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Review

Biomass Energy

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Abstract: To many people, the most familiar forms of renewable energy are the wind and the sun. But biomass (plant material and animal waste) is the oldest source of renewable energy, used since our ancestors learned the secret of fire. Until recently, biomass supplied far more renewable electricity or "biopower" than wind and solar power combined (Washington, 2008). If developed properly, biomass can and should supply increasing amounts of biopower. In fact, in numerous analyses of how many countries can transition to a clean energy future, sustainable biomass is a critical renewable resource (Rachel, 2009a). Biomass is a renewable energy source not only because the energy it comes from the sun, but also because biomass can re-grow over a relatively short period of time. Through the process of photosynthesis, chlorophyll in plants captures the sun's energy by converting carbon dioxide from the air and water from the ground into carbohydrates complex compounds composed of carbon, hydrogen, and oxygen.

Keywords: Biomass, Energy, Biopower

1. Introduction

Biomass covers a whole gamut of energy forms. The definition of biomass is vegetable or plant matter, sometimes animal, that can be converted into an energy source. Other fuel terms which also have biomass as their basis are biofuel, vegioil, bioenergy, bioethanol, biogas & etc. The great advantage of biofuels is that they are considered to be 'carbon neutral' that is that they use up as much carbon dioxide during growth, as they expend as a fuel. Biomass is a little-used term by the public generally, but when you think of wood fires and wood burning stoves it is easy to see that biomass fuel has been in use for centuries. Sourcing Biomass fuel can be sourced from waste or by-products from industrial or agricultural industry: such as wood waste from forestry or furniture industries; straw remains from wheat crops; chicken litter; sewage; manure; used vegetable oil. Other crops are multifunctional where parts of the plant can be used to generate different forms of energy. For example, wheat ears can be used to create bioethanol and biodiesel, whilst the straw can be utilized in generating electricity.

1.1. Types of Beneficial Biomass

Most scientists believe that a wide range of biomass resources are "beneficial" because their use will clearly reduce overall carbon emissions and provide other benefits. Among other resources, beneficial biomass includes

i. energy crops that don't compete with food crops for land
ii. portions of crop residues such as wheat straw or corn Stover
iii. sustainably-harvested wood and forest residues, and
iv. Clean municipal and industrial wastes (Tilman, 2009).

2. Biomass Energy Crops

We face unprecedented challenges to our environment, our economy, and the future security of energy supply. Decisions we make now will affect the planet and the quality and way of life for generations to come. Energy crops can be used for a range of energy markets, for dedicated biomass power stations or co-firing at existing coal power stations. On a smaller scale the crop can be burnt directly as chip on farm to generate heat, qualifying under the Renewable Heat Initiative or dandified into energy crop pellets for use in dedicated boilers at home or in business. For example, an approved 60Kw Biomass boiler installed to provide heating and hot water for a small office block would only require 3 hectares of locally grown Miscanthus as its sole fuel, or less if supplementing local wood supply, that would deliver significant savings over conventional fossil fuel based sources, and provide approximately £6,000 p.a. of RHI payment, related to actual use, which is metered. Currently most biofuels are produced from food based crops like maize, wheat and rape. However, scientific advancements mean that Miscanthus can be used in second generation biofuels using lingo cellulosic conversion. Miscanthus produces significantly lower CO_2 emissions per unit of fuel than many other crops. As it also produces higher yields per hectare of land, much less land is required, enabling more land to be used to produce food crops for consumption.

3. Biomass Grasses

Conventionally, most solid biomass heating fuels wood chips, wood pellets, and cordwood came from forests and the forest products industry. Over the past 15 years, however, growing crops (both herbaceous and woody) specifically for energy has gained widespread appeal, and perennial grasses such as Switch grass, Miscanthus, and Reed Canary Grass present exciting new renewable energy options. Perennial grasses are now being used as a solid fuel in co-fired coal power plants as well as targeted as a choice feedstock for such advanced biofuels as cellulosic ethanol. Despite this focus on generating electricity and producing liquid fuels, perennial grasses can also be pressed into pellets, briquettes, and cubes and used as a heating fuel to replace or complement fuels made from wood fibers. Including a thermal component in the use of solid biomass for energy increases a combustion system's efficiency more than threefold.

4. Evolution of Grass Energy

In the late 1800s, grasses were widely used as a heating fuel in the prairie regions of the United States, an area with little forested land. Farmers in these areas relied on harvested straw and prairie grasses, or "prairie coal," which were often twisted into bundles and burned in simple stoves.

Today, modern solid biomass heating systems are highly engineered, automated, and clean-burning. Like the existing wood pellet market in Europe and the developing market in the United States, grasses may soon be pelleted and delivered in bulk by a special tanker truck, pneumatically blown into storage systems, and automatically fed into the combustion system with no manual labor required.

5. Benefits of Using Grass for Energy

Perennial grasses have many benefits as a bioenergy crop. The simplest way to think of grass is as an efficient and fast growing solar energy collector that is relatively easy to grow, harvest, and process. Grasses not only sequester and store vast amounts of carbon in the root systems and soil, but conveniently occur globally in a wide range of geographies, climates, and soil types. Grasses can be grown on marginal lands ill-suited for continuous row crop production and/or in open rural land currently not in agricultural production. They yield more biomass per acre, and, once established, require far fewer inputs in comparison to annual crops that require more diesel, fertilizer, and pesticides. Additionally, perennial grasses grown for energy can provide a new revenue stream and profit center to farmers and other landowners, and afford important water quality and wildlife benefits. Grasses and other agriculturally produced crops can be grown easily (with conventional equipment), quickly, and in large acreages and volumes. This can help increase the production of biomass fuels by utilizing local resources. Soil erosion, water quality, and wildlife benefits can also be enhanced depending on what type of land and current crop cover is converted to energy crops. Energy studies indicate that significant gains in energy return and reducing carbon emissions can be achieved with using Switch grass as a biomass fuel. Switch grass used for heating has an energy output to input ratio of at least 10 to 1, compared to other bioenergy sources with output to input ratios around 1 to 1. A recent study determined that one acre of farmland is capable of producing an average annual yield of herbaceous biomass sufficient to meet the annual space- and water-heating needs of an average home. An existing energy prospect, with planning and conservation, is the ability for communities to produce their own heating fuel through local farmers growing grasses and farm supply cooperatives (or other aggregating businesses) densifying and delivering fuel. The most promising areas for development of a grass-based energy industry are the north central and northeastern regions of the United States, where there is sufficient agricultural land base and heating costs are high due to long winters. As an alternative fuel for heating, grasses have Btu levels approximately 95 percent of wood. Densified grass fuel is competitive in price with fuel oil, natural gas, propane, and electricity.

