Feasibility Study of Pellet (Saw Dust and Rice Husk) in Bangladesh

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Masters of Science
in
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Dedication

To *my Parents…………*

Acknowledgements

First and foremost, I would like to thank ALLAH, the Almighty without whom I would not has been here and I thank for his unconditional love.

Secondly I would like to thank Dr. S. M. Nasif Shams, my supervisor, he found time to support and advice amidst his already filled up daily schedule.

I further extend my heartfelt gratitude to my parents whose words of advice, care and support have brought here and whose love has kept me going.

Special thanks to all my friends and family for their support, advice and encouragements.

Last but not least, my heart goes to our organization **Institute** of **Energy**, University of Dhaka for making my dreams come true. Thank you once again.

Abstract

This thesis concerns the feasibility of pellet (Saw dust) in Bangladesh. I describe the Biomass situation in the world as well as in Bangladesh. Pellet is one of the useable applications of Biomass. In this thesis we describe what is pellet? How to develop pellet? What are uses of pellet? and add a practical information of a pellet industry (Eco-Fuel Pellet Industry). We know Bangladesh population is increasing and the Bangladesh has needed more electrical energy. The products quantities that use up electricity have grown rapidly. Fossil fuels have been excessively consumed. The traditional energy sources mostly used in Bangladesh are diminishing at a rapid rate thus causing energy crisis all over the country. Supply of power is less than demand in insecure situation in Bangladesh. Considering all these barriers, Renewable energy is being looked at as an alternative for Bangladesh. Biomass from agriculture, especially rice husk and saw dust, is a very promising renewable energy source since it is indigenous and is considered to have environmental benefits. In this thesis, it has been put some statistical data and analysed the data reflecting the possibility of establishing power generation unit using rice husk and saw dust as a fuel.

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Chapter 1

Introduction

Biomass is one of the most promising renewable energy resources on earth which is used in the form of solid, liquid and gaseous fuels. The demand for bioenergy systems in small scale industry is increasing at faster rate due to its lower investment cost. Currently bioenergy is the second largest commercial renewable energy source. Current total biomass energy usage ranges around 12% of world total primary energy consumption, mainly in traditional applications like cooking in developing nations like India, Bangladesh. Also the usage of wood for heating purposes is increasing day-today. Normal domestic wood-burning appliances include fireplaces, pellet stoves and burners, central heating furnaces and boilers for wood logs and wood pellets [1].

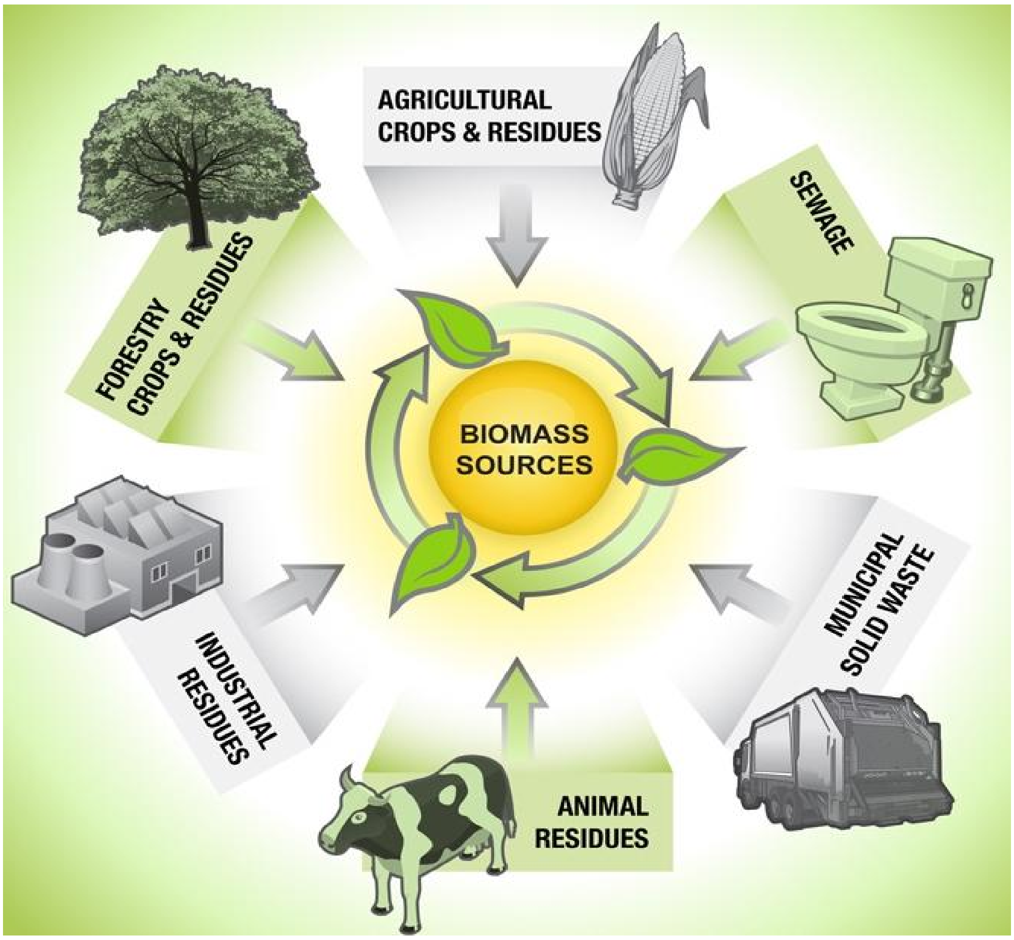


Figure 1.1: Biomass Sources

Biomass can be converted into either heat energy or electrical or energy carriers like charcoal, oil, or gas using both thermochemical and biochemical conversion methods. Combustion is the most developed and frequently applied process used for solid biomass fuels because of its cheap cost and high reliability. During combustion, the biomass first loses its moisture at temperatures up to 100°C, using heat from other particles that release their heat value. As the dried particle heats up, volatile gases containing hydrocarbons, CO, CH4 and other gaseous components are released. In a combustion process, these gases contribute about 70% of the heating value of the biomass. Finally, char oxidizes and ash remains [2].

Among the usage of biomass the wood pellet is also included. Many new techniques are available to turn wood and crop wastes into standardized pellets that are eco-friendly and easy to handle [3].

1.1 Wood Pellets

The wood is cut into small particles by grinding process and is dried. It may then be processed with readily available equipment to make wood pellets. These processed wood pellets have comparatively high calorific value, easy transportation and storage and can be utilized for heat and power. Pellet plants can be built at a wide range of sizes. Smaller plants require less feed. Larger plants will generally offer good economy of scale, but may also face greater costs for feed brought in from a larger growing area [4].

In the production of fuel pellets and briquettes, the feedstock has to be milled, pulped and undergoes steam before being transformed into a denser product. It is in either refined powder form or crop residue that has been put under high pressure so as to be formed into small cylinders like structures of different sizes. At a given pressure, in its phase of production and reduced humidity, the energy density of the wood pellet obtained is about almost double that of the wood. Hence reduction of size is an important treatment of biomass for energy conversion. Reduction of size of the particle increases the total surface area, pore size of the material and the number of contact points for inter-particle bonding in the compaction process [5].

A number of properties are commonly known to affect the success of pelleting, including calorific value, moisture content of the material, bulk density, particle size, fiber strength of the material, lubricating characteristics of the material, and natural binders. Utilization of wood and crop residues as an energy source will serve to reduce consumption of fossil fuels, thereby reducing the emission of greenhouse gases to the environment. Ideal in providing fuel for heating devices, the wood pellet it is pure, non-pollutant, and neutral in carbon dioxide (CO2) emissions. In other words, it doesn’t contribute to the destabilization of the ambient, as whatever carbon dioxide emissions occur from its combustion they are counterbalanced by equivalent amounts of (CO2) that have been absorbed from the plant during its life, process of photosynthesis, it burns completely, without producing smoke, leaving minimum residue of ash, always less than 1%, which can be used as a precious fertilizer for the garden too [6].

1.2 Biomass Conversion Processes

The biomass conversion process (Bio conversion process) has several routes depending upon temperature, pressure, micro-organisms utilized, process and the culture conditions. These routes are classified in following three broad categories.

a. Direct Combustion
b. Thermochemical Conversion
c. Biochemical Conversion

1.2.1 Thermochemical Conversion

Biomass is decomposed in thermo-chemical processes having various combinations of temperatures and pressures. Gasification is a process in which combustible materials are partially oxidized. The product of gasification is a combustible synthesis gas. Since gasification involves the partial oxidization of the feed rather than complete, gasification processes operate in an oxygen-lean environment. Gasification of Biomass is carried out by one of the following two processes.

a. Heating the biomass with limited air or oxygen.
b. Heating at high temperature and high pressure in presence of steam and oxygen.

Biomass can be converted into gases, liquids, and solids through *pyrolysis* at temperatures of 500 -900°C by heating in a closed vessel in the absence of oxygen.

1.2.2 Thermal Properties of Biomass

Each type of biomass has its specific properties which determine its performance as a fuel in combustion. Most important properties regarding thermal conversion of fuels is as follows.

a. Moisture content
b. Ash content
c. Volatile matter content
d. Elemental composition
e. Calorific value
f. Bulk density

1.2.2.1 Moisture Content

The moisture content of biomass is the quantity of water in the material, expressed as a percentage of the material's weight. This weight can be referred to on wet basis and on dry ash free basis. If the moisture content is determined on a ‘wet’ basis, the water's weight is expressed as a percentage of the sum of the weight of the water, ash, and dry-and-ash-free matter. Similarly, when calculating the moisture content on a ‘dry’ basis (however contradictory that may seem), the water’s weight is expressed as a percentage of the weight of the ash and dry-and-ash-free matter. Finally, the moisture content can be expressed as a percentage of the "dry and-ash-free" matter content. In that last case, the water's weight is related to the weight of the dry biomass. Because the moisture content affects the value of biomass as a fuel, the basis on which the moisture content is measured must always be mentioned. This is particularly important because biomass materials exhibit a wide range of moisture content (on a wet basis), ranging from less than 10 percent for cereal grain straw up to 50 to 70 percent for forest residues [7].

1.2.2.2 Ash Content

The inorganic component can be expressed as same as the moisture content on a wet, dry and ash free basis. In general it is expressed on dry basis. It is the inorganic matter left out after complete combustion of the biomass. Generally contains mainly Calcium, Potassium, Magnesium and Phosphorus elements that affect the ash fusion.

The ash value is an integral part of the plant structure that consists of a wide range of elements that represents less than 0.5 % in wood and 10 % in diverse agricultural crop material and up to 30-40 % in rice husks and milfoil. The total ash content in the biomass and the chemical composition of the ash are important. The composition of the ash affects its behavior under the high temperatures of combustion and gasification. For example, melted ash may cause problems in both combustion and gasification reactors. These problems may vary from clogged ash-removal caused by slagging ash to severe operating problems in fluidized-bed systems [7].

1.2.2.3 Volatile Matter Content

Volatile matter refers to the part of the biomass that is released when the biomass is heated (up to 400 to 500°C). During this heating process the biomass decomposes into volatile gases and solid char. Biomass typically has a high volatile matter content (up to 80 percent), whereas coal has a low volatile matter content (less than 20 percent) or, in the case of anthracite coal, a negligible one [7].

1.2.2.4 Elemental Composition

The composition of the ash-free organic component of biomass is relatively uniform. The major components are carbon, oxygen, and hydrogen. Most biomass also contains a small proportion of nitrogen and sulphur.

The carbon (C), hydrogen (H), oxygen (O), sulphur(S) and nitrogen (N) determination in biomass represents the so called elementary analysis. These elements are detected by an elemental analyzer. About 200 mg of sample are burned at 900 ° C in an oxygen atmosphere, so the C is converted into CO2, H in H20, S into SO2 and the N in N2. The first three compounds are detected quantitatively by an IR detector, while N2 is determined by a thermal conductivity detector [8].

1.2.2.5 Calorific Value

The calorific value is one of the most important characteristics of a fuel, and it is useful for planning and control of the combustion plants. It indicates the amount of heat that develops from the mass (weight) in its complete combustion with oxygen in a calorimeter standardize. It is defined as the amount heat energy released during the complete combustion of unit mass of biomass.

There are two types of calorific value (usually expressed in kcal/kg or MJ/kg) might be considered:

1. Higher heating value (HHV): it is the amount of heat released by a complete combustion of a mass unit of a sample at constant volume in an oxygen atmosphere and at the standard conditions (101.3 kPa, 25°C). The HHV takes into account the latent heat of vaporization of water, and it assumes that the water component is in liquid state at the end of combustion.

2. Lower heating value (LHV), doesn't include the water condensation heat. The high heating value can be determined experimentally in the laboratory with adiabatic calorimeter.

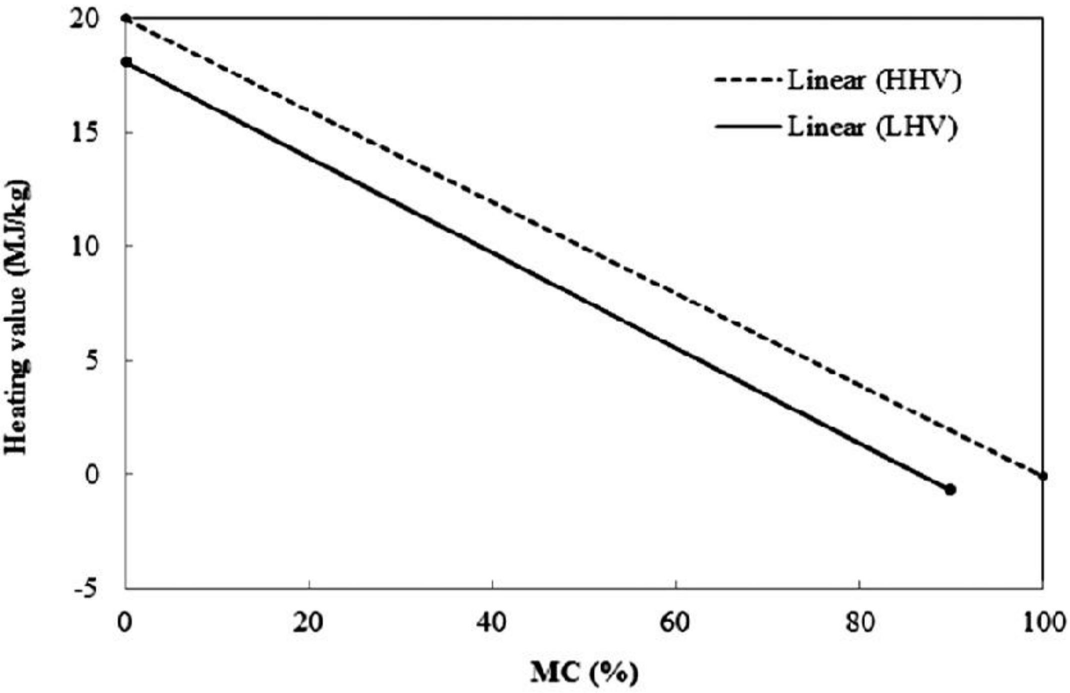


Figure 1.2: Calorific value of biomass as a function of moisture content [7]

The lower heating value is calculated net of fuel moisture and water that forms in the combustion reaction. In practice, the value is obtained by subtracting to the HHV the heat water condensation produced during combustion, using the following formula:

$$LHV = HHV - 51.14 \times Ht$$

Where HHV is the high heating value, Ht is the total hydrogen percentage. To evaluate the performance of biomass combustion in plant we usually refer to the lower heating value, because the most common boilers do not allow to recover the heat of water condensation [8].

