conversion of biomass into a fuel, in addition to the carbon benefits associated with generating electricity from plants that do not have any net carbon emissions.

References

- 193. Investing in a Climate for Change; Engaging the Finance Sector, United Nations Environmental Programme (UNEP), 2008
• Biomass Resources & Technologies
• Global Status
• Biomass Promotion & Policies
• **Biomass Economics**
• Issues & Solutions
• Best Practices
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Slide 23

Biomass Economics
## COST OF BIOMASS POWER

<table>
<thead>
<tr>
<th>Technology</th>
<th>Size (MW)</th>
<th>Typical 2004 Installed Cost US$ per kW</th>
<th>Levelized Cost of Energy (¢/kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid Combustion</td>
<td>20</td>
<td>$1500 – $2000</td>
<td>6.6</td>
</tr>
<tr>
<td>Landfill Gas Co-firing</td>
<td>2</td>
<td>$1200 – $1500</td>
<td>4.4 (Depends on cost of cofuel)</td>
</tr>
<tr>
<td>Gasifier with Bio-oil</td>
<td>Demo</td>
<td>$225 – $300 $1200</td>
<td>3.5 (assuming $32/tonne feedstock)</td>
</tr>
</tbody>
</table>

### Source:
California Energy Commission & NREL
Cost of Biopower

Costs for biopower facilities vary greatly, depending on location, fuel source, type of project, equipment availability, workforce availability and cost, insurance and financing costs, availability and longevity of incentives, siting, environmental review and permitting, and many other factors. Solid combustion is still one of the most inexpensive of the biopower options at $900 (example: wood waste on sawmill site) to $2,800 (example: rice hull on greenfield site) per kW installed, with levelized costs (the break-even price for meeting all fixed and variable costs over the planned life of the project) in 2008 at 6.2¢/kWh, and expected to decline to 5.7¢/kWh in 2017.

Landfill gas capital cost is $1,200 to $1,500 per kW installed with levelized costs in 2008 of 4.1¢/kWh. The capital cost is expected to decline to 3.7¢/kWh by 2017, making this perhaps the most competitive biopower resource compared to fossil fuel plants.

Co-firing capital costs are the cheapest at $250 to $350 per kW installed, with the variable costs depending upon the cost of the co-fired fuel.

Biogas by pyrolysis/hydrolysis is essentially the same cost as solid biomass combustion, but the industry is still new and costs should decline significantly over time. The cost of the pyrolysis method of biogas production is very much dependent upon the cost of the biomass fuel, including transport costs. Choosing the most cost-effective option, whether direct combustion or a gasifier plant, depends largely upon the availability and cost of the feedstock. If there is ample cheap feedstock right next to the facility, a combustion plant is less expensive. But as feedstock costs rise, the increased efficiency of a gasifier plant will make that technology less expensive, especially at larger capacities (above 250 MW).

The most recent proposals for low-cost biogas look to site a number of bio-oil pyrolysis facilities scattered throughout a feedstock-producing area, then transport the high-density bio-oil to a centralized gasifier facility where the bio-oil is converted to gaseous and liquid fuels plus biochar. The biogas can be used for power production, or injected into natural gas systems for general heating use, while the liquid biofuels are used for transportation. The proportions of liquid vs. gaseous biofuels produced can be adjusted depending upon the demand for each fuel in the area. This type of system is now in the demonstration stage in Germany and the United States, but it has not yet been commercialized. Costs for such a system are estimated around $1,200/kW installed, and about 3.5¢/kWh in levelized costs, assuming a $32/tonne feedstock cost, making it directly competitive with fossil fuel power.

Operation & Maintenance (O&M) costs for biopower facilities are on par with that of conventional boiler and gas turbine facilities, averaging around 2¢/kWh, but ranging up to 4¢/kWh or even higher, depending on feedstock source and moisture content, environmental costs (e.g., air emission offsets), labor costs, and other factors. Most promising in reducing overall O&M costs are combined heat and power (CHP) biopower systems, which are becoming popular in the EU (see photo on slide 2). When accounting for the O&M costs of conventional heating systems spread out over hundreds of buildings, the O&M savings of CHP are huge, as low as one-tenth the overall O&M costs when comparing district heating to individual building systems.

