OPTIMAL DESIGN FOR PRODUCTION OF GREEN DIESEL FROM INTEGRATED OIL PALM BIOMASS DERIVED ALCOHOLS BIO-REFINERY

MOHAMAD ADIB BIN ABDUL AZIZ

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

OPTIMAL DESIGN FOR PRODUCTION OF GREEN DIESEL FROM INTEGRATED OIL PALM BIOMASS DERIVED ALCOHOLS BIO-REFINERY

MOHAMAD ADIB BIN ABDUL AZIZ

(B041610152)

A report submitted
In fulfillment of the requirements for the degree of
Bachelor of Mechanical Engineering

Faculty of Mechanical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2020

DECLARATION

I declare that this project report entitled “Optimal Design for Production of Green Diesel from Integrated Oil Palm Biomass derived Alcohols Bio-refinery” is the result of my own work except as cited in the references

Signature :

Name : Mohamad Adib Bin Abdul Aziz

Date : 14/8/2020

APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering.

Signature :

NURUL HANIM BINTI RAZAK
Pensyarah
Fakulti Kejuruteraan Mekanikal
Universiti Teknikal Malaysia Melaka

Supervisor's Name : Nurul Hanim binti Haji Razak

Date : 13/8/2020

ABSTRACT

Biomass has long been viewed as a future opportunity with the ever-increasing need for sustainable and affordable energy sources. Malaysia is one of the world's leading producers with the world's largest palm oil crop. Biomass from the palm oil sector, thus, seems to be a very interesting alternative source of raw materials in Malaysia, including renewable energy. There is a growing interest in biofuels nowadays. Thus, this study focuses on the model-based formulation and optimization of advanced biofuels from integrated oil palm biomass bio-refinery. A simulation approach based on superstructure offers alternatives to biomass production routes to minimize the total cost of the supply chain. Thus, this study aims to analyze the model that integrates comprehensive spatial modelling techniques with the strategic oil palm biomass supply chain network design. This study will also optimize supply chain using simulation software such as GAMS and ArcGIS. Based on the findings, there are 78 potential facilities for oil palm biomass in Johor. Next, the least cost and low GHG supply chain of biofuel was obtained based on various constraints that served as the upper and lower boundaries of the decision variables. With ArcGIS software, spatial data is presented then solved by mathematical optimization programming (Linear Programming) in GAMS software. Lastly, Analytical Hierarchy Process (AHP) are carried out to determine the most optimal supply chain system.

ABSTRAK

Biomas telah lama dilihat sebagai peluang masa depan dengan keperluan sumber tenaga yang mampan dan berpatutan yang semakin meningkat. Malaysia adalah antara pengeluar tanaman kelapa sawit terbesar di dunia. Oleh itu, biomas dari sektor kelapa sawit yang juga merupakan tenaga boleh diperbaharui adalah sumber bahan mentah alternatif yang terbaik di Malaysia. Terdapat permintaan yang semakin meningkat terhadap bahan api bio pada masa kini. Oleh itu, kajian ini memfokuskan pada perumusan berdasarkan model dan pengoptimuman bahan api bio dari kilang bio biomas kelapa sawit. Penggunaan simulasi berdasarkan suprastruktur menawarkan alternatif kepada laluan pengeluaran biomas untuk meminimumkan jumlah kos rantaian bekalan. Oleh itu, kajian ini bertujuan untuk menganalisis model yang mengintegrasikan teknik pemodelan spasial yang komprehensif dengan reka bentuk rangkaian rantaian bekalan biomas kelapa sawit yang strategik. Kajian ini juga akan mengoptimumkan rantaian bekalan menggunakan perisian simulasi seperti GAMS dan ArcGIS. Berdasarkan penemuan dalam kajian ini, terdapat 78 tempat yang berpotensi sebagai kilang biorefineri di Johor. Seterusnya, rantai bekalan bahan api bio yang mempunyai kos dan pelepasan gas rumah hijau paling rendah diperoleh berdasarkan pelbagai kekangan yang berfungsi sebagai batas atas dan bawah pemboleh ubah keputusan. Dengan perisian ArcGIS, data spatial disajikan kemudian diselesaikan dengan pengaturcaraan pengoptimuman matematik (Linear Programming) dalam perisian GAMS. Terakhir, Proses Hierarki Analitik (AHP) dijalankan untuk menentukan sistem rantaian bekalan yang paling optimum.

