VARIOUS METHODS OF PRODUCING ELECTRICITY FROM BIOMASS

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Abstract: The purpose of this paper is to present modern technologies used to produce electricity using biomass. Description of important technologies which allows the optimal use of biomass resources is given. Article shows many ways to maximize the energy potential which is hidden in the biomass. In the following sections examples of power plants are given, and particular analysis of the main technologies used to generate energy from biomass.

Keywords: renewable energy, biomass energy, biomass gasification, combustion of biomass.

1 Introduction

Biomass, a renewable energy source, is biological material from living, or recently living organisms, such as wood, waste, (hydrogen) gas, and alcohol fuels. Biomass is commonly plant matter grown to generate electricity or produce heat. In this sense, living biomass can also be included, as plants can also generate electricity while still alive. The most conventional way in which biomass is used, however, still relies on direct incineration. Forest residues, for example (such as dead trees, branches and tree stumps), yard clippings, wood chips and garbage are often used for this. However, biomass also includes plant or animal matter used for production of fibers or chemicals. Biomass may also include biodegradable wastes that can be burnt as fuel. It excludes such organic materials as fossil fuels, which have been transformed by geological processes into substances such as coal or petroleum [1].

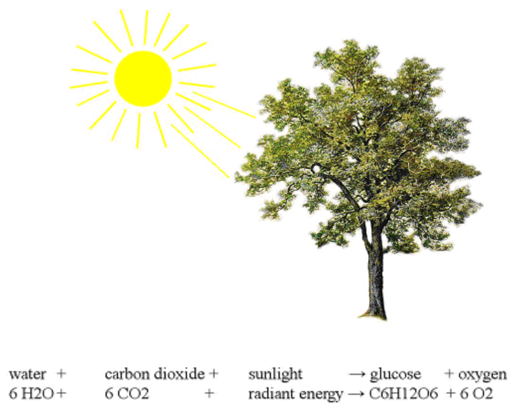

Fig. 1. Chemical process of photosynthesis, source: own

2 Classification of biomass energy

Thermochemical:

a) Direct combustion for immediate heat. Dry homogeneous input preferred.

b) Pyrolysis. Biomass is heated either in the absence of air or by the partial combustion of some of the biomass in a restricted air or oxygen supply. The products are extremely varied, consisting of gases, vapours, liquids and oils, and solid char and ash. The output depends on temperature, type of input material and treatment process. In some processes the presence of water is necessary and therefore the material need not be dry. If output of combustible gas is the main product, the process is called *gasification*.

c) Other thermochemical processes. A wide range of pre-treatment and process operations are possible. These normally involve sophisticated chemical control and industrial scale of manufacture; methanol production is such a process, e.g. For liquid fuel. Of particular importance are processes that break down cellulose and starches into sugars, for subsequent fermentation.

Biochemical:

a) *Aerobic digestion*. In the presence of air, microbial aerobic metabolism of biomass generates heat with the emission of CO2, but not methane. This process is of great significance for the biological carbon cycle, e.g. decay of forest litter, but is not used significantly for commercial bio-energy.

b) *Anaerobic digestion*. In the absence of free oxygen, certain micro organisms can obtain their own energy supply by reacting with carbon compounds of medium reduction level to produce both CO_2 and fully reduced carbon as CH_4. The process (the oldest biological "decay" mechanism) may also be called "fermentation", but is usually called "digestion" because of similar process that occurs in the digestive tracts of ruminant animals. The evolved mix of CO_2, CH_4 and trade gases is called *biogas* as a general term.

c) *Alcoholic fermentation.* Ethanol is a volatile liquid fuel that may be used in place of refined petroleum. It is manufactured by the action of micro-organism and is therefore a fermentation process. Conventional fermentation has sugars as feedstock.

d) *Biophotolysis.* Photolysis is the splitting of water into hydrogen and oxygen by the action of light. Recombination occurs when hydrogen is burnt or exploded as fuel in air. Certain biological organism produce, or can be made to produce, hydrogen in biophotolysis. Similar results can be obtained chemically, without living organism, under laboratory conditions.

Agrochemical:

a) *Fuel extraction.* Occasionally, liquid or solid fuels may be obtained directly from living or freshly cut plants. The materials are called exudates and are obtained by cutting into (tapping) the stems or trunks of the living plants or by crushing freshly harvested material. A well known similar process is the production of natural rubber latex. Related plants to the rubber plant *Herea*, such as species of *Euphorbia*, produce hydrocarbons of less molecular weight than rubber, which may be used as petroleum substitutes and turpentine.

b) *Biodiesel and esterification*. Concentrated vegetable oils from plants may be used directly as fuel in diesel engines; indeed Rudolph Diesel designed his original 1892 engine to run on variety of fuels, including natural plant oils. However, difficulties arise with direct use of plant oil due to the high viscosity and combustion deposits as compared with standard diesel-fuel mineral oil, especially at low ambient temperature (\< ~ 5°C). both difficulties are overcome by converting the vegetable oil to the corresponding ester, which is arguably a fuel better suited to diesel engines than conventional (petroleum-based) diesel oil [2].

