

CHAPTER 1 INTRODUCTION

1.1 Renewable energy overview

Climate change concerns, high oil prices, peak oil demand and increasing government support drive increasing renewable energy legislation, incentives and commercialization [1]. Renewable energy is an energy that is derived from naturally and constantly replenished resources. It includes electricity and heat generated directly or indirectly from sun, wind, tides, hydropower, biomass, geothermal resources and biofuels, as well as hydrogen derived from the renewable resources.

According to Figure 1.1, renewable energy supplied 18.9% of the global energy consumption of 474 EJ, counting traditional biomass, large hydropower (>10 MW production), and other renewable sources (small hydro (<10 MW), modern biomass, wind, solar, geothermal, and biofuels).

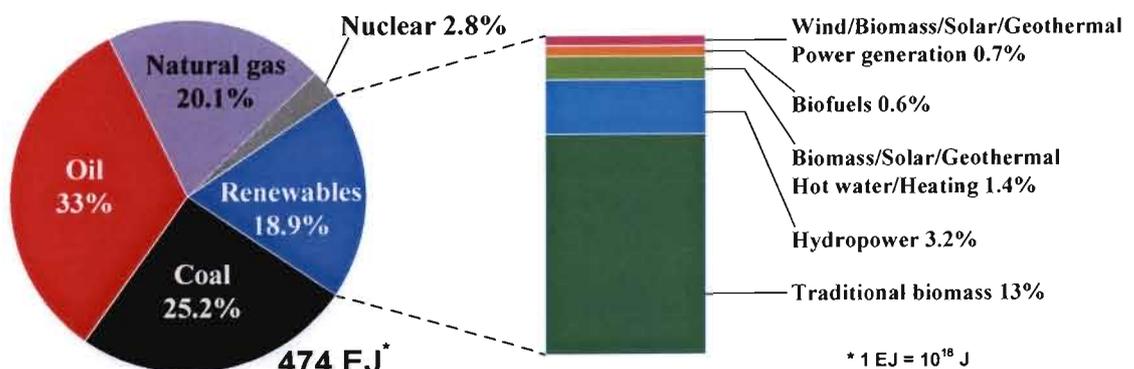


Figure 1.1 Share of renewable energy to global energy consumption in 2008 [2].

Of this 18.9%, traditional biomass which is used primarily for cooking and heating accounted for approximately 13%, and is growing slowly or even declining in some regions as biomass is used more efficiently or replaced by more modern energy forms. Hydropower at a large base (>10 MW) represented 3.2%, and is growing modestly. Other renewable sources accounted for 2.7% in total, and are increasing very rapidly in developed countries and in some developing countries. Renewable energy replaces the conventional fuels in four distinct markets: (i) power generation, (ii) hot water and space heating, (iii) transport fuels, and (iv) rural (off-grid) energy services. However, fossil fuels (coal, oil and natural gas) still dominated the consumption.

In Thailand, well-recognized as one of the top rank exporters of agricultural and food products, biomass has been the traditional renewable energy resource. As shown in Figure 1.2, about 24.4% of the total energy consumption of 2.37 EJ came from renewable energy, with 22% counted by traditional biomass, used mainly as cooking/heating, and 1.4% from biofuels (biodiesel and ethanol) including the garbage. Power from renewable energy represented approximately 0.9%, and is growing very rapidly by the government subsidies. However, the major contribution to the total consumption was fossil fuels, particularly oil for transportation.