1.2.2.6 Bulk Density

Bulk density refers to the weight of material per unit of volume. For biomass it is generally expressed on an oven-dry-weight basis (zero moisture content) with a corresponding indication of moisture content. Similar to biomass moisture contents, biomass bulk densities show extreme variation, from lows of 150 to 200 kg/m3 for cereal grain straws and shavings to highs of 600 to 900 kg/m3 for solid wood. Together, heating value and bulk density determine the energy density-that is, the potential energy available per unit volume of the biomass. In general, biomass energy densities are approximately one-tenth that of fossil fuels such as petroleum or high quality coal [9].

1.2.3 Biochemical Conversion

There are two principal Biochemical conversion processes. Anaerobic digestion involves microbiological digestion of biomass. The process and end products depend up to the microorganisms cultivated and cultured conditions. Fermentation is a process of decomposition of organic matter by microorganisms especially bacteria and yeasts. About 15% of ethanol produced in the world is through fermentation of grains and molasses. Ethanol (Ethyl Alcohol) can be blended with gasoline (petrol) to produce gasohol (90% petrol and 10% ethanol). Processes have been developed to produce various fuels from various types of fermentations [9].

Chapter 2

Biomass

Biomass is a renewable energy resource derived from the carbonaceous waste of various human and natural activities. It is derived from numerous sources including the by-products from the timber industry, agricultural crop, raw material from the forest, mayor parts of household waste and wood.

Biomass is the solar energy stored in chemical form in plant and animal materials, and among the most precious and versatile resources on earth. It provides not only food but also energy building materials, paper, fabrics, medicines and chemicals. Biomass has been used for energy purposes ever since man discovered fire. Today, biomass fuels can be utilization for tasks ranging from heating the house to fuelling a car and running a computer.

Again we can say biomass is biological material derived from living, or recently living organisms. In the context of biomass as a resource for making energy, it most often refers to plants or plant-based materials which is not used for food or feed, and are specifically called lignocellulose biomass [10]. As an energy source, biomass can either be used directly via combustion to produce heat, or indirectly after converting it to various forms of biofuel. Conversion of biomass to biofuel can be achieved by different methods which are broadly classified into: *thermal*, *chemical*, and *biochemical* methods. Wood remains the largest biomass energy source to date [11]; examples include forest residues (such as dead trees, branches and tree stumps), yard clippings, wood chips and even municipal solid waste. In the second sense, biomass includes plant or animal matter that can be converted into fibers or other industrial chemicals, including biofuels.

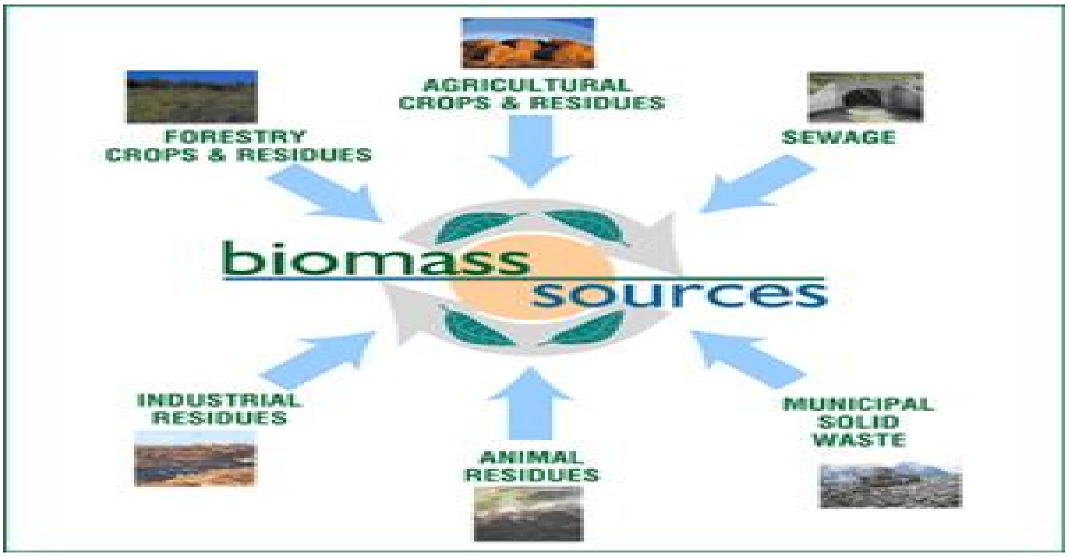


Figure 2.1: Different Sources of Biomass [12]

Plant energy is produced by crops specifically grown for use as fuel that offer high biomass output per hectare with low input energy. Some examples of these plants are wheat, which typically yield 7.5–8 tonnes of grain per hectare, and straw, which typically yield 3.5–5 tonnes per hectare in the UK [13]. The grain can be used for liquid transportation fuels while the straw can be burned to produce heat or electricity. Plant biomass can also be degraded from cellulose to glucose through a series of chemical treatments, and the resulting sugar can then be used as a first generation biofuel.

Biomass can be converted to other usable forms of energy like methane gas or transportation fuels like ethanol and biodiesel. Rotting garbage, and agricultural and human waste, all release methane gas—also called landfill gas or biogas. Crops, such as corn and sugar cane, can be fermented to produce the transportation fuel, ethanol. Biodiesel, another transportation fuel, can be produced from left-over food products like vegetable oils and animal fats [14]. Also, biomass to liquids (BTLs) and cellulosic ethanol are still under research [15-16].

There is research involving algal, or algae-derived, biomass because it is a non-food resource and can be produced at rates five to ten times faster than other types of land-based agriculture, such as corn and soy. Once harvested, it can be fermented to produce biofuels such as ethanol, butanol, and methane, as well as biodiesel and hydrogen.

The biomass used for electricity generation varies by region. Forest by-products, such as wood residues, are common in the United States. Agricultural waste is common in Mauritius (sugar cane residue) and Southeast Asia (rice husks). Animal husbandry residues, such as poultry litter, are common in the UK [17].

2.1 Availability and use of Biomass in Bangladesh

Bangladesh is an agriculture-based country and the available biomass is mainly of agricultural residues like rice husk & rice straw from rice plants, Biogases from sugarcane, Jute stick, residues from Wheat, potato, oilseeds, spices etc. In addition to the agricultural wastes the other sources are dry materials such as dry wood, dried leaf, charcoal, coconut shells etc.

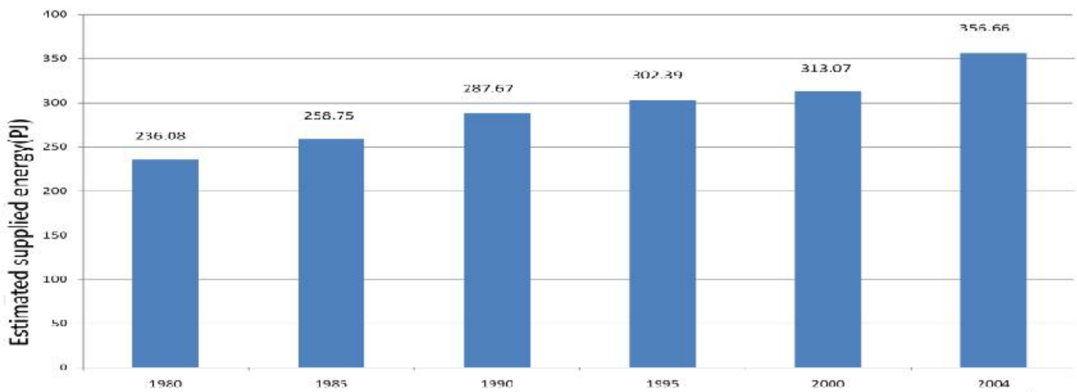


Figure 2.2: Trends of traditional fuel supplied during 1980 to 2004 [18]

Over last 30 years, there has been an increasing trend of biomass fuel supply in Bangladesh. The total supply of biomass fuel was 236.08 PJ in 1980 and has increased over next 20 years to 356.66 PJ (1.73% growths). Traditional fuel supply usually comes from main three sources viz. crop residues, animal dung and trees[19. The percentages of different traditional energy were as follows: cow-dung 20.4%, jute stick 7.5%, rice straw 11.6%, rice husk 23.3%, bagasse 3.2%, fire wood 10.4%, twigs and leaves 12.5% and other wastes 11.1%. Rice husk contributes biggest share of biomass energy and it was 83.04 PJ in 2003-2004. Energy production from rice husk is steadily increasing.

2.2 Biomass in the world

Biomass is considered to be one of the key renewable resources of the future at both small and large –scale levels. It already supplies 14% of the world's primary energy consumption. But for three quarters of the world's population living in developing countries biomass is the most important source of energy. On average, biomass produces 38% of the primary energy in developing countries (90% in some countries). Biomass is likely to remain an important global source in developing countries well into next century.

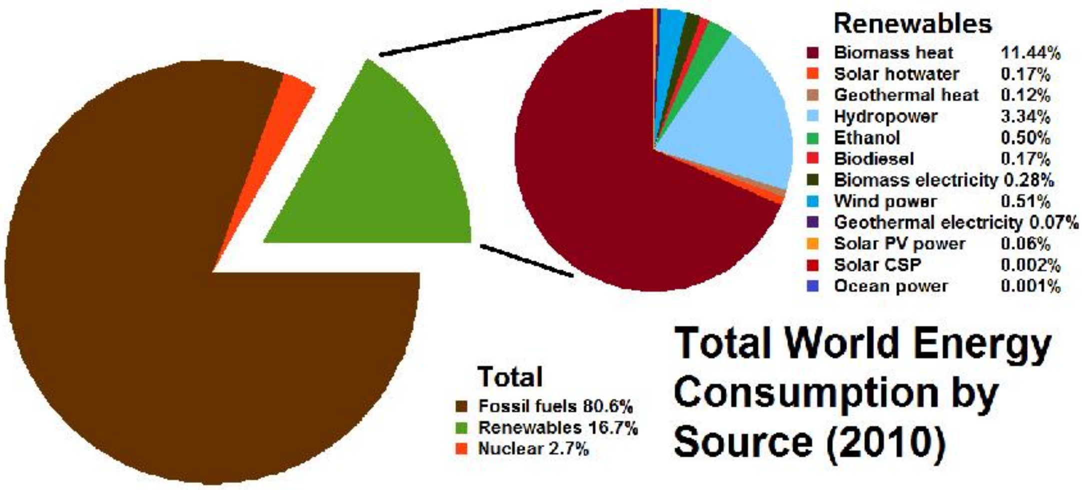


Figure 2.3: Total Energy Consumption of the World (Biomass is around 12.40 in renewable energy) [19]

Table 2.1: World Biomass Energy Potential

Biomass Energy Resources	2020 (Mtoe)
Crop Residue	480-499
Wood	1,791-2025
Energy crops	2971-3535
Animal waste	994
Municipal waste	516
Total	6752-7569

2.3 Biomass in Developing Countries

Despite its wide use in developing countries, biomass energy is usually used so inefficiently that only a small percentage of its useful energy is obtained. The overall efficiency in traditional use is only about 5-15 percent, and biomass is often less convenient to use compared with fossil fuels. In the early 1980s, almost 1.3 billion people met their fuel wood needs by depleting wood reserves.

Table 2.2: Share of Biomass on total energy consumption [18]

Name of country	Percentage (%)
Nepal	95%
Malawi	94%
Kenya	75%
Bangladesh	65%
India	50%
China	33%
Brazil	25%

There is an enormous biomass potential that can be tapped by improving the utilization of existing resources and by increasing plant productivity. Bio-energy can be modernized through the application of technology to convert raw biomass into modern, easy-to-use carriers (such as electricity, liquid or gaseous fuels, or processed solid fuels).

2.4 Biomass Sources

Historically, humans have harnessed biomass-derived energy since the time when people began burning wood to make fire [11]. Even today, biomass is the only source of fuel for domestic use in many developing countries. Biomass is all biologically-produced matter based in carbon, hydrogen and oxygen. The estimated biomass production in the world is 104.9 pentagrams ($104.9 * 10^{15}$ g) of carbon per year, about half in the ocean and half on land [20].

Wood remains the largest biomass energy source today [22]; examples include forest residues (such as dead trees, branches and tree stumps), yard clippings, wood chips and even municipal solid waste. Wood energy is derived by using lignocellulose biomass (second-generation biofuels) as fuel. Harvested wood may be used directly as a fuel or collected from wood waste streams. The largest source of energy from wood is pulping liquor or "black liquor," a waste product from processes of the pulp, paper and paperboard industry. In the second sense, biomass includes plant or animal matter that can be converted into fibres or other industrial chemicals, including biofuels. Industrial biomass can be grown from numerous types of plants including micanthus [20], switchgrass, hemp, corn, poplar, willow, sorghum, sugarcane, bamboo [12], and a variety of tree species, ranging from eucalyptus to oil palm (palm oil).

Based on the source of biomass, biofuels are classified broadly into two major categories. First-generation biofuels are derived from sources such as sugarcane and corn starch. Sugars present in this biomass are fermented to produce bioethanol, an alcohol fuel which can be used directly in a fuel cell to produce electricity or serve as an additive to gasoline. However, utilizing food-based resources for fuel production only aggravates the food shortage problem.[21] Second-generation biofuels, on the other hand, utilize non-food-based biomass sources such as agriculture and municipal waste. These biofuels mostly consist of lignocellulose biomass, which is not edible and is a low-value waste for many industries. Despite being the favoured alternative, economical production of second-generation biofuel is not yet achieved due to technological issues. These issues arise mainly due to chemical inertness and structural rigidity of lignocellulose biomass [21-24].

Plant energy is produced by crops specifically grown for use as fuel that offer high biomass output per hectare with low input energy. Some examples of these plants are wheat, which typically yields 7.5–8 tonnes of grain per hectare, and straw, which typically yields 3.5–5 tonnes per hectare in the UK [25]. The grain can be used for liquid transportation fuels while the straw can be burned to produce heat or electricity. Plant biomass can also be degraded from cellulose to glucose through a series of chemical treatments, and the resulting sugar can then be used as a first-generation biofuel.

The main contributors of waste energy are municipal solid waste, manufacturing waste, and landfill gas. Energy derived from biomass is projected to be the largest non-hydroelectric renewable resource of electricity in the US between 2000 and 2020 [26].

