

# A Short Review on Biomass Thermo-Chemical Conversion: Recent Advances

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**Abstract**—Biomass is long known as a viable source of fuel. However, the industrial revolution has changed mankind's dependence on fossil fuels until today. The depletion of the fossil fuel sources and its escalating price encouraged many research works since two decades ago in the bid to replace fossil fuel with biomass. Biomass has now become an important energy source because of its extensive spread availability and promising potential to reduce global warming. Thermo-chemical conversion of biomass yield variety of solid, liquid and gaseous fuels and have equal importance both at industrial and environmental conservation aspects. This paper provides a review on several thermo-chemical conversion routes of biomass. The technologies of combustion, gasification, pyrolysis, liquefaction and carbonization is reviewed in this paper and highlighting each of their unique advantages. The benefits of biomass co-firing with fossil fuels were also highlighted in this paper.

**Keyword**-Combustion, Gasification, Pyrolysis, Co-firing, Greenhouse Gases (GHG)

## I. INTRODUCTION

The demand for energy has ever been increasing and expected to do so in proportion with population growth. Despite the awareness on the sustainability issues of fossil fuels, most of the energy available today still originates from fossil fuel [1]. The use of fossil fuels mostly produce greenhouse gases (GHG) but also hazardous gaseous such as SO<sub>2</sub> and NO<sub>x</sub> [2]. The emission of GHGs also results in global warming which was believed to be the reason of the climate change and unprecedented disasters like flash flood. Most of GHGs is produced during the combustion of fossil fuels to for electricity generation which converts thermal energy to electricity by steam and gas turbines in the power plant. In a typical developed nation, taking Germany for example, 27% of energy produces consumed by the industry with almost half of it are electrical energy [3].

Many efforts are taken to reduce the GHG emission both at the energy supply side (upstream) and the energy demand side (downstream) where fossil fuels are used. One of the well-known and established method is the co-combustion of the fossil fuel with biomass as well as the utilization of biomass for electrical energy production [4]. Biomass are basically waste produced from the living thing such as animal manure and material which came from plant [1]. The energy produce by biomass is known as bioenergy and it have the greatest potential in substitute the fossil fuel for producing energy with low emission of GHG [5].

## II. CLASSIFICATION OF BIOMASS

Carbonaceous organic material that originally from living source animal and plant are known as biomass such as agricultural residue, forest, animal waste and waste from the food processing [6]. The classification of biomass is needed to help differentiated raw material based on the waste type and detailed about the biomass [4]. There are many variable properties and the composition of biomass such as in bottom ash decomposition, the moisture content, the inorganic constituents and the structural component inside the biomass [7].

Table 1 : General Classification Of Biomass [8]

Biomass groups	Biomass sub-groups, varieties and species
1. Wood and woody biomass	Coniferous or deciduous ; angiospermous or gymnospermous ; soft or hard; stems, branches, foliage, bark, chips, lump, pellets, briquettes, sawdust, sawmill and other form various wood species.
2. Herbaceous and agricultural biomass	2.1 Grasses and flowers (alfafa, arundo, bamboo, bana, brassica, cane, cynara, miscanthus, switchgrass, timothy, other) 2.2 Straws ( Barley, bean, flax, corn, minx, oat, rape, rice, rye, sesame, sunflower, wheat, other)
3. Aquatic biomass	2.3 Other residues (fruit, shells, husks, hulls, pits, pips, grains, seeds, coir, stalks, cobs, kernels, bagasse, food, fodder, pulps, cakes, others).
4. Animal and human biomass wastes	Marine or fresh water algae; microalgae (blue, green, blue-green, brown red) or microalgae; seaweed, kelp, lake weed, water hyacinth, others.

5. Contaminated biomass and industrial biomass wastes (semi-biomass)	Bones, meat-bones meal, chicken litter, various manners, others.
6. Biomass mixtures	Municipal solid waste, demolition wood, refuse-derived fuel, sewage sludge, hospital waste, paper-pulp sludge, waste papers, paperboard waste, chipboard, fireboard, plywood, wood pallets and boxes, railways sleepers tannery waste, other.
	Blend from the above varieties.

### III. BIOMASS THERMO-CHEMICAL CONVERSION TECHNOLOGIES

Biomass has become increasingly popular now and plays important role as one of the source of energy that needed by the people. There were already 62 countries that uses biomass to generate electricity in year 2008 as shown in Figure1 and rapidly increasing for the developing country[9]. There are many technologies and method that can be applied for the conversion of biomass for energy generation. One of the most preferred and established route for energy generation via thermo-chemical conversion methods, namely combustion, pyrolysis, co-firing and liquefaction. There are many type of thermochemical process which is through the combustion, pyrolysis, co-firing and liquefaction [10]. From Figure2 it show how the main process of thermochemical conversion occur and the final product from each process of the thermos-chemical conversion technologies.