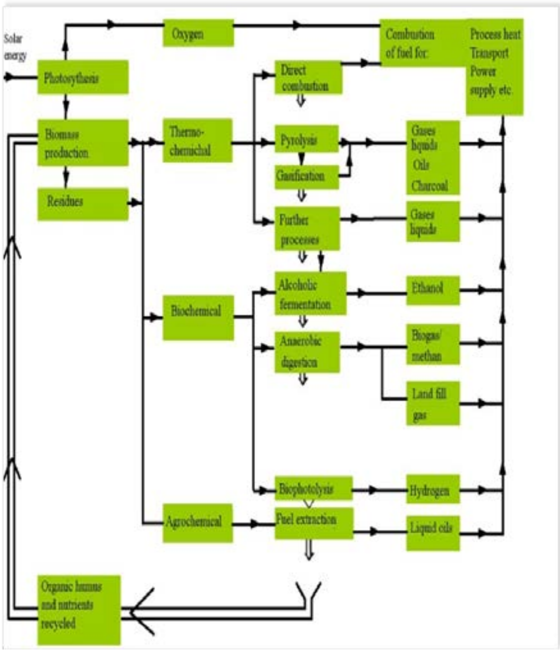

Fig. 2. Biofuel production processes, source: own based on [2]

3 Wood biomass

Wood biomass includes wood chips from forestry operations, residues from lumber, pulp/paper, and furniture mills, and fuel wood for space heating. The largest single source of wood energy is “black liquor,” a residue of pulp, paper, and paperboard production. Burning wood is nothing new, it is the most common form of biomass. For thousands of years people have burned wood for heating and cooking. Wood was the main source of energy in the world until the mid-1800s. Wood continues to be a major source of energy in much of the developing world. In the United States many manufacturing plants in the wood and paper products industry use wood waste to produce their own steam and electricity. This saves these companies money because they don't have to dispose of their waste products and they don't have to buy as much electricity.

4 Biomass gasification

There are several widely used process design for biomass gasification:

a) staged reformation with a fluidized-bed gasifier (the biomass is first pyrolyzed in the absence of oxygen. Then the pyrolysis vapors are reformed to synthesis gas with steam, providing added hydrogen as well as the proper amount of oxygen and process heat that comes from burning the char).

b) staged reformation with a screw auger gasifier (moisture and oxygen) is introduced at the pyrolysis stage, and process heat comes from burning some of the gas produced in the latter.)

c) entrained flow reformation (external steam and air are introduced in a single-stage gasification reactor)

d) partial oxidation (uses pure oxygen with no steam, to provide the proper amount of oxygen. Using air instead of oxygen, as in small modular uses, yields produce gas (including nitrogen oxides) rather than synthesis gas [3].

Biomass gasification is also important for providing a fuel source for electricity and heat generation for the integrated biofinery. Virtually all other conversion processes, whether physical or biological, produce residue that cannot be converted to primary products. To avoid a waste stream from the refinery, and to maximize the overall efficiency, these residues can be used for combined heat and power production (CHP). In existing facilities, these residues are combusted to produce steam for power generation. Gasification offers the potential to utilize higher-efficiency power generation technologies, such as combined cycle gas turbines or fuel cells. Gas turbines systems offer potential electrical conversion efficiencies approximately double those of steam-cycle processes, with fuel cells being nearly three times as efficient . A workable gasification process requires development of some technology: for example, feed processing and handling, gasification performance improvement, syngas cleanup and conditioning, development of sensors, analytical instruments and controls, process integration, and materials used for the systems [3].

