# OVERVIEW OF BIOMASS CONVERSION TECHNOLOGIES

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## ABSTRACT

*A large part of the biomass is used for non-commercial purposes and mostly for cooking and heating, but the use is not sustainable, because it destroys soil-nutrients, causes indoor and outdoor pollution, adds to greenhouse gases, and results in health problems. Commercial use of biomass includes household fuelwood in industrialized countries and bio-char (charcoal) and firewood in urban and industrial areas in developing countries. The most efficient way of biomass utilization is through gasification, in which the gas produced by biomass gasification can either be used to generate power in an ordinary steam-cycle or be converted into motor fuel. In the latter case, there are two alternatives, namely, the synthesis of methanol and methanol-based motor fuels, or Fischer-Tropsch hydrocarbon synthesis.*

*This paper deals with the technological overview of the state-of-the-art key biomass-conversion technologies that can play an important role in the future. The conversion routes for production of Heat, power and transportation fuel have been summarized in this paper, viz. combustion, gasification, pyrolysis, digestion, fermentation and extraction.*

***Keywords:*** *Biomass, Combustion, Gasification, Pyrolysis, Digestion, Fermentation.*

## 1. INTRODUCTION

Global energy-demand is expected to increase from the current 400 ExaJ per year to as much as 700-1,000 EJ per year by the middle of this century. Recent life-cycle analysis suggest that pursuing both strategies of renewable energy sources and renewable feedstocks (i.e. biomass) will be needed to meet these competing demands [1]. Sustainable and renewable natural resources like biomass that contains carbon and hydrogen elements can be potential raw materials for energy conservation [2]. Biomass is one of the most promising renewable energy sources, especially in regions where it is in abundance [3].

Biomass research has been carried out in many countries around the world and various biochemical and thermochemical technologies have been developed for the utilization of biomass for energy production. Such thermo-chemical technologies, especially in the form of combustion and gasification, are considered to be promising solutions for producing energy from biomass; their most advanced forms are fluidized bed combustion and gasification. Materials resulting as by-products of agricultural or agro-industrial activities, e.g. straw, pits, hulls, pods, cobs, etc., are thought to be the most important, especially in under-developed areas of the world where the use of these biofuels for energy-production could cover a substantial gap in the energy bill of the local communities [4,5,6,7].

## 2. COMBUSTION

Combustion of fuelwood, charcoal, and non-woody biofuels is a daily practice for half the world's population. Most of this domestic biomass-burning takes place in the developing world, where, mainly due to economic reasons, vital energy-needs for cooking, heating, and lighting have to be met by biofuels. In many rural regions on the African continent, more than 90 % of the energy requirements are met by biofuels [8,9,10,11].

In developing countries, such as Turkey, these materials are typically burnt in simple stoves with incomplete combustion. Continuous indoor burning of biomass and exposure to large amounts of biomass smoke, starting in childhood, with inefficient conditions for removing smoke and air pollutants, may cause pulmonary diseases such as repetitive upper and lower respiratory infections, and chronic obstructive pulmonary disease [12, 13, 14].

In Pakistan, the combustion-device for indoor cooking reported is ordinary *choolah* (An indigenous single-chamber stove with no aeration vents). A *tanoor* is used for out-door cooking, mainly bread-making. The annual hours of use of the combustion device is 50 % higher in the mountainous areas, compared to plain lands; due to lower atmospheric pressure, the food takes extra time for cooking. The people living in the mountains use their breathing air to ignite the fire, while the residents in the plains are using highly

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inflammable material, such as kerosene and dry grass. The cooking utensils used are ordinary loose-lid type, increasing the time of cooking [15].

