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TECHNOLOGIES AND DEVELOPMENTS OF BIOFUEL – A REVIEW

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TECHNOLOGIES AND DEVELOPMENTS OF BIOFUEL – A REVIEW

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DECLARATION

I, Fatima Rahman, declare that this thesis is the result of my own works and that it has not yet been submitted or accepted for a degree in any other university.

I, hereby, give consent for my thesis, if accepted, to be available for photocopying and for inter-library loans, and for the title and summary to be made available to outside organizations only for research and educational purposes.

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DEDICATED TO

MY BELOVED PARENTS

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ABSTRACT

Energy from fossil fuels has played a very important role in our lives, but such an important role has been clouded out due to the environmental hazards caused from fossil emissions. This has led to a new dimension in energy utilization known as renewable energy fuels. Biofuel, that is fuel made from biomass, derived from materials that were recently living, is recognized as an important renewable and sustainable energy source to substitute fossil fuel. The use and production of biofuels has risen dramatically in recent years. To date, biofuel has been evolved from first to third generation and they are mainly differed in feedstock and production technologies. First generation biofuels produced from food crops are widely available because the production technologies are well developed. However, the recently identified limitations of this generation have caused greater emphasis to be placed on second generation biofuels produced from lingo-cellulosic feedstocks. On the other hand, third generation biofuels produced from algae avoid the issues met with first and second generation biofuels, namely food-fuel competition, land-use change etc. In this review paper, different technologies and developments of these generations are reviewed. As conclusion, to establish the highest sustainability in biofuel production, continuous research and development on all sustainability-related aspects are very much needed.

Table of Contents

List of Acronyms

BTL	Biomass-to-liquid
CO_2	Carbon-di-Oxide
EIA	Energy Information Administration
FAME	Fatty acid methyl ester
FFA	Free fatty acid
IEA	International Energy Agency
I2SI	Integrated Inherent Safety Index
KAHRC	Khwaja Agri-Horticultural Research Centre
MPa	Mega Pascal
NO_x	Oxides of Nitrogen
OECD	Organization for Economic Co-operation and Development
PBR	Photobioreactor
SHE	Safety, Health and Environment
SO_2	Sulfur-di-Oxide
toe	tons of oil equivalent

List of Tables

List of Figures

CHAPTER 1

INTRODUCTION

A carbon or hydrocarbon fuel formed in the ground from the remains of dead plants and animals is known as fossil fuel (Dahiya, 2015). Though they are non-renewable and their reserves are limited, fossil fuels are the dominant energy sources which meet more than 80% of the world's energy demand (Guo et al., 2014). But it is now acknowledged that fossil fuels which are the main sources of energy for the world today are ultimately unsustainable and related directly to air pollution, land and water degradation and climate changes. Moreover, many fossil fuels are being depleted e.g. liquid fuel is expected to end by the middle of the century. So, the use of renewable energy is already growing to face huge challenges as well as to find suitable, sustainable and clean replacements (Alaswad et al., 2015). The only one form of production of renewable energy is the use of biomass that can be utilized to reduce the impact of energy production and on the global environment (Mckendry, 2002). All the organic material on the planet arising from the life sustaining activity of organisms is called biomass. This concept includes wood, agricultural crops, water plants, forests, vegetable and animal remnants, microbial cultures (Voloshin et al., 2016). Biomass has the largest potential and can only be considered as the best option to meet the demand and insurance of future energy or fuel supply in a sustainable manner. The modernization of biomass technologies leading to more efficient biomass production and conversion is one possible direction for efficient utilization of biomass resources (Kocar and Civas, 2013).

Our earth's atmosphere receives more than 15 billion tons of CO_2 every year. A big contributor to increase the level of CO_2 in the atmosphere is the combustion of fossil fuels that is directly associated with global warming (Kamm and Gruber, 2006). So, today, the opinion that environmentally friendly biofuels are a good substitute for fossil fuels is becoming more popular due to the increased attention to the problems of fossil fuels (Voloshin et al., 2016).

The term biofuel is referred to as solid (bio-char), liquid (bioethanol, vegetable oil and biodiesel) or gaseous (biogas, biosyngas and biohydrogen) fuels that are predominantly produced from biomass (Demirbas and Balat, 2008). Now-a-days, it is quite important to produce biofuels from biomass as a renewable energy resource since it is both a clean energy resource and related to the environment, economy, agriculture and rural development (Kocar and Civas, 2013). Not all the biomass is used for fuel production. Three main components of biomass are the molecular precursors of biofuel: a) vegetable oils or animal fats (triglycerides); b) starch and oligomeric sugars; and c) lignocellulose (Mckendry, 2002). Renewability and carbon neutrality are essential requirements for environmental and economic sustainability of biofuels (Singh et al., 2011). Biofuel technology is relevant to both developing and industrialized countries and could be peaceful energy carriers for all countries. The production costs of biofuel can vary widely by feedstock, conversion process, scale of production and region (Demirbas, 2009).

First generation biofuels are produced directly from food crops like corn, wheat and soybeans (Alaswad et al., 2015). Second generation biofuels have been introduced to overcome the food-fuel conflicts associated with first generation biofuels (Singh et al., 2011). These are made from non-food crops such as grass, wood and other organic wastes (UN Report, 2007). On the other hand, the main component of third generation biofuels is microalgae. It is currently considered to be a feasible alternative renewable energy resource for biofuel production to overcome the limitations of first and second generation biofuels (Alam et al., 2015).

Bio-ethanol is a fuel ethanol that is made by fermentation from renewable biomass and has the potential to replace gasoline (Pimentel and Patzek, 2005). Biodiesel is a non-toxic, biodegradable and synthetic diesel-like fuel produced from vegetable oils, animal fats or waste cooking oil (Demirbas, 2009). Biogas is a renewable gaseous fuel alternative to natural gas which is generated by anaerobic digestion of organic wastes. Syngas is another gaseous biofuel which is produced from gasification or pyrolysis of plant materials (Guo et al., 2014).

Biofuels are becoming increasingly important due to large socio-economic impacts and benefits over fossil fuels. But technology development challenges and relatively high production cost are considered as critical barriers to its commercialization (OECD/IEA, 2004). So, the biofuels industry needs ways to combine integrated production technologies and produce value-added byproducts (Guo et al., 2014). Besides, continuous research, information accumulation and development on all sustainability-related aspects are needed to ensure the greatest sustainability in biofuel production process (Liew et al., 2014).

In this review paper, information related to different technologies and developments of biofuels are accumulated and reviewed which would help to conduct further research initiatives. In addition, this review also covers the current status of biofuel production and suggests the improvements required for more comprehensive and systematic assessments in the future.