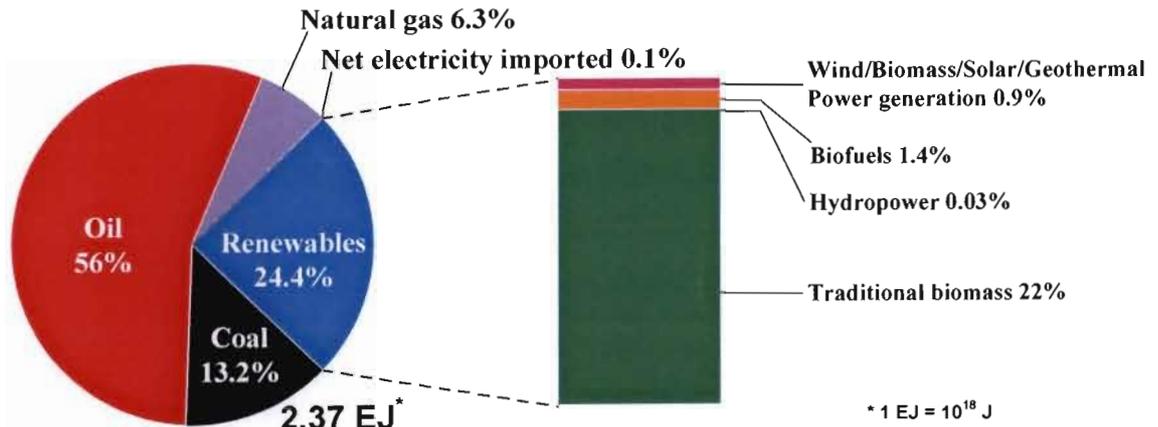


Figure 1.2 Contribution of renewable energy to total energy consumption of Thailand in 2009 [3,4].

Fossil fuels are not considered as biomass by the generally accepted definition [5], in spite of their origin in ancient biomass. Their production and use raise environmental concerns primarily caused by the CO₂ emission from the combustion. A global movement toward the generation of renewable energy is therefore under way to meet an increased energy needs and the attention to the biomass for the commercial power generation is also being paid increasingly.

1.2 Biomass overview

Biomass is biological material derived from living, or recently living organisms. Since the beginning of civilization, biomass has been a major source of energy throughout the world. Biomass, the fourth largest energy source after coal, oil and natural gas, is the largest and most important renewable energy option at present and can be used to produce different forms of energy [6]. In the developing world, wood biomass is a major renewable energy source, representing a significant proportion of the rural energy supply.

Biomass resources include primary, secondary, and tertiary sources [7]. Primary biomass resources are produced directly by photosynthesis and are taken directly from the land. They include perennial short-rotation woody crops and herbaceous crops, seeds of oil crops, and residues from the harvesting of agricultural crops and forest trees (e.g., wheat/rice straw, corn stover and the tops, limbs, and bark from trees). Secondary resources result from the processing of primary resources either physically (e.g., the production of sawdust in mills), chemically (e.g., black liquor from pulping processes), or biologically (e.g., manure produced by animals). Tertiary resources are post-consumer residues as biodegradable wastes including animal fats and greases, used vegetable oils, packaging wastes, and construction and demolition debris.

Using biomass represents an attractive way to environmental benefit by the decreasing CO₂ emission, because it is part of the short carbon cycle. Carbon from the atmosphere is converted into biological matters of plant by photosynthesis, building up lignin, hemicelluloses, cellulose, lipids and etc, as structure and non-structure carbohydrates [8]. On death of combustion, or decay, the carbon goes back into the atmosphere as carbon dioxide (CO₂). This happens over a relatively short timescale and plant matter

can be constantly replaced by planting for new growth. Though biomass is sometimes called a “carbon neutral” fuel since its use as a fuel reasonably stabilize the level of atmospheric carbon, its use can still contribute to global warming due to the processing of biomass, for instance the crops for biofuels are harvested and transported using machinery that burns fossil diesel.

Even though the annual global primary production of biomass was equivalent to 4,500 EJ [6], the biomass presence in the global energy consumption was only 62-66 EJ (13-14% according to Figure 1.1). In Thailand, only 0.53 EJ of biomass, referred to Figure 1.2, was utilized while the estimated biomass production was equivalent to 1.4 EJ [4]. These potentials are highly attractive for commercial power production and biomass contribution to power generation in Thailand has been promoted at present under the 15 Year Renewable Energy Development Plan [9], particularly focusing on the solid agricultural biomass.

1.3 Biomass conversion technology

There are a number of energy conversion technologies that can convert a variety of biomass into heat, power, and fuels as summarized in Figure 1.3.