Biomass can be converted to other usable forms of energy like methane gas or transportation fuels like ethanol and biodiesel. Rotting garbage, and agricultural and human waste, all release methane gas, also called landfill gas or biogas. Crops such as corn and sugar cane can be fermented to produce the transportation fuel ethanol. Biodiesel, another transportation fuel, can be produced from leftover food products like vegetable oils and animal fats [26]. Also, biomass-to-liquids (called "BTLs") and cellulosic ethanol are still under research [27-28].

There is research involving algae, or algae-derived, biomass, as this non-food resource can be produced at rates five to ten times those of other types of land-based agriculture, such as corn and soy. Once harvested, it can be fermented to produce biofuels such as ethanol, butanol, and methane, as well as biodiesel and hydrogen. Efforts are being made to identify which species of algae are most suitable for energy production. Genetic engineering approaches could also be utilized to improve microalgae as a source of bio-fuel [29].

The biomass used for electricity generation varies by region. Forest by-products, such as wood residues, are common in the US. Agricultural waste is common in Mauritius (sugar cane residue) and Southeast Asia (rice husks). Animal husbandry residues, such as poultry litter, are common in the UK.

As of 2015, a new bioenergy sewage treatment process aimed at developing countries is under trial; the Omni Processor is a self-sustaining process which uses sewerage solids as fuel in a process to convert waste water into drinking water, with surplus electrical energy being generated for export [30-32].

2.5 Classification and Different Resources of Biomass and their Use

2.5.1 Fuel wood

Total annual wood fuel consumption of the country is 8 million m3 where domestic cooking accounts for estimated 5.1 million m3 (63%) and the industrial and commercial sectors, 2.9 million m3 (37%). Of the total energy demand, tree and fuels provide 48%, agriculture residues 36%, dung 13% and peat 3% (FMP, 1992).

Figure 2.4: Fuel Wood

Though it is commonly thought that reserve forests are the main source of wood fuel in the country, but from avail information it has been found that village forests are supplying 84% of total consumption. At present there is acute shortages of wood fuel in Bangladesh, due to which poor people put option for other inferior type (not compact, difficult to handle) of biomasses like agricultural residues or animal dung. The future projection of demand and supply of wood fuel by forestry master plan which is shown in table 2.3.

Table 2.3: Wood fuel demand supply projections up to 2013 (in 1000 m^3 per annum)

Year	**2003**	**2008**	**2013**
Estimated demand	9847	10682	11553
Estimated supply	6787	7212	7742
Balance	-3060	-3470	-3811

2.5.2 Forestry crops and residue

Broadly Bangladesh's forests can be divided in to three types. (1) Mangrove forests in the coastal delta, (2) hill forests in the interior, and (3) a smaller area of inland salt (Shorea robusta) forest. The total land under forest area, according to forest Department (BFIR, 2000), is about 16.7. The survey conducted by FAO in 2003 and 2005 shows that 10 per cent of land is covered by forest. The forestry crops grown for use as energy can be burnt to generate steam which in turn can be used to generate electricity [32].

Figure 2.5: Forestry crops and residue

Forestry residues can be defined as any waste product produced in the clearing, harvesting and processing of wood forests. These wastes are often burnt or just left to rot. These materials can be collected and used as fuel either in the domestic or in the production of electricity.

2.5.3 Crop biomass

Agricultural residues contribute significantly to the biomass sector of Bangladesh. Crop residues can be distinguished into field residues and process residues. Field residues are residues that are left in the field after harvesting. In some cases they are just burned as waste [RWEDP 2001]. In Table 2.4, processed agricultural residue productions from different principal corps in the year 2008 are shown [33].

Table 2.4: Processed agricultural residues production in 2008 [RWEDP]

Crop	Cultivated area (Hectares)	Total Crop Production (Metric tons)	Residue	Residue- to- Product– Ratios (RPR)	Processed Residue Production (Metric tons)	Moisture Content (%)
Rice	10262707	28292940	Husks	0.27	7,639,094	12
Maize	2548	2660	Cob	0.27	718	7 to 8
Maize	2548	2660	Husks	0.2	532	11
Coconut	32092	89320	Shells	0.12	10,718	8 to 9
Coconut	32092	89320	Husks	0.42	37,514	10
Groundnut	34715	3538	Husks	0.48	18,978	8
Sugar cane	175152	7378710	Biogases	0.29	2,139,826	49
Jute	577390	1086910	Stalks	2	2,173,820	15
Total	**11119244**	**36982058**			**12,021,201**	

Figure 2.6: Crop Biomass

Field residues are scattered over a wide area, and when mixed with soil are generally uses as organic fertilizer. Process residues are generated during crop processing, e.g. milling. Besides being an energy source, crop residues are used for several other purposes, such as fodder, raw manufacturing materials, etc.

2.5.4 Agricultural crop

The agricultural crops that can be grown as energy sources are sugar cane, corn (maize), wheat, sorghum, sunflowers, grape seed (canola) and soybeans. These crops can be converted to liquid fuels such as ethanol [34].

Figure 2.7: Agricultural Crop

2.5.5 Animal waste

Current animal production provides a good source of animal waste mainly cattle dung that can be used as a source of biomass energy. Strict environmental controls, such as the proper disposal of waste, have made waste-to-energy a viable and possible profitable form of waste management. Total live animals of Bangladesh in 2000 are estimated 59.55 million heads (Table 2.5) of the working cattle 92% was used for cultivation and 0.19% was for transportation [Islam, 2000]. In Table 2.6 the annual dry matter productions of animal residues or manure are given intones. Dry matter fro, animal dung is the matter left after removal of moisture [35].

Figure 2.8: Animal waste

Table 2.5: Live animals in 2000 [FAOSTAT, 2001]

Animals	Head
Cattle	23,652,000
Goats	33,800,000
Sheep	1,121,000
Buffaloes	828,000

Table 2.6: Animals wastes in 1999 [RWEDP, 2001]

Animals	Head
Cattle	757,000
Goats	24,427,000
Sheep	2,018,000
Buffaloes	27,202,000

2.5.6 Municipal and industrial solid wastes

Municipal solid waste (MSW) is just household waste that is collected by garbage collectors and dumped in for landfill or in selected rubbish dumps. This amounts to millions of tons of household waste per year. The food production industry generates large fruit and volumes of waste product. These waste products include scraps from fruit and vegetables, food that is not of commercial standard and even the water that is used to carry off the waste material. These materials can be used to produce ethanol in a fermentation process or biogas in anaerobic digester. The main cities of Bangladesh are already overburdened with solid wastes from different sources. According to the world Banks study, the rural population generates solid waste only 0.15 kg per capita per day, while their urban counterparts generate 0.4 to 0.5 kg per capita per day [World Bank, 2005].

Figure 2.9: Municipal and industrial solid wastes

But attempts have been made to establish private community –bases waste management systems through NGOs. In the capital city of the country – Dhaka, one of the most populated cities in the world with about 10 million inhabitants and area of only 360 km^2, waste disposal system has become one of the major civic projects. It has been estimated by different sources that each day about 300 to 5000 tons of solid waste materials are generated in the city. Recently, waste concern, NGO involved with waste management, has entered into a Memorandum of Understanding (MOU) with the Dhaka City Corporation under which eight new communities based composting plants are being established throughout the city. Waste Concern have demonstrated how creative ventures, in which non-government and private sector organizations support the work of waste disposal authorities, can tackle the serious problems of waste management and generate revenue from a very unconventional source. Their innovative approach has recognized internationally and they are requested to provide technical support to India and Palestine (Waste Concern 2010) [36].

2.6 Biomass Conversion Process to Useful Energy

2.6.1 Thermal Conversion

Thermal conversion processes use heat as the dominant mechanism to convert biomass into another chemical form. The basic alternatives of combustion (Torre faction, pyrolysis, and gasification) are separated principally by the extent to which the chemical reactions involved are allowed to proceed (mainly controlled by the availability of oxygen and conversion temperature). Energy created by burning biomass (fuel wood) is particularly suited for countries where the fuel wood grows more rapidly, e.g. tropical countries. There is a number of other less common, more experimental or proprietary thermal processes that may offer benefits such as hydrothermal upgrading (HTU) and hydro processing. Some have been developed for use on high moisture content biomass, including aqueous slurries, and allow them to be converted into more convenient forms. Some of the applications of thermal conversion are combined heat and power (CHP) and co-firing. In a typical dedicated biomass power plant, efficiencies range from 20–27% (higher heating value basis) [37]. Biomass coffering with coal, by contrast, typically occurs at efficiencies near those of the coal combustor (30–40%, higher heating value basis) [38].

2.6.2 Chemical Conversion

A range of chemical processes may be used to convert biomass into other forms, such as to produce a fuel that is more conveniently used, transported or stored, or to exploit some property of the process itself. Many of these processes are based in large part on similar coal-based processes, such as Fischer-Tropic synthesis, methanol production, olefins (ethylene and propylene), and similar chemical or fuel feedstock's. In most cases, the first step involves gasification, which step generally is the most expensive and involves the greatest technical risk [39]. Biomass is more difficult to feed into a pressure vessel than coal or any liquid. Therefore, biomass gasification is frequently done at atmospheric pressure and causes combustion of biomass to produce a combustible gas consisting of carbon monoxide, hydrogen, and traces of methane. This gas mixture, called a producer gas, can provide fuel for various vital processes, such as internal combustion engines, as well as substitute for furnace oil in direct heat applications [40]. Because any biomass material can undergo gasification, this process is far more attractive than ethanol or biomass production, where only particular biomass materials can be used to produce a fuel. In addition, biomass gasification is a desirable process due to the ease at which it can convert solid waste (such as wastes available on a farm) into producer gas, which is a very usable fuel [41].

Conversion of biomass to biofuel can also be achieved via selective conversion of individual components of biomass [42]. For example, cellulose can be converted to intermediate platform chemical such a sorbitol, glucose, hydroxyl methyl furfural etc. These chemical are then further reacted to produce hydrogen or hydrocarbon fuels.
Other chemical processes such as converting straight and waste vegetable oils into biodiesel are transesterification [47].

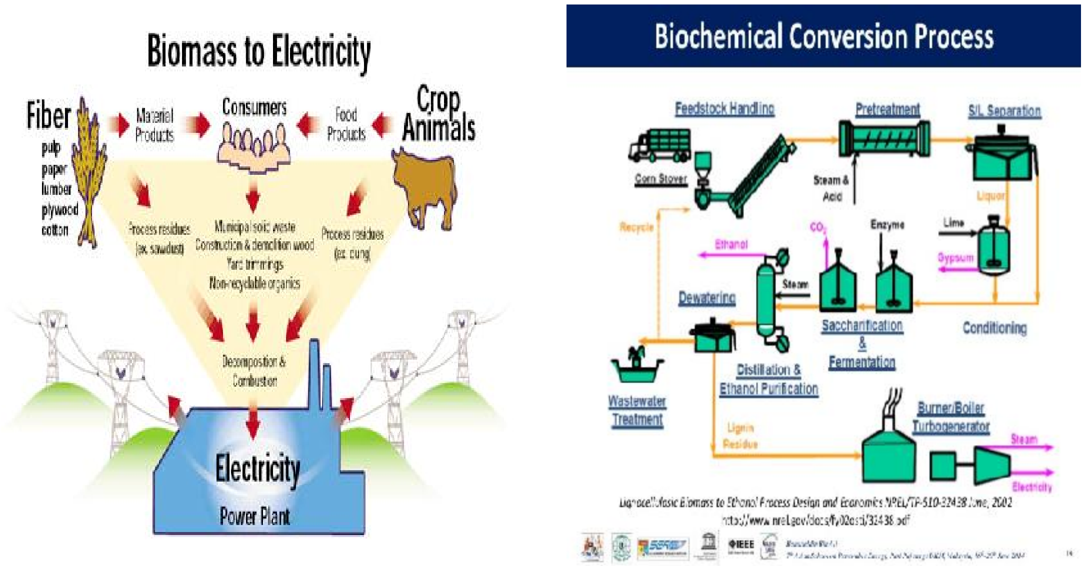


Figure 2.10: Different Conversion of Biomass to Useful Energy

2.6.3 Biochemical Conversion

As biomass is a natural material, many highly efficient biochemical processes have developed in nature to break down the molecules of which biomass is composed, and many of these biochemical conversion processes can be harnessed. Biochemical conversion makes use of the enzymes of bacteria and other microorganisms to break down biomass. In most cases, microorganisms are used to perform the conversion process: anaerobic digestion, fermentation, and composting [45].

2.6.4 Electrochemical Conversion

In addition to combustion, bio-mass or bio-fuels can be directly converted to electrical energy via electrochemical oxidation of the material. This can be performed directly in a direct, direct ethanol fuel cell or a microbial fuel cell. The fuel can also be consumed indirectly via a fuel cell system containing a reformer which converts the bio-mass into a mixture of CO and H2 before it is consumed in the fuel cell [49].

2.7 In the United States

The biomass power generating industry in the United States, which consists of approximately 11,000 MW of summer operating capacity actively supplying power to the grid, produces about 1.4 percent of the U.S. electricity supply. Currently, the New Hope Power Partnership is the largest biomass power plant in the U.S. The 140 MW facilities uses sugar cane fiber (bagasse) and recycled urban wood as fuel to generate enough power for its large milling and refining operations as well as to supply electricity for nearly 60,000 homes [51-52].

2.8 Second-generation biofuels

Second-generation biofuels were not (in 2010) produced commercially, but a considerable number of research activities were taking place mainly in North America, Europe and also in some emerging countries. These tend to use feedstock produced by rapidly reproducing enzymes or bacteria from various sources including excrement grown in Cell cultures or hydroponics. There is huge potential for second generation biofuels but non-edible feedstock resources are highly under-utilized [54-56].

2.9 Environmental Impact

Using biomass as a fuel produces air pollution in the form of carbon monoxide, carbon dioxide, NOx (nitrogen oxides), VOCs (volatile organic compounds), particulates and other pollutants at levels above those from traditional fuel sources such as coal or natural gas in some cases (such as with indoor heating and cooking) [57-59]. Utilization of wood biomass as a fuel can also produce fewer particulate and other pollutants than open burning as seen in wildfires or direct heat applications. Black carbon – a pollutant created by combustion of fossil fuels, biofuels, and biomass – is possibly the second largest contributor to global warming. In 2009 a Swedish study of the giant brown haze that periodically covers large areas in South Asia determined that it had been principally produced by biomass burning and to a lesser extent by fossil-fuel burning [62]. Researchers measured a significant concentration of ^{14}C, which is associated with recent plant life rather than with fossil fuels [63].

Biomass power plant size is often driven by biomass availability in close proximity as transport costs of the (bulky) fuel play a key factor in the plant's economics. It has to be noted, however, that rail and especially shipping on waterways can reduce transport costs significantly, which has led to a global biomass market. To make small plants of 1 MW, economically profitable those power plants have need to be equipped with technology that is able to convert biomass to useful electricity with high efficiency such as ORC technology, a cycle similar to the water steam power process just with an organic working medium. Such small power plants can be found in Europe [64-68].

