CHAPTER 1

INTRODUCTION

1.1 Problem Statement

Gasification process is being increasingly viewed as a useful technology, a means to convert coal and other carbon feedstocks into clean hydrogen and carbon monoxide, which are in turn used to produce a variety of high-value products for the global economy (DOE US, 2007).

The main product of gasification is syngas which mainly comprises of hydrogen and carbon monoxide. The hydrogen which has the ability to store energy is one of the important sources of energy. Unlike the fossil-based energy like petroleum and natural gas which are running out nowadays, hydrogen is renewable and sustainable.

Realizing the increasing demand of world's energy consumption and the running out of the main energy source thus creates an urgent driving force to develop and establish alternatives sources of energy to fulfil the needs of the world. One of the choices for the renewable source of energy is biomass. This is due to its sustainability and availability throughout the year.

In this paper, the investigation will be focused on palm biomass as the alternative source of energy by using gasification technology to produce rich Hydrogen. Palm biomass is chose because Malaysia is one of the major producers of palm oil. C M Chin et al (2008) studied that Malaysia in 2006 produced 15.88 million tonnes of crude palm oil and 1.95 million tonnes of palm kernel oil. In the palm oil extraction process, a relative amount of biomass is simultaneously produced from the mills and fields. Therefore, the abundance and availability of this large amount of palm biomass make them even more attractive as resource for renewable energy.

1.2 Objectives of the Project

The objectives of this project are mainly:

- To conduct physical and chemical characterization methods on three palm biomass samples.
- To identify the suitable characteristics of good gasification feedstocks and observe those characteristics on the samples
- To recommend on the most suitable palm biomass sample to be used in gasification as its feedstock.

1.3 Feasibility of the Project within the Scope and Time Frame

The scopes of study in this project are:

- Research and literature review on theories and facts about knowledge and technologies related to the topics which is taken from various reliable sources
- Experimental work on few analysis procedures to determine the results, is conducted in Chemical Engineering and Mechanical Engineering labs
- Analysis of all results obtained from the experimental work and integrating the findings with the one in literature reviews
- Recommendation on the best suit palm biomass in gasification technology as the feedstock.

This project has been scheduled and planned as such to be feasible within the timeline of the project, which starting from January until October 2009.

1.4 Relevancy of the Project

This project is relevant to the current situation where many researches and studies are on their way to find alternatives for renewable energy resources to meet the high demand of energy from the world citizen while maintaining the good environment condition. Furthermore, the availability of the abundance palm biomass waste from Malaysian Palm Oil industries gives more reasons for this project to be proceeding.

CHAPTER 2
LITERATURE REVIEW

2.1 World Energy

2.1.1 World Energy Demand

In today's world, the demand for energy is increasing at all parts of the globe. Exxon Mobil in its report, Outlook for Energy: A View to 2030 discussed that even with considerable improvements in energy efficiency; the world's energy demand is anticipated to be approximately 40% higher by 2030 than it was in 2005. Also, US Department of Energy (2003) projected that the world energy consumption is to rise by 59% by 2020, reaching 607 quadrillion British thermal units (BTUS). Developing countries are the ones having rapid growth of energy demand. Accordingly, fossil fuels such as oil, coal and natural gas are expected to remain as the dominant energy sources as it has been for decades, as shown in the Figure 1

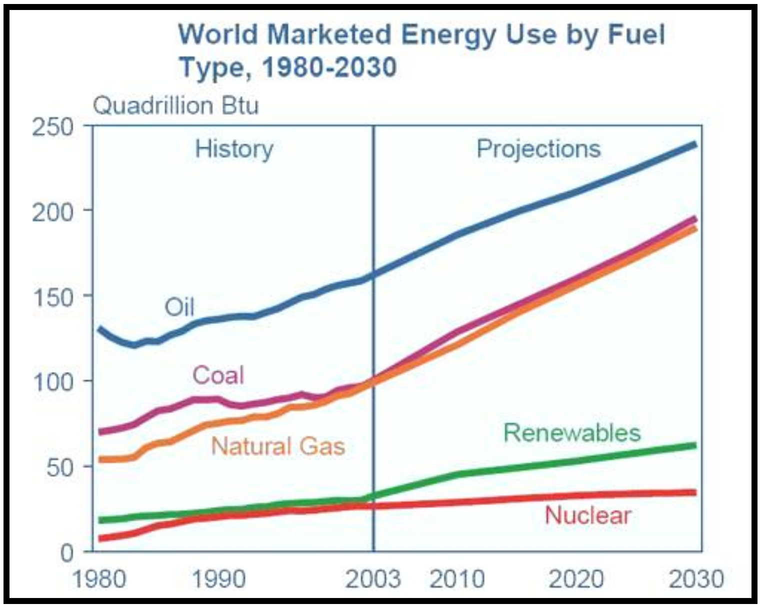
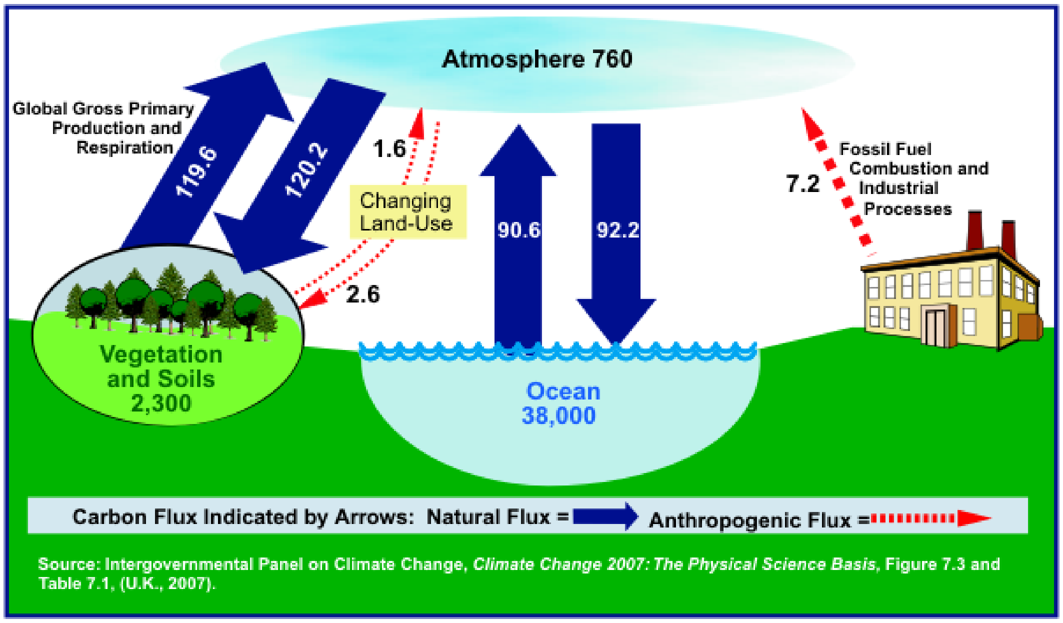


Figure 1: World Marketed Energy Use by Fuel Type, 1980-2030

2.1.2 Environmental aspect

In conjunction with the increasing energy demand, the carbon emissions to the atmosphere are expected to as well increase swiftly. It is anticipated that carbon dioxide emissions are to rise to 7.8 billion metric tons carbon equivalent in 2010 and to 9.8 billion metric tons by 2020. From environmental point of view, this increment in carbon dioxide emissions is very much worrying. Each time fossil fuels undergone combustion process to produce energy, carbon dioxide will be released to the atmosphere (US Department of Energy, 2003).

According to EIA US, 2007, carbon dioxide is on of the several important greenhouse gases which the level had been increased by about 25% since large-scale industrialization began around 150 years back. During the previous years, nearly three-quarters of the caused emissions came from the burning of fossil fuels to produce energy. Concentration of carbon dioxide in the atmosphere is naturally regulated by numerous processes collectively known as the Carbon Cycle shown in Figure 2.



Source: Intergovernmental Panel on Climate Change, *Climate Change 2007: The Physical Science Basis*, Figure 7.3 and Table 7.1, (U.K., 2007).

Figure 2: Global Carbon Cycle (Billion Metric Tons Carbon)

As shown in Figure 2, the loop of carbon between the atmosphere and the land and oceans is mainly involved natural processes such as plant photosynthesis. These natural processes have the ability to absorb some of the net 6.2 billion metric tons of anthropogenic carbon dioxide emissions produced each year. This large carbon dioxide emissions lead to imbalance in carbon cycle accordingly.

In United States, greenhouse gas emissions come primarily from the burning of fossil fuels in energy production. This is because fossil fuels are made up of hydrogen and carbon. When fossil fuels are combusted, the carbon combines with oxygen to produce carbon dioxide. The amount of carbon dioxide produced depends on the carbon content of the fuels. Table 1 shows the amount of carbon dioxide and other greenhouse gases released for combustion of natural gas, oil and coal.

Table 1: Fossil Fuel Emission Levels - Pounds per Billion Btu of Energy Input

Pollutant	Natural Gas	Oil	Coal
Carbon Dioxide	117,000	164,000	208,000
Carbon Monoxide	40	33	208
Nitrogen Oxides	92	448	457
Sulfur Dioxide	1	1,122	2,591
Particulates	7	84	2,744
Mercury	0.000	0.007	0.016

Source: EIA - Natural Gas Issues and Trends 1998

Also reported by EIA, Fossil fuels supply 85 percent of the primary energy consumed in the United States and are responsible for 98 percent of emissions of carbon dioxide. Eighty percent of U.S. carbon dioxide emissions come from the use of coal and petroleum fuels. The residential and commercial sectors have lower emission levels than the transportation and industrial sectors, with the majority of their emissions coming from the combustion of fossil energy to produce electricity. Electricity generation consumes 40 percent of U.S. primary energy and is responsible for 40 percent of carbon dioxide emissions.

The world carbon dioxide emissions are projected to increase by 1.8 percent annually between 2004 and 2030 (Figure 3). Much of the increase in these emissions is expected to occur in the developing world where emerging economies, such as China and India, fuel economic development with fossil energy.