References
197. Biomass Resource Assessment in California, California
KEY ISSUES FOR FINANCING

• Contract stability and assurance of payment
• Experience with the technology
  – local knowledge vs. international knowledge
• Double credits in carbon offset markets
• Public/private partnerships to facilitate feedstock supply
Financing Biopower

At present, biopower plant development is considered a very high credit risk in most developing nations, for a wide variety of reasons. Increasingly, financiers are employing extensive due diligence in the form of “barrier analysis” to justify investments in biopower projects. This analysis would consider:

- Investment barriers (high upfront capital expenditures)
- Technological barriers
- Barriers due to prevailing practice (cultural barriers)
- Institutional barriers (e.g., access to grid, feed-in tariff)
- Price risk of biomass residue
- Biomass collection and storage barriers

A strong national policy combined with public-private partnerships is seen as the best way to promote biopower in many nations. These partnerships address many problems of past projects, such as improper planning for changes in fuel availability, but financing remains the most difficult part of biopower development. Financiers, aware of past biomass project failures, increasingly are involved in verifying every aspect of the project, from siting through operation, to assess the viability of their investment. Verifying adequate feedstock supply and price stability, community acceptance, government and utility cooperation, transmission access, and environmental and labor costs are among the dozens of items a typical bank will consider prior to investing in a biomass project (see following slides on project development flow).

Existing biomass facilities, especially bagasse plants, slowly are becoming more able to get financing for power system upgrades since such upgrades are relatively low-cost power-producing projects. Brazil’s sugar mills increasingly are taking advantage of such opportunities, often with private funding only and no government incentives, because of the revenue potential of such investments. Existing industrial facilities (such as cement plants) with access to local biomass supplies also have incentives to develop self-financed biopower plants on their sites, since many have access to the grid and often are paying relatively high retail rates for their electricity. A recent example is a cement company in India that built a 50 MW biomass plant on one of its sites in Punjab and used its interconnection to the grid to wheel the power to another cement plant it owned in the state, without recourse to policy incentives or government financing.

Contract Stability and Assurance of Payment

The bottom line for most financiers is their confidence in the borrower’s ability to meet his payment requirements throughout the life of the loan. To do this, the borrower will require a stable regulatory environment, motivated and skilled workforce, and a long-term (15-25 years) power purchase agreement with a fair purchase price for the power. Since some types of biomass facilities cost more than other types of renewable generation, a feed-in tariff is probably the optimal policy for achieving a secure revenue stream that will support private financing.

Even in the best of economic times, biomass development has been a highly geographic and niche market. Biomass tends to thrive in locations that are near both major agricultural production areas and major population centers, especially those with little to no local fossil fuel resources.
Experience and Knowledge

Another key to obtaining financing is the ability to secure the experienced workers and professional experts needed to meet project siting, permitting, construction, and operation milestones. This is less a problem for biomass than for many other types of renewables due to its similarities to other types of steam generation. However, acquiring experienced personnel can be difficult if the biomass plant is located in an area with few to no steam power plants. In those areas, smaller-scale biogas projects have proven more successful than large ones, partly because the local workforce is more familiar with the internal combustion engine technology used in smaller biofuel power generating facilities.

Carbon Offset Markets

Biomass may have an advantage in carbon offset markets because of its ability to earn double carbon credits, as mentioned in the previous slide. To the extent that there is increasing global pressure to reduce greenhouse gas emissions, and to the extent biomass is proven effective in doing so, biomass becomes more economically viable compared to fossil fuel power generation.

Joint Private-Public Partnerships

Increasingly, many biomass projects are being developed through joint partnerships involving many partners. The partnerships are as varied as the projects themselves, including parties such as the loan provider, feedstock provider, and/or end-use product purchaser investing in the limited liability company that actually owns and receives revenue from the facility during operation. Many countries also allow and encourage government ownership and financing of such ventures. Public-private partnerships often are associated with public services such as waste disposal and wastewater treatment. These ventures have shown the most success when there is comprehensive participation from the parties involved in all aspects of the project, including national, state, and local governments; private (or quasi-private) companies; and the local community surrounding the project site.