5.1. Choice Grasses for Fuel

No one grass species can be grown effectively in all regions and climates, however, the most broadly considered grasses for energy production are Switch grass (and other native prairie grasses such as Big Bluestem and Prairie Cord grass). Miscanthus, a super high-yielding crop, has garnered much interest and is now being studied. Reed Canary grass is often naturally present and high yielding in wet, marginal areas, however, it is also recognized as invasive—choking out other native wetland species—so its use as an energy crop is more contentious. Each has its own benefits and disadvantages as a biomass fuel source (see panel at right).When considering which is the best choice, the first consideration is generally the yield per acre in any given microclimate/soil type, as this greatly influences the economics of conversion of the crop to a useful form for energy extraction. Another consideration is the mineral/ash content of a given grass on a given plot, which may affect the value of the crop as a dandified fuel for thermal applications. Another consideration may be harvest windows as influenced by local climates. Grasses have 95 percent of the Btu value of wood and several pioneering companies are beginning to produce high-quality grass pellets for heating. Historically, since biomass combustion systems were designed around wood, simply substituting grass for wood in the same combustion system will generally not produce satisfactory results. Grasses have higher ash content and a different chemical composition, therefore distinct combustion systems are needed to handle these differences. During combustion, higher chlorine and potassium levels in grasses vaporize and form salts on boiler walls. These salts can cause 'clinkers' (incombustible residues) in systems not specifically designed to handle grasses, reducing performance markedly. At both the commercial and residential scale, there is a growing number of equipment manufacturers producing multi-fuel combustion systems that show promise, e.g., 80-90 percent efficient “close-coupled” gasified pellet stoves and multi-fuel stoves and furnaces capable of burning moderately high ash pelleted fuels.

6. Manure

Manures collected from animals such as cattle and pigs during periods of the year when they are housed, typically contain 6-10% dry matter and so are not appropriate for combustion or gasification without energetically and financially costly drying. They are also inefficient to transport any distance or store owing to the high proportion of water. However some energy technologies make use of biomass in an aqueous slurry, and these can make efficient use of such 'wet' materials. The high water and low dry matter content means that the most appropriate energy technology for making use of animal slurries is anaerobic digestion for the production of biogas. Dairy cattle typically produce between 42 kg and 64 kg (depending on body weight) of manure per day, so if they are housed for 50% of the year that corresponds to 7.6-11.6 tones pa per cow. Between them the UK herd of 2 million dairy cows produces around 20 million tones of slurry, equivalent to around 2 million tones of dry matter (at 10%). There are also 4.9 million pigs in the UK and 20 million sheep. However, as sheep are kept almost entirely outdoors collecting their manure may not be practical. Animal slurry is widely used as a fertilizer and there are a number of methods to spread it on the land, though recent concerns about loss of ammonia to the air means that Defra now advises against broadcast spreading. Growing environmental concerns coupled with higher energy prices have led to a renewed interest in using animal manure, also known as feedlot biomass, to produce power. This can be accomplished either by burning manure directly for fuel, gasifying it with heat or by turning it into “biogas” through biological decomposition. The best approach to using animal wastes for power depends on the amount of moisture and essentially non-biodegradable solid materials including dirt (generally called ash) mixed with the manure to be used as a feedstock. Each of these methods disposes of large accumulations of manure while mitigating its possible negative environmental effects. Environmental benefits to processing manure into fuel include cleaner air and water. Methane has a global warming effect that is 21 times that of carbon dioxide, so using the methane for energy production significantly reduces greenhouse gas emissions. And because manure that is used in the biogas plant is not washed off land surfaces into local rivers and streams, the local watershed also benefits. Manure also can be used to reduce emissions from traditional fuels. Dry manure has long provided heating and cooking fuel for rural societies. If the water content of manure is low enough (less than 20%), dry manure can be burnt directly. Solid, dry manure includes manure from beef feedlots and dairy dry lots. Burning dry manure can also release energy for the production of biogas. While supplying its own energy needs, a cattle feedlot operation could also solve its manure disposal problem, reduce odors, provide jobs, and increase the local tax base - all by installing a manure-to-energy generator on site. In addition, biogas from manure can be captured and purified to yield pipeline grade methane that is chemically the same as natural gas. Pipeline grade methane can be transported by pipeline for sale to the local power grid to run electric generators (http://www.seco.cpa.state.tx.us/energy-sources/biomass/manure.php).

7. Woody Biomass

The use of biomass to produce energy is becoming more and more frequent as it helps to achieve a sustainable environmental scenario. Woody biomass comprises residues of the wood processing industry, post-consumer woody waste materials and agricultural residues in addition to material arising from forest management or fuels reduction activities. Forest biomass consists of small-diameter woody material, damaged or low-valued trees, the branches (slash) and diseased or insect infested wood. This material represents a huge untapped biomass resource and its removal could improve forest health and reduce the risk of catastrophic wildfire (Fred. D, 2010).

Much of the forest biomass resource is not currently utilized due to its poor physical properties and therefore relatively low value. The expense of removal and transportation further reduces its appeal as a raw material. Developing more markets and processing technologies to use this material would help to recover some of the cost of ecosystem restoration and fuels reduction projects (Stiefel. M, 2007).

The challenges for using woody biomass are many and the economic opportunities limited. Although there is a long list of products that could be produced from woody biomass there are often competing raw materials to make these products that are of higher quality and lower cost. The solutions to providing more opportunities for woody biomass are to encourage the use in efficient energy conversion facilities (power plants, heat and power systems, etc.), use small diameter trees in their round form instead of trying to produce lumber, support the research and development needed to encourage investment in higher value fiber uses for composite materials (such as composite panels and wood fiber/plastic products), and continue the search for cost-effective chemical processing to biofuels and other organic chemicals (Stiefel.M, 2007, 2010).

7.1. Forest Residues

Forest residues consist of small trees, branches, tops and un-merchantable wood left in the forest after the cleaning, thinning or final felling of forest stands, used as fuel without any intermittent applications. Three main sources of forest residues can be distinguished: slash from final fallings, slash and small trees from thinning and cleanings, and un-merchantable wood. In Sweden for example, slash from final fallings constitutes the largest share (over 71% in 1996 and even more dominating in 2003).