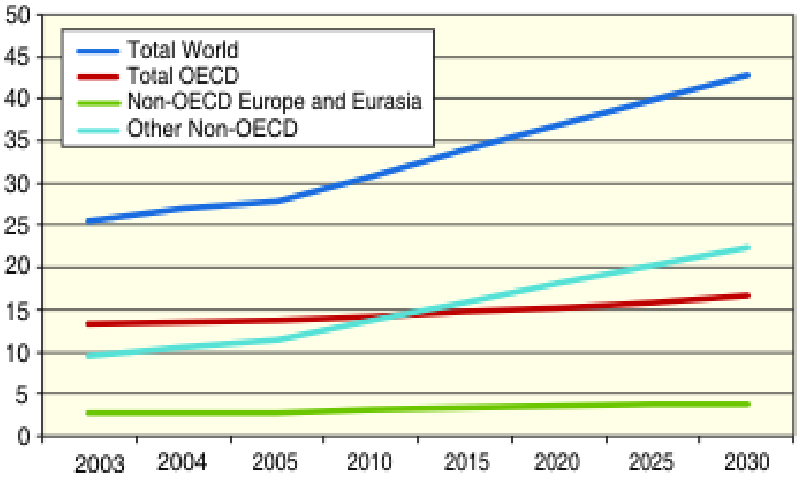


Figure 3: World Carbon Dioxide Emissions by Region, 2003-2030 (Billion Metric Tons of Carbon Dioxide)

Source: Energy Information Administration, International Energy Outlook 2007 (Washington, DC, May 2007).

As the expectation of the emissions of carbon dioxide due to burning of fossil oil is getting higher time by time, it creates an urgent driving force to the investigation of other potential renewable energy which can be sustained and be available at all time to replace the role of fossil fuels such as natural gas, coal and petroleum. One of the available and best solutions is biofuels.

2.2 Biofuel

2.2.1 Overview on Biofuels

Biofuels are the best way of reducing the emission of the greenhouse gases. They can be looked as a way of providing alternative for fossil fuels that are limited in availability. Today, the usage of biofuels is getting wider throughout the world. Among the major producers of biogases are Asia, Europe and America. By using biofuel to produce energy, it can reduce the use of fossil fuels, reduce greenhouse gas emissions and reduce pollution and waste management problems. Biofuels is also the clean energy source because it is biodegradable and non-toxic. Today, with the shortage fossil fuels, the researches of energy crisis and the potential utilization of biofuels as substitute energy producer is given more attention and interest. Biofuels development can be divided into few phases which are the first generation, second generation and third generation

2.2.2 First Generation Biofuels

First generation biofuels are those made from agricultural feedstocks, vegetable oils, and animal fats using conventional technology (Elder, 2008). The fuel is obtained from conventional technique of production and two common types of first generation will be discussed.

- **Biodiesel**

  Biodiesel is a well known type of biofuels. According to National Biodiesel Board (NBB, US), biodiesel is the name of a clean burning alternative fuel, produced from domestic, renewable resources. Biodiesel contains no petroleum, but it can be blended at any level with petroleum diesel to create a biodiesel blend. It can be used in compression-ignition (diesel) engines with little or no modifications. Biodiesel is simple to use, biodegradable, nontoxic, and essentially free of sulfur and aromatics.

  This type of biofuel is mainly produced using a process called transesterification. Transesterification has proven to be the most significant step towards making biodiesel a viable alternative to petroleum derived diesel fuel (M Paynich, 2007). This fuel is very similar to the mineral diesel and is chemically known as fatty acid methyl. The oil is produced after mixing the biomass with methanol and sodium hydroxide. The chemical reaction will then produce biodiesel.

  Biodiesel is very commonly used for the various diesel engines after mixing up with mineral diesel. Now in many countries the manufacturers of the diesel engine ensure that the engine works well even with the biodiesel. As an example, Biopower London is a UK based producer and supplier of biodiesel. Biopower

London is now committed in producing a lubricant which is environmental friendly from biodiesel (Biopower UK, 2006).

- **Syngas**

  This is a gas that is produce after the combined process of gasification, combustion and pyrolysis. Biofuel used in this process is converted into carbon monoxide and then into energy by pyrolysis. During the process, very little oxygen is supplied to keep combustion under control. In the last step known as gasification the organic materials are converted into gases like carbon monoxide and hydrogen. The resulting gas Syngas can be used for various purposes.

  One of the applications of syngas is for Solid Oxide Fuel Cell (SOFC). M Saule, 2007 claimed that SOFCs are the most appropriate fuel cells for withstanding operation with syngas because it can utilize a gas composed of not only hydrogen but also carbon monoxide. Besides, there is also application of syngas as a fuel for high efficiency gas turbine where it used the clean combustion of syngas in Integrated Gasification Combined Cycle (GM Pater, 2007).

2.2.3 Second Generation Biofuels

Supporters of biofuels claim that a more viable solution is to increase political and industrial support for, and rapidity of, second-generation biofuel implementation from non food crops, including cellulosic biofuels (Ralph Sims, 2009) For second generation biofuels, the focus is on the non-food crops, includes waste biomass, the stalks of corn, wood, and wheat. The production process for second generation biofuels use biomass-to-liquid technology such as in extraction of cellulosic biofuels from non-food crops. Other examples are biohydrogen, biomethanol, Fischer-Tropsch diesel, biohydrogen diesel and wood diesel.

2.2.4 Third Generation Biofuels

Third generation biofuels is biofuel produced from algae. Algae are known as high-yield feedstocks to produce biofuels. It has high capability to produce energy. With the higher prices of fossil fuels and the limited sources of fossil fuels, the interest to develop more in third generation biofuels is increasing. The other advantage is that this type of biofuels is biodegradable thus providing a clean energy source which is relatively not harmful to the environment. (E Hartman, 2008)

The United States Department of Energy (DOE US, 2007) estimates that if algae fuel replaced all the petroleum fuel in the United States, it would require 15,000 square miles (38,849 square kilometers), which is roughly the size of Maryland.

2.3 Hydrogen Production

2.3.1 Hydrogen

Hydrogen is the simplest element exists. It is the first element in the periodic table. An atom of hydrogen has one proton and one electron only. It is also the most plentiful gas in the universe. Hydrogen gas is lighter than air and, as a result, it rises in the atmosphere. Hydrogen can only be found in compound form with other elements, such as in water (H_2O), in methane (CH_4), coal, and petroleum. Hydrogen is also found in all growing things, specifically in biomass. It is also an abundant element in the earth's crust. Hydrogen also can be produced from resources like water, fossil fuels, and biomass. Hydrogen also can come from the byproduct of chemical processes.

Hydrogen has the highest energy content of any common fuel by weight (about three times more than gasoline), but the lowest energy content by volume (about four times less than gasoline). Hydrogen has a good potential as energy carrier due to its ability in storing energy.

2.3.2 Hydrogen in Energy Application

Realizing the potential of hydrogen as source of energy, many studies and inventions had been taking place to rejoice it’s prospective. Among the applications are in mobile industries, home and residential usage, space program and fuel cells.

In 2008, nearly 9 million metric tonnes of hydrogen are produced in the United States which is enough to power about 20 million cars or 5 million homes (EIA, 2008). Nearly all of this hydrogen is used in refining industries, and food processing. The major states producers are California, Louisiana, and Texas.

The other primary user of hydrogen as energy fuel is the National Aeronautics and Space Administration (NASA). Historically, NASA has been using hydrogen for years in its space program especially to power the shuttle. The liquid hydrogen is used to lift the space shuttle into orbit while for the shuttle electrical systems, hydrogen batteries will be utilized. The byproduct of the hydrogen application is pure water, which will be use as drinking water.

Another application of hydrogen as energy source is hydrogen fuel cells. Hydrogen fuel cells offer clean and efficient energy, but it is expensive to construct. The fuel cells are powerful as a small size of the fuel cells could power electric cars. Due to the high cost, hydrogen power plant is unlikely to be built, yet it leads to more studies and researches on how to produce hydrogen efficiently with low cost, such as through electrolysis, gasification and steam reforming.

2.3.4 Hydrogen Production Technology

Due to its light weight, Hydrogen does not exist as a single element on earth. Therefore, to produce Hydrogen, it has to be derived from other reactions or to be separated from other elements. Below is to discuss on common methods of hydrogen production.

1. **Steam reforming** – EIA US (2008) reported that currently this method is the least expensive as compared to other conventional methods. Also, it is said that it covers about 95% of hydrogen produced in United States. In industries, this method is used to separate hydrogen atom from hydrocarbon atoms, example in methane (CH_4). This method somehow has its disadvantage. Since methane or other hydrocarbons are fossil fuels, it released greenhouse gases during the process.

   In application, steam reforming is widely used in hydrogen production especially in oil refineries (NYSERDA, 2007). One of the main producers of steam reformer is Linde. Linde is a leading supplier of steam reformer plants with more than 200 constructed units producing capacities of synthesis gas from 1,000 to over 120,000 Nm3/h (Linde Group, 2008)

2. **Electrolysis** – Also known as water splitting method. J Pierre et al, 2007 in their research found that electrolysis of water is the most widely used means to produce hydrogen of high purity and the hydrogen obtained via electrolysis is free from Greenhouse Gas emission.

   There are lots of applications of electrolysis in the industries. In Malaysia, hydrogen is mostly produced by electrolysis for industrial use in oleo chemicals industries and in metal cutting and welding works (W Ramli, 2006). In California, National Vapor Industries Inc, utilizes the technology of water electrolysis in their commercial Hydrogen Generator due to the ease of operation and its durability (NVI, 2009).

3. **Gasification** – This method is an old technology used to produce hydrogen by using biomass as the feedstock. Biomass is not fossil fuel and thus does not release greenhouse gases. Therefore, the hydrogen produced is harmless to the environment and efficient. There are few types of gasification available in the commercial line nowadays. This technology will be further discussed in the next chapter.

2.4 Gasification Technology

2.4.1 Overview on Gasification

Gasification is another technology to produce Hydrogen. It is thermal process which uses high temperature to break down waste in its way to produce energy. It can also be defined as a process where carbon-rich feedstocks such as coal, petroleum and biomass are transformed into gases consisting hydrogen, carbon monoxide, etc under the condition where the temperature is high, the oxygen supply is limited and the pressure is high. B Slater (2008) discussed that gasification is a process in which materials are exposed to some oxygen, but not enough to allow combustion to occur. Temperatures are usually above 750^{o}C.

The main product of gasification is syngas, which is mainly consists of hydrogen and carbon monoxide, with small amount of carbon dioxide, methane and other hydrocarbon gases. Syngas has calorific values that make the syngas highly potential to be source of renewable energy to generate electricity or be used as fuel to the industries. By utilizing gasification to produce energy, the energy is more efficient and clean. Carbon dioxide emission to the atmosphere can be reduced if to compare with the one released by each time fossil fuel is burned to produce energy. Therefore, gasification can be said as one of the choices available to produce efficient and clean renewable energy, alternative to the fossil fuels.

2.4.2 Gasification Process

A. Azali et al (2005) observed that gasification demonstrates as one of the cleanest, most efficient method to produce synthesis gas from low or negative-value carbon-based feedstock such as coal, petroleum coke and high sulfur fuel oil that would otherwise be disposed as waste. The gasification of biomass at around 1073-1223 K to syngas can potentially be used either as a gaseous fuel for power generation or as a feedstock for the synthesis of clean transportation fuels or many other chemicals.