References

- 193. Investing in a Climate for Change; Engaging the Finance Sector, United Nations Environmental Programme (UNEP), 2008
Resource assessment from bottom up and top down

- Top-down uses statistical or GIS approach
- Bottom-up relies on surveys of potential suppliers

Switchgrass grown for biomass fuel
Project Flow, Step 1: Resource Assessment

Biopower project development starts first with the biomass resource assessment by the project developer to determine project size and location. Biomass project siting often involves compromise, as the developer must seek the least-cost combination of feedstock purchase and transport cost, transmission interconnection cost, and land cost. Past resource assessments were relatively crude, often incomplete, and conducted in isolation by individual plant developers, without input by government agencies or industry organizations. The lessons learned from those mistakes has improved the science of such assessments, and made developers aware of the need to enlist governmental and NGO assistance in ensuring such efforts are accurate and comprehensive (e.g., taking into consideration competing demands for the biomass fuel).

Resource Assessment

Resource assessment starts with the developer “building” supply curves, which involve assessing all aspects of future feedstock supply using conventional (surveying) and high-tech (satellite and aerial imaging) methods. Building supply curves has become a complex science, taking into account many factors, such as competition for resources (present and future), resource accessibility (access roads), transport costs, transmission access, seasonal variation, and much more.

The high-tech process starts with statistical estimations of resource availability and competitors and builds GIS (geographic information system) layers of tons/per year to the regional level. The latest “top-down” methods employ advanced GIS software, but all efforts also include tried and true “bottom-up” surveying of potential suppliers by phone and by eye.

Inaccurate assessments of fuel availability have greatly hampered project economics, and difficulty in obtaining contracted waste streams has killed many projects. The California biomass generation industry is an excellent example of the problems associated with not having a sufficient stream of feedstock. In the late 1980s there were 49 biomass plants (800 MW) constructed throughout California’s agricultural areas. Yet 10 years later only 38 plants remained on-line. Eleven plants had shut down for a number of reasons, but a primary one was because too many biomass plants had been built for the available fuel supply. Each of the project developers had analyzed the potential biomass fuel stream and decided there was more than enough for that specific project, but didn’t take into consideration how many other projects were being planned at the same time with the intention of using the same feedstocks. Moreover, when the plants were first planned there was no real market for waste material. Farmers and other waste biomass sources either had to dispose of the waste themselves or pay someone else to do it, or they might be able to sell the feedstock very cheaply. However, as demand for waste increased there was competition to purchase the biomass feedstock, switching the climate rapidly from a buyer’s market to a seller’s market, thereby increasing the cost of fuel and making many facilities uneconomic. State and local governmental agencies and NGOs are increasingly aware of this issue, and many have taken steps to ensure a more coordinated planning effort for biomass resource utilization.

Increasingly, financiers and developers are adopting a phased approach for developing biopower projects. Once the biomass resource is assessed, many developers first develop a pilot plant or other relatively small-scale biopower facility, often out of necessity because of the inability to gain financing for the entire planned project. However, developers and financiers now see that such a plant can act as a method of verifying the biomass resource over a period of time, and then be used as a means to attract further financing for expansion.

Photo credit: NREL
References

- 199. Experts Ponder Future of Biomass Industry
- 320. Bioenergy in Mauritius
PROJECT FLOW, STEP 2: OPTIMAL SIZE AND LOCATION

- Create supply curves
- Secure fuel supply
- Locate facility at optimum point for fuel delivery and transmission access
- Two-three times the needed amount of fuel available within a 50-mile radius
Project Flow Development

Securing Fuel Supply

Once the most cost-effective sources of fuel for the facility have been identified, the fuel supply is secured through binding contractual agreements. Obtaining and securing agreements for fuel deliveries is the most critical part of most biomass projects. Cooperation among the feedstock producers, users, and applicable local, regional, and national governmental agencies is crucial in assuring long-term viability of the project. Many successful projects developed under public-private partnerships involved the biomass suppliers as partners in the project, able to earn profits from project revenues as well as from selling the feedstock.

Once the fuel supply is assessed, the project is sized accordingly, both in generating capacity and in physical size, accounting for such factors as needing to store a season’s worth of agricultural waste for generation throughout the year. Historically, small-scale projects have had the most success in developing nations, but larger ones are becoming more viable as stable renewable energy policy frameworks are established and as technologies improve.