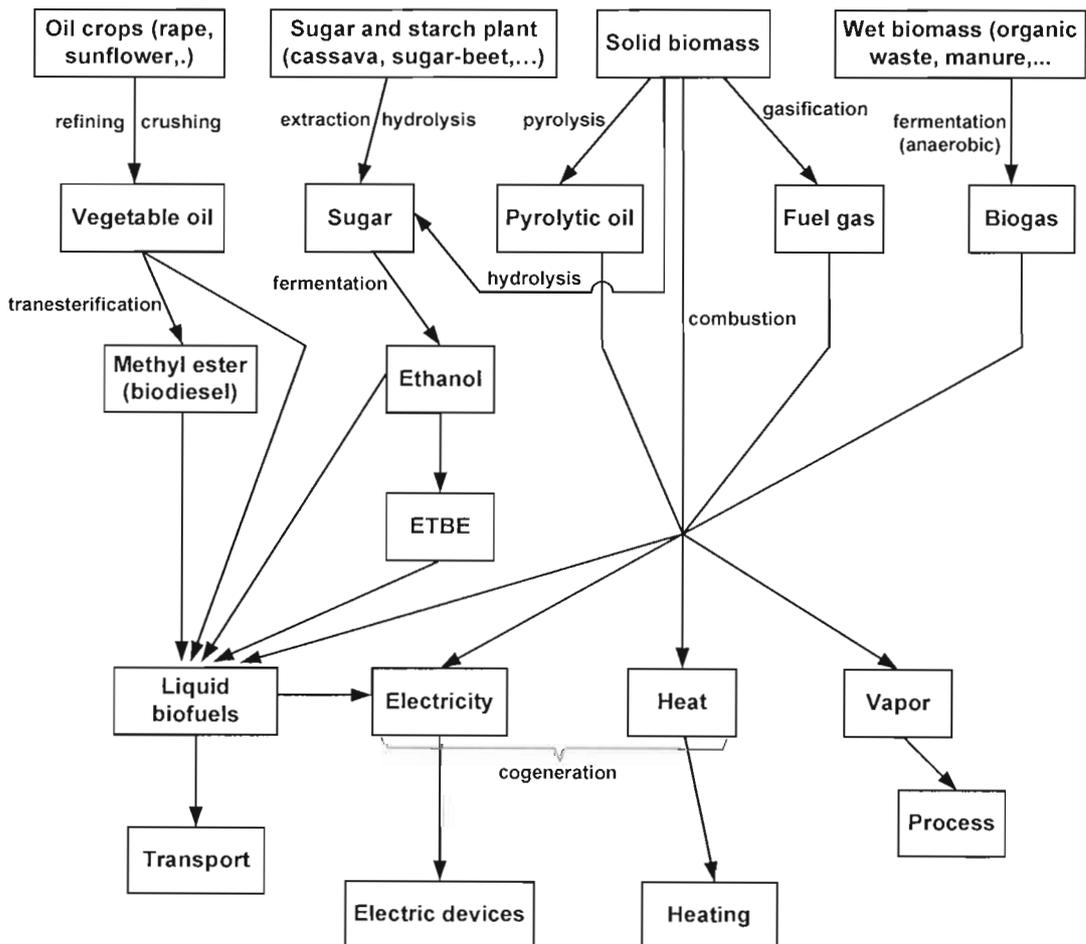


Figure 1.3 Biomass energy conversion overview [7].

Conversion technologies may release the energy directly, in the form of heat, or may convert to other forms, such as liquid biofuel or combustible biogas. While for some classes of biomass resource there may be a number of usage options, for others there may be only one appropriate technology. The most conventional way in which particularly solid biomass is used, however, still relies on the direct combustion.

The combustion is studied intensively over hundred years. The intimate understanding in the behaviors of solid combustion as well as the development in a number of techniques and implements have made it to utilize biomass in a more effective way, as the increasing heat/power productivity with the decreasing emission. Among them, one favorable technique built up is the fluidized bed combustion (FBC) technology.

1.4 Fluidization technology

1.4.1 Fluidization and Fluidized bed

Fluidization refers to the process by which a fluid-like is imparted to granular solid by the application of appropriate external forces [10]. The amount of solid particles is set into motion by blowing a fluid steam upward through a bed at sufficient velocity to locally suspend the particles, but yet not too great velocity to blow the particles out of bed. The bed appears like a boiling liquid and has other features of liquids such as exhibiting buoyancy and hydrostatic head, hence that it is called “fluidized bed”. This behavior is characterized as shown in Figure 1.4.