CHAPTER 2

HISTORY AND CLASSIFICATION OF BIOFUEL

2.1 History of Biofuels

Biofuels in the solid form has been in use since man discovered fire. The first form of biofuel was wood that was used by the ancient people for cooking and heating. Man discovered another way of utilizing the biofuel with the discovery of electricity and it had been used since a very long time for the production of electricity (Guo et al., 2015).

Biofuel was discovered even before the discovery of the fossil fuels but the production and use of biofuel suffered a severe impact due to the exploration of fossil fuels especially in the developed countries. Liquid biofuels e.g. bioethanol and biodiesel have been used in the automotive industry since its inception (Russell, 2003).

Early in 1826, the American inventor Samuel Morey designed an internal combustion engine that was fueled by ethanol and turpentine to run a boat at 7 to 8 mph (miles per hour) (Guo et al., 2015). In 1860, one of the first inventors to convince people of the use of ethanol was a German engineer named Nikolaus August Otto who developed an internal combustion engine ran on an ethanol fuel blend (Songstad et al., 2009). Later, the American industrialist Henry Ford constructed tractors that could be powered by ethanol. But the obstacle that prevented ethanol from being used as an engine fuel in the U.S. was the alcohol tax enacted in the 1860s to fund the Civil War (Carolan, 2009). The first pilot bioethanol plant with a distillation column was established at South Dakota University (Brookings, SD) in 1979 (Songstad et al., 2009).

In 1893, another German engineer Rudolf Diesel invented a compression ignited diesel engine by the use of vegetable oil (Knothe, 2001). At the 1900 World's Fair in Paris, the French Otto Company demonstrated a diesel engine that was fueled by peanut oil. In 1977, the Brazilian scientist Expedito Parente developed the first industrial process for the production of biodiesel (EIA, 2014). In 1989, the world's first industrial-scale biodiesel plant was operated in Asperhofen, Austria to produce biodiesel from rapeseed. The U.S. started its commercial operation in1996 to process waste grease into biodiesel (Guo et al., 2015).

Biogas was used by human beings to prepare warm bath water as early as in the 10th century B.C. in ancient Assyria. Back to more than 2000 years ago, people in China and India already practiced anaerobic digestion of animal manure for a flammable gas. In 1808, the English chemist Sir Humphry Davy determined that the flammable gas from cattle manure ponds was methane. The first recorded anaerobic digestion plant was constructed in Bombay, India in 1859. Biogas was collected from a sewage treatment facility to light street lamps in Exeter, England in 1895. In 1950s, China built 3.5 million family-sized, low-technology anaerobic digesters in the rural area to provide biogas for cooking and lighting (Guo et al., 2015).

In the period of World War II, the reason behind the high demand of biofuels was the increased use as an alternative for imported fuel. But due to geopolitical conflict, a serious fuel crisis again hit the various countries during the period of 1973 and 1979. Later, the constant shortage of fuel attracted the attention of the various academics and governments to the issues of energy crisis and the use of biofuels (Carolan, 2009).

The twentieth century came with the attention of the people towards the use of biofuels where the main reasons for shifting interest were the rising prices of oil, emission of the greenhouse gases and interest like rural development (Nag, 2007).

2.2 Classification of Biofuels

Biofuel is regarded as one of the most promising renewable energy sources (Demirbas, 2009). It has been evolved from the first to the third generations which are primarily differed in the feedstocks and production technologies (Naik et al., 2010).

Depending on the way of biomass usage, biofuels can be classified as - Primary biofuels and Secondary biofuels (Demirbas, 2008).

2.2.1 Primary biofuels

The primary biofuel is the biomass without any additional treatment. That kind of fuel is usually used for heating, cooking and agricultural needs. It is widespread in third world countries (Voloshin et al., 2016). It is also known as traditional biomass (Renewables global status report, 2015). On the one hand, this fuel does not require resource expenses for its processing and the field of its application is rather small (Voloshin et al., 2016).

2.2.1.1 Sources of primary biofuels

Primary biofuels include – Firewood, Wood chips, Wood pellets, Charcoal, Forest and crop residues, Animal waste and Landfill gas (Demirbas, 2008).

2.2.2 Secondary biofuels

The secondary biofuel is produced from biomass (the primary biofuel) by extraction of the most energy intensive substances (Voloshin et al., 2016). Based on the general feedstock for fuel production, the processing methods and historical sequence of the fuel's appearance on the world energy market, the secondary biofuel can be divided into – First generation biofuel, Second generation biofuel and Third generation biofuel (Surriya et al., 2015).

2.2.2.1 First generation biofuel

First-generation biofuels refer to biodiesel and / or bioethanol derived from bio-resources e.g. sugar, starch, corn, vegetable oil or animal fats using conventional technology (Loh and Choo, 2013). The production of the first generation biofuel has induced competition over the utilization of high quality agricultural land for food crops and biofuel feedstock cultivation as it is mainly derived from agricultural food crop. As a result, this has concomitantly engendered the adverse social and economic impacts to the world population and incurred 'food versus fuel' conflict in the society (Liew et al., 2014).

2.2.2.2 Second generation biofuel

The feedstock for second-generation biofuels is generally derived from non-food biomass and non-food crops (Loh and Choo, 2013). Generally, lignocellulosic biomass is identified as the feedstock for the second generation biofuels to overcome the limitations related to first generation biofuel (Kocar and Civas, 2013). This generation is not involved in the food versus fuel issue as lignocellulosic biomass is mainly derived from biomass which does not require usage of agricultural land (Liew et al., 2014).

The potential feedstocks for second generation biofuel include herbaceous and woody plants, agricultural and forestry residues, municipal and industrial solid wastes, process wastes, organic wastes etc. These feedstocks are mainly obtained from agriculture wastes/residues that consist of cellulose, hemicellulose and lignin (Naik et al., 2010). However, lignocellulosic biomass appears in diverse physical characteristics and chemical compositions; therefore, it needs to be pretreated before further converted into biofuel (Agbor et al., 2011).

2.2.2.3 Third generation biofuel

Recently, third generation biofuel has been introduced by the research communities where the feedstock used is mainly algae and microbes (Loh and Choo, 2013). Algae is identified as potential feedstock for biofuel production because it can be grown quickly, all the materials produced are non-toxic and biodegradable and during this growth there is an opportunity to cause greenhouse gas fixation. Besides, it does not need arable land and can be grown without competing with food or feed crops (Alaswad et al., 2015).

Table 2.1 presents the feedstock characteristics and examples of biomass for biofuel production.

Table 2.1 Biofuel production sources (biomasses)

Biofuel Class	**Feedstock characteristics**	**Examples of biomass (Biofuel)**
First generation	Food-based crops	Wheat, barley, corn, potato, sugarcane, sugar beet etc. (Bio-ethanol) Soybeans, rapeseed, sunflower, palm, coconut, used cooking oil, animal fats etc. (Biodiesel)
Second generation	Non-food crops	Forest residues, sugarcane bagasse, straw, wood and grass (Bio-ethanol) Jatropha, cassava or miscanthus (Biodiesel)
Third generation	Algae and microbes	Microalgae and seaweeds (Bio-ethanol) Microalgae (Biodiesel)

Source: After Doshi et al., 2016.