5 Waste and residues

Municipal Solid Waste and Biogas - there are about many landfills that recover methane, which forms as waste decomposes in low-oxygen (anaerobic) conditions. The methane is burned to produce electricity and heat. Wastes and residues from human activity and economic production are a form of “indirect” renewable energy, since they are unstoppable flows of energy potential in our environment. Wastes and residues arise from:

a) primary economic activity, e.g. forestry, timber mills, harvested crops, abattoirs and food processing

b) urban, municipal and domestic refuse, including sewage

The energy generation potential from such wastes is primirily from the biomss content. However, there is usually a significant proportion of combustible waste from mineral sources, e.g. most plastics; such combustion requires regulation to reduce unacceptable emissions. A key factor regarding wastes and refuse is that they are usually available at points or concentration, where they easily become an environmental hazard. Dealing with this problem becomes a necessity [4]. Major waste are:

a) municipal solid waste (MSW) – wastes removed by municipal authorities from domestic and industrial sources it usually contains significant amounts of metal, glass and plastic material. Recycling of most plastics, metal, glass and other materials should occur before landfill or combustion. Nevertheless, non-biomass materials usually remain in significant amounts. MSW is loose, solid material of variable composition, available directly for combustion and pyrolysis. If the composition is acceptable, it may be pressurised and extruded as “refuse derived fuel, RDF”, usually available as dried pellets of about 5 cm dimension for combustion in domestic-scale boilers

b) Landfill and sewage – usually MSW, waste deposited in large pits. A large proportion of MSW is biological material which, once enclosed in landfill, decays anaerobically. The process is slower than in most biogas digesters because of the reduced ground temperature, but when stabilised after many months the gas composition is similar. If not collected, that gas leaks slowly into the atmosphere, along with various smellier gases such as H2S, so causing unpleasant environmental pollution. Therefore, the landfill site should be constructed and capped, e.g. with clay, so the gas can be collected when the pit is full, e.g. by an array of perforated pipes laid horizontally as the landfill is completed or drilled vertically into the buried refuse of an existing site. Regulations in several countries require capture of at least 4-% of the methane from landfill, on order to reduce greenhouse gas emissions. Even without monetary credit for the greenhouse benefits, it is usually profitable to capture and utilise landfill gas if there is an industrial facility nearby which can use the fuel for direct combustion in boilers or engines for process electricity and heat generation. Faced with limited landfills, many municipalities have reduced the amount of landfill per household by obliging households to separate much of the biological material that previously went to landfill, e.g. garden clipping and horticultural compost by chopping and aerobic digestion [5].

6 Combustion of biomass: Co-firing

Co-firing of biomass is mainly performed in coal-fired power plants using the Pulverized Fuel (PF) technology. PF plants pre-treat the fuel by grinding/pulverizing it to small particles. These particles are injected in the steam boiler via combustors. Mainly woody biomass is used for co-firing in PF power plants. Bone dry woody biomass shows satisfactory grindability characteristics. The percentage which can be co-fired is limited due to fouling, agglomeration and corrosion. This is caused by ash composition in connection to the sulphur, chlorine, and phosphorous content of the biomass. The injection of biomass can be either separate from the coal (dedicated combustor) or together with the coal (using the same combustor). Another option is to fire the biomass in a separate boiler, but it is rather an exception than common practice. Typical co-fire percentages in Europe range from 2 to 7% regardless of the installations capacity**.** In Europe many power plants have significant experience with co- firing biomass. Statistics on the amount of biomass in Europe are inconclusive and should be estimated: It is reported that 3.5 million tons of coal are replaced by biomass co-firing in 2004 worldwide. Based on the fact that 100 of the 150 plants with co-firing experience are in Europe, the substituted amount of coal in Europe is estimated to be 100/150*3.5 = 2.3 million tons of coal. With an average electric efficiency of 35% and a caloric value for coal of 4.17 MWh/ton, the electricity generated by co-firing of biomass in coal-fired power plants in EU27 is 9.5 TWh per year. Co-firing percentages range from one percent up to about 20% (on energy basis). Currently, a percentage of 3–5% is most common in Europe. The co-firing percentage is mainly dictated by the coal mill capacity. Since the grindability of fine and dry material is superior to more fibrous and wetter material, wood pellets can be co-fired in higher percentages than wood chips of agricultural residues. Most power plants have boiler capacities ranging from 100 to 750 MWe. Major countries in co-firing are currently Germany, Finland and the UK. A wide variety of biomass materials, including herbaceous and woody materials, wet and dry agricultural residues and energy crops are used.

7 Combustion of biomass: large scale power and CHP

Solid biomass is combusted in a furnace. The flue gas heats water, generating pressurized steam in a boiler. The steam is expanded in a steam turbine where the thermal energy is converted into mechanical energy. To close the water loop, steam condenses, is re-pressurized and returned to the boiler. The steam turbine drives a generator. The electricity from the generator is commonly supplied to the (national) grid. Besides electricity, heat is generated. When this heat is utilized, a CHP-system is created. The heat/power-ratio can, within boundaries, be justified with by the end pressure of the steam expansion. Alternatively, the heat can be utilized without making electricity. In this case, heat from the flue gas is used to make hot water or steam. This can be utilized for several purposes in the build environment (district heating) or industry (process heating). Several types of furnaces are applied. The choice for a furnace type is mainly determined by the feedstock. Many feedstock types require a pre-treatment prior to combustion. Common pre-treatments are size reduction (e.g. chipping of wood) or drying. Flue gas cleaning is in almost all cases required. The complexity of the flue gas cleaning is determined by the feedstock and legislative flue gas requirements. Most flue gas cleaning systems result in a lower overall efficiency. Fly ashes and bottom ash can be recycled to the place of origin, be disposed as waste or can, in some cases, be processed in concrete and cement industry or be utilized as road construction material. The type of application depends mainly on the feedstock and the furnace configuration.