Terrain chipping

Chipping at a landing (generally roadside chipping)

Terminal chipping

Chipping at plant

Combination in the terrain, or at the source, requires a highly mobile chipper suitable for cross-country operations and equipped with a tippable 15–20 m3 chip container. The chipper moves in the terrain on strip roads and transfers the biomass with its grapple loader to the feeder of the chipping device. The load is hauled to the road side and tipped into a truck container, which may be on the ground or on a truck trailer. Large landing areas are not required, but a level and firm site is necessary for the truck containers. When large volumes of forest fuels are produced, the terrain chipping system becomes difficult to control. At present, the role of this system is diminishing (http://www.eubia.org/index.php/about-biomass/biomass-procurement/recovery-of-forest-residues).

Comminution at a landing is the traditional option of forest chip production. The biomass is hauled by forwarders to the landing and bunched into 4 to 5 meter high piles. The forwarder operates independently of the chipper. Comminution is performed at the landing using farm tractor-driven chippers in smaller operations and heavy truck-mounted chippers or crushers in large-scale operations. Landing chippers do not operate off-road and can therefore be heavier, stronger and more efficient than terrain chippers. To avoid the system from "over-heating", the truck-mounted chipper and chip truck can be replaced by a single chipper truck. This blows the chips directly into a container and then hauls the load to the plant. As the chipper truck is equipped with its own chipping device and crane, load capacity suffers and the operation radius around the plant is reduced. On the other hand, as only one single unit is needed, the chipper truck is suitable for small work sites and for delivering chip to small heating plants.

Comminution at a plant makes the chipper and chip truck independent of each other. The technical and operative availability of the equipment increases, control of the procurement process is facilitated, demand for labor is decreased, and the control of fuel quality is improved. Mobile chippers can be replaced by heavy stationary crushers that are suitable for comminuting all kinds of biomass, including stump and root wood and recycled wood. The larger is the fuel flow, the more obvious become the advantages. Since the investment cost is high, only large plants can afford a stationary crusher [9].

When comminution is performed at the plant, truck transportation of biomass takes place in the form of loose logging residues, whole trees or pieces of stump and root wood. The low bulk density of the biomass is the weak link in the system. It is therefore necessary to increase the bulk density of residues.

A new system was developed, where logging residues are compressed and tied into 70 cm diameter, 3 m long bales or composite residue logs. A bale of green residues weighs 500 kg and has an energy content of about 1 MWh. Bales are transported to the roadside using a conventional forwarder and on to the plant using a conventional timber truck. About 12 bales form one forwarder load, and 65 bales or 30 tons form one truck load.

8. Forest Treatments

Forest biomass, generally defined as organic vegetative material, is primarily the excess trees and shrubs that would not be otherwise used for higher value commercial products or needed for environmental protection values. Biomass can be used for a variety of products, including composition wood products, paper, compost, bedding materials, crates and other products. It can also be used for generating electricity, providing heat and producing biofuels. Sustainable forest biomass utilization can provide environmental, economic and social benefits. The Pacific Northwest (PNW) is one of the major timber-producing regions in the United States, and the regional capacity to produce wood on a sustained yield basis is widely recognized. However, several key economic, social, and ecological issues relating to sustainable forestry will play an important role in future wood production of the region. To identify and understand important issues for sustainable wood production in the region, input was provided from a series of meetings with a wide array of forest landowners and managers representing forest industry, small private forest landowners, state forestry and others interested in growing and producing wood. These focus groups identified several key issues for sustainable wood production, and then researchers involved with this effort outlined some of the critical research questions relating to barriers and opportunities for wood production in the region (Reinhart. E., et al, 2011).

8.1. Thinned Trees

Demand for biomass is growing rapidly, as power companies come under increased pressure to find alternatives to fossil fuels like coal. (See NRDC's Forests not Fuel site.) One of the main sources they are targeting is trees harvested as part of wholesale thinning operations. Together with the forest biomass industry, they argue that using thinning to fuel their power plants is an environmental win-win: good for forest management because, they assert, thinning reduces the risk of forest fires and good for the climate since trees can re-grow and are therefore a “carbon neutral” fuel source. The pressing need for sustainable sources of energy make the industries’ claims tempting. But the results of a new report from researchers at Oregon State University strongly suggest that even if thinning needs to be done for non-climate reasons, there’s a price to pay in terms of climate pollution, not the win-win claimed by industry. The study looks at the lifecycle carbon emissions impacts of different levels of thinning on forest plots in eastern and western Oregon. It finds that far from providing a "carbon neutral" fuel source, forest thinning increases net carbon pollution in the atmosphere for more than 50 years, even accounting for tree re-growth and the carbon emissions avoided when thinning are used as biomass to displace fossil fuels. Carbon losses on-site account for the bulk of the effect of thinning on carbon. These results hold for multiple kinds of thinning operations across a wide spectrum of forest locations and types in the Pacific Northwest. And while carbon stocks in the forest can, in time, rebound, it may be many centuries or longer before carbon stocks in a thinned forest catch up to one left unlogged. And while the study doesn't consider the impacts of thinning on fire, this factor would likely show further net emissions of carbon. Restoration thinning requires reintroduction of frequent low intensity fires. The total carbon emitted from this series of fires over time is likely to greatly exceed the carbon emissions from one intense fire every 200 years or so. OSU's findings are part of a growing body of science on the lifecycle impacts of biomass that points to the need for our bioenergy policies to distinguish amongst different sources of biomass. Some, like switch grass grown on non-forested land and other short-rotation energy crops, can reduce carbon pollution or achieve carbon neutrality within 1 to 3 years. But others, like whole trees sourced from practices like thinning, will increase carbon pollution for decades or longer, and cannot be considered sustainable. (See our video on the carbon accounting for whole trees.) And this is just looking at thinning. In addition, these operations risk degrading critical wildlife habitat, soil and water quality. Unfortunately, both federal and state policies are failing to differentiate between the good, the bad, and the ugly when it comes to biomass, maintaining a blanket assumption that all biomass—even the worst kinds, like whole trees—are carbon neutral. With a rapidly growing bioenergy industry adding substantial new demand for biomass to the existing market for forest products, the pressures on our forests have never been greater (Nathanael. G, 2011).