Calculating Project Costs

Final cost estimates for a biomass plant come from the total of:

- Plant capital costs
- Fuel stream procurement and transport
- Variable operating costs, including environmental costs of remediation and pollution control, if any

Truck transport of biomass feedstock is three times more expensive than rail, and 100 times more expensive than ship or barge transport. But trucking is often the only viable alternative, and often becomes the limiting factor in the size of the generating plant: 50 MW capacity and 90 km in fuel transport distance is about average for biomass plants, though plants tend to be smaller in developing nations. To reduce fuel supply risk, developers prefer that there is at least two to three times the fuel needed for a project available within a 90-km radius of the proposed project location.

References

• Biomass Resources & Technologies
• Global Status
• Biomass Promotion & Policies
• Biomass Economics
• Issues & Solutions
• Best Practices
• Success Stories
Issues & Solutions
• Combustion plants (especially MSW) can release pollutants
  – $\text{NO}_x$, $\text{SO}_2$, and particulate emissions
  – Emissions often uncontrolled, creating local opposition

Electrodynamic venturi, reducing dust content to < 1mg/nm$^3$
Issue: Emissions

Power plants using the direct combustion of biomass (particularly when they are burning municipal solid waste) can emit significant harmful emissions, especially particulate emissions, if they are not controlled. Too often, even in developed nations, the emissions from biopower plants have been uncontrolled. The most notable example in the United States was a 16 MW biomass plant at a sugar mill on the island of Maui, Hawaii, that was, until recently, producing thick black smoke loaded with particulate matter into an otherwise pristine environment.

On average, biopower plants have significantly lower harmful emissions per MWh than coal power. However, some biopower plants have a relatively high NOX emission rate compared to other combustion technologies. This high NOX rate, an effect of the high nitrogen content of many biomass fuels, is one of the top air quality concerns associated with biomass. Fortunately there are technical controls that can be used to reduce these emissions, but they are expensive. Emissions control requirements vary from place to place, and include the use of electrostatic precipitators, flue gas scrubbers with downstream fine dust separators (electrodynamic Venturi), selective catalytic reduction devices (SCR or DeNOX), and dioxin burners.

Photo credit: Waste-to-Energy Research and Technology Council

References

- 186. IEA – Bioenergy, 2004 Annual Report, Task 37, Energy from Biogas and Landfill Gas
ISSUES: COMPETITION AND WASTE

- Food security concerns
- Competition for use of land & water
- Feedstock competition for transport fuels
- Competition for residues for soil amendment
- Solves one waste problem but creates another: ash/mineral or sludge disposal
  - Potential to use ash to make sellable products
Slide 30

Issues: Competition and Waste

**Food Security** – One of the most serious challenges to the use of biomass as an energy feedstock is competition for the use of land and water, and the possible displacement of food crops for energy crops or usage. Not only could this lead to food price hikes or food shortages, but the use of fertilizers, on-farm fossil fuel use, and fossil fuel used for transporting the biomass material can result in a negative energy balance (i.e., it takes more energy to produce the fuel than can be extracted from it). Competition for water is closely related to the competition for land if the energy crop requires water for irrigation. In addition, some biomass plants require water for steam production and cooling. To the extent that biopower plants use either biomass waste material or crops that grow on marginal land, then land and water competition is less of an issue.

**Natural Resource Concerns** – Another concern is the conversion of rainforests and other sensitive forest or biological environments in order to plant energy crops. Not only can this result in net carbon emissions and serious ecological loss, but these sensitive lands often have soils that rapidly become unproductive once the indigenous plants/trees are removed.

Though most transport biofuels have been made from corn, sugar, and other food crops, developments in conversion technologies (particularly gasification) will make it increasingly economic to produce biofuels from biomass waste or energy crops previously considered uneconomic for this use. This will increase competition for the use of these resources, possibly leading to price hikes that negatively affect biopower generation prospects and reignite concerns over food security and natural resource issues.

**Competition for Stalks and Crop Residues for Soil Amendments** – Leftover stalks and other crop residues have long been burned in the field, then re-plowed into the earth as a soil amendment. Harvesting these stalks and residues for use as a feedstock is in direct competition with this traditional practice. However, air pollution concerns about open field burning combined with new conversion technologies that produce a soil amendment byproduct can help to reduce the perceived competition. Moreover, there is often more biomass residue created than is necessary for soil amendment purposes.