Meanwhile, R Mamat et al (2001) discussed the theory of gasification technology is generally work on the basis of indirect burning of biomass feedstock with limited air supply to produce gases that can be burnt or used as fuel in a gas engine. Normally the combustion process takes place in two phases: the primary combustion in which the feedstock is burnt at a fairly low temperature so that the fuel gas is released but the heavy residues retained in the ashes/charcoal. At the low temperature, the formation of SOx and NOx will also be reduced. This can be called as understoichiometric combustion. The fuel gases from the primary combustion are then burnt at an extremely high temperature using pre-heated combustion air to ensure low release of oxygen and carbon monoxide.

The gasification processes are divided into three main phases:

1. Pyrolysis of the biomass to produce charcoal and volatile compounds such as steam, methanol, etc by heat contact
2. Exothermic reaction in which part of the charcoal produced is oxidized to carbon dioxide
3. Part of the carbon dioxide, the volatile compounds and steam reduced to carbon monoxide, hydrogen, and methane.

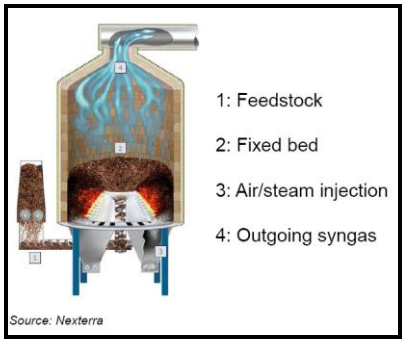
R Mamat et al (2001) also had suggested the ideal reaction in the reactor bed which is

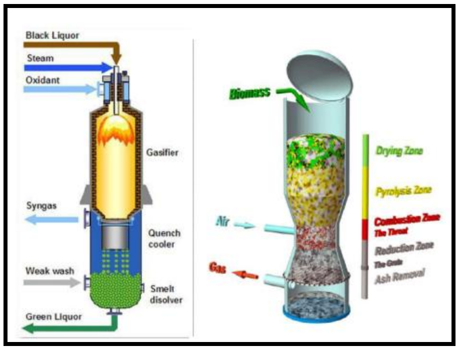
$$2C + O2 + 3.79\ N2 \rightarrow 3.79\ N2 + 2\ CO \text{ (exothermal)}$$

2.4.2 Gasification Development

The development or studies on gasification process is mainly due to the need for clean power or energy production. Currently, there are few types of gasifiers available in the market. They are typically classified according to the means to support the biomass in the reactor vessel, the direction of flow of both the biomass feedstock and oxidant and the way heat is supplied to the reactor (Ciferno and Marano, 2002). Four main categories are typically considered as follows: Updraft fixed bed (UFB), downward fixed bed (DFB), bubbling fluidized bed (BFB) and circulating fluidized bed (CFB). These four gasifier types are briefly summarized in Table 2. The discussion here is referred mainly on Ciferno and Marano (2002) and Hook (2008).

Table 2: Type of Gasifiers and their brief description

Type of Gasifier	**Description**
Updraft Fixed Bed	• Is a fixed bed gasifier with carbon-rich material. Air and/or steam are blown from below the fixed bed. The injected gases will react on the way up and form syngas. Slag will remain on the bed for removal. • ***Advantages***: o Is a simple, proven, low-cost technology o Able to handle biomass with high moisture content o High in thermal efficiency but need • ***Disadvantages***: o During the gasification hydrocarbon-based tar is formed. Due to the large content of tar in the resulting syngas in the UFB gasifier, extensive clean-up systems are required.  Source: Nexterra Figure 4 : Diagram of Updraft Fixed Bed Gasifier
Downdraft Fixed Bed	• The configuration of the downdraft gasifier (DFB) is similar to that of the UFB gasifier, except that the oxidant and product gases flow down the reactor, in the same direction as the biomass feedstock. • ***Advantages***:

	○ Allow the combustion of most of the tar formed and, therefore, minimum clean-up of the syngas is required. ○ Cleaner syngas is produced due to low tar impurities • ***Disadvantages:*** ○ Requires the biomass feedstock to be dried, in order to achieve low moisture content prior to enter the gasifier. ○ The syngas product is at high temperature, thus requiring a secondary heat recovery system. In addition, part of the carbon (char) remains unconverted.  Figure 5: Schematic of a Downdraft Gasifier
Bubbling Fluidized Bed	• Uses a bed of fine, inert particles (sand or alumina) fluidized bed with good thermal characteristics. The oxidant is forced through the bed of inert particles. The gas velocity is such that a “fluidization” process occurs, where the gas bubbles and channels through the “fluidized” particle bed, such that the particles remain in the reactor. • ***Advantages:*** ○ Able to break up the biomass feedstock effectively and ensures good heat transfer in the reactor. ○ High conversion rate of the feedstock is possible with low tar production and a low fraction of unconverted carbon. ○ Support a wide range of fuel particle sizes.
Circulating Fluidized bed	• Operate under the same principle of Bubbling Fluidized Bed gasifier, except that the gas velocities are such that the particles become part of the gas stream. The particles, then, must be separated at the gas exit and returned to the reactor. This configuration is useful for fast reactions.

	• ***Advantages:*** o High conversion rate of the feedstock with low tar production and a low fraction of unconverted carbon. • ***Disadvantages:*** o The heat transfer is less efficient and the range of fuel particle sizes is limited.

2.4.3 Challenges of Gasification

There are few challenges need to be faced in Gasification technology. K Yamashita, 2004 discussed two of them which are the need of syngas cleaning and the pre-treatment of the feedstock. Depending on the type of gasifier, the applications and the characteristics of the fuel, there may be a need for cleaning and cooling the syngas product. This is because hydrocarbon-based contaminants (tar), particulates, ammonia, sulfur, chlorine, alkali metals, etc., may appear in the syngas and have to be removed (Ciferno and Marano, 2002). Biomass Technology Group (2003) discussed on the presence of tar in the Syngas which represents a problem for its use in engines, turbines or fuel-synthesis systems because it can lead to malfunctioning, wearing, and/or increased maintenance costs of the equipment. Initiatives had been done to remove tar and other contaminants via physical and chemical means.

Besides, the feedstock for gasification process plays an important role to ensure the good product. Ciferno and Marano, 2002 determined that pretreatment of the feedstock is essentially vital for the process. Yet, the challenge is there are still difficulties in ensuring a reliable and continuous of right biomass feedstock to the gasifier. Specifically due to the biomass nature characteristic itself – inconsistent moisture content, density, size and energy content of the biomass. And therefore, impact the quality of the gas product and the production of the gasifier. At the end, it is always important to match the right biomass to the right technology of gasification.

2.5 Biomass

2.5.1 Overview on Biomass

Biomass has become greatly important in being the feedstock for gasification process in producing enriched hydrogen. Biomass is seen as a renewable energy source, which can also be defined as the energy from plants and plant-derived materials. These include wood, food crops, grassy plants, residues from agriculture or forestry and the organic component of municipal and industrial wastes (NREL US, 2009)

2.5.2 Biomass in Application

Today, there are many other applications of biomass observed. Biomass can be used for fuels and power production, alternative to the role of fossil fuels. It has become a choice due to its benefits (NREL, US, 2009). The use of biomass energy has the potential to reduce greenhouse gas emissions. The amount of carbon dioxide released from biomass burning is about the same as burning fossil fuels. Yet, fossil fuels release carbon dioxide captured by photosynthesis years ago, while biomass releases carbon dioxide that is largely balanced by the carbon dioxide captured in its own growth. Besides, the use of biomass can reduce the dependency on oil.

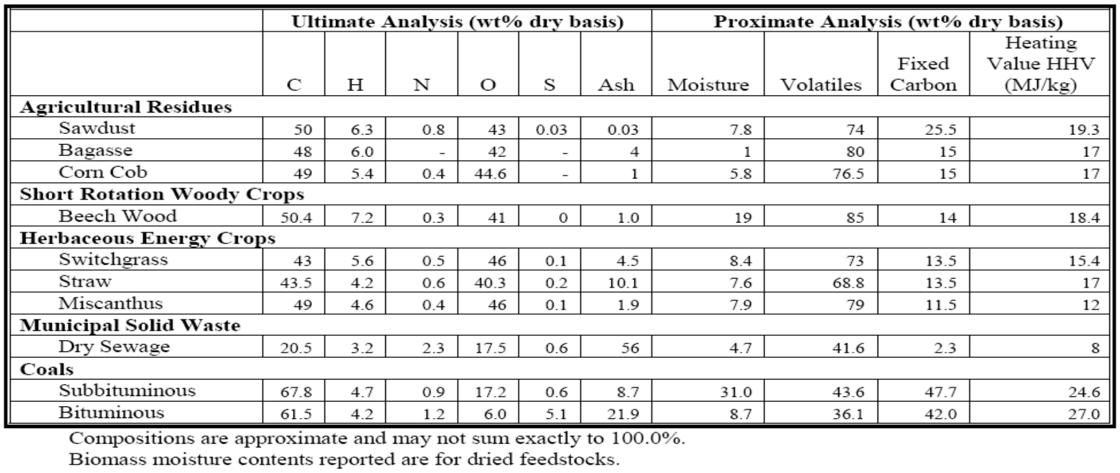
AC Caputo et al (2004) reported that biomass energy utilization has gained particular interest in recent years due to the progressive depletion of conventional fossil fuels that calls for an increased use of renewable energy sources. Moreover, the moderate sulfur and greenhouse gas emissions associated with the use of biomass for energy production respond to the growing pressure of government policies about achievement of better environmental sustainability of power generation processes in terms of air pollution control.

2.5.3 Biomass as Feedstock for Gasification

Biomass is likely to be the feedstock for Gasification process after undergoing few treatment processes. The chemical composition of biomass varies among species, but basically consists of high, but variable moisture content, a fibrous structure consisting of lignin, carbohydrates or sugars, and ash. Biomass is very non-homogeneous in its natural state and possesses a heating value lower than that of coal. The high oxygen and moisture content results in a low heating value for the product syngas, typically <2.5 MJ/m_3 (67 Btu/ft_3). This poses problems for downstream combustors that are typically designed for a consistent medium-to-high heating value fuel. (Ciferno and Marano, 2002)

Ciferno and Marano (2002) also discussed that for gasification process, biomass feedstock preparation should include the selection of biomass and the treatment/drying of the biomass. The cost for feedstock preparation could be high depending on many factors, mainly on the biomass characteristics and the gasifier requirements. Example, high moisture feeds require extensive drying prior to gasification. Table 3 captured the potential types of biomass based on the ultimate and proximate analysis.