ACKNOWLEDGMENT

I would like to express my gratitude to Almighty Allah who has given me the opportunity to go through the total process of final year project and also in writing this report. These years were very interesting and valuable enough, but sometimes it could also be challenging and difficult. I have learned a lot not only about my studies, but also a lot about myself, and eventually, it is fantastic to be able, to sum up, my work in this final year project. But without the help and support of many individuals, this would not have been feasible.

First and foremost, I would like to take this opportunity to express my sincere acknowledgement to my supervisor Madam Nurul Hanim Binti Haji Razak from the Faculty of Mechanical Engineering Universiti Teknikal Malaysia Melaka (UTeM) for her essential supervision, support and encouragement towards the completion of this project report.

I am also grateful to those who help me complete this final year project and to any peers for their moral support and, above all, for their precious friendship. Special thanks to my beloved parent, siblings and friends for their moral support in completing this degree. Lastly, thank you to everyone who had been to the crucial parts for me to complete this project.

TABLE OF CONTENT

	PAGE
DECLARATION	
APPROVAL	
ABSTRACT	**I**
ACKNOWLEDGMENT	**III**
LIST OF FIGURES	**VI**
LIST OF TABLES	**VII**
ABBREVIATION	**VIII**
CHAPTER	
1. INTRODUCTION	**1**
1.0 Introduction	1
1.1 Research Background	1
1.2 Problem Statement	2
1.3 Research Objectives	3
1.4 Scope of Study	3
1.5 Research Scopes	4
1.6 Significance of Research	4
2. LITERATURE REVIEW	**5**
2.0 Introduction	5
2.1 Background of Biofuel	5
2.2 Evolution of Biofuel	6
2.3 Potential of Oil Palm Biomass in Malaysia	7
2.4 Conversion Technologies of Oil Palm Biomass	8
2.4.1 Gasification	9
2.4.2 Pyrolysis	10
2.5 Drawback of Biofuel (Diesel and Biodiesel)	10
2.5.1 Diesel	10
2.5.2 Biodiesel	10
2.6 Green Diesel	11
2.6.1 Fuel Additives (Oxygenates)	11
2.6.2 Physiochemical Properties	12
2.7 Supply Chain Optimization	13
2.8 Research Gap	15

3. STRUCTURAL METHODOLOGY **18**
3.0 Introduction 18
3.1 K-Chart 18
3.2 Process Flow Chart 21
3.3 Generic Methodologies 23
3.3.1 Data Collection and Extraction 23
3.3.2 Superstructure Representation 24
3.3.3 Mathematical Modelling 25
3.3.4 ArcGIS and GAMS Programming 26
3.3.5 Result Analysis 26
3.4 Spatially Biofuel Supply Chain Framework 27
3.4.1 Framework Outline 27
3.4.2 Spatial Data Generation 28
3.4.3 Spatial Analysis 29
3.4.4 Network Optimization 30
4. RESULT AND DISCUSSION **31**
4.1 Introduction 31
4.2 Preliminary Analysis 31
4.2.1 Resource Availability Estimations 32
4.2.2 Network analysis and transportation 33
4.2.3 Suitability Analysis of Potential Bio-Refinery Sites 34
4.3 Model Formulation 39
4.3.1 Material Balance 40
4.3.2 Economics 41
4.3.3 Environments 42
4.4 Results and Discussions 43
4.4.1 Spatial Optimization of Oil Palm Biomass 43
4.4.2 Analytical Hierarchy Process 47
4.4.3 Preliminary Conclusion 50
5. CONCLUSION AND FUTURE WORK **51**
5.1 Introduction 51
5.2 Conclusion 51
5.3 Future Works 52
5.4 Gantt Chart 54
APPENDIX **56**
REFERENCES **74**