**Waste Problems** – The use of biomass waste materials in power plants may eliminate the original waste disposal problem, but direct combustion plants produce ash and minerals, and anaerobic digestion plants produce sludge, which still require disposal. On the positive side, the quantity of waste material is drastically reduced, and this material often can be used as a soil amendment. With proper handling, it should not pollute the water or air, though of course environmental regulations must be enforced to ensure proper procedures are implemented. In addition, depending upon the conversion technology, some of the conversion residue and power plant ash can be a sellable byproduct.
• Biomass Resources & Technologies
• Global Status
• Biomass Promotion & Policies
• Biomass Economics
• Issues & Solutions
• Best Practices
• Success Stories
Similar to those for steam plants:

- ISO/IEEE standards required virtually everywhere
- Hazardous materials handling and retention
- Storm water retention
Because of the general lack of experience and familiarity with biopower plants among policymakers, local authorities, and resource owners, the demonstration of successful examples of biomass facilities is essential to help build public confidence and increase market growth.

**Standards** – Technical best practices for biomass plants are similar to those for any type of steam, gas turbine, or internal combustion engine plant. Gone are the days of completely unregulated power plant development. Virtually every country now requires power plant developers of all types to meet ISO, IEEE, and other widely recognized standards to help ensure safety, performance, and environmental protection. Best practices for direct combustion and anaerobic digester plants are, for the most part, identical to those for coal and natural gas-fired plants, including hazardous material handling and disposal, wastewater treatment, storm water retention, and emissions controls. These actions include meeting recognized safety and efficiency standards for combustion, hazardous waste retention and storage, steam systems, motors and heat exchangers, among others.

**Hazardous materials handling** – Hazardous waste production creates significant issues for biomass facilities that must be handled carefully. These include disposal of ash and minerals from direct combustion plants, the concentrated tars and other substances produced in pyrolysis and gasification processes, and the sludge produced in anaerobic digester plants. But biomass facilities also have the same hazardous waste issues as conventional power plants, such as ammonia handing for emissions control. These facilities must be designed to ensure the safety of operators and the community, following internationally recognized engineering standards.

**Storm water retention** – Heavy rains can cause water to wash through a biomass facility, carrying toxic waste and chemicals onto neighboring land, and into drainage systems and other places where they can do harm. Storm water retention basins are needed to protect surrounding lands from contamination due to runoff from the power plant site. Even the best maintained systems can have inadvertent leaks or spills of oils and other contaminants, so plants must be prepared to deal with such situations.

**Photo credit:** NREL
Focus on sustainability

- Forest and field management
- Replace nutrients in fields
- Select fuel with high heat rate & low emissions
- Promote carbon neutrality

Poplar grown for biomass fuel
Best Practices – Feedstocks

Forest and Field Management – Feedstock best practices begin in the field, with sustainability being the key goal, both for the environment and the provider. Brazil, for instance, has placed considerable emphasis on finding the right balance of taking as much cane waste (tops and leaves) as possible from the field for biopower production, while leaving a sufficient amount to sustain operations in the field. The national government in Brazil has published extensive guidelines for best practices in sugar cane fields, and farmers are using them because they see the benefits almost immediately. Croatia and Finland have similar guidelines for their extensive forestry industries. Whether applied to a field or a forest, sustainable practices are essential to control erosion and noxious weeds, and to minimize water, herbicide, and pesticide use and expense.

Replace Nutrients in Fields Where Waste was Removed – Another critical issue is replacing the nutrients in fields where crop wastes were removed. Burning of chaff, hulls, and other crop residue has been practiced for centuries in many areas of the world, while in others the residue is left in the field and plowed under to decay into compost. If that waste is removed to use as a fuel, other nutrients must be put back into the soil.

Best practice includes leaving some waste in the field. In addition, many biomass plants produce a byproduct, such as sterilized animal waste from anaerobic digesters, or biochar from pyrolysis plants, that make excellent fertilizers for local farming operations. The key to sustainability lies in continuous, ongoing work with feedstock providers to improve their operations and lower their costs.

Select Fuel with High Heat Rate and Low Emissions – Proper moisture control is important for feedstocks, especially for direct combustion and most pyrolysis and gasification plants, which generally must use low-moisture content fuels only. Anaerobic digester plants, as well as some gasification plants using hydrothermal processes, require higher moisture content, and their components must be designed accordingly to withstand the corrosion caused by the higher moisture. Municipal solid waste must be sorted to remove valuable recyclables, as well as hazardous and toxic materials, before the remaining waste can be burned or converted to synthetic biogas.