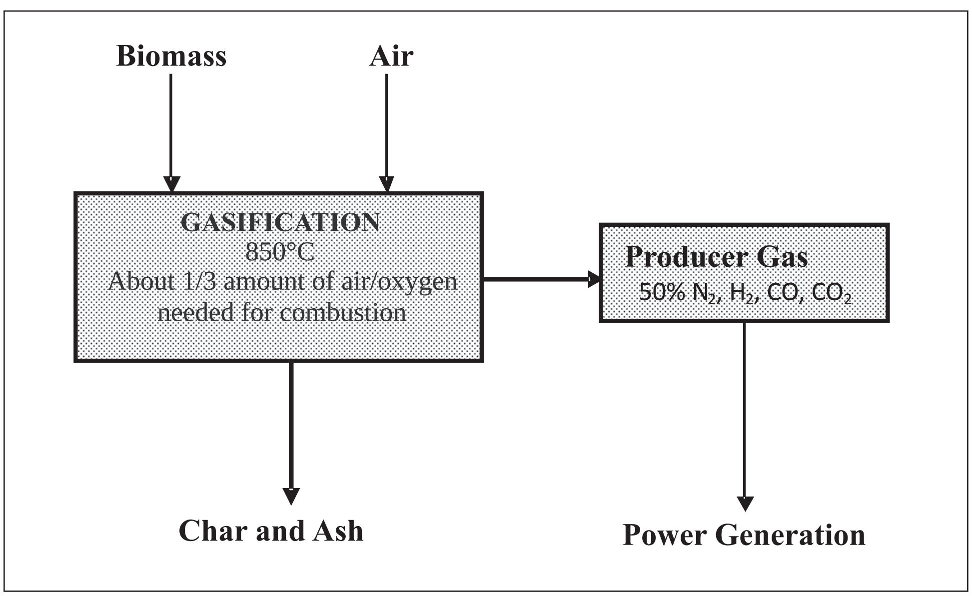
Traditional use of wood generally has a low efficiency (sometimes as low as 10 %) and is generally accompanied with considerable emissions, e.g. of smoke and soot. Technology development has led to the application of strongly improved heating systems, which are, for example, automated, have catalytic gas cleaning and make use of standardized fuel (such as pellets). The efficiency benefit compared to open fireplaces is considerable; open fireplaces may even have a negative efficiency over the year (due to heat loss through the chimney), while advanced domestic heaters can attain efficiencies of 70 to 90 % with strongly reduced emissions. The application of such systems is widespread in Scandinavia, Austria and Germany. In Sweden, in particular, a significant market has developed for biomass pellets, which are fired in automated firing systems [16].

Larger-scale combustion of biomass for the production of electricity (plus heat and process steam) is applied commercially worldwide. Many plant configurations have been developed and deployed over time. Basic combustion-concepts include pile burning, various types of grate firing (stationary, moving, vibrating), suspension firing and fluidized-bed concepts. An example for the application of biomass combustion for power generation is seen in the paper and pulp (P&P) industry for combustion of black liquor and waste incineration. Conventional boilers for combined production of power and process steam, and recovery of pulping chemicals is common technology for the P&P sector. Waste incinerators were widely deployed, starting in the nineteen eighties, in countries like Germany and the Netherlands, combined with very stringent emission standards. Biomass burning became the key waste-to-energy technology deployed in Europe, but it is relatively expensive. In recent years, advanced combustion concepts have penetrated the market. The application of fluided-bed technology and advanced gas-cleaning allows for efficient operation and production of electricity (and heat) from biomass [17].