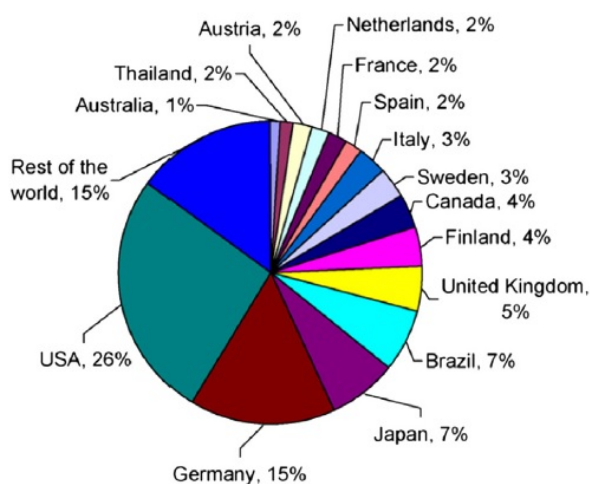


Figure1: Global Biomass usage for generate electricity[9]

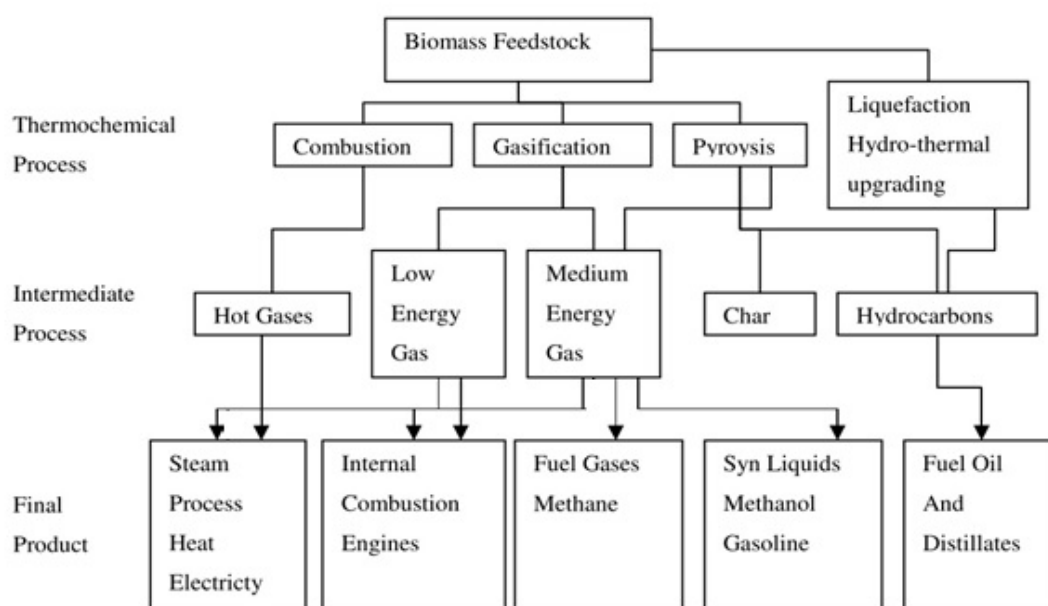


Figure2: Main processes, intermediate energy carries and final product from thermochemical conversion of biomass[6]

### A. Combustion

Combustion is the most easiest process of thermochemical for the convert biomass with presence of air as the supply of the oxygen as combustion agent to produce heat energy[11]. The complete combustion for the biomass occur with present of air to make the oxidation which produce H<sub>2</sub>O and CO<sub>2</sub>. Homogenous and heterogeneous reaction is the process that usually consist in the combustion process and the solid fuel of biomass is depend on the size of the particle which with different properties of biomass [12]. Combustion process are recently being pick as the thermos conversion method for biomass to generate the heat energy because it have high fuel flexibility[11].