It is important to note that the characteristics of the biofuel itself may not change between these 'generations' but the source from which the fuel is derived changes (Olabi, 2009).

2.2.3 Solid, Liquid and Gaseous fuels

2.2.3.1 Solid biofuels

2.2.3.1.1 Firewood

Since the dawn of modern human beings wood and other plant materials have been directly burned for heating and cooking. Firewood was the predominant fuel of the whole world for domestic purposes before the discovery of fossil fuels. It is normally packed in bundles and traded in volume. At 220–300° C or higher temperature, most dry plant materials ignite in air to cause fire (flame), releasing the inherent bioenergy in heat and light (Guo et al., 2014).

It is renewable, readily available, cheap and energy efficient. However, it is bulky, low in energy density and causes high hazardous emissions from incomplete combustion (Guo et al., 2014).

2.2.3.1.2 Wood chips

Wood chips are small pieces of wood from cutting tree trunks and branches with a wood chipper. It has been increasingly used for heating (bio-heat) and electricity generation (bio-power) (Guo et al., 2014).

It is more convenient to transport, handle and store than firewood as well as has lower SO_2 and NO_x emissions than coal. However, it is bulkier and lower in energy density than coal, involves chipping cost and tends to decay during storage (Guo et al., 2014).

2.2.3.1.3 Wood pellets

Wood pellets are a more processed biofuel product. Pellets are made by grinding wood chunks into sawdust through a hammer mill and subsequently compressing the sawdust through 6–8 mm holes in the die of a pelletizer (Guo et al., 2014).

It is suitable for precise combustion, convenient to transport, handle and store and has lower SO_2 and NO_x emissions. However, higher processing cost and lower energy content than coal are two major constraints of using wood pallets (Guo et al., 2014).

2.2.3.1.4 Charcoal

Pyrolysis techniques have been developed to transform wood into charcoal which is a carbon enriched, porous and grayish black solid. Heating wood materials in a kiln at around 400° C in absence of air until no visible volatiles are emitted yields high quality charcoal (Guo et al., 2014).

It is stable, ensures higher energy content and clean burning. However, it is costly, bulky, inconvenient for transport and cannot be used in liquid fuel and gas burners (Guo et al., 2014).

2.2.3.2 Liquid biofuels

2.2.3.2.1 Bioethanol

Bioethanol is ethanol produced from vegetative biomass through fermentation (Guo et al., 2014). It is an important biofuel since it has the potential to replace gasoline (Pimentel and Patzek, 2005). Bioethanol produced from food crops is viewed as first-generation biofuel which competes with animal feed and human food. To minimize the adverse impacts second-generation bioethanol from non-food lignocellulosic plant materials has been explored (Guo et al., 2014).

2.2.3.2.2 Biodiesel

A yellowish liquid derived from vegetable oil, animal fats, algal lipids or waste grease through transesterification in the presence of alcohol and alkaline catalyst is called biodiesel. In chemical structure, it is mono-alkaline esters of fatty acids (Guo et al., 2014). So, it is also known as fatty acid methyl ester (FAME) (Kamaruddin et al., 2013). It is a non-toxic, biodegradable and combustible liquid fuel (Hedden, 2008). But the main problem with the use of biodiesel is its oxidation and polymerization occurring during combustion or storage (Sangeeta et al., 2014).

2.2.3.3 Gaseous biofuels

2.2.3.3.1 Biogas

A renewable gaseous fuel which is alternative to natural gas is called biogas. It is produced through anaerobic digestion of organic wastes. Anaerobic digestion has been utilized by animal farms, wastewater treatment plants and even individual households to manage waste and / or to produce energy (Guo et al., 2014).

Raw biogas consists of 60–65% of methane (CH_4), 30–35% of CO_2 and small percentages of water vapor, H_2 and H_2S (Weiland, 2010). Intensive feedstock collection and waste disposal is a limitation of it (Guo et al., 2014).

2.2.3.3.2 Syngas

Syngas is another gaseous biofuel produced from gasification or pyrolysis of plant materials (Guo et al., 2014). Chemically, it consists of 30–60% CO, 25–30% H_2, 5–15% CO_2, 0–5% CH_4 and lesser portions of water vapor, H_2S, NH_3 and others depending on the feedstock types and production conditions (NETL, 2013). In gasification operation, carbon-rich materials such as coal, petroleum, natural gas and dry plant biomass is rapidly heated to above 700° C in the high temperature (e.g. 1200° C) combustion chamber of a gasifier and partially burned in the presence of controlled air flow to yield syngas (Guo et al., 2014).

CHAPTER 3

GENERAL DISCUSSION ON BIOFUEL GENERATIONS

3.1 First Generation Biofuel

The first generation biofuels have attained commercial level production in several countries which have generally been produced from food and oil crops as well as animal fats through conventional technology (Singh et al., 2011).

The most conventional biofuels produced among this generation are bioethanol and biodiesel.

3.1.1 Technology for bioethanol production

Bioethanol is normally produced via fermentation process which is a biochemical reaction that breaks down complex organic molecules such as carbohydrates into simpler materials such as ethanol, carbon dioxide and water (Liew et al., 2014).

There are several feedstocks which can be used in fermentation e.g. sugar from sugarcane and starch from corn (Blottnitz and Curran, 2007). But it is identified that starchy crops have higher energy content than the others (Patni et al., 2013).

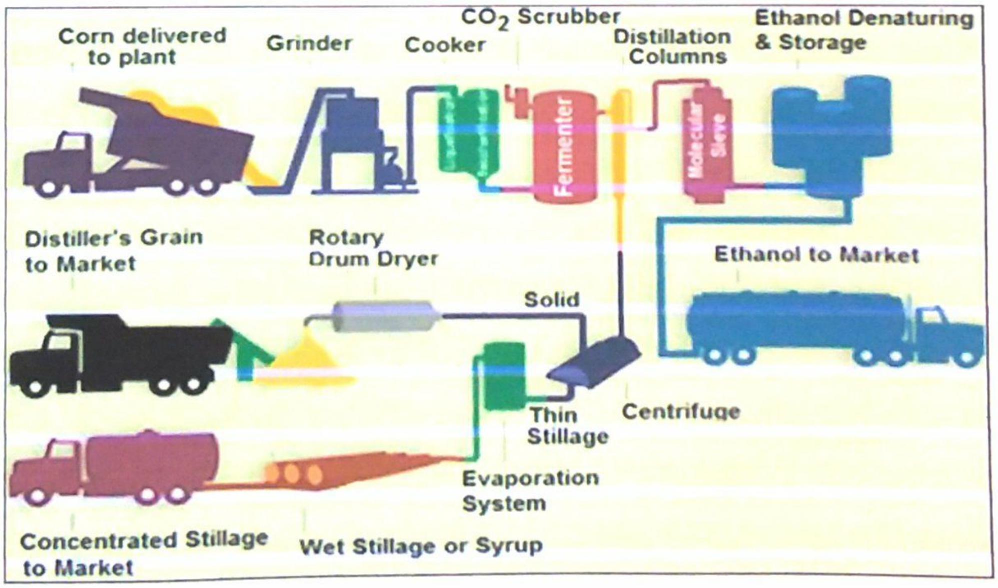

Figure 3.1. Technical flow chart of bioethanol production from corn in the U.S. (Renewable Fuels Association, 2013)