## 3. GASIFICATION

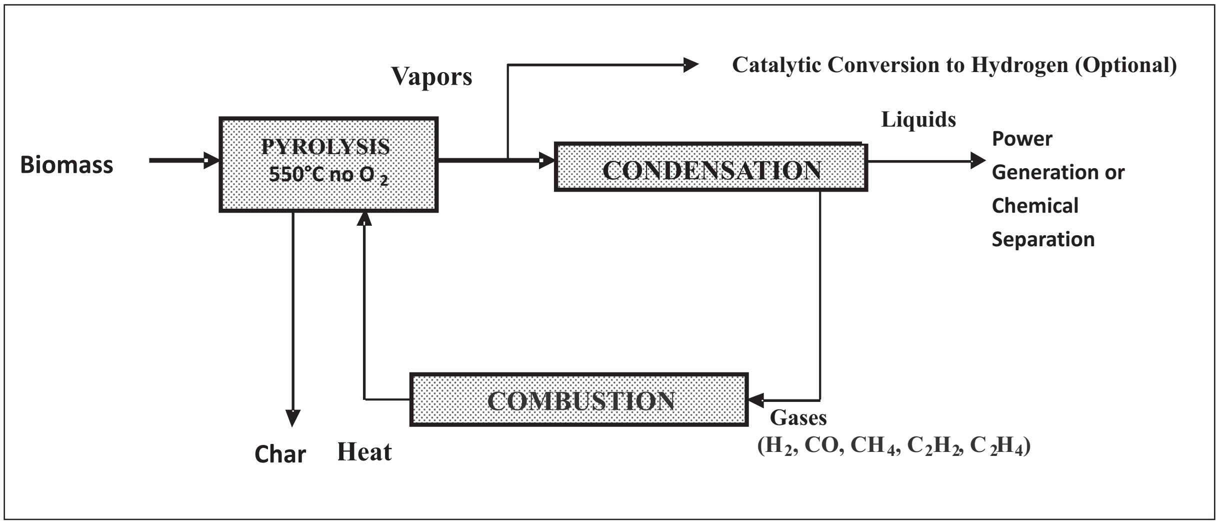
Gasification, as a means to convert a diversity of solid fuels to combustible gas or syngas, received considerable attention in the nineteen eighties worldwide, especially in Europe. Gasification converts biomass into fuel gas, which can be further converted or cleaned prior to combustion (e.g. in a gas turbine; when integrated with a combined cycle) [18].

The most efficient way of utilizing biomass as a renewable energy source is through gasification. A




**Source:** *US Department of Energy, “Energy Efficiency and Renewable Energy” EERE (2005)*

**Figure-1: Biomass Gasification**




**Source:** *U.S Department of Energy, "Energy Efficiency and Renewable Energy" EERE (2005)*

**Figure-2: Biomass Liquefaction via Pyrolysis**

particularly attractive feature of this method is that the gas produced by gasification of biomass can either be used to generate power in an ordinary steam cycle or be converted into motor fuel (Figure-1) [19].

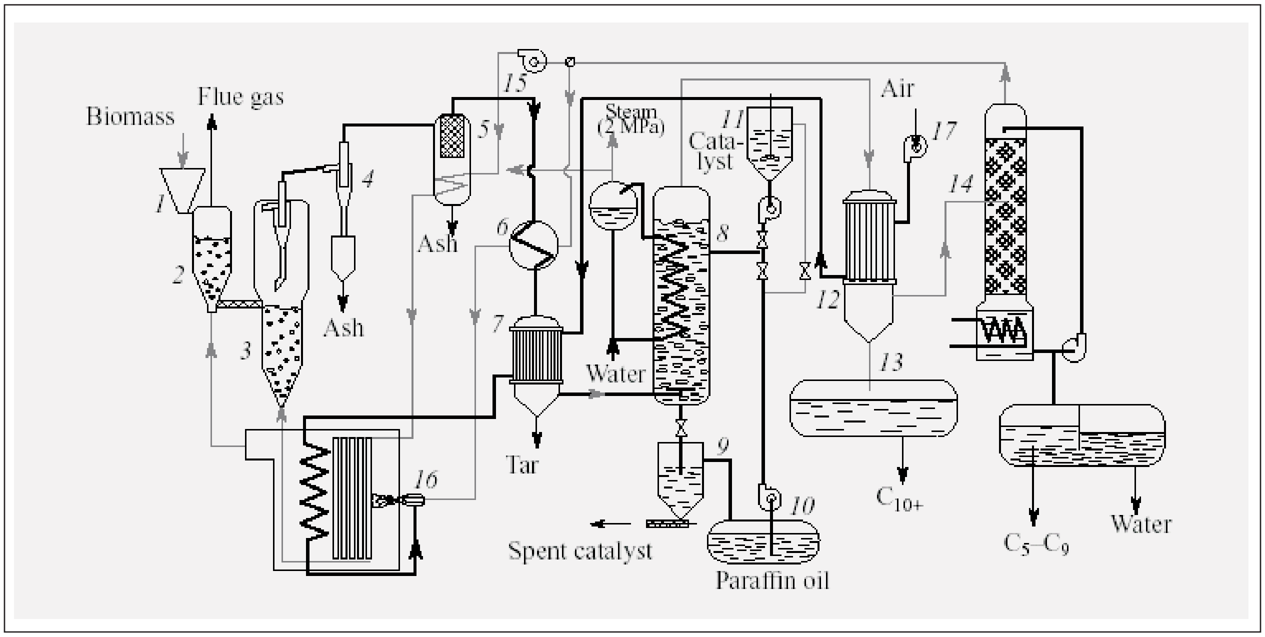
In the latter case, there are two alternatives, namely: (a) the synthesis of methanol and methanol-based motor fuels, and (b) Fischer-Tropsch hydrocarbon synthesis (Figure-2). These processes have long been implemented in the industry, and the prospects of their application in the production of motor fuels are governed by world oil-prices. However, considering the huge amounts of wood waste at wood-working facilities, as in some parts of Russia, motor fuel production at small-scale plants in the immediate vicinity of raw material sources may be profitable [20].