8 Combustion of biomass: waste incineration

A special case of biomass combustion is waste incineration. The technologies used are similar to biomass combustion, however, special pre- and after-treatment is required since the fuel composition of waste fluctuates in time, contains more pollutants and is fluffier in morphology. Only grate-fired technologies are applied in waste incineration. Optimization of combustion technology and fuel properties is not possible due to the varying composition of the fuel (waste). Compared to dedicated biomass plants, waste incineration plants have larger capacities. The heat that is generated in waste incineration plants is used to generate steam that is commonly used for the production of electricity by steam turbines. In some cases, heat is utilized as well. Waste incineration plants only utilizing heat are uncommon. Based on the Dutch average waste composition, about 600 kWh electricity is produced per ton of waste. The availability of waste incineration plants is typically 90 – 92%. Since waste consists of biological material and materials with a fossil origin, not all electricity produced from waste is ‘green’. Only the combustion of the organic fraction of waste generates green electricity. In the Netherlands, the average biogenic fraction of waste is periodically determined and the fraction of electricity that is considered green is based on that.

Fig. 3. Waste incineration plant, Amsterdam, Netherlands, source: ECOFYS

The first waste incineration plant on the site in Amsterdam was commissioned in 1993, had an electric efficiency of 21%, and processed about 765.000 ton MSW per year. Throughout the years, the capacity and efficiency have increased from 765 kton to 850 kton and from 21 to 22% respectively. In 2008, a new, improved waste incineration plant was commissioned at the same location, referred to as “High Efficiency-plant”. This state of the art water-cooled grate fired plant generates electricity with a gross efficiency of 34% and a net efficiency of 30% which is significantly higher than the 22% gross efficiency of the ‘old’ plant (still in use). The steam temperature and pressure are 440°C and 125 bar instead of the more common 400°C and 40 bar. The capacity of the new plant is 530.000 ton of waste per year. Heat is delivered to nearby industry. In the future, heat will be supplied to a heat distribution grid for residential heating. The project was budgeted on 370 M€ however, the actual investment was at least 25 M€ higher. The annual turnover is 110 million Euros.

9 Digestion of biomass: manure digestion

Manure is fed to an anaerobic (without oxygen) reactor, the digester, where it is converted into biogas by bacteria. Most digesters are stirred tanks, but plug-flow digesters are used as well. Most reactors are operated at a temperature level of around 35 C. This is the so-called mesophilic system. Systems at a higher temperature level (55 C, thermophilic system) are used as well. The residence time in digesters is typically in the order of 30 days, which makes the equipment rather large. Biogas contains 55 to 70 vol-% methane; the remaining part is carbon dioxide with small amounts of other gases such as hydrogen and hydrogen sulphide.

After removal of moisture and hydrogen sulphide (if necessary), the biogas is fed to a gas engine. The engine drives a generator. The electricity from the generator is commonly supplied to the (national) grid. Waste heat from the engine cooling is used for maintaining the required temperature in the digester. The remaining solid material after digestion is called digestate.

Digestate is used as fertilizer and has, compared to undigested manure, an added value as fertilizer. To improve the biogas efficiency, so- called co-substrates are often added to the digester. This can be dedicated energy crops such as corn, but often waste products from food industry are used.

Fig. 4. Manure co-digestion plant, Beltrum, Netherlands, source: ECOFYS

9 Conclusions

In the previous paragraphs, major biomass technologies were discussed. It is very important to constantly develop and improve them. Biomass energy is locally available energy source with the highest versatility among the renewable energies; that is to say, it can be made available in solid, liquid or gaseous forms. No other energy source can open such a new opportunities for agricultural and forest development, additional jobs and enhanced rural infrastructure. It is not by chance that bio-energy development is gaining momentum in many countries, both developing and industrialized. Globally there is a growing confidence that RES in general is maturing rapidly in many areas of the world and not just in niche markets. It is important to recognize that the development of biomass energy will largely be dependent on the development of the RES industry as whole, as it is driven by similarly energy, environmental, political, social and technological considerations.

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Primary Paper Section: J

Secondary Paper Section: JE, DM