In fermentation process, the sugar in starchy crops is fermented into bioethanol using the enzyme produced by yeast. This process is performed in the absence of oxygen (Figure 3.1). It is important to note that the water produced as byproduct must be removed after this process. It can be done by distilling the bioethanol solution until achieving the purity of 95% - 96% and then followed by dehydration using molecular sieve to further prepare the bioethanol into fuel grade (Kuhad et al., 2011).

3.1.2 Technology for biodiesel production

Biodiesel is normally produced through transesterification which is a chemical process and where the glycerin is separated from the fat or vegetable oil (Figure 3.2). The process leaves behind two products - methyl esters (the chemical name for biodiesel) and glycerin (a valuable byproduct usually sold to be used in soaps and other products) (Liew et al., 2014).

Transesterification process should be carried out in presence of catalyst or enzyme or under supercritical condition (Singh et al., 2014).

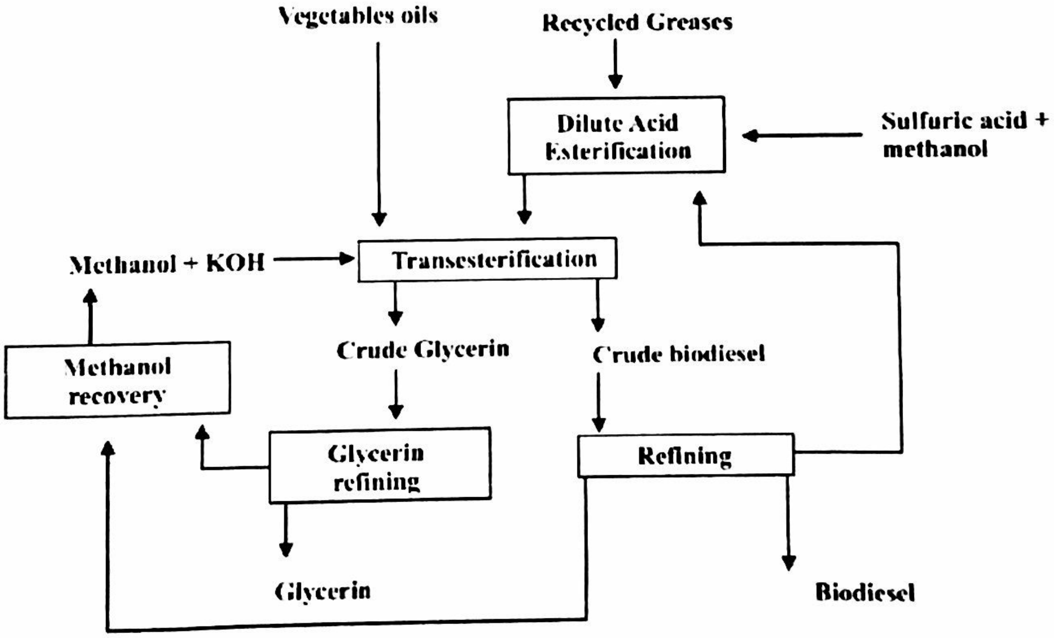

Figure 3.2. Technical flow chart of biodiesel production from vegetable oil (Renewable Fuels Association, 2013)

There are four basic methods of this process namely base-catalyzed, acid-catalyzed, enzymatic and supercritical transesterification (Liew et al., 2014).

3.1.2.1 Base-catalyzed transesterification

This process is mainly used on oil reactant with free fatty acids (FFA) less than 0.5 wt.% or pure vegetable oil because the presence of FFA could reduce the biodiesel yield due to soap formation following the reaction between FFA and base catalyst. Furthermore, it makes the purification process more complicated. One of the limitations of this method is high production cost because pure vegetable oil is expensive (Zhang et al., 2003).

3.1.2.2 Acid-catalyzed transesterification

In acid-catalyzed transesterification process waste oil is used which is a cheaper feedstock. This process is introduced as a more direct alternative to resolve the issue of FFA content in oil. It can also be used to convert waste cooking oil (which contains more than 10 wt.% FFA) into biodiesel without the need of pretreatment process. But it has lower yield (about 82% mass conversion) when 200% excess of methanol is used (Demirbas, 2009).

3.1.2.3 Enzymatic transesterification

Enzyme catalyzed transesterification for biodiesel production has not received much commercial attention due to longer reaction time and higher production cost. But this process is beneficial because it can prevent soap formation and have the ability to esterify both FFA and triglycerides in one step without the need of a washing step (Du et al., 2008).

3.1.2.4 Supercritical transesterification

Supercritical transesterification is an improved method of acid-catalyzed reaction as it could generate 100% yield under supercritical operating condition at 350° C and 19 MPa. In this process, FFA and oil are converted into biodiesel simultaneously without catalyst (Lee et al., 2011).

3.1.3 Advantages and disadvantages of first generation biofuels

First generation biofuels are biodegradable (Doshi et al., 2016) and its production cost is cheaper that allow poorer communities to have access to renewable source of transportation fuel (Liew et al., 2014). However, viability and sustainability of this generation is questionable as it contributes to higher food prices due to competition with food crops. In addition, it competes for scarce water resources in some regions and has a negative impact on biodiversity (Singh et al., 2011).

3.2 Second generation biofuel

Second generation biofuels are produced from lignocellulosic biomass which is highly presented in plant biomass in comparison with oils and starch. It is the main component of cell walls and consists of three components: cellulose (40-50%), lignin (15-20%) and hemicellulose (25-35%) (Mckendry, 2002).

Cellulose is a straight glucose polymer with certain rigidity that impedes its hydrolysis. Hemicellulose is an amorphous polymer containing several different types of sugars: D-xylose, L-arabinose, D-galactose, D-glucose and D-mannose. Lignin is an amorphous polymer which consists of phenyl propane units and provides stiffness and stability against many hydrolytic enzymes (Figure 3.3) (Voloshin et al., 2016).