On combustion, the carbon from biomass is released into the atmosphere as carbon dioxide (CO_2). The amount of carbon stored in dry wood is approximately 50% by weight. However, according to the Food and Agriculture Organization of the United Nations, plant matter used as a fuel can be replaced by planting for new growth. When the biomass is from forests, the time to recapture the carbon stored is generally longer, and the carbon storage capacity of the forest may be reduced overall if destructive forestry techniques are employed [69-73].

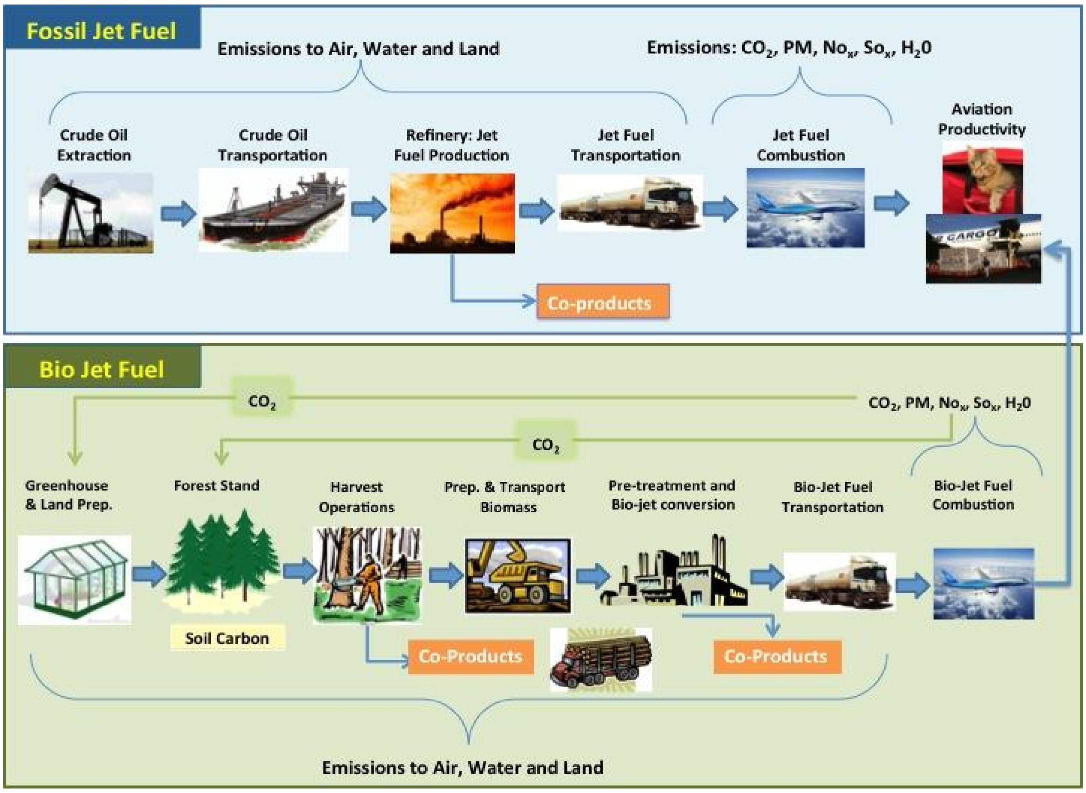


Figure 2.11: Fossil Fuel and Bio Fuel

Industry professionals claim that a range of issues can affect a plant's ability to comply with emissions standards. Some of these challenges, unique to biomass plants, include inconsistent fuel supplies and age. The type and amount of the fuel supply is completely reliant factors; the fuel can be in the form of building debris or agricultural waste (such as deforestation of invasive species or orchard trimmings). Furthermore, many of the biomass plants are old, use outdated technology and were not built to comply with today's stringent standards. In fact, many are based on technologies developed during the term of U.S. President Jimmy Carter, who created the United States Department of Energy in 1977 [70].

The U.S. Energy Information Administration projected that by 2017, biomass is expected to be about twice as expensive as natural gas, slightly more expensive than nuclear power, and much less expensive than solar panels. In another EIA study released, concerning the government's plan to implement a 25% renewable energy standard by 2025, the agency assumed that 598 million tons of biomass would be available, accounting for 12% of the renewable energy in the plan [74].

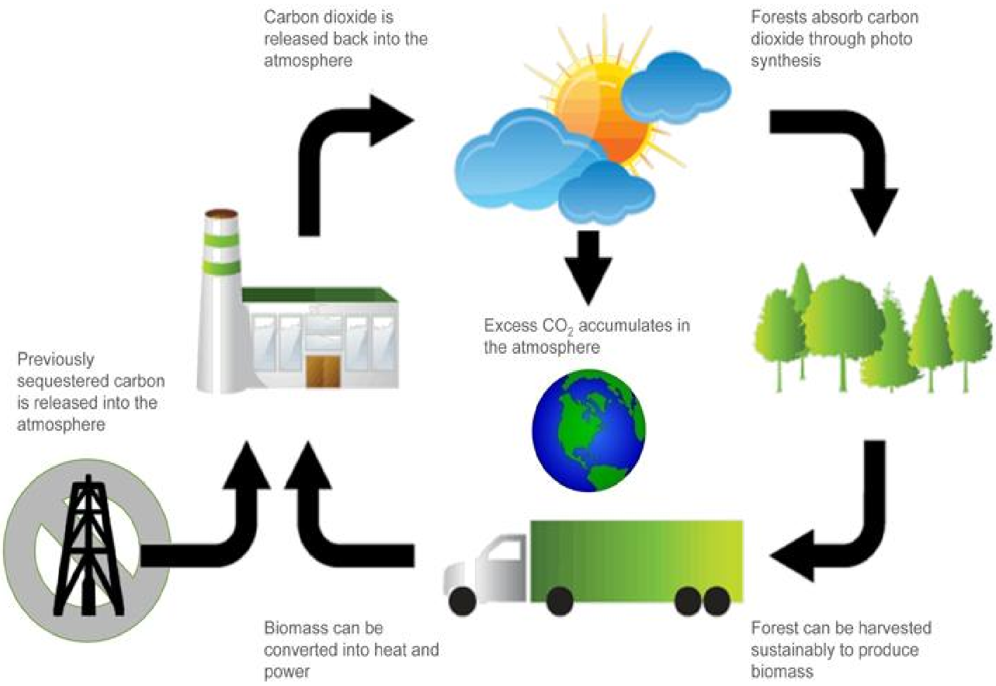


Figure 2.12: Utilization of Biomass

The adoption of biomass-based energy plants has been a slow but steady process. Between the years of 2002 and 2012 the production of these plants has increased 14%. In the United States, alternative electricity-production sources on the whole generate about 13% of power; of this fraction, biomass contributes approximately 11% of the alternative production. According to a study conducted in early 2012, of the 107 operating biomass plants in the United States, 85 have been cited by federal or state regulators for the violation of clean air or water standards laws over the past 5 years. This data also includes minor infractions [75-77].

Despite harvesting, biomass crops may sequester carbon. For example, soil organic carbon has been observed to be greater in switch grass stands than in cultivated cropland soil, especially at depths below 12 inches. The grass sequesters the carbon in its increased root biomass. Typically, perennial crops sequester much more carbon than annual crops due to much greater non-harvested living biomass, both living and dead, built up over years, and much less soil disruption in cultivation.

The proposal that biomass is carbon-neutral put forward in the early 1990s has been superseded by more recent science that recognizes that mature, intact forests sequester carbon more effectively than cut-over areas. When a tree's carbon is released into the atmosphere in a single pulse, it contributes to climate change much more than woodland timber rotting slowly over decades. Current studies indicate that "even after 50 years the forest has not recovered to its initial carbon storage" and "the optimal strategy is likely to be protection of the standing forest" [78-79].

The pros and cons of biomass usage regarding carbon emissions may be quantified with the ILUC factor. There is controversy surrounding the usage of the ILUC factor.

Forest-based biomass has recently come under fire from a number of environmental organizations, including Greenpeace and the Natural Resources Defence Council, for the harmful impacts it can have on forests and the climate. Greenpeace recently released a report entitled "Fuelling Biomes" [81] which outlines their concerns around forest-based biomass. Because any part of the tree can be burned, the harvesting of trees for energy production encourages Whole-Tree Harvesting, which removes more nutrients and soil cover than regular harvesting, and can be harmful to the long-term health of the forest. In some jurisdictions, forest biomass removal is increasingly involving elements essential to functioning forest ecosystems, including standing trees, naturally disturbed forests and remains of traditional logging operations that were previously left in the forest.

Environmental groups also cite recent scientific research which has found that it can take many decades for the carbon released by burning biomass to be recaptured by re-growing trees, and even longer in low productivity areas; furthermore, logging operations may disturb forest soils and cause them to release stored carbon. In light of the pressing need to reduce greenhouse gas emissions in the short term in order to mitigate the effects of climate change, a number of environmental groups are opposing the large-scale use of forest biomass in energy production [82].

Chapter 3

Pellet

3.1 What is Pellet?

Pellets are fuels made from compressed organic matter, or, biomass. Pellets can be made from any one of five general categories of biomass: industrial waste and co-products, food waste, agricultural residues, energy crops and virgin lumber. **Wood pellets** are the most common type of pellet fuel and are generally made from compacted sawdust and related industrial wastes from the milling of lumber, manufacture of wood products and furniture, and construction. Other industrial waste sources include Empty Fruit Bunches [EFB], palm kernel shells, coconut shells, and tree tops and branches discarded during logging operations. So-called "black pellets" are made of biomass, refined to resemble hard coal and were developed to be used in existing coal-fired power plants. Pellets are categorized by their heating value, moisture and ash content, and dimensions. They can be used as fuels for power generation, commercial or residential heating, and cooking. Pellets are extremely dense and can be produced with a low moisture content (below 10%) that allows them to be burned with very high combustion efficiency [84].

3.2 Global Pellet Outlook

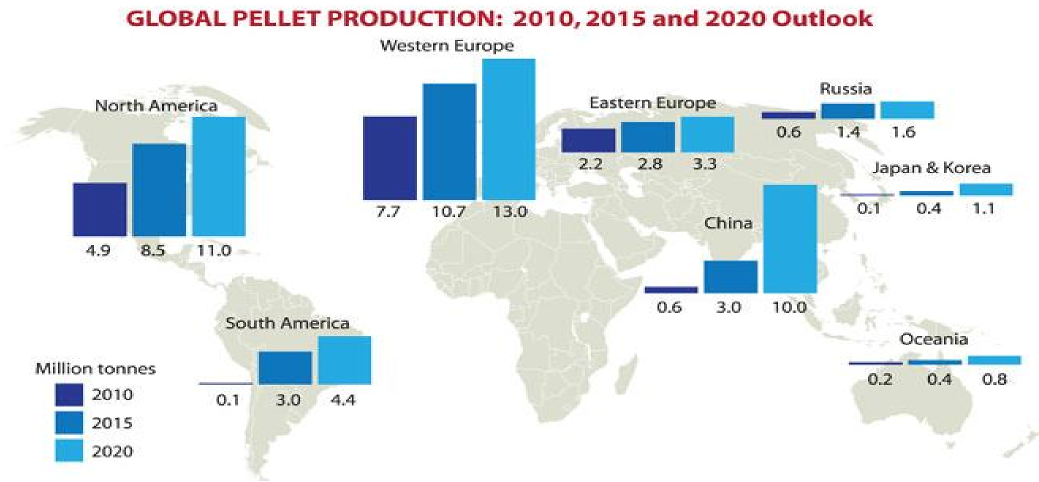
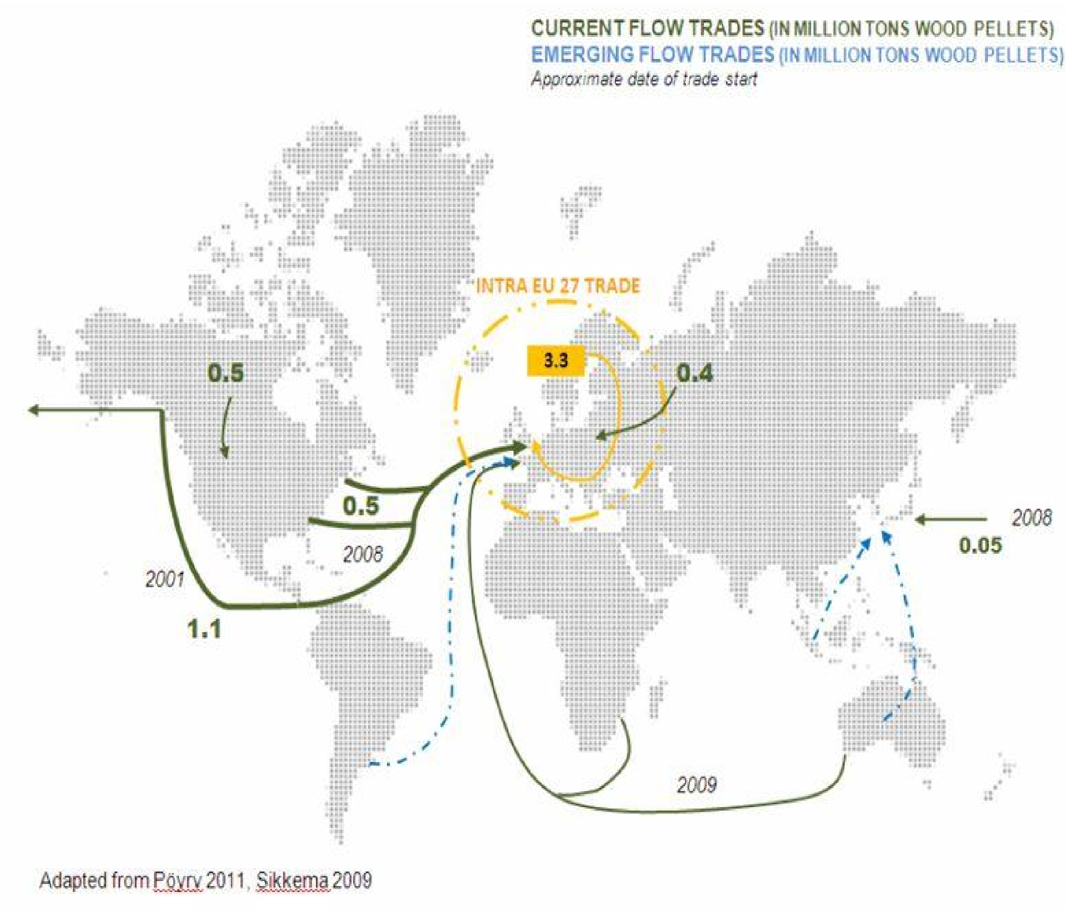


Figure 3.1: Global Pellet Outlook 2010, 2015 and 2020 [84]

The world production volume of wood pellets was about 14 Mio. Ton in 2010 (Poyry, 2011). The production capacity was unequally distributed amongst the largest producers, US – Canada and Scandinavia and emerging producing countries, such as Australia, South Africa and South America. These different origins also imply different types of wood feedstock and production systems (either from forest industry wastes or forest residues, or from plantations).