Table 3 : Potential Biomass Gasifier Feedstocks



	Ultimate Analysis (wt% dry basis)						Proximate Analysis (wt% dry basis)			
	C	H	N	O	S	Ash	Moisture	Volatiles	Fixed Carbon	Heating Value HHV (MJ/kg)
Agricultural Residues										
Sawdust	50	6.3	0.8	43	0.03	0.03	7.8	74	25.5	19.3
Bagasse	48	6.0	-	42	-	4	1	80	15	17
Corn Cob	49	5.4	0.4	44.6	-	1	5.8	76.5	15	17
Short Rotation Woody Crops										
Beech Wood	50.4	7.2	0.3	41	0	1.0	19	85	14	18.4
Herbaceous Energy Crops										
Switchgrass	43	5.6	0.5	46	0.1	4.5	8.4	73	13.5	15.4
Straw	43.5	4.2	0.6	40.3	0.2	10.1	7.6	68.8	13.5	17
Miscanthus	49	4.6	0.4	46	0.1	1.9	7.9	79	11.5	12
Municipal Solid Waste										
Dry Sewage	20.5	3.2	2.3	17.5	0.6	56	4.7	41.6	2.3	8
Coals										
Subbituminous	67.8	4.7	0.9	17.2	0.6	8.7	31.0	43.6	47.7	24.6
Bituminous	61.5	4.2	1.2	6.0	5.1	21.9	8.7	36.1	42.0	27.0

Compositions are approximate and may not sum exactly to 100.0%.
Biomass moisture contents reported are for dried feedstocks.

Source: US Department of Energy, National Energy Technology Laboratory, 2004

From Table 3, we could observe that there are few importance characteristics that owned by the biomass which make them as potential feedstock for gasification process. The characteristics are:

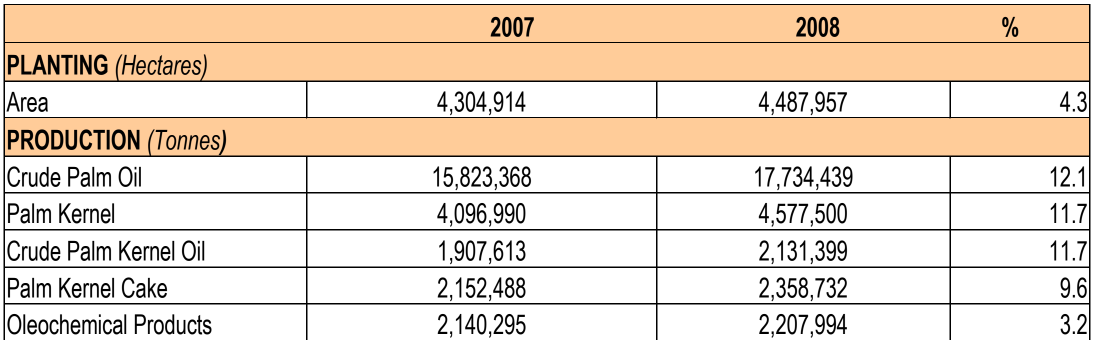
- High in Carbon and Hydrogen content, Low in Nitrogen and Sulfur content
- Acceptable range in moisture content
- High in Fixed Carbon content
- High in Heating Value content

All of these characteristics however also depend on the requirement of the gasifiers as well.

2.5.4 Palm Biomass as Feedstock for Gasification

CM Chin et al (2008) researched on the potential of palm biomass for generating renewable energy. In the research, the scope is focused on Malaysian palm biomass which is the waste resulted from the vast Palm Oil industries in Malaysia. Malaysian Palm Oil Board, in its summary of palm oil performance year 2008 recorded that the total palm oil production and palm oil planting area are increased 12.1% and 4.3% respectively (Table 4). These increments indicate that the palm oil industries is expanding wider and thus, providing more reasons for utilization of its biomass waste in the energy production.

Table 4: Summary of Planting and Production of Palm in Malaysia 2008



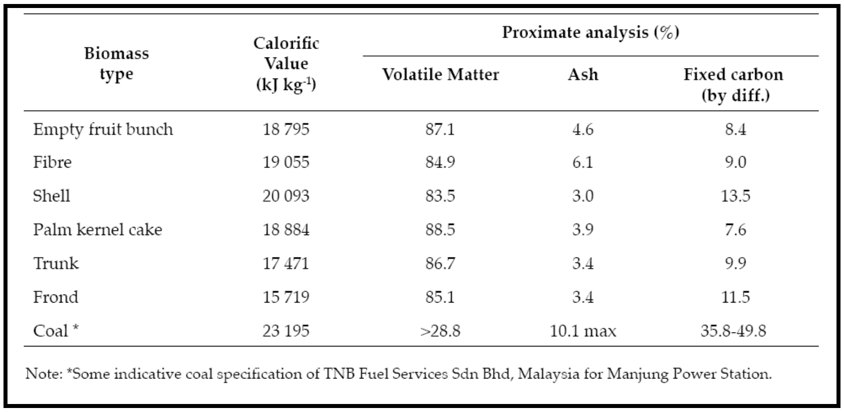
	2007	2008	%
PLANTING *(Hectares)*			
Area	4,304,914	4,487,957	4.3
PRODUCTION *(Tonnes)*			
Crude Palm Oil	15,823,368	17,734,439	12.1
Palm Kernel	4,096,990	4,577,500	11.7
Crude Palm Kernel Oil	1,907,613	2,131,399	11.7
Palm Kernel Cake	2,152,488	2,358,732	9.6
Oleochemical Products	2,140,295	2,207,994	3.2

* % indicates the increment percentage from year 2007 to 2008

Source: Malaysian Palm Oil Board, Summary of 2008 Performance, 2008.

In the process of extracting the oil from palm tree, a voluminous amount of biomass is simultaneously produced from the mills and also from the field. The biomass from the mills includes Empty Fruit Bunches (EFB), mesocarp fiber, palm kernel shell and liquid effluent. In the estates, fronds are regularly trimmed, while during felling for replanting the whole oil palm tree including trunk and fronds are available. These various forms of biomass have high calorific value and characteristic which make them available as commercial solid fuels and feedstocks, as shown in Table 5 and 6. (C M Chin et al, 2008)

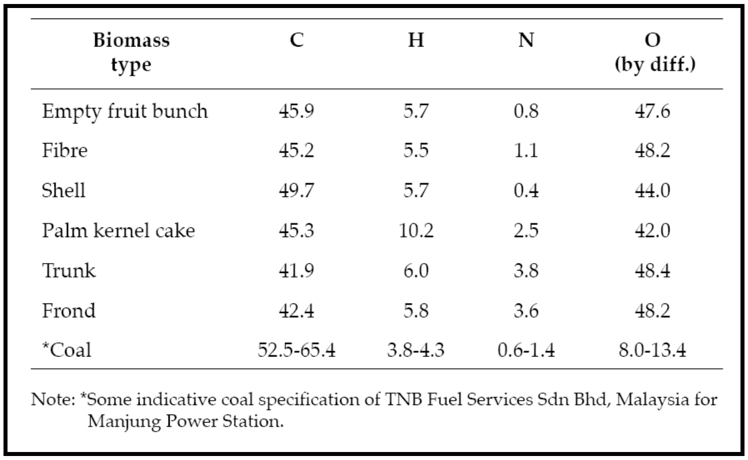
Table 5 : Proximate analysis on Palm Biomass



Biomass type	Calorific Value (kJ kg^{-1})	Proximate analysis (%)		
		Volatile Matter	Ash	Fixed carbon (by diff.)
Empty fruit bunch	18 795	87.1	4.6	8.4
Fibre	19 055	84.9	6.1	9.0
Shell	20 093	83.5	3.0	13.5
Palm kernel cake	18 884	88.5	3.9	7.6
Trunk	17 471	86.7	3.4	9.9
Frond	15 719	85.1	3.4	11.5
Coal *	23 195	>28.8	10.1 max	35.8-49.8

Note: *Some indicative coal specification of TNB Fuel Services Sdn Bhd, Malaysia for Manjung Power Station.

Table 6: Ultimate analysis on Palm Biomass



Biomass type	C	H	N	O (by diff.)
Empty fruit bunch	45.9	5.7	0.8	47.6
Fibre	45.2	5.5	1.1	48.2
Shell	49.7	5.7	0.4	44.0
Palm kernel cake	45.3	10.2	2.5	42.0
Trunk	41.9	6.0	3.8	48.4
Frond	42.4	5.8	3.6	48.2
*Coal	52.5-65.4	3.8-4.3	0.6-1.4	8.0-13.4

Note: *Some indicative coal specification of TNB Fuel Services Sdn Bhd, Malaysia for Manjung Power Station.

Source: Malaysian Palm Oil Board (MPOB), 2008

2.6 Biomass Characterization

2.6.1 Overview on Biomass Characterization

A major component of all biomass to power, fuels, and products research is to do characterizing the biomass feedstock, products, and intermediates. Biomass characterization is so important in determination of accurate considerations during the conversion technologies. In the Refineries newsletter from National Research Energy Laboratory (NREL, 2008) said that one reason NREL is so effective in biomass technology research and development is because of its capabilities to analyze biomass and intermediates from the processing. Biomass gasification and pyrolysis both require precise characterization of the breakdown products being generated, so that processes can be fine-tuned to produce optimal end products.

2.6.2 Characteristics of Biomass Feedstock for Gasification

Generally, in this project, the aim of performing biomass characterization is to determine the most suitable biomass to further been used in gasification technology in producing enriched hydrogen. Few conditions are needed to be determined such as the low moisture content, low ash percentage, high heating value and the suitable chemical composition of the biomass samples. Chemical biomass composition and structure includes the lignin, cellulose and hemicellulose compositions. All these conditions will be determined by using few analysis methods which includes proximate analysis, ultimate analysis, and other experimental methods.

2.6.3 Lignin, Cellulose and Hemicellulose

In general, structure of a plant cell wall is as shown in Figure 6. The lignin can be described as a complex polymer of phenylpropane units, which are cross-linked to each other with a variety of different chemical bonds giving the cell wall its main mechanical strength. (MDECP, 2009) Also, lignin helps the plant to resist moisture and biological attack. However, lignin can interfere with enzymatic conversion of cellulose and hemicellulose components. Lignin is the most intractable component of the plant cell wall, the higher the proportion of lignin the lower the bioavailability of the sample.