The experiments with gasification of wood in argon/steam plasma proved the capacity of plasma for complete gasification of wood (with production of syngas having high content of hydrogen and carbon monoxide). Despite very low mass flow-rates of plasma generated in water stabilized arc, the mixing of treated material with plasma and intensive energy transfer is ensured in the reactor. The flow within the reactor is almost completely controlled by gasification of the material, as the flow-rate of gas coming from gasification is up to hundred times higher than the flow-rate of plasma. Therefore, the gasification rate is high, especially for high feeding rates of material. Syngas, with calorific value double the power spent for the process, is produced. The measured dependencies indicate that further increase of the material feeding-rate would result in even higher ratio. The efficiency of the process could be increased substantially by utilizing the power lost to the cooling-water in the torch and in the reactor [21].

Heat production using gasifiers is commercially established. Finland in particular was successful in the 1980s in deploying smaller scale gasifiers for heat production (Bioneer). Nevertheless, gasification for production of heat finds a strong competitor in combustion. A key concept pursued for a long period of time was the use of agricultural residues close to the source, thus minimizing transport distances. A wide array of concepts for gasifiers, gas cleaning and system-integration for such concepts was proposed and tested in a wide variety of conditions. Technology was also exported to many developing countries, with support from international bodies such as the World Bank [18].

## 4. PYROLYSIS AND LIQUEFACTION

Pyrolysis converts biomass to liquid (bio-oil), gaseous and solid (char) fractions at temperatures around 500°C in absence of oxygen. With flash-pyrolysis techniques (fast pyrolysis) the liquid fraction can be maximized (up to 70 % of the thermal biomass input). Bio-oil contains about 40 weight percent of oxygen and is corrosive and acidic. Crude bio-oil can, in principle (after some modifications and only for better quality oils), be used for running engines and turbines [22].




**Source:** *Analyzing Biomass Conversion into Liquid Hydrocarbons (Theoretical Foundations of Chemical Engineering) [35].*

**Figure-3: Schematic Diagram of a Plant for Biomass Conversion into Liquid Hydrocarbons**

Most renewable sources used in the pyrolysis of biomass have been higher plants, including woody materials, rather than marine microalgae, although the latter are the main primary producers in oceans and they constitute the largest biomass in nature (Figure-3) [23].

Liquefaction and HTU (Hydro thermal upgradation) is a process that converts biomass to bio-crude at a high pressure, in water and moderate temperature. This is another way of producing 'raw intermediate liquids' from biomass [24].

## 5. DIGESTION

### 5.1 Biogas

Digesters maintain suitable conditions for bacteria to digest the biologically active component of the manure, resulting in the production and capture of biogas, which is 60-80 % methane and, thus, highly combustible [25].

Thermal conversion of wood to produce charcoal and volatiles is very old technology, the use of which has considerably reduced over the years due to the utilization of liquid fuels and coal. However, the recent concerns over global warming and requirements to reduce greenhouse gas emissions [26] have placed biomass fuels, such as wood, straw, bagasse, peat and municipal solid waste, at the forefront in reduction of the pollution as biomass is considered to be $CO_2$ neutral. These fuels have the advantage of being renewable and their conversion to energy provides a sustainable waste-management practice as they primarily consist of wastes [27]. Current research trends in biomass utilization are based on designing co-firing technologies, in which biomass is combusted in mixtures with other fuels, mainly coal. Biomass-conversion technologies can also consist of pyrolysis and gasification of the renewable-energy sources in order to produce higher calorific-value fuels, i.e. oil-liquids, hydrocarbon rich gases [28] and/or hydrogen [29].