3.3 Wood Pellets Production and Trade Flows

The main stream is from Canada and US. Canada plays a major role in trade flows. While nearly the half of the production was exported to the US in 2002, their main market is now Europe, with exports of about 1.4 million tons in 2010 (about 90% of exports). Canada consumes only 40-50 thousand tons pellets a year. Figure 2, shows a global overview of wood pellets trade flows [85].



Map of wood pellets trade flows worldwide (2010 status).

Figure 3.2: Wood Pellet Trade Flow [85]

Within Europe, industrial wood pellets are exported from the Baltic countries, Finland and Russia to Sweden, Denmark, Belgium, the Netherlands and UK by vessel (EUBIONET 3). Russia also exports significant amounts; While

Australia, South America and South Africa have seen an increase of their production capacity.

3.4 Global Wood Pellet Market Overview

The global economy is gradually recovering from the worst economic downturn since the Great Depression. The World Bank predicted that global gross domestic product (GDP) growth for 2010 would be 3.3 percent, which is double the 2008 level (World Bank 2010). This new phase of global expansion will stimulate demand for more energy including wood pellets [86].

The major wood pellet-producing countries in North America and Europe are Canada, Germany, Sweden and the United States. The major consumer countries for wood pellets are Belgium, Denmark, The Netherlands, Sweden and the United States. The major wood pellet importing countries are Belgium, Denmark, the Netherlands and Sweden. The United States produces a large quantity of wood pellets but also consumes a large quantity. In contrast, Canada produces a large quantity of wood pellets but exports approximately 80 percent of its production [86].

3.4.1 Asian's Wood Pellet Markets

The Asian wood pellet market is expanding at a steady pace. This can be seen in the quantity of wood pellet exports from the Port of Prince Rupert, British Columbia, to Asia, which increased 33 percent in the first half of 2010 over the same period in the previous year (Prince Rupert Port Authority 2010). The west coast is in a strong position to supply Asia with wood pellets, drawing on both timber supply and proximity to Asian markets.

Most of the wood pellets shipped to Asia are directed to two markets. The first is the industrial energy sector, where pellets are used for co-firing with coal at power plants and in large boilers. The second is the home heating market, where pellets are used in pellet stoves. Generally, wood pellets shipped to the industrial energy markets in Asia are shipped via bulk carrier rather than by container ships. The three largest consumers of wood pellets in Asia are China, South Korea, and Japan; the following sections provide an overview of their general economies, energy needs, and wood pellet markets.

3.4.1.1 China's Wood Pellet Market

Biomass fuel development is a top priority in China. One area China is examining to supplement its coal use is wood pellets (Wang 2005). China's production of wood pellets was estimated to be 8,00,000 metric tons in 2008 (Swaan 2008) and 1 million metric tons in 2009 (Yamamoto et al. 2009). China's wood pellet consumption relies primarily on domestic production, and imports are minimal. In 2008, China imported approximately US$10.3 million dollars of wood fuel; only a fraction of this figure was for wood pellets (FAO 2010). However, the Chinese currency has appreciated against the U.S. dollar, which may make U.S. wood pellets more cost-competitive in the Chinese market. As in Japan, the major market for wood pellets in China is for co-firing at coal power plants. In summary, China has the second largest energy market in the world and is searching for ways to increase its percentage of renewable energy. However, China's wood pellet import volume is still relatively small, thus strong efforts would need to be made in market development [87].

3.4.1.2 South Korea's Wood Pellet Market

In 2009, South Korea's total pellet market was estimated to be 30,000 metric tons, with 10,000 metric tons being imported and 20,000 metric tons being produced domestically (Han 2009). Wood pellet demand was projected to more than double by 2012 to 7, 50,000 metric tons, then increase to 5 million metric tons by 2020.

These projections are based on South Korea increasing its portion of renewable energy in order to meet the 11 percent renewable energy requirement by 2020. This 2020 requirement combined with firm economic growth, makes South Korea a strong wood pellet market. However, currently its import quantity is fairly low, so U.S. exporters would need to establish relationships and invest in business development [88].

3.4.1.3 Japan's Wood Pellet Market

The wood pellet industry is firmly established in Japan and is used for home heating as well as for power generation. In 2003, Japan produced an estimated 2400 metric tons of wood pellets, which increased to 60000 metric tons by 2008. The Japan Wood Pellet Association reports that there are 55 wood pellet manufacturing facilities in Japan (Japan Wood Pellet Association 2010).

In addition to domestic production, Japan imported approximately 49,000 metric tons of wood pellets in 2009 (Murray 2010). A majority of the imported wood pellets are sourced from Canada. Additionally, the Port of Prince Rupert has exported 1,20,723 metric tons of wood pellets to Asia as of August 2010, is a 36 percent increase from the same time the previous year (Port of Prince Rupert 2010). A large portion of Japan's wood pellets are being used for electric power generation. Kansai Electric Power Corporation, a leader in this field, started using wood pellets for co-firing with coal at its Maizuru power plant in August 2008. The wood pellets will furnish approximately 120 million kilowatt hours of electricity per year, which is about 2 percent of the Maizuru plant's total output (Canada Trade Commission 2008) [89].

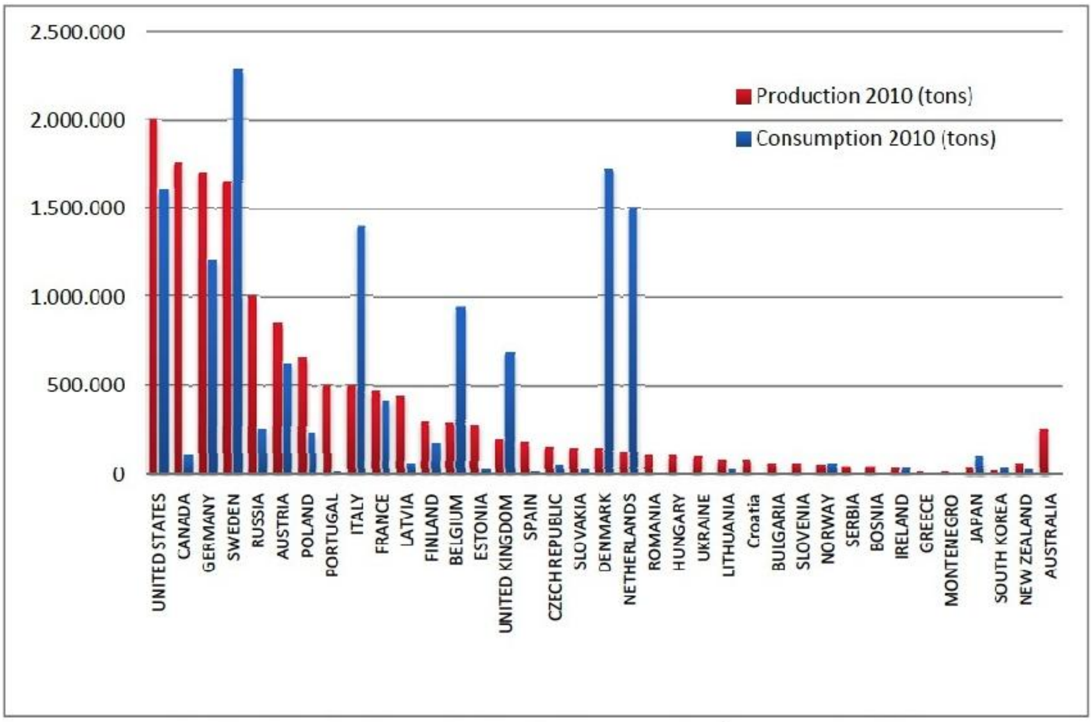


Figure 3.3: Global Pellet Production and Consumption [89]

3.4.2 Europe's Wood Pellet Market

The availability of raw material, competitive prices and diversified energy policies favour development of a wood pellet industry in Europe. Sweden, Denmark, Germany and Austria have the most highly developed pellet markets; the others like Italy, Belgium, France and UK recently have been following that trend. In 2006 the production of pellets in Europe was about 4,500,000 tonnes, with Sweden, Austria and Germany as main producers. Almost 300 pellet plants are located in EU ranging from small scale producers with an annual capacity from 2,000 to 150,000 tonnes of pellets. The figure 3.2, presents a map of wood pellets locations [90].

In 2006 in Europe, wood pellets consumption accounted for around 5,500,000 tonnes, which indicates significant amount of import. Wood pellets are used both in electricity and heat production (in large, medium and small scale) and their application varies from country to country. Nevertheless, their primary use (in stoves, furnaces or industrial applications) depends significantly on the national renewable energy policies, forestry structures, the scale of woodworking industries and the heating habits.

Heat demand is a very important part of energy market in European Union (accounting for about 50% of the European energy market) where low temperature heat from quality heat sources such as pelletized biomass are considered essential to meeting future energy needs. In Sweden, Denmark and Finland wood pellets are used for both: electricity and heat production. In Netherlands and Belgium utilities use pellets in co-firing in power production while in Germany, Austria, Italy and France pellets are used almost entirely in central heating and single stoves [91].

3.4.2.1 Sweden's Wood Pellet Market

Sweden is the biggest European producer of wood pellets accounting for 1,458,000 tonnes in 2006. Total capacity of 35 pellet plants in Sweden is estimated for an over 1,600,000 tonnes/year (with 2 plants producing over 130,000 tonnes and 15 producing over 30,000 tonnes a year). The pellets distribution network is well established, with truck transport common for shorter distances, while sea shipping proving economical for longer distances.

The raw material used for Swedish pellets production includes sawdust, shavings, chippings and a wide range of other forestry by-products, depending on the quality requirements for the different fields of application. Several of the new plants and the plants under construction aim at using also round wood for raw material. Recently built pellet plants, especially the bigger ones, have installed dryers to handle also wet fraction of sawdust. So far, it is only the pellet plant at the Monsters pulp and paper mill, which produces pellets from bark (obtained as by-product from the logs debarked before pulp production). The amount of bark is so high that the plant today has a capacity of 50,000 tonnes a year [92].

3.4.2.2 Germany's Wood Pellet Market

German wood pellet production is still relatively small. However, favourable tax laws for installation of biofuel combustion systems and large quantities of available wood fibre (7 million tonnes of scrap wood from sawmills and commercial timber alone) make Germany one of the most promising pellet markets in Europe. About 30% of the country is covered in woodland. Commercial wood pellet production has started in several locations in Germany in the last decade. Currently 32 processing facilities produce an estimated 550,000 tonnes of wood pellets, thereof 420,000 tonnes for domestic consumption. The main sources for the raw material are saw dust, wood chips and other wood residues. The pellet producer German Pellets GmbH is going to increase pellet production in Germany. By October 2007 its installed annual capacity will draw up 780,000 tonnes of pellets. Thus it will be the biggest pellet producer in Europe. The production capacity for wood pellets is forecast to reach the 1,200000 tonnes in 2007 [93].

3.4.2.3 Austria's Wood Pellet Market

In Austria pellets production is an attractive business for the wood-processing industry therefore it has been developing very dynamically. In 2006, about 27 companies are producing pellets, three of them with a production capacity of more than 70,000 tonnes/year. The total production capacity at present amounts to about 600,000 tonnes/year, which is expected to increase in the years to come. According to the Austrian Energy Agency, for 2007 a production capacity of one million tonnes of pellets is forecasted. In 2005, Austrian pellet plants produced approximately 450,000 tonnes of pellets and for 2006 the domestic pellets production raised above 600,000 tonnes. For 2007 a production capacity of one million tonnes of pellets is forecasted by the Austrian Energy Agency.

3.4.2.4 Denmark's Wood Pellet Market

Danish production of wood pellets reached 200,000 tonnes in 2005, and according to Force the production level remained at the same level in 2006. It is growing over the years but relatively slowly (since 2000 the production increased only by 40,000 tonnes). Denmark is the location of 3 large pellet plants: one with the capacity of 280,000 tonnes and two above 80,000 tonnes. Overall pellet production capacity is 400,000 tonnes which unused represents only 50% of the 2005 pellet demand in Denmark [93].

3.4.2.5 Finland's Wood Pellet Market

In 2005, the indigenous consumption of pellets was 59,000 tonnes, and increased in 2006 to 100,000 tonnes. When comparing direct fuel prices in heat production, pellets are competitive against fuel oils, but are more expensive than coal. Consequently, pellets are used in applications where light fuel oil is an alternative fuel. However, the price difference in the total heating costs between pellets and fossil fuels has been relatively small, which has retarded the growth of the domestic consumption of pellets.

3.4.2.6 Italy's Wood Pellet Market

Italy is the most important Mediterranean pellet market, with over 90 production sites. Nevertheless, national production, of approximately 300,000 tonnes in 2006, cannot satisfy the growing demand. Recently the pellets market has seen significant growth. Pellets producers are very variable in size and hence the production varies considerably: the smaller producer produces 300 tonnes/year, while the biggest ones produce 25-30,000 tonnes/year. Regarding the distribution on the territory of pellets producers, nearly the 80 per cent of them is located in the North of Italy, where the largest producers are located. In the North, the Veneto region covers about 35% of the market; in fact, the North-East is one of the most industrialized zone in Italy and it is also a "wood industrial district", that is an area specialized in the wood industry. With the market increasing, the proportion covered by the North Italy has decreased, passing from more than 80 per cent to about 77 per cent; this decreased has been in favour of the producers located in Central Italy, where the production has increased of about 4.5% [94].

3.4.2.7 Norway's Wood Pellet Market

Norway is steadily increasing its wood pellets production, with the volumes of 34,000 tonnes in 2004, 42,000 tonnes in 2005 and 51,000 tonnes in 2006. Production is rather equally allocated to domestic use and for export.

3.4.3 North America's Wood Pellet Market

3.4.3.1 Canada's Wood Pellet Market

Manufacture and export of wood pellets in Canada has grown exponentially in the past several years, primarily on the west coast. There are at least 23 pellet plants in Canada, out of which almost half in British Columbia. Production has reached 1,400,000 tonnes in 2006 and several new pellet mills as well as expansion of existing mills are being planned or implemented in the next year. Princeton has recently upgraded to 75,000 tonnes and Armstrong to 50,000 tonnes. These plants are being built to take advantage not only of the surplus mill residue situation in British Columbia, but also the huge potential wood supply from Mountain Pine Beetle affected stands [94-95].

3.4.3.2 United States Wood Pellet Market

In the US, pellet mills across the country receive, sort, grind, dry, compress, and bag wood and other biomass waste products into a conveniently handled fuel. Today, over sixty pellet mills across North America produce in excess of 800,000 tonnes of fuel per year, a figure that has more than doubled in the last five years.

Green Circle Bio Energy Inc., a newly established renewable energy company is in the phase of constructing wood pellet plant in Florida. The plant has a planned production capacity of 500,000 tonnes of wood pellets, and will be the largest wood pellet plant in the world. Its production is targeted mainly for export to European Union.