FIGURE	LIST OF FIGURES	PAGE

2. 1	Biomass to bioenergy conversion pathways. (Sharma et al., 2015)	8
2. 2	Biomass gasification for alcohol production (Demirel, 2018)	9
2. 3	Basic superstructure for the supply chain of green diesel	14
3. 1	K-Chart	20
3. 2	Process Flow Chart of this study	22
3. 3	Generic methodologies in solving the optimization problem	23
3. 4	Superstructure of the transportation network of biomass	25
3. 5	Framework Outline of this study	27
3. 6	The input and output of spatial data generation components	28
3. 7	The input and output to obtain actual transportation distance calculation	29
3. 8	Input and output for network optimization for this study	30
4. 2	GIS-based biomass resource assessment with spatial modelling approach	32
4. 3	Road map in Johor	33
4. 4	Feedstock availability and potential location for bio-refinery in Johor	35
4. 5	Logistic Cost	44
4. 6	Green House Gas (GHG) Emission	45
4. 7	Supply Chain of Biofuel in Johor	46
4. 8	Dynamic sensitivity	47
4. 9	Perfomance sensitivity	48
4. 10	Ranking of potential location to set up bio-refinery	49
4. 11	Superstructure of Optimal Biofuel Supply Chain	50

TABLE	LIST OF TABLES	PAGE

2. 1	Comparison of various types of biomass (Demirel, 2018)	7
2. 2	Comparison between different types of renewable diesel	13
2. 3	Research Gap	15
4. 1	Potential locations of bio-refinery for this study	36
4. 2	Technoeconomic analysis	39
4. 3	Optimization Result	44
4. 4	Optimization Result for Green House Gas	45
4. 5	Overall result biofuel supply chain	50
5. 1	Gantt Chart for FYP	54

ABBREVIATION

AHP	-	Analytic Hierarchy Process
AIMMS	-	Advanced Interactive Multidimensional Modelling System
BR	-	Biorefinery
CAPEX	-	Capital Expenditure
CFPP	-	Cold Filter Plugging Point
CH_4	-	Methane
CO	-	Carbon Monoxide
CO_2	-	Carbon Dioxide
EFB	-	Empty Fruit Bunch
GAMS	-	General Algebraic Modeling System
GHG	-	Green House Gas
GIS	-	Geographic Information System
GUI	-	Graphical User Interface
H_2	-	Hydrogen
LP	-	Linear Programming
MF	-	Mesocarp Fiber
MPOB	-	Malaysian Palm Oil Board
N_2	-	Nitrogen
NO	-	Nitrogen Oxide
NO_2	-	Nitrogen Dioxide
OPEX	-	Operational Expenditure
OPF	-	Oil Palm Frond
OPT	-	Oil Palm Trunk
OPP	-	Oil Palm Plantation
PKS	-	Palm Kernel Shell

POME	-	Palm Oil Mill Effluent
SCM	-	Supply Chain Management
SCOR	-	Supply Chain Operation Reference
SIRIM	-	Standard and Industrial Research Institute of Malaysia

CHAPTER 1

INTRODUCTION

1.0 Introduction

This chapter will be discussing on the structural sustainability study of integrated oil palm biomass bio-refinery to produce advanced biofuels in Malaysia. This research is motivated to assess the appropriateness of the modelling and optimization of oil palm biomass's supply chain to be implemented in Malaysia through the development of a new systematic modelling framework. The following sections will be covered in this chapter including the research background, problem statement, research objectives, research scopes and significant research.