In these technologies, biomass undergoes thermal treatment and decomposition, where volatiles and tars are evolved, followed by consequent heats of reactions [30].

Therefore, to be able to understand and design the conversion processes during biomass decomposition, thermal investigation of the devolatilisation is essentially an initial stage.

### 5.2 Landfill Gas Utilization

A specific source of biogas is landfills. The production of methane-rich landfill-gas from landfill sites makes a significant contribution to atmospheric methane emissions. In many situations, the collection of landfill gas and production of electricity by converting this gas in gas-engines is profitable and the application of such systems has become widespread. The benefits are obvious: useful energy-carriers are produced from gas that would otherwise contribute to a build-up of methane GHG in the atmosphere, which has stronger GHG impact than the $CO_2$ emitted from the power plant [31].

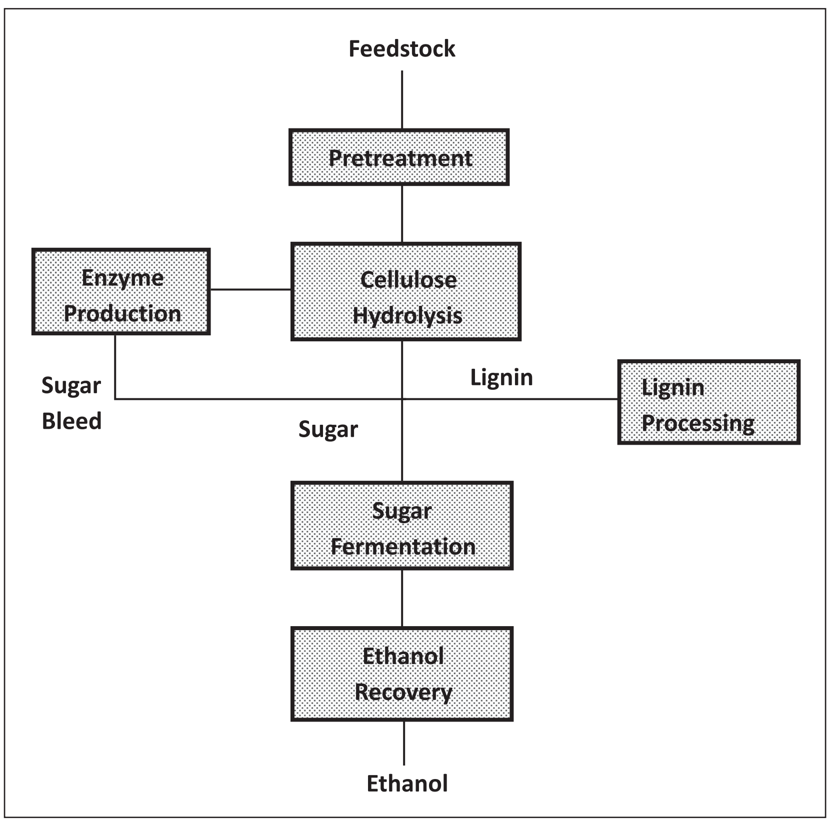
## 6. PRODUCTION OF TRANSPORTATION FUEL

### 6.1 Gasification

Methanol, hydrogen and Fischer-Tropsch diesel can be produced from biomass through gasification. All routes need very clean syngas before the secondary energy-carrier is produced using relatively conventional gas-processing methods. Besides MeOH, hydrogen and FT (Fischer-Tropsch) liquids, DME (DiMethyl Ether) and SNG (Synthetic Natural Gas) can also be produced from syngas. We will however focus on the first three fuels mentioned. Several routes involving conventional, commercial, or advanced technologies under development are possible. A train of processes to convert biomass to the required gas specifications precedes the methanol or FT reactor, or hydrogen separation. The gasifier produces syngas, a mixture of CO and $H_2$, and a few other compounds. The syngas then undergoes a series of chemical reactions. The equipment down-stream of the gasifier for conversion to $H_2$, methanol or FT diesel is the same as that used to make these products from natural gas, except for the gas cleaning train. A gas turbine or boiler, and a steam turbine optionally employ the unconverted gas fractions for electricity co-production [32].