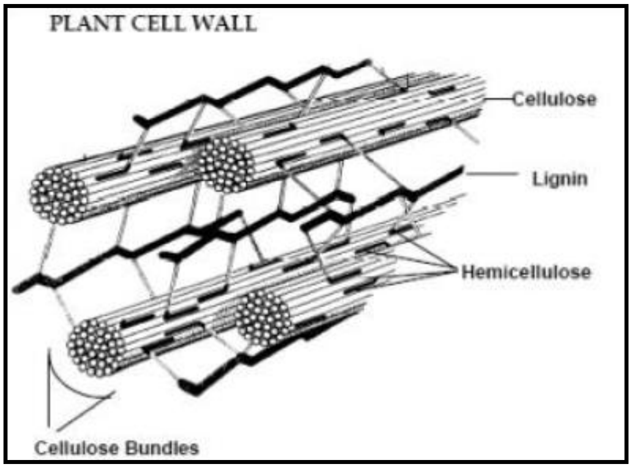


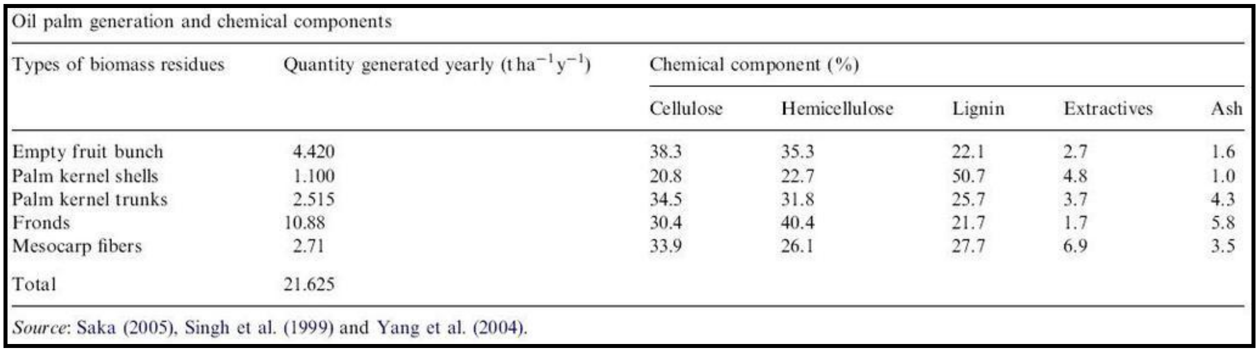
Figure 6: Structure of a plant cell wall

Source: BioCentrum-DTU, Denmark's Technical University

Another component of the plant cell wall is cellulose, which is a long chain of glucose molecules, linked to one another primarily with beta-glycosidic bonds. Hemicellulose meanwhile is branched polymer of xylose, arabinose, galactose, mannose, and glucose, of which xylose is the largest amount. Hemicellulose binds bundles of cellulose fibrils to form micro fibrils, which enhance the stability of the cell wall. They also cross-link with lignin, creating a complex web of bonds which provides structural strength, but also challenge microbial degradation of the plant material. (T Richard, 2005)

These three structure Lignin, cellulose and hemicellulose composition varied from a biomass to another biomass. The determination of this composition distribution in the biomass samples can lead to a better understanding and knowledge of the relationship of these cell wall structures towards the biomass potential as biomass feedstock for gasification process. Table 7 shows the composition of lignin, cellulose and hemicellulose of palm biomass (Kelly-Yong et al, 2007)

Table 7: Oil palm generation and Chemical Components



Oil palm generation and chemical components

Types of biomass residues	Quantity generated yearly ($t\,ha^{-1}\,y^{-1}$)	Chemical component (%)				
		Cellulose	Hemicellulose	Lignin	Extractives	Ash
Empty fruit bunch	4.420	38.3	35.3	22.1	2.7	1.6
Palm kernel shells	1.100	20.8	22.7	50.7	4.8	1.0
Palm kernel trunks	2.515	34.5	31.8	25.7	3.7	4.3
Fronds	10.88	30.4	40.4	21.7	1.7	5.8
Mesocarp fibers	2.71	33.9	26.1	27.7	6.9	3.5
Total	21.625					

Source: Saka (2005), Singh et al. (1999) and Yang et al. (2004).

2.6.4 Effect of Moisture content

The majority of the gasification technologies reviewed requires feedstock moisture to be below a specified level. This level varies from less than 10% for Lurgi to less than 70% for Foster Wheeler, according to Bridgewater, 1993. Gasification of high moisture content biomass is possible but at the expense of a higher system energy requirement and a dirtier syngas. High moisture content fuels generally decrease reactor-operating temperature and, therefore, may increase methane content and lower hydrogen content.

Also, the high oxygen and moisture content results in a low heating value for the product syngas, typically <2.5 MJ/m3 (67 Btu/ft3) as reported by Ciferno and Marano (2002). The costs for feedstock treatment in gasification process will increase for difficult to handle feeds (e.g., straw) and high moisture feeds (e.g., >30%) that require extensive drying prior to gasification.

Denisse Arroyo (2000) discussed that the moisture content of the most biomass fuel depends on the type of fuel, its origin and treatment before it is used for gasification. Moisture content of the fuel is usually referred to inherent moisture plus surface moisture. The moisture content below 15% by weight is desirable for trouble free and economical operation of the gasifier. Higher moisture contents reduce the thermal efficiency of gasifier and results in low gas heating values. Igniting the fuel with higher moisture content becomes increasingly difficult, and the gas quality and the yield are also poor.

2.6.5 Others Characteristic for Biomass Feedstock

Ash content in a biomass is an integral part of the plant structure which consists of a wide range of mineral matter such as salts of calcium, potassium, silica, and magnesium. Ash content depends on the type of the plant and the soil contamination in which the plant grows. (WR Livingston, 2007) Ashes can cause a variety of problems particularly in up or downdraught gasifiers. Slagging or clinker formation in the reactor, caused by melting and agglomeration of ashes, at the best will greatly add to the amount of labour required to operate the gasifier If no special measures are taken, slagging can lead to excessive tar formation and/or complete blocking of the reactor. A worst case is the possibility of air-channelling which can lead to a risk of explosion, especially in updraft gasifiers. To determine the ash content, proximate analysis will be done.

Besides determine the ash content, the volatile matter percentage can also be determined by proximate analysis. Volatile matter evolves in the form of gases, light hydrocarbons and tars. Volatile matter of biomass is higher than of coal, which typically around 75% dry basis. High volatile matter content of biomass makes it more readily devolatilized than solid fuels such as coal, liberating less fixed carbon, hence making them more useful for pyrolysis and gasification. (A Dutta, 2007)

The fixed carbon content of the coal is the carbon found in the material that is left after volatile materials are driven off. This differs from the ultimate carbon content of the coal because some carbon is lost in hydrocarbons with the volatiles. Fixed carbon is used as an estimate of the amount of coke that will be yielded from a sample of coal. Fixed carbon is determined by removing the mass of volatiles determined by the volatility test, above, from the original mass of the coal sample. It is used as %C in computation for calorific value. Fixed carbon ignition temperature is approximately 750 to 900ºF. (Chemical Processing, 2008)

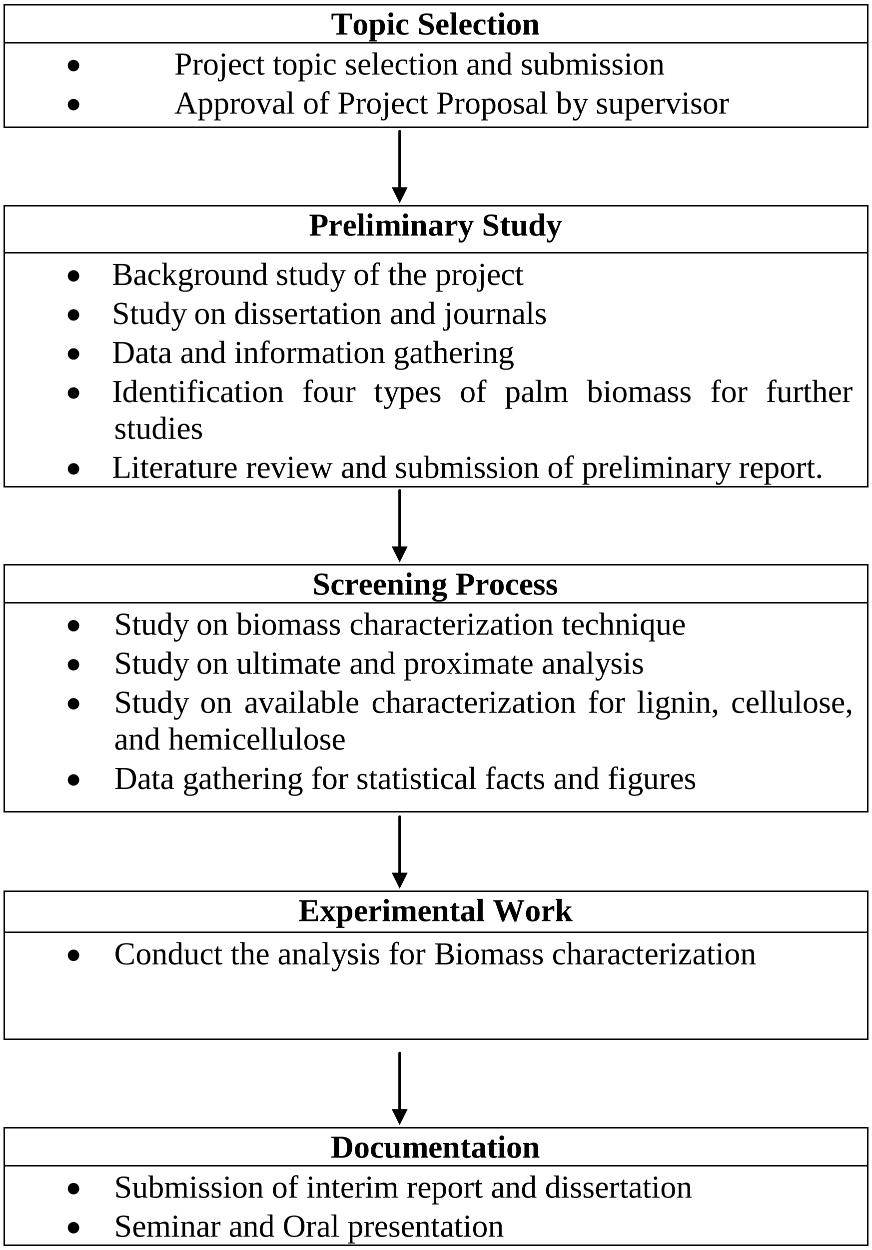
Ultimate analysis, at the other hand, determines the percentages of carbon, hydrogen, nitrogen, sulfur, chlorine and (by difference) oxygen in the gaseous products and ash after the complete combustion of an organic material of a sample. A Dutta (2007) discussed that biomass has a lower C/H ratio than that of coal. It is typically around 8-10. Biomass needs to have a higher bound oxygen content and lower sulfur content than that of coal. Amount of Nitrogen and Chlorine (related to NOx and corrosion) vary significantly among biomass fuels. Chlorine is directly related to corrosion. Thus, a right biomass that will be used as feedstock for gasification should consider all these factors in order to ensure the efficiency of the process itself as well as the cost feasibility.