3.4.4 Latin America's Wood Pellet Market

Pellets production is just starting in Latin America and supply of biomass residues for that purpose is not a barrier at the moment. However, the lack of industrial capacity and the logistic barriers are serious constraints. Exports of pellets, at present, have been made for domestic uses. However, pellets costs from given Brazilian sites, according to some analysis, showed competitiveness if compared with market prices also for large scale uses in Europe [96-97].

Chapter 4

Economics of Producing Fuel Pellets from Biomass

Lignocellulosic biomass (biomass from plants), in its original form usually have a low bulk density of 30 kg/m^3 and a moisture content ranging from 10% to 70% (wb). Pelleting increases the specific density (gravity) of biomass to more than 1000 kg/m^3. Pelleted biomass is low and uniform in moisture content. It can be handled and stored cheaply and safely using well developed handling systems for grains (Fasina and Sokhansanj, 1996).

Forest and sawmill residues, agricultural crop residues, and energy crops can be densified into pellets. Pellets are cylindrical, 6 to 8 mm in diameter and 10 to 12 mm long. Melin (2005) reports that in North America, more than 1.2 million t (In this article, t indicates tonne in SI Units) of fuel pellets are produced annually. Most of the U.S. pellets are bagged and marketed for domestic pellet stoves. In Canada, pellets produced from sawdust and wood shavings are exported to European countries – Sweden and Denmark.

The recent increases in oil and gas prices and climate change have boosted the demand for biomass. In spite of their many desirable attributes, biomass pellets cannot compete with fossil fuel sources because it is still expensive to densify biomass. To produce biomass pellets economically, a detailed economic analysis is required taking into consideration plant capacity, feedstock cost, drying cost, and plant utilization time [94].

4.1 Pelleting Operation

Apart from animal feed, alfalfa and sawmill residues are the other two biomass that are pelletized extensively in Canada. Figure 4.1 shows the unit operations and the flow of biomass in a typical biomass pelleting operation that consists of three major unit operations, drying, size reduction (grinding), and densification (pelleting). The biomass is dried to about 10% (wb) in the rotary drum dryer. Superheated steam dryers, flash dryers, spouted bed dryers, and belt dryers are also common in European countries (Stahlet al., 2004; Thek and Obernberger, 2004) but they are not used in North America (to the knowledge of the authors). The drying medium is the flue gas from the direct combustion of natural gas. Solid fuels, especially biomass fuels, are gradually replacing natural gas because of recent price increases in fossil fuels [94].

After drying, a hammer mill equipped with a screen size of 3.2 to 6.4 mm reduces the dried biomass to a particle size suitable for pelleting. The ground biomass is compacted in the press mill to form pellets. The individual pellet density ranges from 1000 to 1200 kg/m3. The bulk density of pellets ranges from 550 to 700 kg/m^3 depending on size of pellets. Pellet density and durability are influenced by physical and chemical properties of the feedstock, temperature and applied pressure during the pelleting process (Mani et al., 2003). In some operations, the ground material is treated with super-heated steam at temperatures above 100°C before compaction. The superheated steam increases moisture and temperature of the mash causing the release and activation of the natural binders present in the biomass. Moisture also acts as a binder and lubricator (Robinson, 1984).

In some operations, binders or stabilizing agents are used to reduce the pellet springiness and to increase the pellet density and durability. Most widely used binders for pelleting of animal feeds are calcium lignosulfonate, colloids, bentonite, starches, proteins and calcium hydroxide. Biomass from woody plants contains higher percentages of resins and lignin compared to agricultural crop residues (straw and stover). When lignin-rich biomass is compacted under high pressure and temperature, lignin becomes soft exhibiting thermosetting properties. The softened lignin acts as glue [95].

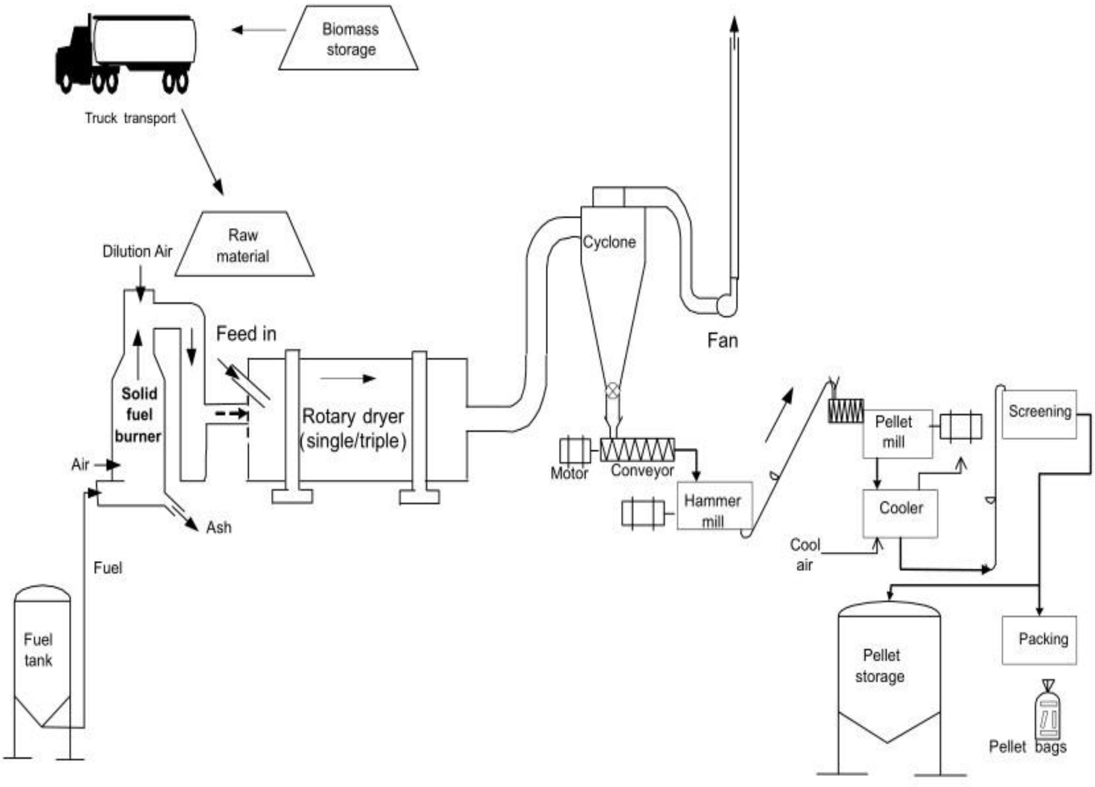


Figure 4.1: Schematic layout of a typical biomass pellet plant [95]

The temperature of pellets coming out of the pellet mill ranges from 70°C to 90°C. The elevated temperature is due to the frictional heat generated during extrusion and material pre-heating. Pellets are cooled to within 5°C of the ambient temperature in a cooler. The hardened cooled pellets are conveyed from the cooler to storage areas using mechanical or pneumatic conveying systems [96]. Pellets may be passed over a screen to have fines removed and were weighed before being stored in enclosed storage areas.

4.2 Pellet Production Costs

The cost of pelleting includes fixed (capital) and operating costs. The purchase cost of different equipment was collected from the manufacturers and published literature sources. All capital cost components follow the economy of scale, i.e. expansion of the unit size with respect to its characteristics dimensions will reduce the capital cost, non-proportional to the actual size of expansion. For notations used in this article, see the List of Nomenclatures at the end of the text [96].

The total capital cost, Cc ($/y) was calculated by:

$$Cc = eCeq \text{ ……………………..(1)}$$

where e is the capital recovery factor and Ceq is the cost of the equipment ($). The capital recovery factor was calculated using equation 2:

$$e=i(1+i)^{N}/(1+i)^{N}-1 \text{ ……………..(2)}$$

where i is the interest rate (decimal) and N is the lifetime of the equipment (years). The equipment cost, Ceq, was found from the general relationship.

$$Ceq = \mathrm{a_{eq}P^{neq}} \text{ ………………….(3)}$$

where a_{eq} is the unit cost of the equipment ($), neq is the scaling factor of the equipment, and P is the characteristic parameter of the equipment. The following cost versus capacity relationship was used wherever the specific equipment cost for a particular capacity was not available,

$$C_{eq}1=C_{eq}2(C_1/C_2)^{g} \text{ ……………….(4)}$$

C1 and C2 are the capacity of equipment 1 and 2; *g* is the exponent. The exponent value for process equipment ranges from 0.4 to 0.8. We used the exponent value of 0.6 in this study. The total cost, CT, was calculated by [97]:

$$CT = Cc + Cop \text{ …………………..(5)}$$

where Cop is the operating cost ($/y). The production cost, *C*P ($/kg), for any product was estimated from equation 6:

$$C_p=C_T/t_{top}G_p \text{ …………………….(6)}$$

where *t*op is the total operating hours of the plant per year (h/y) and Gp is the production rate (kg/h).

Equipment price relationships quoted in different years are adjusted to 2004 U.S. dollar values by taking into account for inflation factors (Consumer Price Index) published by National Aeronautics and Space Administration (NASA) cost estimating web site (NASA, 2004). Installation cost of the equipment was in the range of 40% to 75% of the purchase cost. The purchase and installation cost of various equipment were taken from Perry and Green (1999) and Walas (1990). The capital cost of hammer and pellet mills were received from equipment manufacturers. The capital cost includes the land cost, purchase, installation and maintenance, office building construction cost, and costs of dump trucks, forklifts and front-end loaders. Cost analysis of dump trucks, front-end loaders, and forklifts was based on the ASAE standard EP496.2 (*ASAE Standards*, 2003) [96-97].

We assumed a 6% interest rate. The maintenance of equipment and building was assumed to be 2% of the capital cost except for the pellet and hammer mills. Pellet and hammer mills have high repair and maintenance cost (10% of the purchase cost) due to the wear and tear of the equipment. The operating cost includes the cost of the raw material, heat energy cost for drying, electricity cost, and personnel costs. The heat energy cost for the dryer depends on the type of fuel used and the fuel cost. Costs for five different dryer fuels (wet biomass, dry biomass, fuel pellets, natural gas, and coal) were calculated. Personnel costs were included in pellet production, marketing, and administration [96]. In order to produce wood pellets, no steam conditioning or external binders were used. Because lignin in the sawdust acts as a natural binder during pelletization, the cost of steam or binders was not included in the cost analysis. The base case pellet cost estimation was used to investigate the effect of plant capacity, raw material cost, and dryer fuel options on the pellet production cost.

4.3 Nomenclature

Cc = total capital cost ($/y)
CE = cost of electricity ($/kWh)
Ceq = equipment cost ($)
CP = production cost ($/kg)
Cop = operating cost ($/y)
CT = total annual cost ($/y)
e = capital recovery factor
g = exponent for the capacity of equipment
GP = production rate of the product (kg/h)
i = annual interest rate (%)
N = life time of the equipment (y)
neq = scaling factors for equipment
P = characteristic parameter for any equipment (eg. heat transfer area, length, flow rate etc.)
top = operation hours per year (h/y)
a_{eq} = unit cost of equipment ($)
Ceq1 = equipment cost ($) for the capacity, C1
Ceq2 = equipment cost ($) for the capacity, C2

Chapter 5

Pellet Manufacturing Process

Wood pellets have increased tremendously in popularity as a heating fuel during recent years, with many homeowners and commercial facilities choosing pellet stoves or boilers over traditional wood-fired equipment due to their relative ease of use. As a result, the demand for fuel pellets has also grown quickly. However, wood is not the only suitable feedstock for manufacturing pellet fuel. A wide array of biomass materials can be used to manufacture pellets, most notably perennial grasses such as switchgrass or miscanthus [53]. Not only that, but the necessary equipment for making pellets is available at a variety of sizes and scales, which allows for everything from the smallest scale (single homeowners manufacturing for their personal use only) to the largest commercial plants producing more than 500 million tons of pellets per year.

Figure 5.1: Wood Pellet [53]

5.1 Properties of Biomass Pellets

Biomass pellets are generally a superior fuel when compared to their raw feedstock. Not only are the pellets more energy dense, they are also easier to handle and use in automated feed systems. These advantages, when combined with the sustainable and ecologically sound properties of the fuel, make it very attractive for use. The standard shape of a fuel pellet is cylindrical, with a diameter of 6 to 8 millimeters and a length of no more than 38 millimeters. Larger pellets are also occasionally manufactured; if they are more than 25 millimeters in diameter, they are usually referred to as “briquettes” [53].

A high-quality pellet is dry, hard, and durable, with low amounts of ash remaining after combustion. The most common pellets currently on the market must have an ash content of less than 1-2 percent. Pellets should have chloride levels of less than 300 parts per million and no more than 0.5 percent of fines (dust). Many

biomass feedstocks have a higher ash content than the standard allows. In addition, some grasses and other materials generate ash that tends to form clumps and deposits at high temperatures. Because of this, most wood pellet stoves are not suitable for burning fuel pellets made from materials other than wood [54-55].
ENplus means:

- Quality management
- Integration of the whole supply chain into the certification scheme
- Security of pellet supply
- Continuous monitoring system of the production and trade volume
- Sustainability
- A fix part of raw material from sustainable forestry

Definition of a minimum percentage of certified wood (PEFC, FSC)

ENplus-A1	ENplus-A2	EN-B
• Stem wood • Chemically untreated wood residues	• Whole trees without roots • Stemwood • Logging residues • Chemically untreated wood residues	• Forest, plantation and other virgin wood • Chemically untreated wood residues • Chemically untreated used wood [1]

[1] no demolition wood

Figure 5.2: Definition of a minimum percentage of certified wood (PEFC, FSC) [51-57]

Quality parameters	Unit	DINplus	ENplus-A1	ENplus-A2	EN-B
Diameter	mm	$4 \leq D \leq 10$	6 (± 1)[4]	6 (± 1)[4]	6 (± 1)[4]
Length	mm	$\leq 5 \times D$	$3{,}15 \leq L \leq 40$ [1]	$3{,}15 \leq L \leq 40$ [1]	$3{,}15 \leq L \leq 40$ [1]
Bulk density	kg/m^3	-	≥ 600	≥ 600	≥ 600
Net calorific v.	MJ/kg	≥ 18 *	≥ 16,5	≥ 16,5	≥ 16,0
Moisture	w-%	≤ 10	≤ 10	≤ 10	≤ 10
Fines	w-%	≤ 1	≤ 1 [2]	≤ 1 [2]	≤ 1 [2]
Mechanical durability	w-%	≥ 97,7 *	≥ 97,5	≥ 97,5	≥ 95,5
Ash	w-% [3]	≤ 0,5 *	≤ 0,7	≤ 1,5	≤ 3,0
Ash melting behavior (DT)	°C	-	≥ 1200	≥ 1100	≥ 1100

Figure 5.3: ENplus Table

[1]Amount of pellets longer than 40mm can be 5 w-%. Maximum length shall be < 45 mm
[2]Fines at factory gate in bulk transport, Fines in small bags, when delivered to end-user; Fines in small bags at factory gate: 0,5 M-%;
[3]Water free (wf)
* values based on diffrent test methodes

Quality parameters	Unit	DINplus	ENplus-A1	ENplus-A2	EN-B
Chlorine	w-% [1]	≤ 0,02	≤ 0,02	≤ 0,03	≤ 0,03
Sulphur	w-% [1]	≤ 0,04	≤ 0,05	≤ 0,05	≤ 0,05
Nitrogen	w-% [1]	≤ 0,3	≤ 0,3	≤ 0,5	≤ 1,0
Copper	mg/kg [1]	-	≤ 10	≤ 10	≤ 10
Chromium	mg/kg [1]	-	≤ 10	≤ 10	≤ 10
Arsenic	mg/kg [1]	-	≤ 1	≤ 1	≤ 1
Cadmium	mg/kg [1]	-	≤ 0,5	≤ 0,5	≤ 0,5
Mercury	mg/kg [1]	-	≤ 0,1	≤ 0,1	≤ 0,1
Lead	mg/kg [1]	-	≤ 10	≤ 10	≤ 10
Nickel	mg/kg [1]	-	≤ 10	≤ 10	≤ 10
Zinc	mg/kg [1]	-	≤ 100	≤ 100	≤ 100

Figure 5.4: Component table of Pellet [52]

[1]water free (wf)

5.2 A Description of the Pelleting Process

The process of manufacturing fuel pellets involves placing ground biomass under high pressure and forcing it through a round opening called a "die." When exposed to the appropriate conditions, the biomass "fuses" together, forming a solid mass. This process is known as "extrusion." Some biomass (primarily wood) naturally forms high-quality fuel pellets, while other types of biomass may need additives to serve as a "binder" that holds the pellet together. However, the creation of the pellets is only a small step in the overall process of manufacturing fuel pellets. These steps involve feedstock grinding, moisture control, extrusion, cooling, and packaging. Each step must be carried out with care if the final product is to be of acceptable quality.