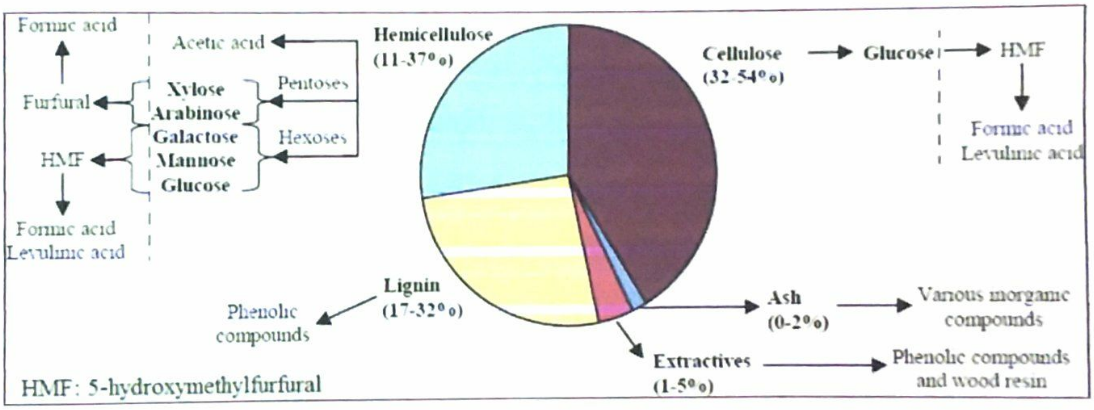

Figure 3.3. Composition of lignocellulosic materials and their potential hydrolysis products and further degradation compounds (Taherzadeh and Karimi, 2007).

3.2.1 Technology for lignocellulosic biomass conversion

The production of biofuels from lignocellulosic feedstocks can be achieved through two different processing routes such as - Biochemical pathway and Thermo-chemical pathway (Sims et al., 2009).

3.2.1.1 Biochemical pathway

In biochemical process, the primary feedstock for producing bioethanol is lignocellulosic biomass with carbohydrates (Liew et al., 2014). In this process, enzymes and other microorganisms are used to convert cellulose and hemicellulose components of the feedstocks to sugars prior to their fermentation to produce ethanol (Sims et al., 2009).

3.2.1.1.1 Steps of biochemical process

The first step of biochemical process is pretreatment which is significant to increase the yield of sugar and could attribute to as high as 60% of the total production cost (Cardona et al., 2010). It is done to soften the cellulosic material to make the cellulose more susceptible to being broken down (Mosier, 2015).

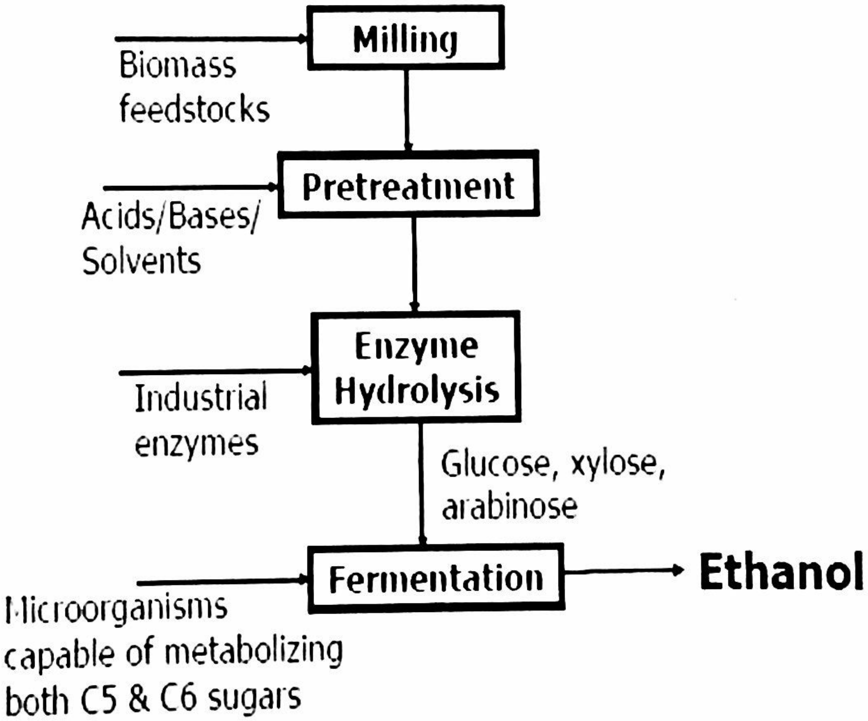

Figure 3.4. Biofuel production from lignocellulosic biomass through biochemical process (Mosier, 2015)

The second step of this process is hydrolysis where the cellulose and other sugar polymers are broken down into simple sugars through the action of biological catalysts called enzymes (Mosier et al., 1999).

In fermentation stage, produced simple sugar is fermented into bioethanol using the enzyme produced by yeast in the absence of oxygen. As these microorganisms digest the sugar, they produce ethanol, carbon dioxide, hydrogen and other products (Figure 3.4) (Mosier, 2015).

3.2.1.2 Thermo-chemical pathway

Thermo-chemical process is also known as biomass-to-liquid (BTL) which includes Liquefaction, Pyrolysis and Gasification methods to convert biomass into energy, gas and liquid products (Figure 3.5) (Liew et al., 2014).