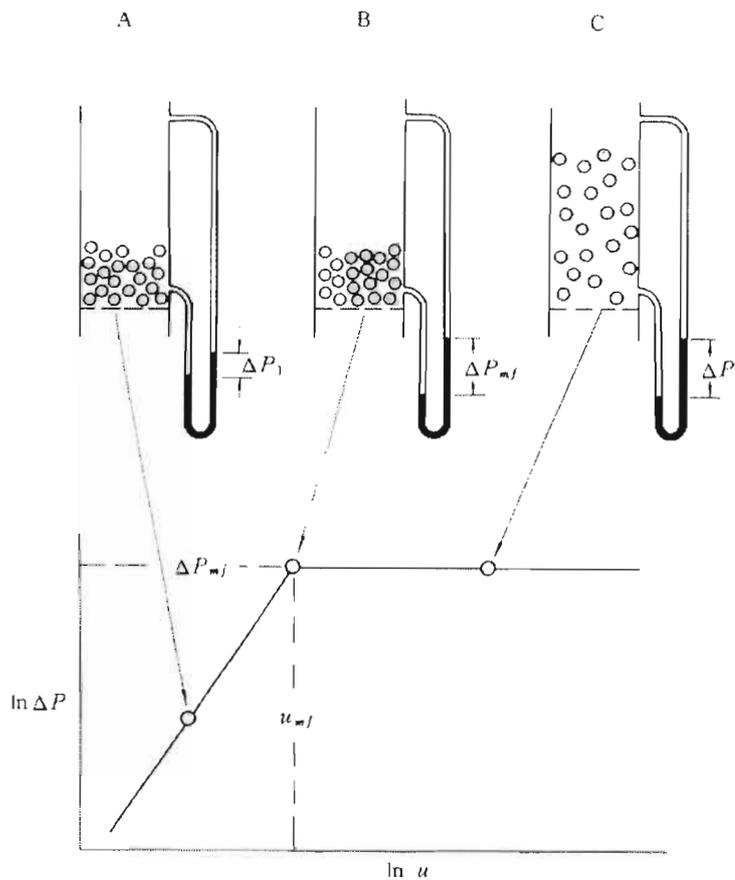


Figure 1.4 Characteristic of increasing fluid flow fluidization [10].

When fluid flow starts at relatively low velocity through a static bed of solid particles, the interstitial pores among the particles offer sufficient resistance to the fluid to create a corresponding drop in pressure in the flow direction. As the velocity increases, this pressure drop increases correspondingly until at some flow rate, this pressure drop equals the weight of this granular. At this point, the solid particles start to lose contact from their neighbors, which have up to this point offered mechanical support, and become buoyed up hydro-dynamically. As it increases further, the particles, which are now suspended, cannot offer greater resistance due to their limited masses. Instead, the flowing fluid pushes the particles further apart to make way for increased flow and the pressure drop remains constant at the same level corresponding to the solid weight.

1.4.2 Solid combustion application [11]

When fuel particles enter the hot bed of inert materials, such as sand, fluidized by the upward flowing air, their temperatures are raised to the point at which the moisture is vaporized and then are further increased to the point at which a certain part of the organic compounds is volatilized. Until reaching their self combustion temperatures, fuel char particles are burnt continually in the bed. A part of released heat is circulated to the recently fed fuel particles by the inert bed, acting as the heat reservoir, while the major one is utilized, for instance to boil water into steam. During combustion, fuel particles can be spread uniformly across the bed due to the chaotic bed mixing induced by the passing air bubble. The temperature field in a fluidized bed is rather uniform due to the intense in-bed heat transfer as a consequence of this bed mixing. This feature of fluidized bed combustor provides the advantages as summarized below:

- High fuel flexibility, both in size, rank and type.
- High combustion efficiency with low combustion temperature.
- High rate of heat transfer due to the turbulent mixing of bed.
- Effective emission control of SO₂ through removal by reaction with the poisonous gases capture additives.
- Expensive pretreatment and preparation of fuels are not needed.