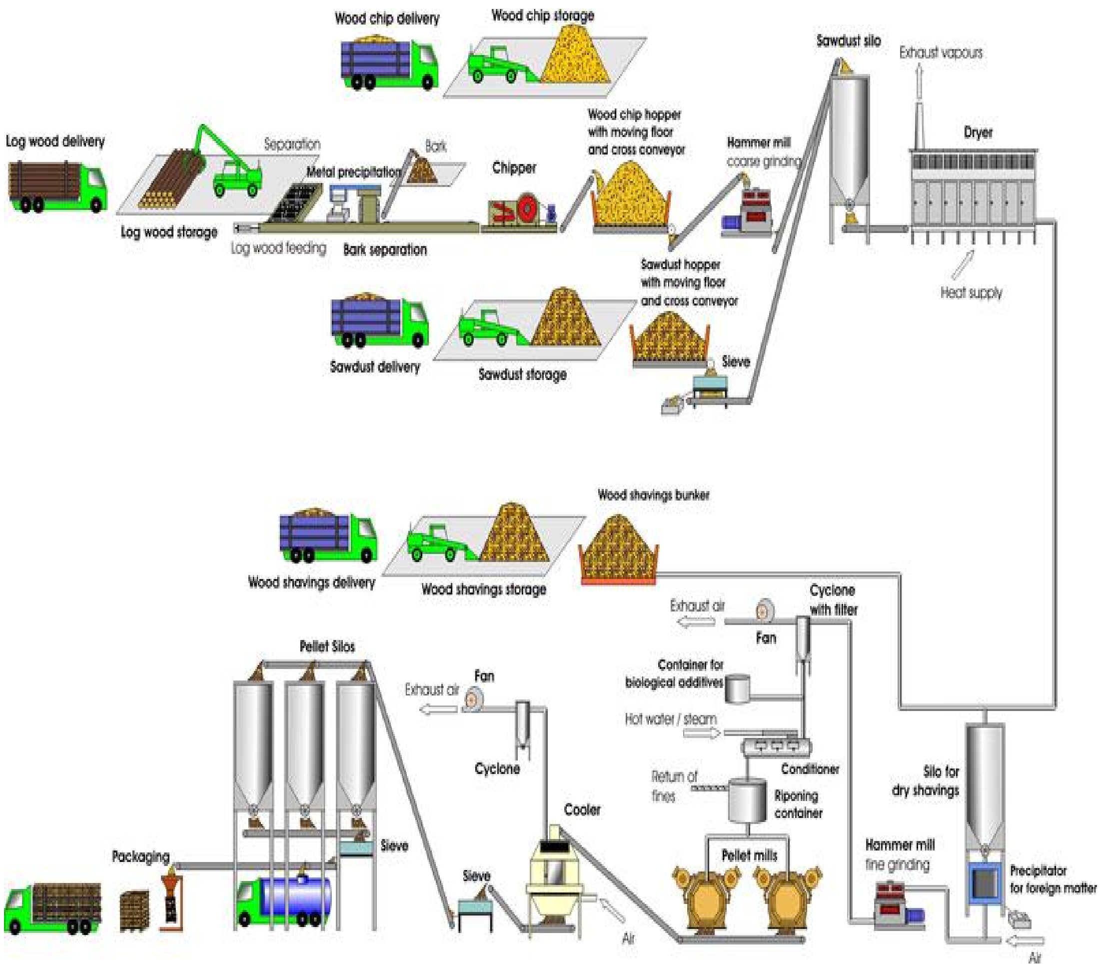


Figure 5.5: Full Process of Pellet Manufacturing [55]

5.2.1 Raw Material

The production of wood pellets begins with the generation of the raw material. In most cases this raw material is a byproduct of some other wood processing operation. Hardwood flooring mills are one example: They produce large quantities of clean (no bark or dirt), dry sawdust and small scrap blocks in their operations. This byproduct makes an ideal raw material for pellet production; however, as the interest in pellet production grows, some mills are generating pellet-making raw materials directly from trees (i.e. “round wood”) [55].

5.2.2 Feedstock Grinding

Standard-sized pellet mills generally require biomass that is ground to particles that are no more than 3 milli-meters in size. Several types of equipment are available to carry out this task. If the biomass is quite large and dense (e.g., wood), the material is first run through a “chipper,” and then run through a hammer mill or similar device to reduce the particles to the required size. Smaller and softer biomass (e.g., straw) can be fed directly into the hammer mill without first being chipped.

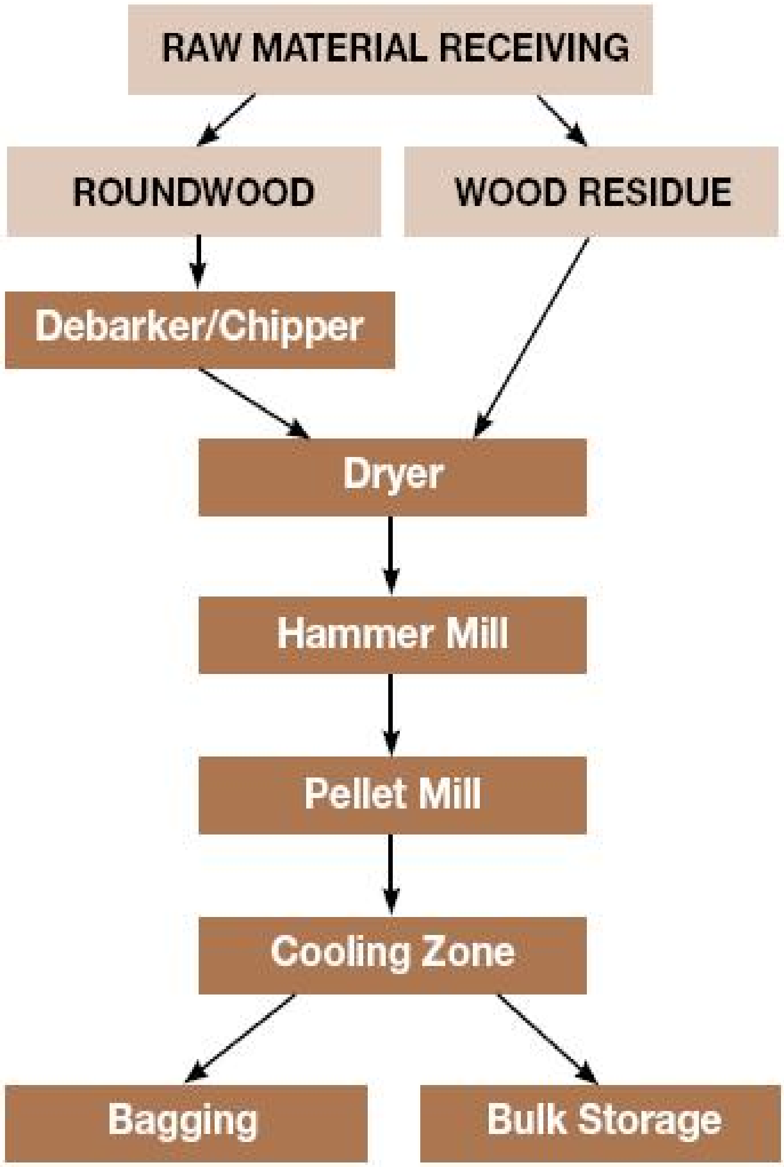


Figure 5.6: Manufacturing Process [58]

5.2.3 Moisture Control

Maintaining an appropriate moisture level in your feedstock is vital for overall quality of the final pellets. For wood, the required moisture level of the feedstock is at or near 15 percent. Other types of biomass have other requirements—you may need to experiment a bit. Moisture can be removed from the feedstock by oven-drying or by blowing hot air over or through the particles. If the feedstock is too dry, moisture can be added by injecting steam or water into the feedstock [59].

5.2.4 Extrusion

The pellet is actually created in this step. A roller is used to compress the biomass against a heated metal plate called a “die.” The die includes several small holes drilled through it, which allow the biomass to be squeezed through under high temperature and pressure conditions. If the conditions are right, the biomass particles will fuse into a solid mass, thus turning into a pellet. A blade is typically used to slice the pellet to a predefined length as it exits the die. Some biomass tends to fuse together better than other biomass. Sawdust is an especially suitable feedstock for pelleting because the lignin that is naturally present in the wood acts as a glue to hold the pellet together. Grasses tend to not fuse nearly as well, and the resulting pellets are less dense and more easily broken [60]. The proper combination of input material properties and pelleting equipment operation may minimize or eliminate this problem. It is also possible to add a “binder” material to the biomass to help it stick together, or to mix a fraction of sawdust, with similar results. Distillers Dry Grains (a product of the corn ethanol industry) are reported to improve the binding properties of some biomass [4].

5.2.5 Cooling

Pellets, as they leave the die, are quite hot (~150°C) and fairly soft. Therefore, they must be cooled and dried before they are ready for use. This is usually achieved by blowing air through the pellets as they sit in a metal bin. The final moisture content of the pellets should be no higher than 8 percent [61].

5.2.6 Packaging

Once the pellets are formed and cooled, they are packaged in bags or stored in bulk. Pellets can be stored indefinitely but they must be kept dry to prevent deterioration.

5.2.7 Energy Requirements for Pellet Manufacture

Pellet manufacture requires quite a bit of energy, both for drying damp feedstock and for running the various pieces of machinery. Large plants typically burn a portion of their feedstock to provide heat for drying, whereas smaller facilities often use other means. As a rule of thumb, a pelletizer requires between 50 and 100 kilowatts of electrical demand for every ton per hour of production capacity. In addition, electricity is usually needed to operate any chopping, grinding, drying, cooling, and bagging equipment that is in use. If a reliable source of electricity is not available, gasoline or diesel-based equipment is available [61].

Chapter 6

Pellet Quality

6.1 Quality Fuel is More Important than Species

Traditionally, hardwood has been the preferred fuel in wood stoves and fireplaces because it naturally has a lower moisture content, is a denser fuel, burns longer, and has hotter coals. Softwood is known for burning hotter initially, easy to light, having more pitch or sap, more sparks and sound as it burns, but burns up more quickly. The pelletizing process takes away many of these differences, and at Cypress Pacific Marketing, we test all of our pellet brands, ensuring you're receiving a consistent quality product whether it's softwood or hardwood [98].

After wood chips are ground into sawdust, they are dried to a consistent moisture level. The sawdust is then compressed into pellets at a common density, about 40lbs per cubic foot. It doesn't matter if the sawdust came from a softwood species, hardwood species, or a blend; they are all compressed to the same density. If you look at BTUs of different species of wood, they are very similar. Wood pellets are about 8000 BTUs per pound at 6% moisture [98].

Figure 6.1: Softwood & Hardwood

6.2 Quality is Most Important

After you normalize the moisture content and density, the wood pellets have about the same heat value, but there are still some differences between pellet mills and brands. Ash content, ash characteristics, and pellet length do affect burn and maintenance requirements.

While premium pellets are all under 1% ash content, that could be anywhere from around 0.25% to 0.8%. After 10 bags of fuel (or approximately 400lbs), that could make the difference between 1lb of ash or over 3lbs of ash. With good maintenance habits, you may not even notice, but it's still three times the ash.

The ash has to go somewhere. Some ash is very high in heavy minerals that in extreme temperatures will melt and re-harden into dirty glass, forming clinkers and scale in the firepot. Some ash will collect in the firebox as heavy fly ash, while some lighter fly ash will collect in your heat exchanger. Still more could settle in your vent system, with the lightest ash being exhausted out your vent [98]. The difference could be the species, or just the side of the mountain it was grown on. Your appliance will perform best with regular maintenance to keep ash under control.

Pellets also come in different lengths. Usually they are between 0.25 inches and 1.5 inches. In most pellet appliances, shorter pellets feed faster than longer pellets. As you change from one length to another, you may have to increase or decrease the feed rate of your appliance. In order to get the same burn you may need to decrease the feed rate a little for shorter pellets and increase it for longer pellets. Other than slight changes in feed rate, the burn characteristics and heat value should be very close to the same.

6.3 Pellet Benefits

Wood pellets were first engineered in the 1970s in response to an energy shortage in the U.S. and are generally manufactured from wood waste generated in saw mills, furniture manufacturing facilities, paper mills, etc. Burning wood pellets can be used as a substitute for electricity; wood-fueled fireplaces and stoves; or fossil fuels, such as propane or natural gas. Pellet fuel is burned in appliances, such as freestanding stoves, fireplace inserts, furnaces or commercial burners.

Convenience

1. Clean and allergy-free. No dust or dirt is brought into the home with pellet fuel.
2. Stored in less space. Four times more pellet fuel can be stored in a given space than cordwood or wood chips. A winter's supply of pellets for an average home occupies a space roughly 6' x 6' x 6', which makes them easy to store in a small area of a dry garage, basement, utility room or shed [98].
3. Easy to use. Load once a day. Precisely regulated fuel feed automatically operates the stove according to owner-determined settings.

Efficiency

- ✓ More efficient fuel than cordwood. Pellets have five to 10 percent moisture content in comparison to 30 to 60 percent for cordwood and woodchips. This means pellets are a more efficient fuel.