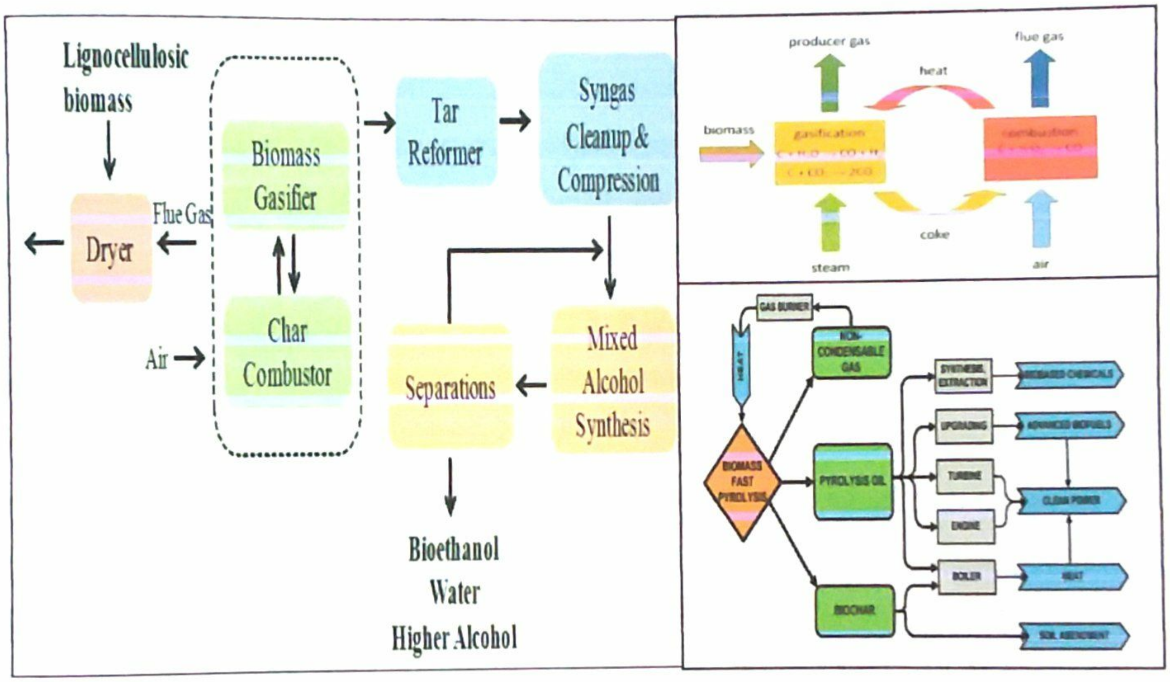

Figure 3.5. Biofuel production from lignocellulosic biomass through thermo-chemical process (Liew et al., 2014)

3.2.1.2.1 Liquefaction

The main feedstock used for liquefaction is the biomass with high lignin content e.g. woody materials, sawdust, kraft pulp etc. The process takes place at temperature of 350° C – 370° C and pressure of 5 MPa - 20 MPa. The main product produced in this process is heavy oil which is highly viscous and contains water insoluble oils (Maldas and Shirai, 1997).

During liquefaction, the biomass is depolymerized or broken down into small molecules which are unstable and reactive. However, those molecules can be re-polymerized into the liquid product with various ranges of molecular weights. The use of catalyst in liquefaction is critical to improve the reaction kinetics and product yield (Maldas and Shirai, 1997).

In this process, produced liquids are very much easier to transport since liquefaction reduces the volume considerably. Besides, it produces a number of useful chemicals and any feedstocks can be introduced in this process (Liew et al., 2014). However, this technology has not been demonstrated at a reasonable scale (Maldas and Shirai, 1997).

3.2.1.2.2 Pyrolysis

Pyrolysis is a thermal degradation process which occurs in the absence of oxygen and produces bio-char (solid), bio-oil (liquid) and other gaseous products (Liew et al., 2014).

In this process, the wood is first grinded and then delivered to a high-heat reactor with a temperature of approximately 932° F (500° C). At this temperature, the wood turns into a vapor. Following this transformation, it is cooled, condensed and recollected in the liquid bio-oil, gases and char forms (Hubbard, 2015).

There are two types of pyrolysis process (Suopajarvi et al., 2013). Slow Pyrolysis is mainly used to produce bio-char at temperature of 300° C – 700° C and residence time of 30 sec - 200 sec (Zhang et al., 2010). On the other hand, the term fast pyrolysis comes from the fact that the time between heating and cooling is decreased substantially (Jacobson, 2013). It is used to produce liquid fuels (bio-oil and bio-crude) at temperature of 400° C – 700° C and residence time of 1 sec – 5 sec (Zhang et al., 2010).

In this process, toxic components and pathogens are degraded by the use of high temperatures. There is also a reduction in water volume due to the high operating temperature. Again, the supply of external fuel can be limited by the use of produced gases as fuel. However, this process is complex and requires high operational and investment costs. Produced ashes contain high heavy metals that are regarded as dangerous waste and must be disposed of (Jacobson, 2013).

3.2.1.2.3 Gasification

When biomass is heated with partial oxygen, carbon dioxide and / or steam under temperature of 800° C – 900° C or even higher, then the gaseous mixture of CO, CO_2, CH_4, H_2 and other impurities such as N_2, S, alkali compounds and tars are generated (Naik et al., 2010). The gaseous product is normally known as synthetic gas or syngas which is primarily used to produce fuels and intermediate chemicals (Suopajarvi et al., 2013).

In this process, wood is subjected to high temperature in a furnace that range between 1112° F – 1832° F (600° C – 1000° C) (Basu, 2013). At these high temperatures, the wood is converted directly into biogas. Byproducts of this process include ash, tars, char and other hydrocarbons (Hubbard et al., 2007).

This process reduces greenhouse gas emissions and capable of producing a marketable product (electricity) and has a high recovery rate of resources. Besides, it ensures minimal risk of health consequences and low risk of water pollution (Basu, 2013). However, high capital cost is a major problem of this process. The recovery and use of the bottom ash in other applications can be problematic (Suopajarvi et al., 2013).

3.2.2 Basic difference between biochemical and thermo-chemical process

The major difference between the biochemical and thermo-chemical routes is that the lignin component of the biomass is a residue of the biochemical enzymatic hydrolysis process which can be used for heat and power generation. On the other hand, in thermo-chemical process the lignin is converted into synthesis gas along with the cellulose and hemicelluloses biomass components (Sims et al., 2009).

3.2.3 Technology development challenges for lignocellulosic biomass conversion

To overcome the technological and cost barriers as well as to ensure success in the commercial development of second generation biofuel technologies, significant progress is required in a number of areas that are outlined below (Sims et al., 2009) -

3.2.3.1 Improved understanding of feedstocks and costs reduction

It is required to understand the currently available feedstocks, their geographic distribution, production, transport, storage and processing costs. Further experience in the production of various dedicated energy crop feedstocks in different regions needs to be undertaken to understand the yield potentials, biomass characteristics and production costs. Besides, the ideal characteristics for specific feedstocks need to be identified in order to maximize their conversion efficiencies to liquid biofuels (Sims et al., 2009).

3.2.3.2 Improved technology for biochemical and thermo-chemical routes

Feedstock pretreatment technologies are inefficient and costly. So, improvements in various pretreatment options need to be achieved to maximize the efficiency of pretreatment in opening up the cellular structure of the feedstock for subsequent hydrolysis. Development of new and / or improved enzymes should be continued (Chandra et al., 2007).

On the other hand, cost effective and reliable methods of large scale biomass gasification remain fairly deceptive in spite of many years of research, commercial efforts and recent progress. So, the goal should be to develop reliable technologies that have high availability and ability to produce clean gas (Sims et al., 2009).

3.2.3.3 Co-products and process integration

Valuable co-products generated during the production of second generation biofuels offer the potential to increase and improve the overall revenue and economics of the process. So, all co-products associated with biofuel production process should be taken into account (Sims et al., 2009).

3.2.4 Advantages and disadvantages of second generation biofuels

Second generation biofuels are produced from non-edible feedstocks or wastes and thus limit the direct food versus fuel competition and creates less pressure on crop/agricultural resources compared to first generation. Besides, it is more efficient, environmental friendly and increases land-use change and land-use efficiency (Singh et al., 2011). However, it requires high capital cost, includes complex production process, suffers from insufficient supply when depends on residual or waste biomass and can raise pressure to convert existing forestland or cropland (Doshi et al., 2016).