Whatever the feedstock source, ensuring proper moisture and heat content (heat rate, or the amount of heat produced per kilogram of combusted material) in the feedstock, and designing and controlling the feedstock accordingly, is of prime importance. High moisture content greatly reduces combustion efficiency and increases costs in direct combustion and most pyrolysis and gasification plants. In tropical nations high ambient humidity levels can greatly increase the moisture content of the feedstocks. This is why measurement of moisture content is critical. The International Standards Organization has established standards and procedures for measuring the moisture content of crops or crop residues and wood waste, and most nations now require biopower plants owners to follow these standards. Biomass plants can be designed to use feedstocks of any moisture level, but high moisture feedstocks require significantly more expensive boilers because extra corrosion protection is needed, such as insulated brick lining and grate feeders made of corrosion-resistant alloys. High moisture levels also greatly reduce the heat content of the feedstock, requiring significantly more (often double) fuel than for dry feedstock.

Once the moisture content and heat rate is established, the boiler feed rate (or biogas converter feed rate) is calculated, and adjusted as necessary to meet heat and power objectives. Best practices for feedstock also continue through the entire chain, however, by ensuring that hazardous wastes are kept to a minimum, separated from useful waste products, and then
Promote Carbon Neutrality – The latest best practice, still in its nascent state, is promoting carbon neutrality. Without carbon neutrality implemented as a best practice, some carbon benefits can be lost. A key example is in the transportation of feedstock to the plant. Truck travel generally has a far greater carbon footprint than rail, and rail has a larger footprint than shipping. A comprehensive effort is needed to ensure carbon capture opportunities are not lost.

Photo credit: NREL
• Sustained contact with local officials, labor, industry, and community leaders

• Need for a local “champion”

• Education and training for farmers, plant operators and local community

• Benefits to local community
Successful biopower projects must cultivate relations with local officials, labor and industry groups, and community leaders. Even more important than forming this triad is sustaining it. Too often, after financial incentives and outside expertise are gone, local support dries up and projects end up in ruin. Conversely, many projects that are designed and implemented solely on the local scale suffer because of a lack of expertise and focus. The most successful biomass projects are sustained joint public/private efforts.

**Need for Local “Champion”**

Successful projects must have good relations with local leaders, as local labor cooperation is essential in building the project and ensuring a sustained feedstock supply. Quite often, developers point to “local champions” as crucial in promoting biomass development on the local, regional or even national level. These include civic, religious, non-governmental organization, and labor leaders. Having a local leader with strong support among the community has been essential for many projects and the industry in general, especially in those areas where persistent effort was needed to overcome deep-rooted problems, such as poor public perception of the industry due to past failures.

**Education and Training**

Though strong leadership and outside expertise often are essential to get a project through permitting, engineering, procurement, and construction, once a project is established the local community can successfully operate and maintain the plant, but only with sufficient education and training for plant operators and the community in general. This includes training for farmers providing waste products or dedicated crops, technical training for present and future operators (such as vocational training at local schools), public information to promote the project and industry in general, and ensuring the project provides as many benefits as possible for the local community, as well as for the project owners.
• Biomass Resources & Technologies
• Global Status
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• **Success Stories**
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Success Stories
SUCCESS STORY: INDIA

- Biomass plants utilizing agricultural and wood waste
- Biomass gasification electricity application
- Incentives for rural electrification

Producer gas engines at 1 MW plant in Tamil Nadu State

100 kW biomass gasifier at Gosaba Rural Energy Cooperative, West Bengal State
Success Story: India

The government of India strongly encourages development of biomass energy, at both the national and state levels. All renewable energy policy and regulation is under the jurisdiction of the Ministry of Non-Conventional Energy Source (MNES). MNES estimates that biopower potential in India is 19,500 MW. MNES has backed R&D efforts on new biomass technologies, resource assessment, and system modeling of the biomass energy sector. As a result, India is now one of the leading countries in biomass energy development, with more than 1,000 MW of installed generating capacity.

Biomass plants in India use rice hulls, cane trash, coconut fronds and shells, wood waste, and dedicated material from tree farms. A 4.5 MW plant in Karnataka is a typical example. It consumes about 150 tonnes of biomass per day to generate approximately 100 MWh of energy. The facility uses cane trash, coconut fronds, rice hulls, sawmill waste, and eucalyptus firewood as fuel. The ash collected from the boiler is processed and used as organic fertilizer.