By its prominent features, FBC is found suitable for a wide variety of fuels, especially the low grade fuels such as lignite and solid agricultural biomass. Presently this technique has been achieved to be the commercial scale power plants using biomass.

1.5 Problems of biomass firing in fluidized bed

Although FBC is a mature technique, many operational problems associated with the ash are frequently encountered in its application to biomass [12]. They are particularly connected with the unique alkali content. The relatively rich alkali of biomass cause the ash forming constituents to melt at relatively low temperature leading to a number of the critical ash-related operational problems [13] viz,

- The formation of fused or partly-fused ash agglomerates and slag deposits at high temperatures within furnaces and stoves.
- The formation of bonded ash deposits and accumulations of ash materials at lower temperatures on surfaces in the convective sections of boilers.
- The accelerated metal wastage of furnace and boiler components due to gas-side corrosion under ash deposits, and due to ash particle impact erosion or ash abrasion of boiler components and other equipment.
- The formation and emission of sub-micron aerosols and fumes.
- Biomass ash impacts on the performance of flue gas cleaning equipment.

- The handling and the utilization/disposal of ash residues from biomass combustion plants, and of the mixed ash residues from the co-firing of biomass in coal-fired boilers.
- Bed particle agglomeration caused by fused or partly-fused ash materials in the fluidized bed boiler.

Particularly, bed agglomeration is a common reason for decreased availability of the biomass fired fluidized bed boiler. It deteriorates the fluidization quality, which then disturbs the combustion process in the furnace. An increase in bed particle size, due to the agglomeration, is then translated into an increase in the minimum fluidization gas velocity. As a result, the superficial air/gas velocity must be increased in order to maintain the fluidization state. If it is not increased accordingly or the whole bed agglomerates in the extreme case, fluidization can no longer be maintained, namely defluidization, leading to an unscheduled shutdown with costly loss.

Defluidization by the bed particle agglomeration is one major challenge faced by the thermal based fluidized bed technologies for the power generation. The intimate insight to its behaviors concerning the fates of inorganic elements on the bed agglomeration and the contributions of the bed operating parameters on the defluidization is required to prediction and tackling, for the success of applying FBC to produce energy from the specific biomass.

1.6 Research objectives

This work aimed to find out the approach to predict the bed agglomeration behaviors during fluidized bed combustion of agricultural residues. The specific objectives were

1. To investigate the bed agglomeration tendency regarding to the biomass ash properties and the fluidized bed operating conditions.
2. To elucidate the plausible mechanisms of bed agglomeration and relevant inorganic behaviors.
3. To propose the developed mathematical models.

1.7 Scopes of work

1. Investigating experimentally by combustion of the representative agricultural residues as palm kernel shell, palm empty fruit bunch, corncob and rice straw in the laboratory and pilot scale bubbling fluidized bed facilities using only quartz sand as inert bed material at different bed (combustion) temperature, superficial air velocity, bed particle size and static bed height, of the operating conditions.
2. Developing the mathematical models to predict the bed agglomeration behaviors.

1.8 Research Methodology

To achieve this work, the study workflow was performed below:

1. Characterizing the materials.

Firstly, the physical and chemical properties as well as the ash compositions of selected biomass were necessary to be characterized intensively since they were handled in fuel

preparation and subsequently tested in fluidized bed. Similarly, the quartz sand was also characterized.

2. Performing the agglomeration test

The steady state combustion in fluidized bed reactors under the atmospheric condition was carried out to study the effects of biomass ash properties and operating conditions on the bed agglomeration tendency. The behaviors and states of bed during combustion were monitored until complete defluidization.

3. Characterizing the agglomerates

The morphology and chemistry of agglomerate samples from the bed at defluidization were studied in order to identify the inorganic behaviors and the interactions between the released ash constituents and bed particles responsible to the bed agglomeration.

4. Developing the mathematical models

The mathematical models were developed based on analyzing the laboratory scale experimental results.

5. Verifying the models.

The results of lab and pilot scale tests as well as the previously published data were used to verify these models.