3.3 Third Generation Biofuel

Third generation biofuel is connected with algal biomass and the use of algal biomass for fuel synthesis is relatively new direction of bioenergetics. From different investigations, it is found that algal biomass can accumulate high amount of lipids in comparison with biomass of oil plants and for this reason it is considered as a good source for biofuel production (Allakhverdiev et al., 2010).

The main difference between algal and plant bioenergetics is in the technology of biomass up-building. Plant bioenergetics requires the usage of valuable resource (arable lands) and provides relatively low yield in a ratio of the organic feedstock mass to the mass of biofuel synthesized (Chisti, 2007). On the other hand, algal biomass can grow in conditions which are unsuitable for plant growth such as saline soils and waste water. So, the usage of algae is an interesting potential feedstock for biofuels production (Wang et al., 2008).

3.3.1 Algae as a source of biofuel

Algae are a diverse group of uni and multi-cellular photoautotroph. They may be considered as biological solar panels that fix CO_2 from the atmosphere to absorb energy from sunlight for growth and the production of intracellular storage compounds (Chisti, 2007). Besides, they are plant like organisms which always use photosynthesis and usually aquatic in nature (Demirbas, 2010).

It can be classified into two categories – Macro-algae (Seaweeds) and Microalgae (Alaswad et al., 2015).

3.3.1.1 Macro-algae (Seaweeds)

Macro-algae or seaweeds are multi-cellular that exhibit differentiated cell structure and function. They do not have true roots, stems, leaves or vascular tissue but have simple reproductive structures. They can grow in either salt water or fresh water. They are often fast-growing and can reach sizes of up to 60 m in length (Figure 3.6). Based on their pigmentation, most of them can be classified into three broad groups: i) Brown seaweed (Phaeophyceae); ii) Red seaweed (Rhodophyceae) and iii) Green seaweed (Chlorophyceae) (Carlsson et al., 2007).

Figure 3.6. Seaweeds in Cummingston coast, Moray, Scotland (Alaswad et al., 2015)

3.3.1.1.1 Advantages of macro-algae (Seaweeds) over other feedstock

Major advantages of seaweeds over their terrestrial counterparts are shorter life cycles, easier cultivation process, cost-effectiveness and involvement of environment friendly methods (Mchugh, 2003). The marine seaweeds do not need any fresh water or fertilizers to grow and so their cultivation does not cause any change in land use and competition with the food industry (Morand and Merceron, 2005). Besides, they have higher volumetric production rates than microalgae that require relatively mild conditions for processing compared to lignocellulosic biomass and can be collected (by hand) without costs payable to landowners (Tedesco et al., 2014).

3.3.1.1.2 Harvesting and cultivation of macro-algae (Seaweeds)

Inshore cultivation is considered to be the most feasible means of production of macro-algae biomass depending on the transport costs and greenhouse gas emissions. However, the sites for inshore cultivation need to be selected carefully (Roberts and Upham, 2012) and should always be established in natural water areas such as bays or tidal pools in positions where there is low tidal activity. Seaweeds may be cultivated on lines or ropes, in nets or grown in seabed. The productivity of cultivation depends on temperature, high nutrient concentration, sufficient radiation from the Sun, moderate currents and suitable wave action of the site (Ask and Azanza, 2002).

An alternative to this approach is offshore cultivation where there is no problem about occupying valuable parts of the coastline and in some cases cultivation can be taken place in tanks using natural or artificial light with the supply of nutrients and phytohormones (Alaswad et al., 2015).

3.3.1.2 Microalgae

A microscope is required to observe microalgae due to their size (always smaller than 0.4 mm in diameter) (Figure 3.7). This category includes diatoms and cyanobacteria that have high growth rates (Chisti, 2007). Their photosynthetic mechanism is similar to land based plants but due to simple cellular structure they have efficient access to water, CO_2 and other nutrients. They are able to grow in aqueous solutions with a wide range of salinities, chemical compositions and both arable and non-arable land without the need for herbicides or pesticides (Carlsson et al., 2007).

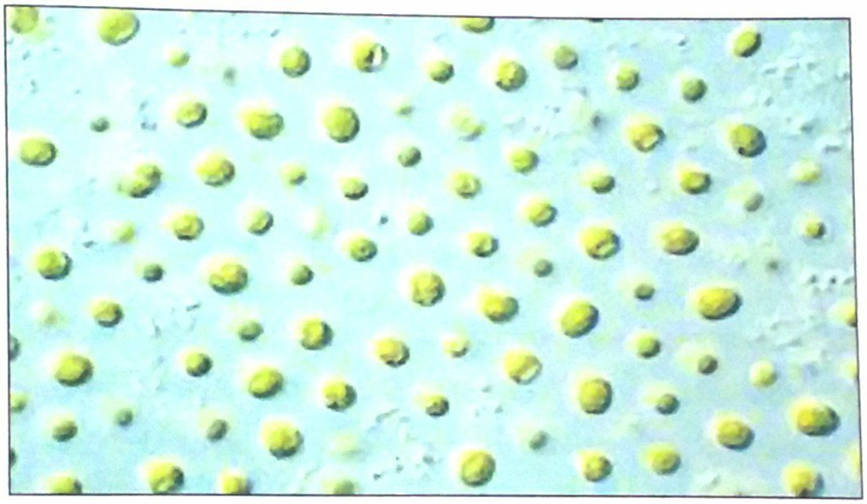

Figure 3.7. Microscopic view of Microalgae (Rashid et al., 2013)

3.3.1.2.1 Advantages of microalgae over other feedstock

Microalgae have various advantages when compared to other feedstocks such as they can synthesize large amount of neutral fats (20-50%) from the dry mass; the products from microalgae can be obtained throughout the year in contrast to terrestrial plants; they require less water and absorb a lot of CO_2 than terrestrial plants (Voloshin et al., 2016).

3.3.1.2.2 Harvesting and cultivation of microalgae

Harvesting of microalgae is a major challenge due to their small size and low concentration in the culture medium. So, different technologies have been developed for the cultivation of microalgae using open air systems (ponds) and closed systems including photobioreactors (PBRs) (Alaswad et al., 2015).

The largest industrial systems of microalgae cultivation are included in open air systems. It refers to shallow ponds or tanks with large surface areas. The major advantages of open ponds are that they are easier to construct and operate compared with other systems (Lundquist et al., 2010). But poor light utilization, evaporative losses, losses of CO_2 to the atmosphere, contamination by wild animals and other living organisms and the requirement for large areas of land are major disadvantages of these systems (Darzins et al., 2010).

Photobioreactors are included in close systems which have either flat plates or tubes for producing efficient microalgal crops as the control over the production environment is much greater than open ponds (Lundquist et al., 2010). Major benefits of photobioreactors closed systems are cost-effectiveness, temperature control, better control of CO_2 transfer and protection from climate related impacts (Guanyi et al., 2015).