CHAPTER 3

PROJECT METHODOLOGY

3.1 Project Procedures

Below is the flow chart of project planned:



Topic Selection

- Project topic selection and submission
- Approval of Project Proposal by supervisor

Preliminary Study

- Background study of the project
- Study on dissertation and journals
- Data and information gathering
- Identification four types of palm biomass for further studies
- Literature review and submission of preliminary report.

Screening Process

- Study on biomass characterization technique
- Study on ultimate and proximate analysis
- Study on available characterization for lignin, cellulose, and hemicellulose
- Data gathering for statistical facts and figures

Experimental Work

- Conduct the analysis for Biomass characterization

Documentation

- Submission of interim report and dissertation
- Seminar and Oral presentation

Figure 7: Flow Chart of Project Procedures

3.2 Gantt Chart of Experimental Work

	ACTIVITIES	JUN		JULY				AUG				SEPT				OCT			
		W3	W4	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4	W1	W2	W3	W4
1	**Revision from FYP1**																		
	- Lab Procedure/ Methodology	**	**																
	- Meetings with SV	**	**																
2	**Raw Material**																		
	- contact FELCRA			**															
	- fetch the material from FELCRA			**	**														
3	**Preparation of Sample**																		
	- drying process (oven)				**														
	- grinding					**	**												
4	**Moisture analysis**																		
	- experiment using HMA							**	**										
5	**Elemental Component analysis**																		
	- experiment using CHNS							**	🟨	🟨									
6	**Heating Value analysis**																		
	- experiment using Bomb Calorimeter									**	**								
7	**Lignin analysis**																		
	- refer to patent 3674434 US Patent										🟨	🟨	**	**					
8	**Proximate analysis**																		
	- experiment using TGA										🟨	🟨				**	**		
9	**Discussion on finalized result**												🟨	🟨				**	**
10	**Conclusion / recommendation**													🟨	🟨				**
11	**Report – dissertation**															🟨	🟨		NOV
12	**Presentation**																		NOV

****** indicates when the activities are done in actual

3.3 Raw material

After considering the availability and economic point of view, the raw materials to be used in this project would be the Kernel shell, Fronds, and Palm fiber. All this samples need to undergo pretreatment phase first before being used in further analysis.

3.4 Raw material Preparation

The four biomass samples were received prior to the experiment day. All of them are collected from FELCRA, Perak. The samples will be first weighed to obtain the initial mass of each sample. Next, the samples will be put into the oven for drying purposes at a temperature of 100^oC for about two days. This drying process is conducted in order to remove most of the moisture within the samples. The dried samples will then be placed into desiccators to avoid any moisture contact with them.

Then, the dried samples will be grinded into small size of particles by using the pestle and mortar grinder. This is to make sure the particles size of all samples is the same through out the project. Furthermore, this is to prepare the samples to meet the requirements of testing equipment that mostly needs small amount of samples only. After that, sieve shaker is used to separate the samples according to the desired particle size, which in this project is less than 250 micrometer. Now, the samples are ready for further testing.

3.5 Moisture Content Determination

The equipment use at this stage is the Halogen Moisture Analyzer (HMA). The procedure for the experiment is as follows:

1. About 2.0g of the sample is prepared and distributed properly onto the designated plate from the analyzer to ensure there is only a layer of sample on the plate.

2. The timer of HMA is set to 15 minutes of operation at temperature of 105^oC. Every one minute, the weight percentage of the sample is recorded by the analyzer.
3. After 15 minutes, the plate is removed from the analyzer and the result is printed.
4. The result shows the weight percentage of the sample for each minute of operation.
5. The sample is removed from the plate and the plate is cleaned.
6. Steps 1 to 5 are repeated with other samples.

The moisture content is determined by taking into calculation the loss in weight of the sample when heated under controlled temperature, duration and pressure. The percent moisture in the sample is calculated as follows:

$$\text{Moisture content in sample (\%)} = [(A - B)/A] \times 100$$

Where,
A = weight of sample used, gram
B = weight of sample after heating, gram

3.6 Carbon, Hydrogen, Nitrogen and Sulfur Composition Determination

The equipment to be used in this test is Carbon Hydrogen Nitrogen Sulfur (CHNS) Analyzer. All samples will be tested to obtain the percentage of carbon, hydrogen, nitrogen and sulfur composition of those samples.

Standard Operating Procedure (SOP)

1. Pressure of Helium, O2 and compressed air are set to 40 psi
2. The ambient monitor is checked for proper values
3. The CO2, H2 and sulfur IR Cells reading is ensured to be between ‘7.5-9.2’ volts
4. The Oxidation Furnace Temperature is set to 1000oc

5. The Reduction Furnace Temperature is set to 650oc
6. Leak check is run if necessary
7. The ‘Auto/Manual’ switch to is set Auto when using carousel
8. The gas switch is set to analyze position
9. The furnace temperature is allowed to be stable
10. The blank analysis and standard samples is run
11. The experiment samples is run
12. The result of the analysis is printed from the analyzer copier

Samples Preparation

1. A CHNS tin capsule is weighed
2. Approximate of 2.0mg of standard sample is put into the capsule
3. The capsule is closed properly before weighing the weight
4. The procedures are repeated for all other samples
5. Those samples is inserted into the slot inside the analyzer
6. The weight of the samples is input into the analyzer
7. The analysis is completed in 3 minutes for each run

3.7 Heating Value Determination

Heating Value is the amount of heat released during the combustion of a fuel. It can be measured in units of energy per amount of the material. Bomb calorimeter is the equipment used to measure heating value of each sample. Bomb calorimeter is capable to determine the heating values of the solid materials under standardize condition.

1. About 2.5g of the samples are pressed to form a tablet test sample.
2. The tablet test sample is placed inside the bomb unit on top of the igniter string.
3. Mass of the sample is given to the bomb calorimeter.
4. Each sample is analyzed for 30 minutes.
5. Heat of combustion is displayed at the bomb calorimeter screen each time the heat released through the process.

3.8 Proximate Analysis by Using Thermogravimetric Analyzer (TGA)

The equipment used to determine the ash content, volatile matter content and fixed carbon content of the biomass sample is Thermogravimetric Analyzer (TGA). TGA is a type of analysis performed in samples to determine the changes in weight in relation to change in temperature. This analysis relies on a high degree of precision in three measurement parameters which are weight, temperature and temperature change. As many weight loss curves look similar, the weight loss curve may require transformation before results may be interpreted. A derivative weight loss curve can be used to tell the point at which weight loss is most apparent. Again, interpretation is limited without further modifications and disconsolation of the overlapping peaks may be required. The analyzer usually consists of a high-precision balance with a pan (generally platinum) loaded with the sample. The pan is placed in a small electrically heated oven with a thermocouple to accurately measure the temperature. The atmosphere may be purged with an inert gas to prevent oxidation or other undesired reactions. A computer is used to control the instrument.

Analysis is carried out by raising the temperature gradually and plotting weight against temperature. The temperature in many testing methods routinely reaches 1000°C or greater, but the oven is so greatly insulated that an operator would not be aware of any change in temperature even if standing directly in front of the device. After the data is obtained, curve smoothing and other operations may be done such as to find the exact points of inflection. (TA instrument, 2009)

For this project, the step-by-step procedure is referred from Fara Eusniza (2002).

1. Firstly the sample is hold inside the TGA at 50^{o}C for 1 minute before being heated up from 50^{o}C to 110^{o}C at 60^{o}C/min with nitrogen gas flow rate of 20 ml/min.
2. At 110oC, the sample is hold isothermally for 5 minutes to enable any moisture released from the sample.

3. Then, the sample is heated up to 900^oC at 100^oC/min to measure the volatile matter present in the sample.
4. The sample is then being hold at 900^oC for about 15 minutes to allow all volatile matters expelled from the sample.
5. The purge gas is then switched to Oxygen at a flowrate of 30 ml/min after 22 minutes of elapsed time.
6. The fixed carbon content is oxidized or further combusted, leaving the ash content as the residue.
7. Total time required is approximately 30 minutes for each run. TGA will give us a curve to be then analyzed.

3.9 Chemical Content Determination

For chemical composition determination, the sample is tested for its lignin content. The procedure is referred to X.S Chin and J.Y Zhu (1999) and United States Patent 64753339 B1, Method for Rapidly Determining a Pulp Kappa Number using Spectrophotometry. The method and apparatus is by direct measurement. The process is based on upon relationship between lignin content and Kappa number which is calculated by considering the absorption intensities of the solutions undergoing oxidation. The equipment used in the analysis is UV Visible Spectrophotometer

Chemicals/reagents:

Standardized 0.02 mole/L potassium permanganate, K_2MnO_4 and 2.0 mole/L sulfuric acid H_2SO_4

Procedure:

1. Approximately 0.1 g of biomass sample is weighed.
2. 5 ml of 0.02 mole/L K_2MnO_4 and 20 ml of 2.0 mole/L H2SO4 is weighed before mixing both chemicals together to form acidic reacting solution.
3. Before mixing the reacting solution with biomass sample, UV Visible Spectrophotometer is ensured to be in ready mode.

4. Once mixing the biomass sample to the reacting solution, a sample is quickly taken to be run in UV Visible Spectrophotometer.
5. About 1 minute later, when the analysis for the first run is done, the sample is removed and installed another sample from the mixture of biomass and reacting solution.
6. Step 5 continued until the end of oxidation reactant of the biomass sample.
7. The absorbance at the initial and end of oxidation is recorded
8. Step 1-7 are repeated for the rest two biomass samples

Standard Operating Procedure of UV Visible Spectrophotometer:

1. The equipment is turned on and initialized to the software at the connected PC.
2. Photometric test option is selected
3. All parameters is filled in the windows
4. Distilled water is prepared in cuvette (Quartz 10mm) which will be the reference solution
5. The cuvette with distilled water and a blank cuvette are inserted into the sample holder.
6. A test is run for both samples to calibrate the equipment
7. The equipment is ready for further use

Calculation

The Kappa number can be determined by calculating the kappa number based on the equation:

$$K = \frac{a}{w}\left(1 - \frac{A_e}{A_0}\right),$$

Where

K = Kappa number
a = amount of reacting solution with strong acidification
w = amount of sample
A0 = oxidation agent absorption intensity before oxidation occurs
Ae = oxidation agent absorption intensity at oxidation reaction end point

CHAPTER 4

RESULT AND DISCUSSION

4.1 Moisture Analysis Result

The result for moisture analysis using Halogen Moisture Analyzer is shown in Figure 8.