1.1 Research Background

Currently, one of the most crucial energy sources in every region of the world is biomass (Thran *et al*., 2010). Biomass can be considered as one of the energies that can be replenished and has the potential to become one of the significant sources of energy in the future. So, it is essential to develop and utilize various renewable energy sources. One of the approach to utilize biomass as a major source of energy is through the utilization of the remaining agricultural products, plantations or waste of forest products, including oil palm biomass. Oil palm is one of the potential assets as a source of biofuel. The crude palm oil produced is the main raw material to produce biofuels in the form of biodiesel. However, the development and utilization of biomass as a source of biofuel often face various obstacles. For instance, oil palm biomass also faces several problems that arise within the supply chain context such as inaccessibility to forest land, resulting in a high cost of production and that keep the investors away, the government forbids the usage of biomass for food, materials and traditional bioenergy.

The attempts to fully exploit biofuel potential through agroindustry activities cannot be separated from supply chain management. Supply chain management can be considered as a network of organization employed in complex operations and including several processes. The globalized market causes an increase in demand for the supply chain. To overcome the complexities, the management of an organization needs coordination in order to improve the performance of the supply chain. In an endeavour to be able to compete in the global market and networked economy, an organization needs to rely on effective supply chains or effective networks.

One of the key concerns of supply chain management is both the coordinating producer and supplier. Typically, the supply chain for palm biomass begins from suppliers provide the raw material to be consumed in refinery process. Then, manufacturer will consume the raw material to convert into semi-finished or finished product. Next, the products will be delivered to the wholesaler in a large quantity for marketing. Wholesaler will sell the products to the retailer based on their demand for the item. Lastly, the product will reach the end consumer.

1.2 Problem Statement

The parameters that are considered within the general design of the biofuel supply chain of are listed below.

- A set of locations: oil palm biomass plantations, potential bio-refineries, and demand centre.
- Logistic options: The transportation modes.
- Capacity limitations: Availability of feedstock at oil palm plantations, capacity of bio-alcohol production at bio-refinery and demands of bio-alcohol at demand centre.
- Economics data: Feedstock costs, transportation costs, capital expenditures and operating expenditures.
- Environmental impact data (CO_2 Emission): Feedstock acquisition, transportation, conversion technology.

Important decision variables in designing the optimize supply chain of green diesel are listed as follows:

- The selection of feedstock suppliers.
- The selection of location to set up bio-refinery for the conversion process.
- The selection of transportation modes.

In this supply chain model, there are two objectives need to be achieved that are economic objective and environmental objective. The challenges faced in the biofuel supply chain planning network are how to achieve the two objectives. The economic objective is to obtain the least cost in the supply chain while the environmental objective is to obtain the least carbon dioxide emission in the supply chain. So, in order to obtain the most optimal biofuel supply chain system, the selection of decision variables that are stated above is important so that the two objectives for biofuel supply chain can be achieved.

1.3 Research Objectives

(i) To develop a GIS-AHP optimization framework of oil palm biomass to biofuel production via Linear Programming (LP)

(ii) To design a strategic optimal network design of oil palm biomass to biofuel including the resources availability assessment, optimal biorefinery localization, transportation network analysis and optimization (GAMS, AHP & ArcGIS)

1.4 Scope of Study

This study is mainly to focus on the network planning of the supply chain for production of green diesel from oil palm biomass in Malaysia. This study also will contributes towards supply chain optimization of green diesel planning operation by considering several of cost factors such as biomass cost, transportation cost, bio-refinery capital expenditure, and as well as bio-refinery operating expenditure. Apart from that, this particular study will develop green diesel platform planning and optimization for biodiesel production process and network design within the supply chain planning. The improvement in performance measurement will be identified by using simulation such as GAMS and ArcGIS which is a geographic information system (GIS) software. The use of simulation software is essential in designing the most optimize supply chain system.

1.5 Research Scopes

For Objective (i)

Developing an optimal supply chain optimization (SCO) for palm oil biomass (OPF) to biofuel.

For Objective (ii)

Adopting a computer-aided tool to build least logistic cost and low greenhouse gas (GHG) emission of an optimal SCO for OPF to biofuel.