### B. Gasification

Carbon dioxide (CO<sub>2</sub>) and hydrogen (H<sub>2</sub>) gas are the main product from gasification that can produce heat and later electricity or being converted to liquid hydrocarbons[13]. Most of substances as biomass have been convert to the syngas via the thermo-chemical conversion by using gasification process[14]. In the industrial of gasification there are important processes[13] :

- Pyrolysis reaction : The heating of solid fuel usually greater than 700°C to produce the charcoal and release the volatiles
- Oxidation reaction : To produce the gasifying agent (steam and CO<sub>2</sub>), the char and volatile is being combusted with oxygen O<sub>2</sub>
- Reduction reaction: Char, tar, and hydrocarbon are gasified with CO<sub>2</sub> and steam to produce synthetic gas (syngas), which mainly composed of CO, H<sub>2</sub> and CH<sub>4</sub>.

This techniques is an environmental friendly and will produce less emission of GHG compared to fossil fuel by using waste or plant matter to generate energy and the cost are more competitive compared to the conventional energy resources [15].

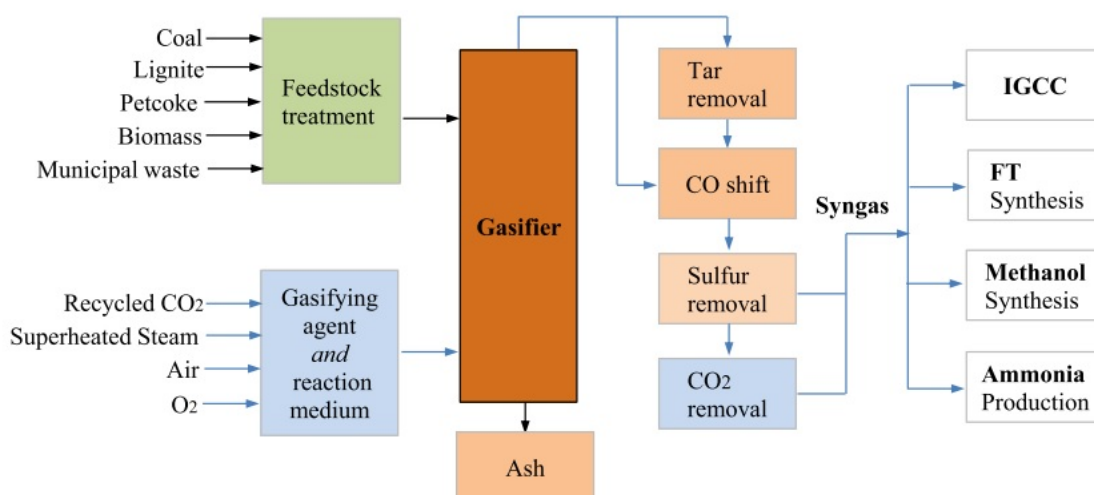


Figure 3: Possible plant configurations for different gasification application[13].

### C. Pyrolysis

Unlike combustion and gasification, in pyrolysis, the chemical reactions occurs in the absence if air. Several type of pyrolysis is repeated in the literature such as fast pyrolysis, slow pyrolysis, intermediate pyrolysis, flash pyrolysis, vacuum pyrolysis, ablative pyrolysis and microwave pyrolysis [16]. Pyrolysis is one of the promising technique for biomass to be converted into bio-oil and used alternative fuel [17]. Usually for the slow pyrolysis process it will produce charcoal as it main product because of it low heating rate with constant temperature [18].

### D. Liquefaction

Hydrothermal liquefaction is the thermal-chemical conversion that using water as the main role in the process. Water at high temperatures behaves as a reactant and as catalyst that causes organic material to disintegrate and reform by adding hydrogen ions into hydrocarbons. Liquefaction have the advantage over pyrolysis and gasification process because liquefaction doesn't need dry biomass to do the process and it reduced the energy needed to drying the biomass. This process is the direct conversion of biomass to liquid fuels[19].

### E. Carbonization

Carbonization is a thermochemical process that converts biomass into hydrochar and functionalization carbon material which through the slow heating rate, carbonization is extension from the pyrolysis process where the main product is in the form of gas yield with little amount of fluid[20]. There are two type of carbonization which is vapour phase carbonization and solid-state carbonization where the process are depends on the heating temperature [21]. The formation of solid bio char depends on the operating temperature of the process.

### F. End products

The bio-oil produced from pyrolysis can be directly used in place of fuel oil or diesel in static operations such as a boiler, turbine, or engine to generate electricity. It can also be upgraded to a transportation fuel through hydroprocessing in the presence of hydrogen and a catalyst[22]. A wide range of chemicals such as resin, fertilizers can be extracted from the bio-oil. The product gas can directly be used in boiler, gas turbine, engine, or fuel cell to produce electricity, heat, or combined heat and power. A range of chemicals can also be derived from this gas. High heating value gas, can be converted to a transportation fuel[23]. Solid char is the main output of the carbonization and slow pyrolysis process. The solid residue known as biochar can be used as soil conditioner, insulation, or a catalyst (as activated carbon) and can reduce global warming emissions.