### 6.2 Fermentation and Hydrolysis

A cellulosic feedstock material, such as straw, corn stover, or grass, is subjected to pre-treatment, i.e., cooked in the presence of acid to break down its fibrous structure. After pre-treatment, the material has




**Source:** *Tolan Iogen's process for producing ethanol from cellulosic biomass [33]*

**Figure-4: Production of Ethanol from Cellulosic Materials**

a muddy texture. Cellulase enzymes are added to the pre-treated material to hydrolyze the cellulose to the simple sugar glucose; this is known as cellulose hydrolysis. The cellulase enzymes are made at the plant site by using a wood-rotting fungus in large fermentation vessels. This is known as cellulase enzyme production. After enzymatic hydrolysis, the sugars are separated from the unhydrolyzed solids, which include lignin and residual cellulose. These solids are burnt to provide energy for the entire process (Lignin processing). The sugars are fermented (sugar fermentation) to ethanol, using simple brewer's yeast (to ferment the glucose) and more recently developed microbes for the sugars more difficult to ferment, including xylose and arabinose. In ethanol recovery, the ethanol is recovered by conventional distillation (Figure-4) [33].

Starch-based or sucrose-based processes are already widely used to make ethanol. The leading starch-based material is corn, which is widely used to make ethanol in the U.S. Starch is converted to glucose by grinding (in a dry milling process) or by steeping in dilute sulfurous acid (in a wet milling process), then using starch-degrading enzymes known as amylases. The glucose is then fermented to ethanol. Sucrose-based feedstocks include sugar cane (Brazil) and sugar beets (Europe). These feedstocks are ground and washed with water to extract the sucrose, which is then fermented to ethanol by yeast. Other feedstocks used to make small amounts of fuel ethanol in some regions include potatoes and Jerusalem artichokes. The conversion of cellulosic biomass to ethanol is more difficult than starch or sucrose. However, cellulose is available in much greater quantity and offers the potential for much greater ethanol production than the others. In addition, ethanol from starch and sucrose faces competition for the feedstock from the food and cattle-feed industries, which exerts pressure on the price of the ethanol. Most cellulosic biomass is free of competition from other uses. Cellulosic biomass can be grown in a wider variety of climates and soils than starch and sucrose and, therefore, represents a new agricultural opportunity in many areas. Finally, ethanol from cellulose is expected to be neutral, relative to the production of greenhouse gases. Corn, sugarcane, and sugar beets require large amount of energy-intensive fertilizers and do not have the energy-generation from the lignin- byproduct that is present in cellulosic biomass. Corn, sugarcane, and sugar beets all contain a small amount of cellulose and hemicellulose. Cellulose conversion technology represents an opportunity to improve the yields and decrease the wastes from these processes. Many cellulosic materials, including straw and grass, contain up to 10% starch. This is converted to glucose during pre-treatment and carried through to glucose fermentation, where it is converted to ethanol. Ethanol is produced from cellulosic materials in various ways. The main features of the different ethanol processes are outlined in Figure-4 [32].

### 6.3 Extraction

Oilseeds, like rapeseed, can be extracted and converted to esters and are well suited to replace diesel oil as "bio-diesel". Rapeseed production and subsequent esterification and distribution are established processes in Europe [34].

## 7. CONCLUSIONS

Biomass is a fuel that people are familiar with, due to traditional use of biomass fuel. It currently provides the majority of energy to the domestic sector in developing countries. However, continued use of traditional biomass will provide for basic needs, but it will not solve the problem of providing the modern energy-services required for economic growth and improved living standards.

Modern commercial energy-production from biomass for industry, power-generation or transport fuel has a significant contribution and this contribution is growing faster, but its use should be carefully modernized to fit into a sustainable development path.

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