1.6 Significance of Research

The results of this study will determine the level of transportation management to mobilize the biomass of palm oil throughout the supply chain, leading to increased productivity and cost reduction. The recommendations based on the results of this study can help to organize strategic planning for supply chain system in order to optimize the current logistic system. Thus, the significance of this study will contribute to uncovering about the supply chain processes and the appropriate strategies that can be implemented to optimize the performance of the operations. The planning is to minimize the cost of the entire supply chain of biofuel from bio-waste feedstock fields to end-users, simultaneously satisfying demand, resource, and technology constraints.

CHAPTER 2

LITERATURE REVIEW

2.0 Introduction

This chapter presents the literature that was reviewed to come up with significant knowledge about the diesel fuel and the production of advanced biofuels from the integrated oil palm biomass. Section 2.1 explained about the background history of biofuels. In Section 2.2 the evolution of biofuels is discussed .In Section 2.3, the potential of oil palm biomass in Malaysia is discussed. The explanation of conversion technologies adopted to process solid oil palm biomass to liquid fuel is in Section 2.4. Section 2.5 provides the overview of the biofuel. Section 2.6 describes the introduction of green diesel and fuel additives used to increase the properties for green diesel are discussed. Section 2.7 discussed about supply chain optimization. Lastly, Section 2.8 provides the research gap for scientific literature.

2.1 Background of Biofuel

Secured supplies of energy are vital to ensure the technological developments for each country. Currently, the implementation of renewable energy usage is pursued in every state as it provides a safe and clean source of energy (Jiang Y & Swinton S, 2009). Biofuels must contain over 80 % of renewable resources, such as biomass, derived directly from the process of photosynthesis. Biofuels are used for basic energy needs and are used to blend or replace conventional fuel such as petroleum. In recent years, biofuels are becoming part of sustainable development all over the world as they are produced mainly from a feedstock of biomass**.** Biomass is a renewable source that contains very few sulphurs and carbon content. Thus, the utilization of biofuels can control greenhouse gas (GHG) emissions and can minimize adverse effects on the environment. For instance, bioethanol and biodiesel are the biofuels that are most commonly used nowadays. The percentage of biofuels in renewable energy utilization keeps increasing due to improving conversion technologies of biomass to biofuels. This has resulted in an increase of biofuel quality and minimize the cost of biofuel.

2.2 Evolution of Biofuel

Currently, biofuel can be classified into four generations. The first generation biofuel is mainly produced from food crops, and the commodities are derived from corn, sugar cane, and any sugar or starch. The production of the first-generation biofuel is through the technological method that is called enzymation. Enzymation is a process of enzyme digestion that releases sugars from starchy material in the food crops. Usually, the raw resources used have higher octane ratings that evaluate the fuel tends to burn in a way that suited the engine. However, a debate on food conflict as biomass and sustainability evaluation of such resources has limited the usage of the first-generation biofuel (Chakrabortty A, 2008).

This has reached the stage where the second and third generation of biofuel are introduced. The second generation refers to non-food type biomass that is called as lignocellulosic biomass. Lignocellulosic biomass is the raw materials that include waste biomass, wheat stalks, corn stalks, waste crops and others. The third-generation biofuel mainly refers to algae. Researchers are currently conducting experiments to identify mechanisms for the decomposition of cellulose into sugars, so, no marketing production has yet started. One of the advantages the second and the third generation is high content in lignin and cellulose that makes it ideal for higher carbon content, making it more effective and desirable to use in the development of bioenergy.

The fourth-generation biofuels are still ongoing and have not drawn attention as much as the first, second and third generations. Some organizations are starting to adopt the concept of biochemical and thermochemical processes that able to produce a better option for fuels such as green petrol and green diesel. The technologies that are used in developing the fourth generation include pyrolysis, gasification and organism genetic manipulation to secrete hydrocarbons. The generation biomass can be referred in Table 2.1.