8.2. Short-rotation Trees

Wood from trees is a biomass fuel that has been used for millennia and it is therefore natural to consider trees as potential energy crops. Conventional forestry, however, operates on a relatively long time scale. This involves committing an area of land to forestry for many decades, with the bulk of the income from the investment not realisable for many years, which provides poor cash flow. If the primary purpose is not the production of timber for saw logs, but for energy, then there is not the requirement to operate on such a long time scale. In addition, the annual rate of increase in biomass per hectare tends to be greater when trees are only a few years old than later in their lifetime, although this varies from species to species. Consequently, there is considerable interest in short rotation operations that harvest fast growing trees for biomass when they are just a few years old. As the stems are harvested young, the biomass produced tends to have a relatively high proportion of bark. While short rotation coppicing (SRC) cuts the tree back to a stool to promote the growth of multiple stems, on a regular cycle of roughly 2-4 years, it is also possible to practice something more closely akin to conventional forestry, though on a shorter timescale. Short rotation forestry (SRF) consists of planting a site and then felling the trees when they have reached a size of typically 10-20 cm diameter at breast height. Depending on tree species this usually takes between 8 and 20 years, and is therefore intermediate in timescale between SRC and conventional forestry. This has the effect of retaining the high productivity of a young plantation, but increasing the wood to bark ratio. It is currently proposed that the stem wood only would be removed from the site, with bark stripped during harvesting and left on site with other residues to return nutrients to the soil (Raffaele S, 2010).

9. Urban Wastes

During the course of everyday living, society generates a number of waste products including glass, plastic, paper, aluminum and other metal cans, yard clippings, wood, construction materials, etc. Household garbage (trash) and some commercial wastes (such as paper, cafeteria food wastes, etc.) are termed municipal solid waste (MSW) and are disposed of in MSW landfills. The construction of new buildings and structures along with the renovation, remodeling, and demolition of existing buildings and structures generates construction and demolition wastes (C&D) which are mostly disposed of in C&D landfills, although some (generally remodeling wastes from home do-it-yourself activities) are also disposed of in MSW landfills. The wood component of MSW and C&D wastes either alone, or combined with other organic components (refuse derived fuels) can be recovered and used for bioenergy and bioproducts. Additional urban biomass resources include the capture of gases produced by the decay of organic materials that have been land filled, and biosolids generated in the wastewater treatment of sewage. The wood component of MSW includes durable wood components (e.g., cabinets, furniture), packaging materials (e.g., pallets, crates) and some construction materials. Yard trimmings are mostly leaves and grass, but about 25% is wood. Estimated MSW wood quantities generated vary by study, ranging from 19 to 34 million green tons. Much of the wood waste is in a format not readily useable and must first be sorted and processed, is contaminated (e.g., painted, stained, pressure or chemically treated), or if clean, already collected and used to produce other products (e.g., mulch, recycled pallets, firewood, etc.). When these considerations are accounted for, estimated quantities available for bioenergy and bioproducts are significantly lower and higher priced than frequently assumed. Wood is usually the largest component of construction and renovation wastes and is a small component of demolition wastes. Construction wastes are generally cleaner, less contaminated, and more easily sorted at the generation site than demolition wastes and are therefore more readily useful for bioenergy and bioproducts. Renovation wastes are intermediate to construction and demolition wastes. Estimated combined construction and renovation wood waste quantities range from 9 to 23 million green tons and estimated demolition wood waste quantities range from 23 to 28 million green tons, depending on study. As with MSW, when sorting and processing costs are considered, and contaminated materials excluded, available C&D wood wastes are significantly lower and higher price than assumed.

10. Converting Biomass to Biopower

Biopower, or biomass power, is the use of biomass to generate electricity. There are six major types of biopower systems: direct-fired, coffering, gasification, anaerobic digestion, pyrolysis, and small, modular. Most of the biopower plants in the world use direct-fired systems. They burn bioenergy feedstocks directly to produce steam. This steam is usually captured by a turbine, and a generator then converts it into electricity. In some industries, the steam from the power plant is also used for manufacturing processes or to heat buildings. These are known as combined heat and power facilities. For instance, wood waste is often used to produce both electricity and steam at paper mills. Many coal-fired power plants can use cofiring systems to significantly reduce emissions, especially sulfur dioxide emissions. Cofiring involves using bioenergy feedstocks as a supplementary energy source in high efficiency boilers. Gasification systems use high temperatures and an oxygen-starved environment to convert biomass into a gas (a mixture of hydrogen, carbon monoxide, and methane). The gas fuels what's called a gas turbine, which is very much like a jet engine, only it turns an electric generator instead of propelling a jet. The decay of biomass produces a gas - methane - that can be used as an energy source. In landfills, wells can be drilled to release the methane from the decaying organic matter. Then pipes from each well carry the gas to a central point where it is filtered and cleaned before burning. Methane also can be produced from biomass through a process called anaerobic digestion. Anaerobic digestion involves using bacteria to decompose organic matter in the absence of oxygen. Methane can be used as an energy source in many ways. Most facilities burn it in a boiler to produce steam for electricity generation or for industrial processes. Two new ways include the use of micro turbines and fuel cells. Micro turbines have outputs of 25 to 500 kilowatts. About the size of a refrigerator, they can be used where there are space limitations for power production. Methane can also be used as the "fuel" in a fuel cell. Fuel cells work much like batteries but never need recharging, producing electricity as long as there's fuel. In addition to gas, liquid fuels can be produced from biomass through a process called pyrolysis. Pyrolysis occurs when biomass is heated in the absence of oxygen. The biomass then turns into a liquid called pyrolysis oil, which can be burned like petroleum to generate electricity. A biopower system that uses pyrolysis oil is being commercialized. Several biopower technologies can be used in small, modular systems. A small, modular system generates electricity at a capacity of 5 megawatts or less. This system is designed for use at the small town level or even at the consumer level. For example, some farmers use the waste from their livestock to provide their farms with electricity. Not only do these systems provide renewable energy, they also help farmers and ranchers meet environmental regulations. Small, modular systems also have potential as distributed energy resources. Distributed energy resources refer to a variety of small, modular power-generating technologies that can be combined to improve the operation of the electricity delivery system.