- ✓ Higher Btu content than cordwood. Wood pellets have a Btu output content of 350,000 per cub. Ft. of fuel, versus 70,000 to 90,000 for cordwood or wood chips. This means pellets produce more heat.

Environmental

- ✓ All natural fuel. Once compressed and dried, pellets hold their form with natural lignin, which means no glue or binders are required.

- ✓ Cleaner burn. Pellet fuel has proven to provide the cleanest burn of any solid fuel. Pellet stoves exhaust an average of 1.2 particulate grams per hour – well below the United States EPA wood burning limit of 7.5 grams. This is because the combustion air can be easily regulated, which optimizes the burn efficiency, and because of pellet's low moisture content [98].

Sustainability

- ✓ Energy from waste. Pellet fuel is made of waste products, such as pallets and manufacturing excess. It is a practical way to utilize biomass materials from sustainable forest initiatives, especially for commercial application.

- ✓ Other Biomass products. Cornstalks, straw, wastepaper and even animal waste can be converted into pellets.

6.4 High quality pellets come in all colors and sizes!

There are more to pellets than just softwood or hardwood. Matching pellets to appliance is an important step in order to receive the highest heat output, cleanest combustion, and highest efficiency. Here are some things to consider when choosing your fuel.

6.4.1 Wood Pellet Color

When choosing a fuel, you may notice that there are many different colors of fuel. Usually the lighter fuels are softwood while the darker pellets are hardwood. The fuel in the center of this photo is made from lodge pole pine that died from pine beetle infestation. The enzyme they secrete into the wood makes it blue, so the pellets turn out darker. Some softwood whole-tree pellets are also darker because of the bark and needles mixed with the wood. In other words, it's tough to pick a "best" pellet based on color [99].

6.4.2 Wood Pellet Length

From one brand to another, or even from one season to another of the same brand, it's very likely that the pellets you buy could be shorter or longer in length on average. This is very normal. There are several variables that determine the length of a pellet during manufacturing and any one of them could be different from brand to brand or season to season. How does this affect burn? Longer pellets will feed less fuel into the firepot with every rotation of the augur than shorter pellets. If everything else in the appliance stays the same, and the only difference in the fuel is the pellet length, the shorter pellets will provide more fuel to the firepot than the longer pellets [100]. You will need to reduce the feed rate or increase air flow through the firepot to maintain the correct fuel to air ratio. If you don't, you could have incomplete combustion, leading to more and darker ash, blackened glass, a lazy fire, and lower combustion and heat transfer efficiency.

6.4.3 Wood Pellet Density

Pellet manufacturers compress the wood fiber to a consistent density of at least 40lbs per cubic foot. That means that if you fill a cubic foot container with the pellets (just pour them in), it should weigh at least 40lbs. But it's difficult to compress to that exact density consistently, so most pellet mills compress to 41lbs or 42lbs. It's not uncommon that the pellet could be as dense as 44lbs or more. If one bag of wood pellets is denser than another, it will deliver more fuel to the firepot with each rotation of the augur than the less dense pellet. If you have two brands of pellets, you can stack eight bags of one brand on top of each other next two eight bags of the other brand. The taller stack is the less dense pellet. Being less-dense or more-dense isn't bad, but it does change the fuel-to-air ration in the appliance [101]. If you switch from a less-dense pellet to a more-dense pellet, you will need to reduce your feed rate or increase airflow through the firepot to maintain the correct fuel to air ratio.

6.5 Different Types of Pellet Heating Systems

There are several different types of pellet heaters available. Based on the location choices you have available to you and your heating goals, one type will most likely meet your needs the best. You may need more than one unit in your home in order to satisfy your heating needs. These are guidelines only. Your pellet heating system professional will be able to help you determine which unit will fit your specific heating needs.

6.5.1 Size, Design, Operation and Features

Pellet heat systems come in many different sizes and designs. Size, in terms of heating ability, is determined by consumption rate. In other words, how many pounds of fuel does the appliance use per hour. There is usually a low and a high number, giving you the range of heat output capable by the appliance. For example, if the appliance consumes 1.5 pounds per hour on low and 4 pounds an hour on high, the consumption rate is about 12,000 to 32,000 BTUs per hour. If the efficiency of the appliance is 75%, then you'll get 9,000 to 24,000 BTUs per hour into your home. Maybe that's kind of technical, but in general that's how pellet heaters are sized. From simple and clean styling for basements and utility rooms to elaborate enamel finishes for formal living rooms and bedrooms, pellet stove designs vary greatly. You're sure to find an appliance that fits your home's décor while meeting your heating needs. It's important to learn about the operation of the brand or model that you're interested in. Different brands and models have different control systems, maintenance procedures, and operational features. Your appliance dealer can explain the proper procedures for operating and maintaining your appliance [98].

6.5.2 Pellet Stoves

Pellet stoves are free standing heat systems. They can be installed in almost any room and are best used as a secondary focal point, meaning you may have another focal point in the room like an entertainment center, library, or picture windows. They can be installed against a flat wall or in a corner. Venting for the appliance can usually be installed directly out an exterior wall, straight up a few feet and then turn to go out an exterior wall (if in a basement), or straight up through a ceiling and roof. Make sure you are using venting appropriate for you installation. Most pellet stoves need a non-combustible surface on the floor [99]. Pellet stoves are also a great replacement for existing wood stoves and can usually be positioned closer to a combustible wall than the wood stove, taking up less space in the room.

6.5.3 Pellet Inserts

Pellet inserts are normally installed in wood burning fireplaces. If you have a wood burning insert already installed in the fireplace that will need to be taken out. Wood burning fireplaces can be either masonry site-built fireplaces, or factory built fireplaces. Either way, you will need to take measurements of your fireplace (height, width at the front and rear, and depth at the top and bottom) with you to your local appliance dealer in order to know what appliances will fit into your fireplace. If it's been used, you'll need to clean your fireplace and chimney before installation. Normally, part of the insert will sit back into your firebox and part of the insert will sit out onto your hearth. A surround panel will finish off the space between the insert and your fireplace opening, providing a clean and finished appearance. Pellet fireplace inserts are generally vented straight up through the existing flue. A continuous stainless steel flexible liner is the most common method. If you don't have a fireplace, but like the appearance of fireplace inserts more than a freestanding stove, many pellet inserts can be installed without a fireplace [98]. Simply frame in a small alcove into a wall, or install a cabinet mantel, and the pellet insert can be placed in the opening and give the appearance of a fireplace. See the installation manual or ask your dealer if that type of installation is available.

6.5.4 Pellet Furnaces & Boilers

A pellet furnace or boiler can be used in conjunction with your existing central heating system. These more utility styled heat systems have larger fuel storage hoppers designed to hold several days use of fuel. They are normally installed next to your existing furnace or boiler with your existing heating system set up to use the pellet system as the primary heat source, and your existing furnace or boiler as the backup system set to come on if you were away and your pellet system ran out of fuel.

Chapter 7

Pellet Industry Inspection

7.1 Eco-Fuel Industry

For thesis purpose I visited accompany named Eco-Fuel Industry [Figure 7.1], it's mainly produce pellet and briquette for Pellet Cooking Stove. It situated Rani-Mohol on Chittagong Road. Industry is large enough for Pellet and briquette production. It is about 22000 sq. meter. The costing of the industry for establishment is around 3 crore taka. The raw material of the company mainly wood dust to produce pellet and briquette. The sources of the raw material are different saw mills, furniture design house from Chittagong. Every three to four days raw materials come from Chittagong sources and per track contain around 800 to 900 sacks which is 10,000 to 15,000 kg proximately. From industry assumption around 100 tons saw dust get spoil per day in Bangladesh.

Figure 7.1 : Eco-Fuel Industry, Rani-Mohol, Chittagong Road

7.2 Pellet and Briquette Production Procedure

Raw materials comes from Chittagong are not prepare enough to produce pellet and briquette. In these the rate of moisture content is very high. For this reason it will be dried with two process, manually and automatic. Manually the raw material dried on an open space by radiation of the sun [Figure 7.2]. After that the raw materials take into automatic process, because good enough of moisture content sustains. In the automatic process, the moisture content of the raw materials total remove. Automatic process simple a drier that dry the raw materials and remove the moisture content. After that raw materials go to the processing unit of the pellet [Figure 7.3].

Figure 7.2: Raw Materials are drying by manually

Figure 7.3: Raw Materials Ready for Pellet Processing after Automatic Process

In the processing unit, heavy pressure and temperature is imposed to the raw materials and there are different shape of diameter of dice of pellet convert the raw materials to pellet as well as briquette [Figure 7.4 & 7.5]. The pellet or briquette goes to the cooling unit by the roller from processing unit to cooling unit [Figure 7.6]. After that pellet are ready to collect and package. Then manager inspect the ready pellet and sort out the low quality pellet [Figure 7.7]. Once good quality pellet are sorted then it go to packaging unit. After packaging it is ready to go to market or client [Figure 7.8 & 7.9].

Figure 7.4: Pellet Processing Unit

Figure 7.5: Pellet Processing Unit Control Panel

Figure 7.6: Ready pellet is going to cooling unit

Figure 7.7: High quality pellet is ready for Packaging

Figure 7.8: Packaging Unit

Figure 7.9: Pellet is ready to go to market or client

7.3 Electric Power Consumption of Industry

No	Equipment	Power Consumption
01.	Dryer Unit	15.3 KW
02.	Booster Motor	80 KW
03.	Main machine (Processor Unit)	13 KW (2 no. of 5.5KW motor with 2KW small motor)
04.	Compressor	0.75 KW
05.	Cutting(Packaging Unit)	0.37 KW
06.	Cutting Upper (Processor Unit)	4 KW
07.	Dryer of Pellet	2.22 KW
08.	Cutting (For Packaging)	1.11 KW
09.	Others	3KW
	Total	**120KW (approximately)**

7.4 Costing of Pellet and Briquette

Pellet	Briquette
1. Pellet Production Costing Price 15tk/kg.	Briquette Production Costing Price 12tk/kg.
2. Pellet Dealer Price 19.80tk/kg.	Briquette Dealer Price 15tk/kg.
3. Pellet Selling Price 22tk/kg.	Briquette Selling Price 18tk/kg.

7.5 Test Report of IFRD:

Science for Life

INSTITUTE OF FUEL RESEARCH & DEVELOPMENT (IFRD)
Bangladesh Council of Scientific & Industrial Research (BCSIR)
Dr. Qudrat-i- Khuda Road, Dhanmondi, Dhaka-1205, Bangladesh
Office: +880 2 8622908, Fax: +880 2 8613022, e-mail: ifrd@bcsir.gov.bd

Ref. No. IFRD/Adhoc-215(part-1)/Ad-67/15 Date: 27.04.2015
Analytical Service Cell No. Fu-76, Date: 21.04.2015

Subject: Test report of supplied fuel pellet sample

The test result of fuel pellet sample supplied by Shah Alam, Life engineering, 89, Bijoy Nagar, Aziz co-operative Market, Dhaka-1000, Ref. No. Nil of dated 21.04.2015 is as follows:

Test Result

Sl. No.	Name of the Test	Result
1.	Moisture Content ,% (w/w)	10.09
2.	Ash Content, % (w/w)	3.74
3.	Volatile matter, % (w/w)	69.37
4.	Fixed Carbon, % (w/w)	16.8
5	Calorific Value, kcal/kg	4128.31

27.04.15
(Dr. Md. Abdur Rouf)
Analytical Service In-charge
IFRD, BCSIR
Dr. Mohammad Abdur Rouf
Principal Scientific Officer
IFRD, BCSIR
Dhaka-1205

27.4.15
Research Coordinator
BCSIR
Badhan Saha
Scientific Officer
Analytical Service Cell
BCSIR, Dhaka

(Mahfuza Khanam)
Director
IFRD, BCSIR
27.04.15
Dr. Mohammad Abdur Rouf
Principal Scientific Officer
IFRD, BCSIR

Shah Alam
Life engineering
89, Bijoy Nagar, Aziz co-operative,Market
Dhaka-1000

7.6 Summary

Overall Eco-Fuel Industry is good enough quality industry of pellet and briquette in Bangladesh. With pellet and briquette they also produce pellet cooking stove, that is very eco-friendly. The pellet and briquette of the eco-fuel industry is good enough from our measurement as well as IFRD report. By producing pellet and briquette in local market we can develop local job market and our local product is better than china and Africa. In our future work, we will visit to others newly invested pellet industry to inspect their product and develop a feasible comparison study of pellet and briquette of our local market.

8. Conclusion

Pellet is one of the new forms of biomass fuel for ICS (Improved Cook Stove) and power generation purpose in Bangladesh. In this thesis the feasibility of pellet in Bangladesh has been investigated for the first time. As discussed in this thesis pellet is made of saw dust or rice husk which is generally waste material in Bangladesh. Geographical condition of Bangladesh is favourable for rice production, forestry and currently a lot of rice husk and saw dust is being used inefficiently whereas the countries like Vietnam, Thailand, China are using this opportunity to generate power at comparatively low cost. Bangladesh produces almost about 26 to 27 million tons of rice per year presently. 70% of the total paddy goes to the rice mills and the total husk can be approximated to 5.2 to 5.4 million tons per year. Considering only 67% of it can be used for power generation, we can produce about 300 to 320 MW power at present. If the amount of milled rice can be increased to 80% from 70% and 75% of total husk can be utilized by increasing efficiency in the system, then the total generation can be increased to about **28%** and 370 to 400 MW power can be produced. Some practical problems while establishing rice husk cogeneration plant. To solve the above mentioned problems, it is proposed some suggestions that believed to be helpful in this regard. From above discussion it is concluded that Husk can be used as alternative fuel of power generation in Bangladesh.

Similarly saw dust can also can use as fuel of power generation in Bangladesh. From rice husk and saw dust we can produce pellet and this pellet can be used in power plant or Improved cook stove as a fuel. Pellet cook stove and improved cook stove is environment friendly and easy to use. Every day around 100 ton saw dust is being used inefficiently. These are the huge biomass potential sector of our country. By using rice husk and wood pellet to produce pellet, we can implement new power plant which can be increased the total power generation up to 700-800 MW. As well as we can export pellet in Europe zone. At the end we can say that by implementing Biomass Power Plant and Pellet Industry, a huge job sector will be opened for a large number of people. It will be helpful for our economic and power sector both.

9. Future Work

- We will try to use other biomass as industrial waste and co-products, food waste, agricultural residues, energy crops and virgin lumber to produce pellet or make them efficient to use in power generation.

- If pellet industry will be developed in locally, then the costing of pellet decreases and a huge job sector will be opened. In near future work we will work with portable pellet industry that is already implemented in China.

- In rural areas there are numerous small size saw mills which produce small amout of saw dust in regular basis. It has been found that the small size of pellet machines can be very effective to reduce cost of making pellet. A research will be conducted in future to design and manufacture new portable type pellet machine.

- In future we should work with the pellet quality, as it's moisture content, calorific value, ash content and other materials.

- A study will be conducted in development of the required policy to import low cost pellet which can help us to preserve our forest.

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