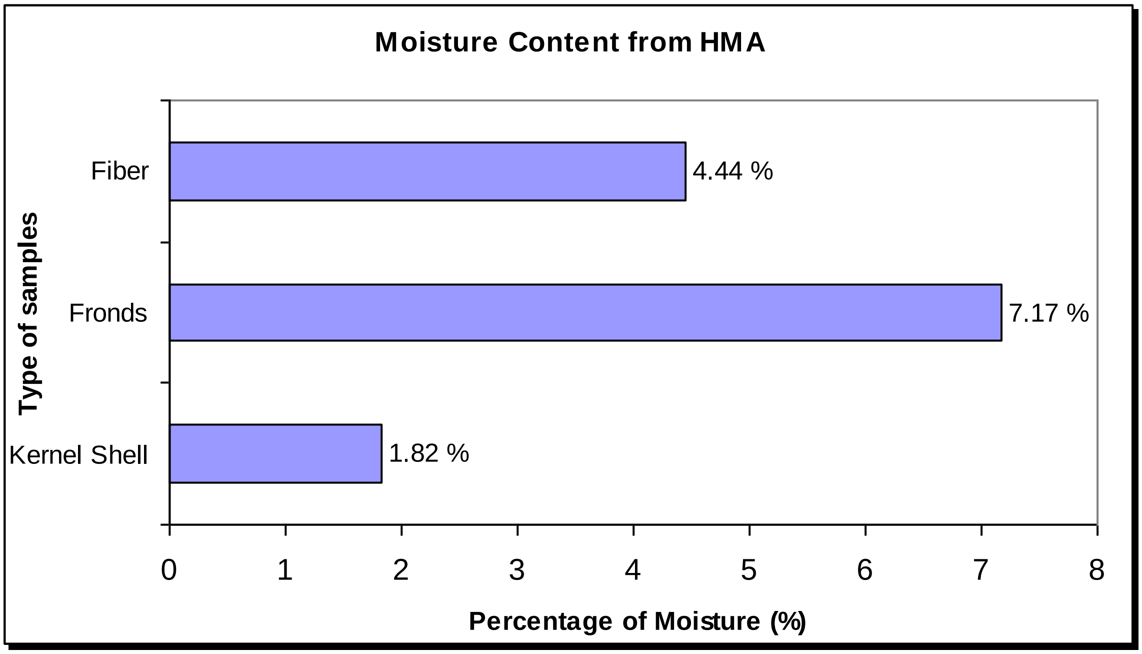


Figure 8: Moisture Content Analysis using Halogen Moisture Analyzer (HMA)

Figure 8 described the amount of moisture content in percentage relative to the weight of the samples of palm biomass. From the bar chart, it is observed that Kernel Shell is having the lowest value of moisture percentage which is 1.82 %. It is followed by Fiber with 4.44% of moisture and Fronds with 7.17% of moisture content within the sample.

Amount of moisture would give effects to gasification process as per discussed earlier in the previous chapter. Thus, it is essential to ensure that the amount of moisture in the feedstock is to be kept at minimum level. The moisture content will significantly affects the quality of the gas produced by the gasifier and the pretreatment requirement of the biomass itself. According to Cifeno and Marano (2002), acceptable range of moisture content in gasifier feedstock is depended on the type of gasifier. However, the normal range is between 10% and 15%.

Therefore, from the result obtained from HMA, all types of palm biomass – kernel shell, fronds and fiber can be considered to be the feedstock for gasification process because the moisture contents are within the acceptable range.

4.2 Carbon, Hydrogen, Nitrogen and Sulfur Composition Analysis Result

The result of elemental Carbon, Hydrogen, Nitrogen and Sulfur component analysis by using CHNS Analyzer is shown in Figure 9.

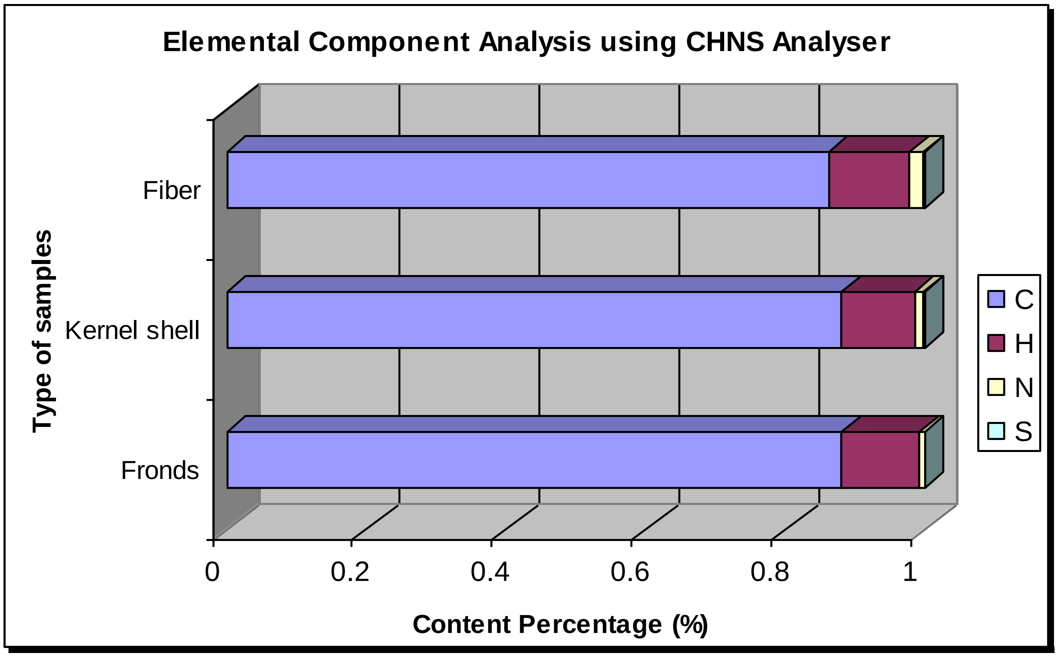


Figure 9: Carbon, Hydrogen, Nitrogen, and Sulfur content from CHNS Analyser

Table 8 below showed the percentage of those components obtained from the CHNS analyzer.

Table 8: Elemental Components of Samples

Type	Component Percentage (%)				
	Carbon	Hydrogen	Nitrogen	Sulfur	Oxygen
Fronds	42.040	5.272	0.328	0.029	52.331
Kernel shell	45.610	5.452	0.709	0.045	48.186
Fiber	45.520	6.103	1.093	0.085	47.200

The result of CHNS analysis showed us the breakdown of the components in those types of palm biomass in percentage. From the result, the percentage of Oxygen can be calculated by percentage difference.

According to the obtained result, Kernel shell is having the highest percentage of Carbon content with a value of 45.61%. The least amount of carbon is found in Fronds with only 42.04%. Meanwhile, Fiber shows 45.52% of carbon content. For Oxygen content, Fronds contained highest percentage which is 52.33%, followed by Kernel shell with 48.19% and finally Fiber with 47.20%.

As for hydrogen content, Fiber has the highest hydrogen content which is 6.10% followed by Kernel shell and Fronds with 5.45% and 5.27% respectively. Most of the palm biomasses contain less than 1.0% of nitrogen except Fiber which has nitrogen content with the value of 1.09%. Sulfur contents for all of the samples are less than 1.0%. This finding is good because high nitrogen and sulfur content may affect the operation of the gasifier and would result in the need of gas treating at the end of the process. (Higman and van der Burgt, 2003)

From this analysis, we can conclude that biomass sample which having high Carbon content and high Hydrogen content with low Nitrogen and Sulfur content is much preferable to be utilized as feed to gasification process. Therefore, all three samples of palm biomass tested have these points with the most suitable are Fiber and Kernel Shell.

4.3 Heating Value Analysis Result

Heating value for all three biomass samples can be determined in two ways which are by manual calculation and by experimental work.

For manual calculation, the High Heating Value (HHV) can be determined based on Dulong’s formula. This formula is utilizing the result of elemental component analysis in order to get the HHV. The formula is as follows:

$$\mathbf{HHV = 33.83\ C + 144.25\ (H - O/8) + 9.42\ S \qquad (MJ/k)}$$

where,

C – Carbon, H – Hydrogen, S – Sulfur, A – Ash, O – Oxygen content in fraction

The result for HHV using Dulong’s formula is shown below in Table 9.

Table 9: High Heating Value using Dulong’s formula

Biomass Sample	HHV(Dulong's Formula) MJ/kg
Fronds	12.3938
Kernel Shell	14.6101
Fiber	15.7003

From the result in Table 9, it is observed that Fiber is having the highest HHV which is 15.7 MJ/kg, followed by Kernel shell and fronds with 14.6 MJ/kg and 12.4 MJ/kg respectively. Based on this formula, the higher the carbon and hydrogen content would result in higher HHV. Somehow, these results are slightly deviated from the one shown in Table 5 in Literature Review chapter. Yet, the trend of the result is similar where fronds are having the least heating value. These differences may occur due to the error in elemental component analysis and the effect of the moisture content trapped within the samples.

At the other hand, for experimental work using bomb calorimeter, the result obtained is as shown in Figure 10.

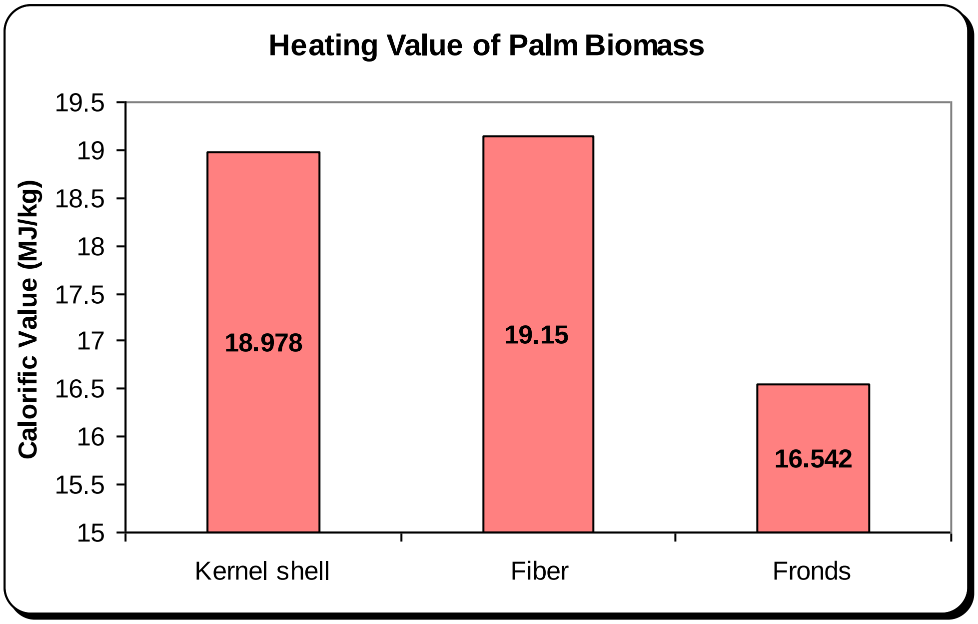


Figure 10: Heating Value analysis result using bomb calorimeter

From Figure 10, Fiber has the highest heating value which is 19.15 MJ/g and followed by kernel shell with 18.98 MJ/g. Meanwhile, fronds have the least value of heating value which is 16.54 MJ/g. All of the values obtained through this experiment can be considered very much similar to the literature review (Table 5).