11. Direct Combustion

Giant King Grass is suitable as a fuel for direct combustion (burning) in 100% biomass electricity-generating power plants. Today, biomass power plants are fueled by agricultural and forestry waste such as corn stover, wheat straw, rice husks and wood waste. The price of agricultural waste has increased dramatically in China and India due to market demand, and in many areas, growing Giant King Grass as a dedicated energy crop is less expensive and more reliable than using waste. Agricultural waste is seasonal, because it is only available after the food crop such as corn is harvested. The corn Stover must be gathered over long distances because the yield is quite low, then dried, baled, stored and utilized as fuel until the next agricultural waste crop is available. Reliability, consistency and cost of biomass fuel are the major issues facing biomass power plants today. A dedicated Giant King Grass plantation co-located with a power plant is a cost effective and reliable solution to producing clean electricity. Giant King Grass has been analyzed by DP Clean Tech which has built and operates dozens of biomass power plants in China and Europe. They conclude that Giant King Grass has energy content, physical properties and ash properties very similar to corn stover that they use routinely as a fuel. Other potential customers have analyzed Giant King Grass and have come to the same conclusion. VIASPACE Green Energy is pursuing several opportunities for co-located Giant King Grass plantations and biomass power plants. The fast-growing nature and proven, dependable energy characteristics of Giant King Grass allows power plants to run 24 hours a day, seven days a week without interruption or variable output due to availability or inconsistent performance of the fuel. Direct combustion (or "direct-fired") systems burn biomass in boilers to produce high pressure steam. The steam turns a turbine connected to a generator- the same kind of steam-electric generator used in fossil fuel power plants. As the turbine rotates, the generator turns, and electricity is produced. This is the simplest and oldest way to generate electricity from biomass. To increase the energy-producing efficiency of direct combustion, power plants also operate cogeneration facilities, which capture waste heat and "secondary" steam and use it to heat buildings and provide steam and heat for industrial processes such as ethanol production or drying of chemical and wood products.

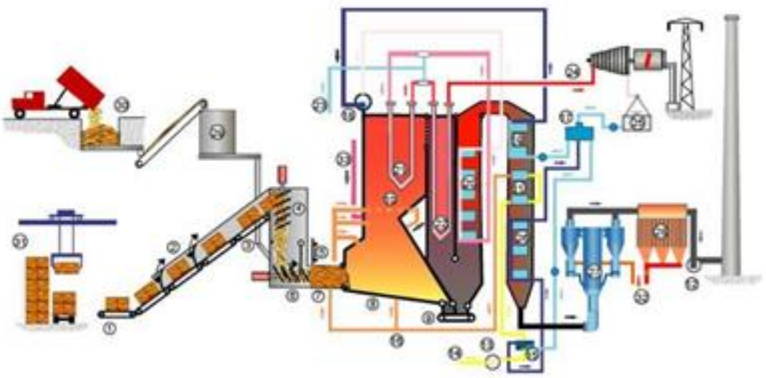

Figure 1: Schematic of Direct Combustion Process. Biomass is delivered and burned in the boiler which heats water into steam that powers a steam turbine and generator. Schematic of Direct Combustion Process. Biomass is delivered and burned in the boiler which heats water into steam that powers a steam turbine and generator.

12. Co-firing

The primary reason for co-firing coal with biomass is as a means of reducing the potential environmental impacts associated with the combustion of fossil fuels. Given that co-firing requires large amounts of biomass fuels, co-firing typically works best with large coal-fueled utilities that have materials handling capability already on site. However, other industrial users – cement plants, heating plants, etc. – could also make use of biomass co-firing (http://www.biomassenergycentre.org.uk/portal). As with other renewable energy sources, biomass cannot compete on an economic footing with coal (or other fossil energies) due to low thermal efficiency, high cost, variable impacts on boiler and milling equipment, and high technical risk. Biomass typically has low bulk energy density, is wet and is strongly hydrophilic and therefore, requires a great deal of fuel handling technology compared to its heating contribution (http://www.energy.psu.edu/factsheets/CoFiringBiomass.pdf). While fuel costs may be low, transportation, preparation, and handling costs for biomass can rapidly exceed total fuel costs for other fossil options. Potential for increased corrosion rates in boilers due to higher alkali levels in biomass fuel. Biomass fuels can have as much as 50% moisture – moisture in a boiler will reduce efficiencies (http://www.bioenergywiki.net/index.php). As ash fusion temperatures for most biomass fuels are far less than coal ash fusion temperatures (as low as 750 Celsius vs. over 1,000 Celsius for coal) there is a strong possibility that the rate and extent of boiler slagging will increase .Negative impacts on fly ash usability as ASTM specifications require that fly ash be derived wholly from coal combustion. Initial tests indicate a need for updating this specification as biomass-containing fly ashes behave in a manner similar to coal only fly ashes (http://www.ieabcc.nl/database/cofiring.html; http://www.ieabcc.nl/publications/paper_cofiring.pdf). European tests indicate that co-firing with biomass can have a significant negative impact on SCR catalysts (deactivation) if not managed properly. Co-firing is the process of replacing part of the fossil fuel supplied to a power station or boiler with a 'carbon lean', renewable alternative (http://www.ieabcc.nl/database/cofiring.php). Usually it is used to refer to the use of solid biomass within coal fired power stations, however co-firing of vegetable (mainly palm) oils to substitute heavy fuel oil (HFO) is also undertaken, and co-firing of other potential befouls such as tall oil from the paper industry, pyrolysis oil or producer gas is also possible. Co-firing coal with biomass is a potentially valuable tool to help decrease greenhouse gas and other emissions in coal-fueled boilers. Use of biomass at low to moderate biomass to coal ratios appears to produce the best performance enhancements and can result in overall life-cycle energy consumption reductions, as well as reduced solid waste generation. However, there are many potential obstacles to biomass use that can decrease efficiencies, as well as increase costs, maintenance (corrosion, slagging, etc.), and boiler down time if biomass use is not managed very carefully (http://www.energy.psu.edu/factsheets/CoFiringBiomass.pdf; http://www.treepower.org/cofiring/NREL-lifecycle.pdf).

12. Repowering

Coal plants can also be converted to run entirely on biomass, known as "re-powering." (Similarly, natural gas plants could also be converted to run on biogas made from biomass; see below.)

13. Combined Heat and Power (CHP)

Many electricity generation processes make use of a heat engine. The efficiency of the heat engine depends on the ratio of the input heat of the working fluid to the output heat. This typically requires a form of heat exchanger to transfer heat into a cooling fluid i.e. water or air. Due to the relatively low efficiency of most heat engines, the energy available in this cooling fluid may be two or more times as much as in the electricity generated. This heat energy in most conventional power stations is simply dissipated to air and/or river or sea water, in cooling towers.