Table 2. 1 Comparison of various types of biomass (Demirel, 2018)

Generation	Type	Source	Examples
First	Food crops	Starch crops	Corn, wheat
		Sugar crops	Sugarcane, sugar beet, sweet sorghum
		Feed	Grass
Second	Lignocellulosic crops	Woody	Short-rotation crops, willow poplar
		Herbaceous	Miscanthus, switchgrass
Third	Aquatic	Microalgae	Chlamydomonas rheinhardii, chlorella
		Macroalgae	Seaweed
		Water	Salt marshes, seagrass
		Water plants	
Wastes	Natural	Agricultural	Animal manure, crop residues
		Forest	Logging residues, tree wastes
	Human-made	Municipal	Solid waste, sewage sludge, waste oil Pulp
		Industrial	and paper industry, sludge

2.3 Potential of Oil Palm Biomass in Malaysia

Malaysia is among the important palm oil producers in the world. The oil palm tree is a beneficial crop that can help to improve the socio-cultural activities. The main problem is its substantial amount of biomass wastes after the oil palm trees are cultivated. Wastes such as empty fruit bunches (EFB), palm kernel shells (PKS), mesocarp fiber (MF), palm oil mill effluent (POME), oil palm trunks (OPT), and oil palm fronds (OPF) are produced following harvesting of oil palm fruits palm oil processing or during oil palm trees replantation (Mushtaq *et al*, 2015). Usually, these fronds and trunks and EFB are kept in the plantations and left to decompose naturally for nutrient replacement. The high potential value of these wastes is often ignored for more profitable purposes. The growing amount of waste of oil palm biomass every year urges the government to take further action. Then, the National Biomass Strategy 2020 is introduced in 2011. The strategy aims to ensure the biofuel and bio-based chemical industries are driven to the highest level (Ng *et al*, 2012). In addition, the priority is also on the production of biofuels of the second generation derived from lignocellulosic biomass from oil palm wastes. The oil palm tree can be regarded as a carbon-neutral element since the amount of carbon emitted is the same as they absorbed during their entire life during the combustion or decompose process. So, oil palm biomass can be considered as one of the most important renewable sources of material and energy. This is because this biomass produces less adverse impacts on the environmental. Thus, oil palm biomass is very sustainable for the environment (Panwar *et al*, 2011).

2.4 Conversion Technologies of Oil Palm Biomass

Currently, the most common conversion process applied to the biomass including biochemical, thermochemical and physical process. Thermochemical processes are considered as most of the biofuel production is produced through the process of pyrolysis and gasification. The conversion of solid biomass to liquid fuel is essential because the volumetric heat content can be increased and also minimize the logistic cost (Dhyani & Bhaskar, 2018). The conversion pathways are displayed in Figure 2.1