From the result, we can study that the heating values for all three palm biomass sample; fiber, kernel shell and fronds, are at high value and this indicates the relevancy of using these biomass as source of energy.

4.4 Chemical Component - Lignin Analysis Result

For chemical component determination, the result obtained from the experimental work is as per shown in Figure 11.

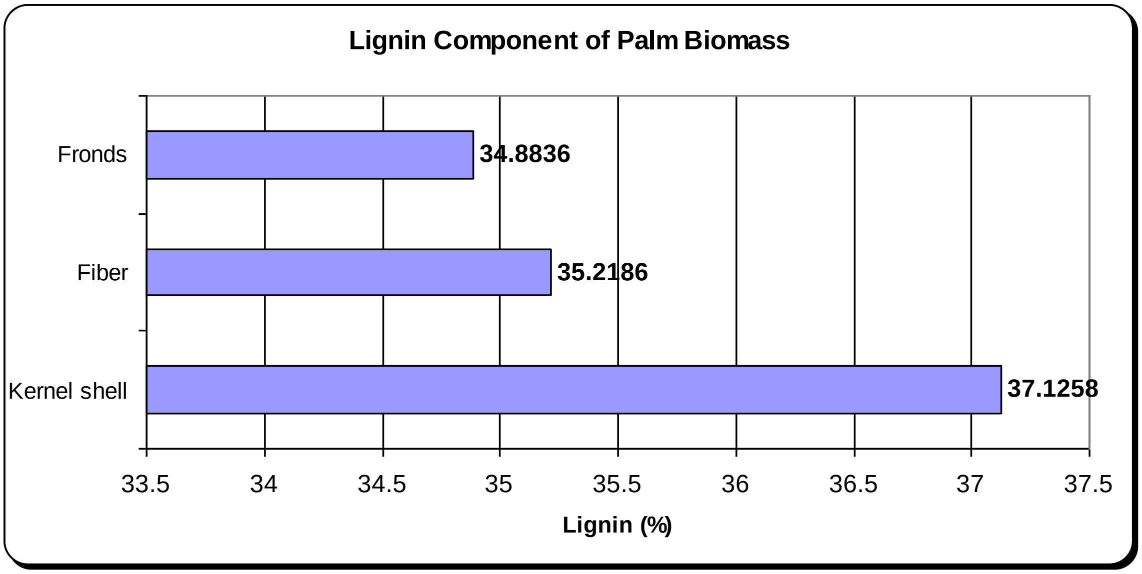


Figure 11: Lignin Component Result of Palm Biomass

From the result, Kernel shell is having the highest lignin percentage as compared to other samples, which is 37.1%. The second highest of the lignin percentage is Fiber with 35.2% and the least is Fronds with 34.88%. The trend of the result is similar to the values in Table 7. These values are slightly different from the values shown in Table 7, except for Kernel shell where the difference is large. This may caused by some identified errors:

- Systematic error while doing the measurement of the volume of the reacting solution and during the weighing activities
- Instrument error may happen when the UV Visible Spectrophotometers not well calibrated using standard solution which is distilled water
- The time delay to conduct the run of each sample also may cause the A_o and A_e result to be inaccurate.

As discussed before, lignin can interfere in conversion of cellulose and hemicellulose into syngas. Therefore, the higher the lignin, the more difficult the conversion process is. That is the main reason of having feed pretreatment to reduce the lignin interruption. Considering this, it can be said that Fronds which having the least lignin content is highly preferable to be utilized in gasification. This is because; it could lessen the cost of pretreatment as well as shorten the time period of feed preparation.

4.5 Proximate Analysis Using Thermo Gravimetric Analyzer (TGA)

Proximate analysis had been done by using Thermo Gravimetric Analyzer (TGA) for all three samples. From this analysis, three important criteria are determined which are volatile matter, fixed carbon, ash content in weight percentage. A thermogram or TGA profile plot is obtained for each sample.

From the TGA profiles, values for volatile matter, fixed carbon and ash content is determined for all samples and the results are in Figure 12

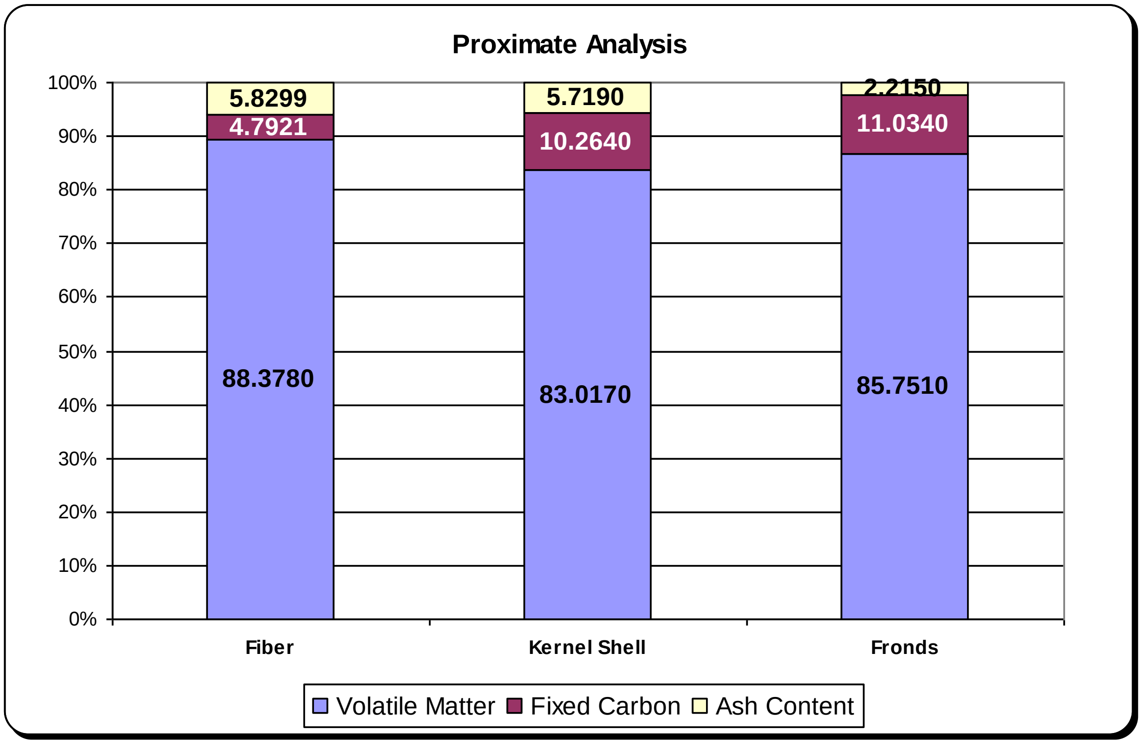


Figure 12: Proximate Analysis result from TGA

Result shows that volatile matter for fiber is the highest among the three samples, followed by fronds and kernel shell. During experimental run, it was observed that some of kernel shell was not completely combusted thus leaving some residue or ash of 5.7190 wt%. The high value of ash in kernel shell is contributed by the low value of volatile matters. This is parallel with the literature review where high volatile matter content of biomass makes it more readily devolatilized than solid fuels (A Dutta, 2007). In ranking, fiber has highest ash content which is 5.83 wt%, second highest is 5.72 wt% and the least is fronds with 2.22 wt%. These are still within the acceptable range of ash content for gasification.

Volatile matters and fixed carbon are fuel elements of biomass while moisture content and ash content are referred as impurities, Charles (1996). The result shows that the sum of volatile matters and fixed carbon content of fronds is the highest which is 96.78 wt%. The second highest is kernel shell with 93.28 wt% and the least is fiber 93.17%. In overall, all three samples are characterized by high volatile content. Thus, these fuels produce relatively small amounts of char. Also, the char is more porous and reacts relatively fast. For this reason, fuels with high volatile matter content are easier to gasify. However they produce tar and thus require strategies to remove those tars. (P Basu and SC Bhattacharya, 2006)

4.6 Matrix Evaluation of Results

All the results obtained are tabulated into matrix table below:

Table 10: Matrix Evaluation

Characteristic	**Type of Palm biomass**		
	Fronds	**Fiber**	**Kernel Shell**
Low moisture content	1	2	3
High C content	1	2	3
High H content	1	3	2
Low N content	3	1	2
Low S content	3	1	2
High Heating Value	1	3	2
Low lignin content	3	2	1
Low ash content	3	1	2
High volatile matter	2	3	1
High fixed carbon content	3	1	2
TOTAL	21	19	20
PERCENTAGE (%)	35.00	31.67	33.33
RANKING	1st	3rd	2nd

Note: 3 = best, 2 = good, 1 = fair

* indicates the analysis is not done yet

From the matrix evaluation, at the moment, Fronds are the most preferable biomass to be the feedstock for gasification process, due to the following characteristic:

- Low in moisture content which will result in low cost for the feed preparation since no drying or heating process required
- High content of Carbon and Hydrogen, but low Nitrogen and Sulfur content because the high percentage of Carbon and Hydrogen will contribute to high conversion of energy. Less Nitrogen and Sulfur is necessary to ensure the process is environmental friendly.
- High heating value because feed with high heating value can produce higher amount of energy as it is converted
- Low lignin content because it will ease the gasification process and no feed pretreatment is required thus lowering the feed preparation cost.
- Low ash content because ash content can lead to increment in cost of operation for the gasifiers and will cause less efficiency of the gasifiers
- High volatile matter because biomass with high volatile matter is easier to gasify and thus lower the operating cost
- High fixed carbon content because fixed carbon is one of the fuel element of biomass

CONCLUSION AND RECOMMENDATION

Palm biomass has great potential to be fully utilized as renewable energy source, alternative to the fossil fuel. With its minimum harmful greenhouse gases emissions to the air, palm biomass has become an interest to the researches and studies to find a better and more efficient way of extracting the energy from the biomass. In Malaysia, the large amount of abundance palm biomass has given the project a relevant reason to be proceeding. Furthermore, with the current increment of attention to the running out of fossil fuels in world reservoirs, had created a driving force for this project to be completed successfully. Fronds are the best type of palm biomass which could give the most efficient rich hydrogen production could be determined after being tested by few analysis tools during this experiment. It has the characteristics of good feedstock for gasification like low moisture content, high heating value, high carbon and hydrogen content, low ash content, etc. The discovered potential of this type of palm biomass should be a step forward to help in accelerating the research and development of renewable energy to meet the higher energy demand in the future. Further researches are recommended to be done to run a trial run of biomass gasification in conventional gasifiers in order for us to observe the exact amount of hydrogen produced from that gasification process. That can strengthen the findings and conclusion of this project.

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