Applications of CHP

I. CHP is most suitable when there is year round demand for heat to balance the demand for electricity, but is useful: When there is a requirement for space heating or process heat close to the generator
II. To provide low temperature (up to 90ºC) hot water heating for local district schemes
III. For applications that require (low grade) process heat, especially those that can supply their own fuel (i.e. sawmills and wood process industry which use heat for timber drying and steaming)

IV. At sites such as hospitals, leisure centers, greenhouses, and retirement complexes which have a year round heat demand

V. To provide steam for other industrial applications

VI. Where there is a requirement for environmentally responsible disposal of waste (i.e. sewage sludge, clinical waste or agricultural residue) and where transport costs for disposal are high

VII. To power an absorption refrigerator to provide cooling in summer, giving tri-generation.

The use of renewable fuels for power generation is on the rise, an increase that can be attributed to the price surge and volatility of traditional fuels, as well as a general desire to use more environmentally friendly materials for power generation. Wind, solar, and biomass are experiencing strong market growth, but of these renewable energy sources, only biomass can be used to efficiently produce both heat and power, by fueling a combined heat and power (CHP) system.

One cost-effective approach to sourcing biomass for CHP is to use opportunity fuels—waste materials from agricultural or industrial processes that are available at or close to the CHP site. Utilizing these opportunity fuels may have additional benefits, including displacing purchased fossil fuel, freeing up landfill space, and reducing tipping fees associated with waste disposal. Opportunity fuels include:

i) Biomass such as wood and wood wastes, sawdust, and combustible agricultural wastes.

ii) Biogas created in anaerobic digesters from the breakdown of organic matter such as wastewater sludge or farm waste.

iii) Black liquor: a byproduct of the pulping process.

14. Considerations for a Successful Biomass CHP Project

- **Proximity to fuel source**: Biomass is most economical as a fuel source when the CHP system is located at or close to the biomass fuel stock. In some cases, the availability of biomass in a location may prompt the search for an appropriate thermal host for a CHP application. In other circumstances, a site may be driven by a need for energy savings to search for biomass fuel within a reasonable radius of the facility.
- **Portfolio Standards**: States can use portfolio standards to increase the adoption of renewable energy generation, energy efficiency, and other clean energy technologies. Biomass-fueled CHP represents a permissible renewable energy resource in all renewable portfolio standards. In some states, renewable energy credits can be generated from the use of biomass to power a CHP system, which can provide projects with an additional revenue stream.

- **Grants, loans, or tax credits**: Befouled CHP projects often qualify for additional state incentives that traditional CHP systems are ineligible to receive. Financing is often available for biomass/biogas projects and/or CHP projects through federal, state, and local grants, loans, or tax credits.

15. Biomass Gasification

Wood and other types of biomass can be heated in a restricted supply of air to produce an energy-rich gas. This ‘producer gas’ can be used to run an engine and generator, providing electricity from biomass at village level, or at larger scale. It can also be used as a low-carbon alternative to fossil fuels for heating.

15.1. How Biomass Gasifiers Work

The gasification of biomass takes place in four stages:

i) Drying: water-vapor is driven off the biomass.

ii) Pyrolysis: as the temperature increases the dry biomass decomposes into organic, vapours, gases, carbon (char) and tars.

iii) Reduction: water-vapor reacts with carbon, producing hydrogen, carbon monoxide and methane. Carbon dioxide reacts with carbon to produce more carbon monoxide.

iv) Combustion: some of the char and tars burn with oxygen from air to give heat and carbon dioxide. This heat enables the other stages of the gasification process to take place (Peter Q, et al, 1999).

15.2. How Gasification Systems Are Used

Clean producer gas can be used in either a compression-ignition engine (diesel engine) or in a spark ignition engine (gasoline engine). The engines produce mechanical power which can be used directly, or else to drive an alternator to generate electricity. The compression ignition engine has higher efficiency but most designs need between 10 and 20% diesel for ignition, and cannot run on pure producer gas. Ashden Award-winner Saran Renewable Energy uses producer gas from a downdraft gasifier to run a 128 kW dual-fuel engine and generator, providing an independent electricity source in a village in Bihar where the grid supply is very unreliable. The feedstock for the gasifier is wood and a fast-growing woody native plant called dhaincha. Producing feedstock generates income for local farmers.Ashden finalist Husk Power Systems has recently commercialized a 35 kW compression-ignition engine that runs on pure producer gas. Each downdraft gasifier and engine provides power to about 500 households and small businesses through a local grid, usually in places which have never been reached by the mains grid. The main fuel used for these gasifies is readily-available rice husk. This is a tricky material to gasify, and successful operation is achieved by a rigorous cleaning and maintenance programme.Producer gas can also be burned to provide heat for rural industries, such as cardamom drying and silk reeling, where a high degree of temperature control is required. Used in the way the gas does not require the amount of cleaning that is needed to burn it in an engine (Chopra. S, 2007).

16. Potential for Biopower

Biopower uses biogenic materials to produce electricity for industrial and commercial consumption. woody biomass produces 67 percent of electrical power while biogenic municipal solid waste (MSW), landfill gas, and agricultural and other byproducts produce the remaining 33 percent (EIA, 2010). Regional fuel sources, ecologic variation, and productivity levels strongly influence biomass production and markets, such as with agricultural waste biopower production development closest to areas with strong agriculture markets recent improvements in biomass collection and storage, and in the development of feedstock markets, have reduced the economic and logistical constraints that limited biomass growth in the past. Increased production, sales, and shipments of wood pellets is one example of a growing biomass market. Overall, biopower is widely distributed across the world with power plants in all regions, though primary fuel sources vary regionally.

As with many large power projects, high capital costs can be a limitation to implementing biopower technology solutions. However, because of the range of technologies available, including incorporation into existing systems, biomass configurations may be more readily available than other types of renewable that require independent infrastructure. For example, capital costs for co-feed, a type of co-firing plant that mixes biomass with coal prior to grinding, are the least expensive of all biopower options (Billion, 2011). To more accurately compare costs of various technologies and fuel sources, the levelized cost of electricity (LCOE) takes into account equipment costs, discount rate, economic life, feedstock costs, operating and maintenance, and efficiency.