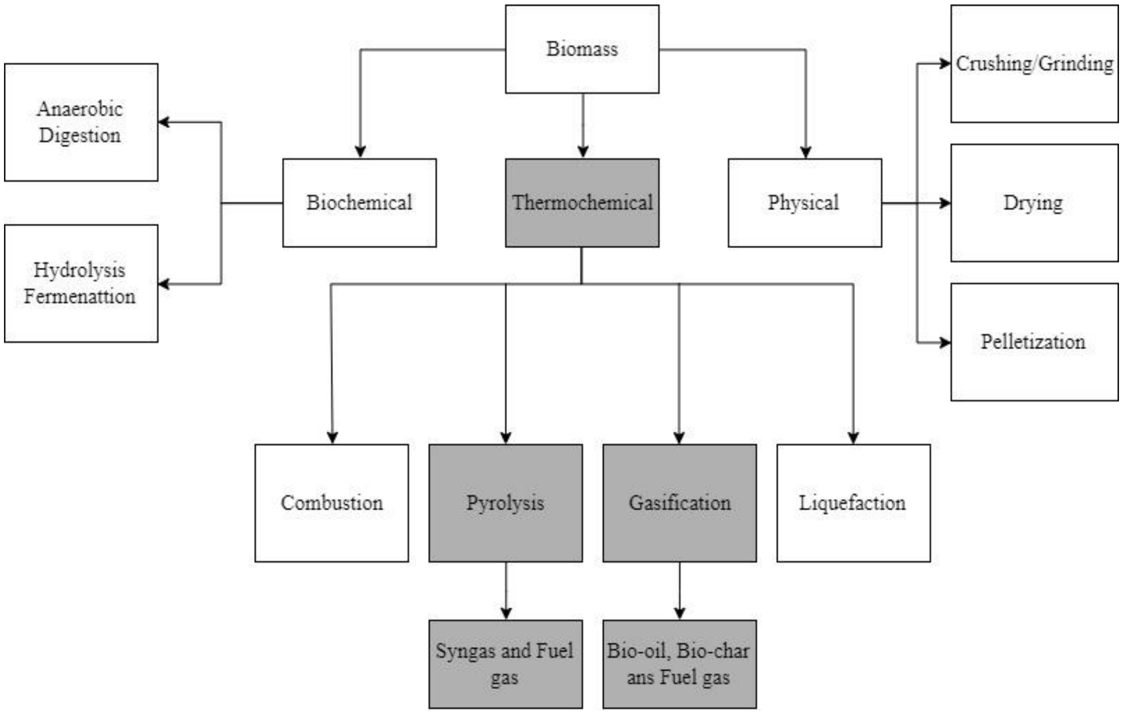

Figure 2. 1 Biomass to bioenergy conversion pathways. (Sharma et al., 2015)

2.4.1 Gasification

The mixture of combustible gas that is released from biomass is known as gasification process (Ingle & Lakade, 2016). During this conversion process, partial oxidation of carbonaceous material takes place, which is also known as indirect combustion. Gasification process requires a high temperature that ranges from 800 C up to 1800 C and under a relatively low amount of oxidant in order for the reaction to occur. Biomass is broken down into several elements throughout the process including hydrogen (H_2), carbon monoxide (CO), carbon dioxide (CO_2), nitrogen (N_2) and hydrocarbon molecules, like methane (CH_4) (Awalludin *et al*., 2015). This mixture of synthesis gases is called syngas. Syngas can be converted into bio-diesel fuel via the combination of biomass gasification and Fischer-Tropsch synthesis (Hu *et al*., 2012). Gasification process can be applied to all solid wastes from oil palm plantation such as EFB, MF, OPF, OPT and PKS. Gasification of OPT waste has been observed to produce more energy and hydrogen gas compared to other wastes with the same gasification conditions (Nipattummakul *et al*., 2012). Production of alcohol via biomass gasification is presented in Figure 2.2.

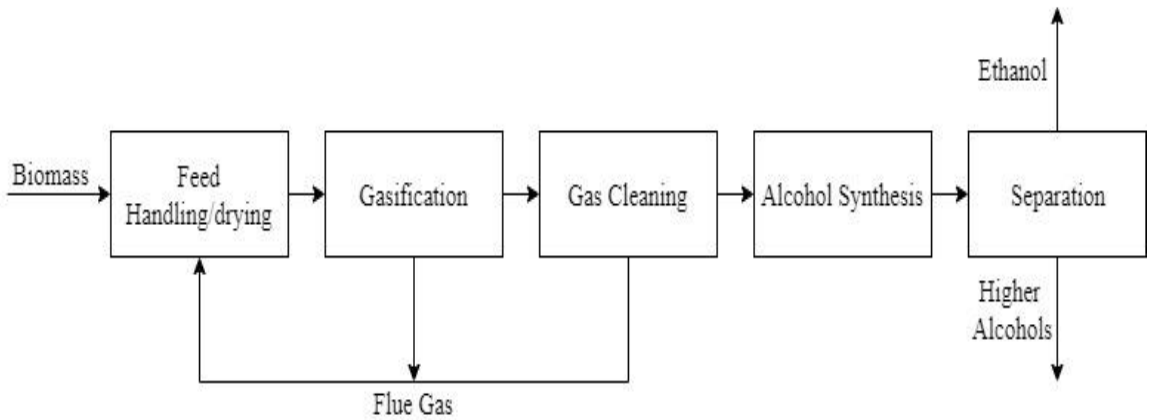

Figure 2. 2 Biomass gasification for alcohol production (Demirel, 2018)