## IV. BIOMASS CO-FIRING WITH FOSSIL FUEL

### A. Benefit of Co-Firing

Biomass co-firing with coal is a low-cost technology for efficiently and cleanly converting lignocellulosic biomass to electricity. In this process, the primary fuel (coal) is partially substituted by biomass in a high efficiency boiler. Depending on the boiler capacity and efficiency, the percentage of biomass co-firing varies the thermal efficiency between 5 and 20 percentage [24]. The substitution of biomass has a positive effect environmentally due to the total amount of GHG reduction. Co-firing takes the advantage of the power plant's economies of scale and saves fossil fuels.

Biomass co-firing with coal/natural gas could be a competitive thermochemical conversion technology due to its environmental benefits when compared with only coal combustion[25]. The fluidized bed technologies have been found to be good options for co-firing coal with biomass/plastic waste because of their fuel/flexible feature. The effect of blending up to 20% of biomass/plastic waste in circulating fluidized bed (CFB) in negligible for the performance of the co-firing system when compared with systems fuelled solely by coal

As the replacement of the fossil fuel for the stationary thermo-chemical conversions, co-combustion is one of the simple ways for utilizing biomass. Moreover, the energy produce by the blending of biomass with the fossil fuel such as the coal are increasing as the biomass is a source of the renewable energy and it also can be considered as the carbon neutral with function to reduce the emission of GHG [9].The ash from biomass combustion indicated the low bottom ash content compare to the coal and the ash contain the alkali properties on it because of the present of element such as potassium and calcium [26].Moreover, in many cases the co-combustion of biomass and the coal showed cost-effective technique in producing electricity in the substitute of the coal at the power plant[24].From Figure with a variety of biomass both at conditions or in oxygen riches conditions as reported by [27]. Figure 4 and Figure 5 the emission of GHG for variety of co-combustion of biomass with a coal showed decreasing trend with the increasing amount of biomass in the blending ratio[28]. This show that, the influence of biomass in the co-combustion is proven as GHG reducer. In addition, the bottom ash produced by the co-combustion of biomass show has smaller amount of unburnt carbon.

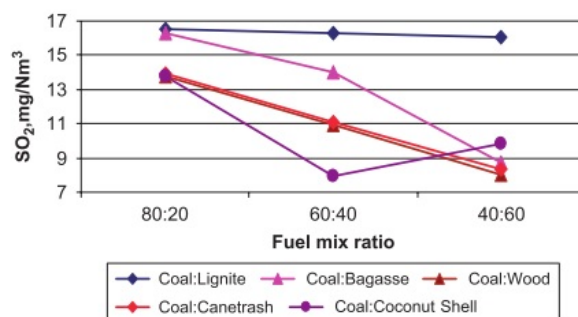


Figure 4 : SO<sub>2</sub> emission for variation of biomass fuel blending with coal[28].

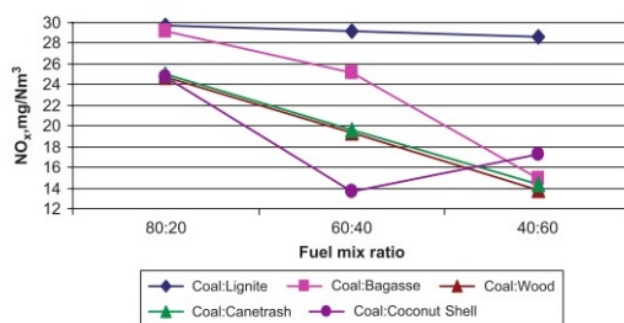


Figure 5: NO<sub>x</sub> emission for variation of biomass fuel blending with coal[28]

## V. BENEFITS FROM BIOMASS IN GHG REDUCTION

The benefits of using biomass a substitute for fossil fuels particularly coal is obvious, particularly in terms of GHG offset as well as reducing the demand for fossil fuels. However, due to the different chemical and physical properties of biomass compared to coal for instance, the amount of biomass required maybe higher. Taking coal for example, 1 tonne of coal will require biomass greater than 1 tonne to produce the same amount of heat energy. On the other hand, but the biomass is usually cheaper, available in abundance and also renewable[29]. From the co-combustion and co-gasification of biomass, the emission of GHG have showed positive feedback by the reducing/decreasing of the GHG.

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