17. Anaerobic Digestion

Anaerobic digestion is a collection of processes by which microorganisms break down biodegradable material in the absence of oxygen (http://www.ieabcc.nl/publications/paper_cofiring.pdf). The process is used for industrial or domestic purposes to manage waste and/or to produce fuels. Much of the fermentation used industrially to produce food and drink products, as well as home fermentation, uses anaerobic digestion. Anaerobic digestion occurs naturally in some soils and in lake and oceanic basin sediments, where it is usually referred to as "anaerobic activity" (Koyama. T, 1963; Macalalag. M, et al, 1973). This is the source of marsh gas methane as discovered by Volta in 1776 (Alexander J. B. 1978; MacGregor, A. N., 1973). The digestion process begins with bacterial hydrolysis of the input materials. Insoluble organic polymers, such as carbohydrates, are broken down to soluble derivatives that become available for other bacteria. Acidogenic bacteria then convert the sugars and amino acids into carbon dioxide, hydrogen, ammonia, and organic acids. These bacteria convert these resulting organic acids into acetic acid, along with additional ammonia, hydrogen, and carbon dioxide. Finally, methanogens convert these products to methane and carbon dioxide (Stiefel. M, 2007). The methanogenic archaea populations play an indispensable role in anaerobic wastewater treatments (Humenik, F. *et al.* 2007).

It is used as part of the process to treat biodegradable waste and sewage sludge. As part of an integrated waste management system, anaerobic digestion reduces the emission of landfill gas into the atmosphere. Anaerobic digesters can also be fed with purpose-grown energy crops, such as maize (Tabatabaei.M, 2010).

Anaerobic digestion is widely used as a source of renewable energy. The process produces a biogas, consisting of methane, carbon dioxide and traces of other 'contaminant' gases (Jyllands. P, 2011). This biogas can be used directly as fuel, in combined heat and power gas engines (www.clarke-energy.com) or upgraded to natural gas-quality biomethane. The nutrient-rich digestate also produced can be used as fertilizer.

About anaerobic digestion

The products of this process are:

Biogas (principally methane (CH_4) and carbon dioxide (CO_2))

A solid residue (fibre or digestate) that is similar, but not identical, to compost

Liquid liquor that can be used as a fertilizer.

NB The term whole digestate can be used to describe the unseparated fiber and liquor.

AD has been used to process sewage sludge since the 19th century.

It is also the natural process that can break down organic material in pools and marshes to produce marsh gas and in landfill to produce landfill gas.

AD is typically performed on biological material in aqueous slurry. However there are an increasing number of 'dry' digesters.

Using the outputs from the anaerobic digestion of biomass material

The methane can be burned for heat or electricity generation.

The solid residue of the AD process can be used as a soil conditioner, however its properties:

The solid residue can, alternatively, be burned as a fuel, or gasified.

Provided the requirements of the Anaerobic Digestate Protocol the digestate is no longer classified as a waste by the Environment Agency and so handling and storage regulations are eased.

Anaerobic digestion processes

There are two basic AD processes, which take place over different temperature ranges.

Mesophilic digestion takes place between 20ºC and 40ºC and can take a month or two to complete. Thermophilic digestion takes place from 50-65ºC and is faster, but the bacteria are more sensitive. Will depend on the AD feedstock used

May or may not contain useful levels of nitrate or phosphate

May be contaminated with heavy metals.

17. Energy Density

Another important consideration with biomass energy systems is that unprocessed biomass contains less energy per pound than fossil fuels—it has less "energy density." Green woody biomass contains as much as 50% water by weight. This means that unprocessed biomass typically can't be cost-effectively shipped more than about 50-100 miles by truck before it is converted into fuel or energy. It also means that biomass energy systems may be smaller scale and more distributed than their fossil fuel counterparts, because it is hard to sustainably gather and process more than a certain amount of in one place. This has the advantage that local, rural communities will be able to design energy systems that are self-sufficient, sustainable, and adapted to their own needs. However, there are ways to increase the energy density of biomass and to decrease its shipping costs. Drying, grinding and pressing biomass into "pellets" increases its energy density. Compared to raw logs or wood chips, biomass pellets can also be more efficiently handled with augers and conveyers used in power plants. In addition, shipping biomass by water greatly reduces transportation costs compared to hauling it by truck. Thus, hauling pelletized biomass by water has made it economical to transport biomass much greater distances—even thousands of miles, across the Atlantic and Pacific, to markets in Japan and Europe. In the last few years, the international trade in pelletized biomass has been growing rapidly, largely serving European utilities that need to meet renewable energy requirements and carbon-reduction mandates. Several large pellet manufacturers are locating in the Southern US, with its prodigious forest plantation resource, to serve such markets (Pirraglia.A, et al. 2010).

18. Environmental Risks and Benefits

Like all energy sources, biomass has environmental impacts and risks. The main impacts and risks from biomass are sustainability of the resource use, air quality and carbon emissions.

18.1. Sustainability

Biomass energy production involves annual harvests or periodic removals of crops, residues, trees or other resources from the land. These harvests and removals need to be at levels that are sustainable, i.e., ensure that current use does not deplete the land's ability to meet future needs, and also be done in ways that don't degrade other important indicators of sustainability. Because biomass markets may involve new or additional removals of residues, crops, or trees, we should be careful to minimize impacts from whatever additional demands biomass growth or harvesting makes on the land. Markets for corn stover, wheat straw and other crop residues are common and considerable research has been done on residue management. In addition, participation in some federal crop programs requires conservation plans. As a result of established science and policy, farmers generally leave a certain percentage of crop residues on fields, depending on soil and slope, to reduce erosion and maintain fertility. Additional harvests of crop residues or the growth of energy crops might require additional research and policy to minimize impacts. However, because woody biomass is often a low-value product, sustainability standards must be relatively inexpensive to implement and verify. Thankfully, we can improve the sustainability of biomass harvests with little added cost to forest owners through the use of existing forest management programs, including 1) biomass BMPs, 2) certification or 3) forest management plans. Sustainability standards should ensure nutrients removed in a biomass harvest are replenished and that removals do not damage long-term productivity, especially on sensitive soils. Coarse woody material that could be removed for biomass energy also provides crucial wildlife habitat; depending on a state's wildlife, standards might protect snags, den trees, and large downed woody material. Biodiversity can be fostered through sustainability standards that encourage retention of existing native ecosystems and forest restoration. Lastly, sustainability standards should provide for the regrowth of the forest—surely a requirement for woody biomass to be truly renewable.