Biomass gasification has become the favored type of biomass energy production technology because it provides both electricity and fuel for cooking. Development of alternative cooking fuels is considered vital to the overall success of biomass energy development in India, since such fuels improve the lives of residents who previously spent tremendous resources procuring cooking fuel and reduces competitive pressure on the use of biomass for power production.

Hundreds of biomass gasification power plants have been installed in India in recent years, for both mini-grid rural electrification and for supply to the main grid. Most are small, ranging from 100 kW to 1 MW, and use a wide variety of feedstocks, including agricultural waste, human and animal waste, and Juliflora, a common legume woody weed. Many of the facilities are dedicated to a single use, such as irrigation pumping or electrification of a school. Biogas created from animal manure has the added benefit of sterilizing the manure, producing a valuable fertilizer.

Incentives for biomass gasification and electricity production in rural areas vary depending on the plant capacity, ownership, and location. In the case of an electricity plant owned by the community, up to 90% of the total initial cost is borne by the national government, with the rest met by the community, local, or state government.

Gosaba Power Plant – Many community-owned plants are located in remote areas, such as the marshes and islands of the Delta Region of the Sunderlands in West Bengal state, where more than two-thirds of the area’s three million residents previously lived without power. A typical example is the island of Gosaba, about 80 km south of Kolkata. Previously, Gosaba had only a few diesel generators for individual buildings, powered by fuel brought via a 90-minute boat ride from the nearest port. After a 500 kW dual-fuel biopower plant was installed on the island (using 70% biomass and 30% diesel) development increased dramatically. Ten new hotels, dozens of shops, and a bank cropped up to take advantage of the reliable power that was in operation for 16 hours each day. The island is now a shopping center for surrounding communities, as well as a tourist attraction.

The Gosaba plant was 100% funded by the government, but is owned by the Gosaba Rural Energy Cooperative. Fuel comes from local farmers and a 70 hectare energy crop plantation. The plant employs 22 workers. Initial cost of the plant was Rs.100 lakh (about $210,000).

Photo credit: Ministry of Non-Conventional Energy Source (India)
References

- 200. Summary of Biomass Power Generation in India
- 201. An Assessment of a Biomass Gasification Based Power Plant in the Sunderbans
- 258. Biomass Energy Potential and Profits: India
SUCCESS STORY: CROATIA

• 47% land used for forestry

• Wood-processing industry provides fuel

• Increased efforts to use agricultural residues

• Backed by strong national policy

• Will meet national biomass 2020 goal
Success Story: Croatia

Forestry in Croatia accounts for 47% of the country’s land use. A large wood-processing industry provides fuel for district heating, individual stoves, small boilers, and combined heat and power. There is now an increased effort to utilize agricultural residues for both power production and the production of liquid biofuels. This biomass production is backed by strong national policies that include feed-in tariffs for all renewables, currently 0.113-0.164 €/kWh (roughly 14.6 to 21.1 ¢/kWh). Croatia also has renewable tax credits and public investment loans for financing. The country is on track for reaching its goal of 15% of energy generation from biomass and waste by 2020.

The ratification of an Energy Law, Energy Market Laws, and an Energy Activity Regulation Law required the production of numerous sub-legislative documents that were completed in 2007. Croatia now has the necessary state policy instruments for renewable energy production, a financial support mechanism, and a statement of the obligations and responsibilities of players in the energy sector. Existing feed-in tariffs for bioelectricity are among the highest in Europe. Growth in biopower development has slowed with the downturn in Croatia’s economy this year, but biomass in Croatia has the technical potential of 50-80 PJ by 2030, second only to hydro among renewable sources.

References

SUCCESS STORY: BRAZIL

- World’s largest sugar producer
- Bagasse fuel is byproduct of sugar production
- 12,000 MW expected by 2014
- Credit lines available to finance new plants and upgrades
- Best practices and new technologies increasing efficiency
- Co-ops building transmission & distribution
- Biomass now competing successfully after incentive phase-out
Success Story: Brazil

Until recently Brazil has focused primarily on developing hydroelectricity as its main source of electric power and as a means to offset the costs of imported fossil fuels for electric power generation. Hydropower currently provides about 75% of the nation’s power needs, down from 92% in 1980. Hydropower development grew steadily in that period, from 15 Terawatt hours (TWh) in 1980 to nearly 450 TWh today. But recent droughts and changes in patterns of precipitation have undermined the reliability of the electricity system, and further development of hydropower deep in the Amazon basin has proven very expensive.