2.4.2 Pyrolysis

Pyrolysis is a thermal degradation of organic matter that occurs in the range of (400–600) °C at atmospheric pressure. Pyrolysis process usually occurs without the presence of oxygen. The most common products that were obtained after the process including fuel gas, bio-oil and charcoal. These three types of pyrolysis which are slow pyrolysis, intermediate pyrolysis and fast pyrolysis. Generally, slow pyrolysis and fast pyrolysis are preferred to be used in the industry. The bio-oil product can be obtained when the vapour formed by the pyrolysis process undergoes rapid cooling (Awalludin *et al*., 2015). Considering the fact that the biomass has the potential to be converted to fuel, the pyrolysis process is widely used to convert from solid raw materials to liquid product.

2.5 Drawback of Biofuel (Diesel and Biodiesel)

2.5.1 Diesel

Diesel fuel is a mixture of hydrocarbons obtained by distillation of crude oil. The important properties which are used to describe diesel fuel include cetane number, fuel volatility, density, viscosity, cold behaviour, and sulphur content (Gad, 2014). Diesel fuel is among the contributing factors to pollution issues around the world. For example, the emissions of diesel fuel can cause adverse effects on respiratory health, pollution of air, and global climate change. The formation of particulate matter can be significantly reduced by minimize the sulphur content in the composition of diesel fuel.

2.5.2 Biodiesel

Biodiesel refers to animal or vegetable oil-based diesel fuel that is consisting of long-chain alkyl (methyl, ethyl, or propyl) esters. Biodiesel has more enormous advantages in terms of performance compared to the standard diesel fuel (Silitonga et al., 2013). The distinctive characteristic of biodiesel is that the fuel does not contain sulphur and aromatics compound in its composition (Özener *et al*., 2014). Hence, biodiesel can be utilized as an alternative fuel that can help to provide cleaner emission, especially when burnt in diesel engines. Although biodiesel has a lot of advantages, it still has a few drawbacks. For instance, the usage of biodiesel has caused an increase in nitrogen oxides (NO) emissions which can lead to the formation of acid rain and smog. Besides, a lower energy output was produced when compared the biodiesel to petrol-diesel (McCarthy *et al*, 2011). So, more biodiesel is needed to produce the same amount of energy to petrol-diesel.

2.6 Green Diesel

Green diesel is referred to as the second generation diesel that is obtained biologically from petroleum-like fuels. Green diesel and biodiesel have a definite chemical distinctive feature. Commonly, green diesel is produced through the reaction of hydrogenation in which the feedstock reacts with hydrogen (H_2). To hydrogenate triglycerides into high-cetane diesel fuel, a substantial amount of hydrogen and a catalyst are required to produce green diesel (Kalnes *et al*., 2009). The product yielded from the chemical reaction that is a liquid hydrocarbon fuel has the advantage of being fully compatible with petrol-diesel (Demirel, 2018). The blends of green diesel and petrol-diesel in a diesel engine have an effect which can reduce the emissions of unburned hydrocarbons and carbon monoxide.

2.6.1 Fuel Additives (Oxygenates)

In recent times, the reliance on petrol-diesel should be reduced to diminish the harmful emission in the air by considering a cleaner fuel option from renewable sources. Currently, to solve the energy and environment problems, researchers are using biodiesel in diesel engines with or without additives. Adding oxygenated fuels such as alcohols, esters and ethers can significantly help to improve the combustion efficiencies of diesel due to having complete combustion (Vijay Kumar *et al*., 2018). But, there was no massive change in the case of emission of carbon monoxide (CO).