Air quality

Especially with the emissions from combustion systems, biomass can impact air quality. Emissions vary depending on the biomass resource, the conversion technology (type of power plant), and the pollution controls installed at the plant. The table below from the National Renewable Energy Laboratory and Oak Ridge National Laboratory compares air emissions from different biomass, coal and natural gas power plants with pollution control equipment.

Because most biomass resources and natural gas contain far less sulfur and mercury than coal, biomass and natural gas power plants typically emit far less of these pollutants than do coal-fired power plants. (http://www.eia.doe.gov/oiaf/analysispaper/biomassAS). Sulfur emissions are a key cause of smog and acid rain. Mercury is a known neurotoxin.

18.2. Carbon Emissions

The critical difference between biomass fuels and fossil fuel, is that of fossil and contemporary carbon. Burning fossil fuels results in converting stable carbon sequestered millions of years ago into atmospheric carbon dioxide (when the global environment has adapted to current levels). Burning biomass fuels however, returns to the atmosphere contemporary carbon recently taken up by the growing plant, and currently being taken up by replacement growth. If wood fuel is sourced from well managed woodlands, then carbon released from the wood during combustion will be removed from the atmosphere as the remaining trees and seedlings photosynthesize.

18.3 Beneficial Biomass

Most scientists believe that a wide range of biomass resources are "beneficial" because their use will clearly reduce overall carbon emissions and provide other benefits. Among other resources, beneficial biomass includes

i. energy crops that don't compete with food crops for land
ii. portions of crop residues such as wheat straw or corn Stover
iii. sustainably-harvested wood and forest residues, and
iv. clean municipal and industrial wastes (Tilman. D. et al. 2009).

Beneficial biomass use can be considered part of the terrestrial carbon cycle—the balanced cycling of carbon from the atmosphere into plants and then into soils and the atmosphere during plant decay. When biopower is developed properly, emissions of biomass carbon are taken up or recycled by subsequent plant growth within a relatively short time, resulting in low net carbon emissions.

Beneficial biomass sources generally maintain or even increase the stocks of carbon stored in soil or plants. Beneficial biomass also displaces carbon emissions from fossil fuels, such as coal, oil or natural gas, the burning of which adds new and additional carbon to the atmosphere and causes global warming.

Among beneficial resources, the most effective and sustainable biomass resources will vary from region to region and also depend on the efficiency of converting biomass to its final application, be it for biopower, biofuels, bioproducts, or heat.

18.4. Harmful Biomass

In theory, burning biomass (any kind of plant material) to derive energy is a carbon-neutral endeavor, meaning that the carbon dioxide released during the process is in turn absorbed by other plants and put to use in photosynthesis, and as such does not contribute to the greenhouse effect. Biomass is also flexible: It can be turned into ethanol to power up automobiles, or can be burned like coal to generate heat and/or electricity. Factor in that biomass feedstock is usually inexpensive, widely available and a seemingly perfect alternative to the carbon-spewing, foreign-derived fossil fuels we rely on so much these days. Typically unmarketable trees, brush and logging debris becomes the feedstock for biomass processing plants or for coal-fired power plants equipped to "co-fire" with plant material. But environmentalists warn that some timber companies and their utility and state customers are taking things too far by leveling entire forests—including some within publicly owned national forest land—to generate more feedstock for otherwise underutilized biomass energy production facilities. Among the negative environmental impacts, chopping down forests to burn for ethanol production—even if replanted as tree plantations—is like biting the hand that feeds you. "Natural forests, with their complex ecosystems, cannot be regrown like a crop of beans or lettuce," reports the nonprofit Natural Resources Defense Council, a leading environmental group. "And tree plantations will never provide the clean water, storm buffers, wildlife habitat, and other ecosystem services that natural forests do." Another negative for biomass is that burning it, like coal or anything else, produces air pollution including sulfur dioxide, nitrogen oxides, particulate matter and a variety of toxic substances. According to NRDC, these pollutants increase the incidence of asthma, heart disease, lung cancer and other respiratory ailments, and premature death.

Perhaps most troubling about plans to cut down forests for biomass feedstock is taking carbon neutrality out of the equation, given the fact that tree loss in and of itself is already responsible for some 20 percent of the world's total carbon pollution. "When biomass is harvested from forests, carbon stored in the soil is released into the atmosphere," reports NRDC. "This is in addition to the carbon that is emitted when the wood is burned for energy. And there's no guarantee the lost trees will ever be replaced." NRDC concedes that there is still a place for biomass in the alternative energy universe, but cautions that "only biomass that is carefully chosen, grown responsibly, and efficiently converted into energy can reduce carbon and other emissions compared to fossil fuels." The group would like to see Congress put in place tighter regulations on biomass harvesting and processing. "Biomass can be harvested and utilized in ways that reduce pollution and protect forest habitats, but only with sustainability safeguards and proper accounting for carbon emissions—including carbon released due to deforestation," concludes NRDC.

19. Conclusions

When done well, biomass energy brings numerous environmental benefits—particularly reducing many kinds of air pollution and net carbon emissions. Biomass can be grown and harvested in ways that protect soil quality, avoid erosion, and maintain wildlife habitat. However, the environmental benefits of biomass depend on developing beneficial biomass resources and avoiding harmful resources, which having policies that can distinguish between them. In addition to its many environmental benefits, beneficial biomass offers economic and energy security benefits (http://www1.eere.energy.gov/biomass/biomass_basics_faqs.html). By growing our fuels at home, we reduce the need to import fossil fuels from other states and nations, and reduce our expenses and exposure to disruptions in that supply. Growing our use of beneficial biopower will require policy to guide industry to the right kinds of resources, public confidence that biomass can be a sustainable and beneficial climate solution, and the use of appropriate biomass conversion technologies and applications. There are many potential biomass sources available, with varying advantages and disadvantages. Although municipal solid waste is heavily regulated and faces opposition from the public it does provide a feasible solution to waste production and can prove economically viable for large commercial power plants. Commercial and industrial wastes can provide a large amount of biomass material and is promising for use on the site where it is produced. Forestry production and residues are seen as a very promising biomass fuel source and the conversion process into fuel is comparatively simple, as are the regulations surrounding it. Agricultural residues and wastes have a large potential for use as a biomass fuel. However, some residues, such as slurry, are particularly wet so are more suited to anaerobic digestion onsite, and therefore not widely available. Energy crops are in their infancy at the moment but hopefully with time they will become more popular and the technology and information can be improved for greater yields, thus providing a reliable biomass fuel source for the future.

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