Generating power with biomass resources is one strategy being used to diversify Brazil’s electricity supply. Brazil is the world’s largest sugar producer and bagasse and sugar cane trash are byproducts of sugar production. The Brazilian government, sugar cane farmer co-ops, and power industry associations have teamed together to promote biopower production, focusing especially on the use of sugar cane trash and bagasse. (“Trash” consists of the tops and leaves of the sugarcane plant, which typically are burned off before harvest or removed at harvest and left on the field to decompose. “Bagasse” is the material left over after the sugar has been extracted.) Sugar mills have heavy incentives to self-generate to avoid high retail electricity prices. But increasingly they are seeing the opportunity for additional revenue from excess power sales.

At present, a major activity in the Brazilian power market is upgrading bagasse-fueled power plants to advanced boilers or biomass-gasifier/gas turbine (BIG/GT) technology that has potential to increase efficiency five-fold. Electricity production can be increased from 50-60 kWh/ton for cane processed with conventional high pressure steam turbine technology firing only bagasse, to 250-300 kWh/ton with a BIG/GT system using both bagasse and trash. With new laws and regulations forcing the phase-out of cane burning in the field, and Brazil’s sugar cane crops reaching 315 million tons/year, use of advanced boiler or BIG/GT technology has the potential to reduce CO₂ emissions by up to 40 million tons per year.

Best practices developed for the industry include cost/benefit analysis of trash removal from fields, as trash provides many benefits, including water retention and weed control. A set of guidelines was produced to determine the best balance of trash removal versus leaving the trash in the field, and is now being followed by most major farms.

The country’s state energy administration agency – the Empresa de Pesquisa Energética (EPE) – buys and distributes biopower from the mills and other facilities. EPE held its first exclusive bioenergy auction on April 30, 2009. Under this “green reserve” auction the government sets a price ceiling and companies bid downwards from that point. Besides organizing the auction, the federal government has taken other steps to facilitate and speed up the participation of a large number of sugar refineries, and the industry is expected to grow substantially over the next three years. Brazil had 3,000 MW of installed biomass in 2003, 7,800 MW in 2007, and officials expect to have 12,000 MW installed by 2014.

Brazil’s renewable promotion policies started in 2001 with the Programme of Incentives for Alternative Electricity Sources (PROINFA) that mandated a 10% renewable energy target. Later, Brazil moved away from a renewable energy target to a hybrid feed-in tariff (FIT) policy. Brazil’s FIT mandated favorable rates for up to 3,300 MW of biopower, wind turbines, and small hydro, with rates pegged to the individual capacity factor of each project. Costs associated with PROINFA programs were recovered through surcharges on utility bills, with low-income customers exempted from those surcharges. Additionally, the National Bank for Economic and Social Development (BNDES) offers special financing for renewable projects, providing up to 70% of the capital costs (excluding site acquisition and imported goods and services) at interest
rates of 2% of basic spread and up to 1.5% of risk spread. No interest is charged during construction. Further, because many sugar refineries are in isolated areas without transmission access, farm and industry co-ops have formed to finance and build transmission and distribution lines to connect mills to the grid.

The current government of Luiz Inácio ‘Lula’ da Silva appears to be steering away from the feed-in tariff toward a tendering system, in which renewables must compete directly with all other sources of power in a price-only auction. The da Silva administration especially criticized the lack of progress in wind power development under the FIT plan, which was much slower than expected. Many of the incentives provided under PROINFA expired at the end of 2008, and the government has not yet released a replacement policy.

However, the incentives and financing provided under PROINFA and from the private sector helped spawn a biopower industry that continues to thrive, even though it is now competing head-to-head with hydropower and imported fossil-fueled power. The industry appears poised to continue growing and competing even without significant government support, largely thanks to the technological improvements in conversion and generating technology and to the high cost of retail electricity. Introduction of a worldwide carbon offset market is likely to further spur the industry.

References

- 202. Biomass Power Generation: Sugar Cane Bagasse and Trash
- 203. Renewable Energy Policy Brazil