3.3.2 Technology for producing biofuel from algae

Biofuel production processes from algal biomass are complex, technologically challenging and economically expensive (Alam et al., 2015). After the stage of cultivation and preparation of biomass, the conversion of biomass into biofuels stage occurs (Voloshin et al., 2016).

The conversion technologies can be separated into four basic categories: biochemical conversion; thermo-chemical conversion; chemical reaction and direct combustion. Biochemical process includes anaerobic digestion, alcoholic fermentation and photo-biological hydrogen production; thermo-chemical conversion involves thermal decomposition of organic components to fuel products such as gasification, liquefaction and pyrolysis; chemical reactions involve transesterification of extracted oil from algal biomass and in direct combustion the dried algal biomass can be burnt directly to provide heat and power (Figure 3.8) (Singh et al., 2011).

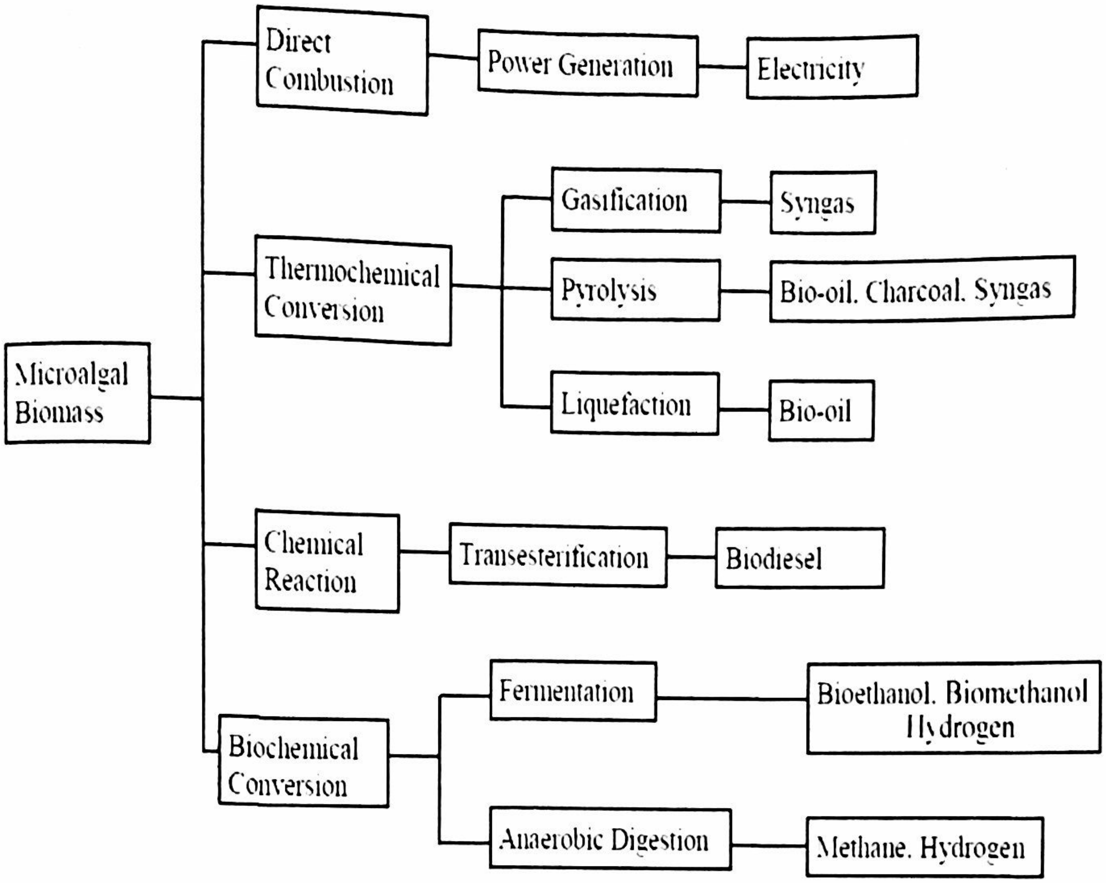

Figure 3.8. Methods of processing algal biomass (Chisti, 2007)

3.3.2.1 Technology for producing bioethanol and biodiesel from algae

Production of bioethanol from algal biomass begins with the collection and drying of algae that have been cultivated in a suitable water environment. In the next step, the starch of algae is released from the cells with the aid of mechanical equipment or an enzyme. When the cells begin to degrade, *Saccharomycess cerevisiae* yeast is added to the biomass to begin fermentation. The end product of fermentation is ethanol. Then, the ethanol is drained from the tank and pumped to a holding tank to be fed to a distillation unit and finally bioethanol is obtained (Figure 3.9) (Demirbas, 2010).

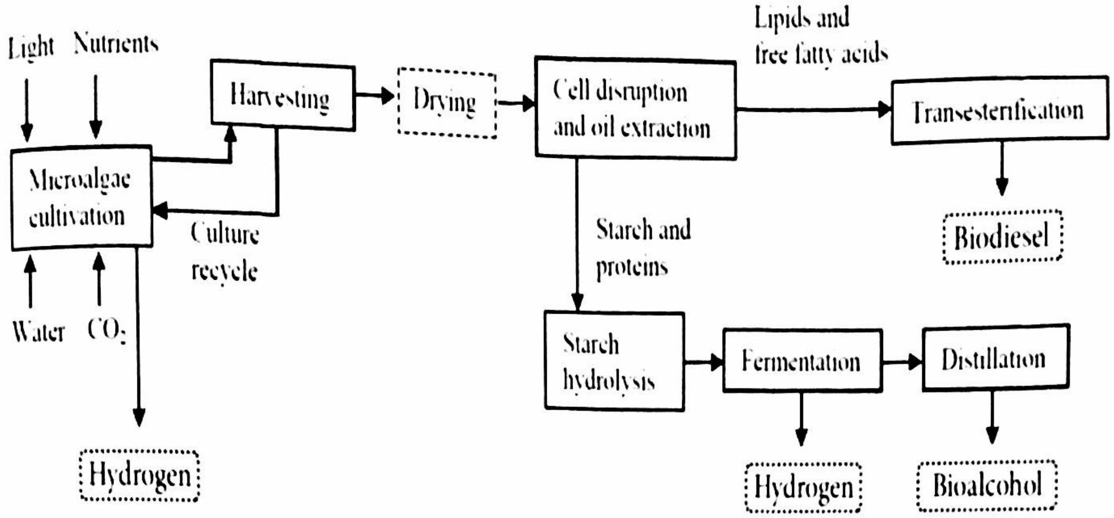

Figure 3.9. Bioethanol and biodiesel production technology from algal biomass (Nigam and Singh, 2011)

For the production of biodiesel from algal biomass, at first, algae produce biomass under special conditions. In the next stage, this biomass is subjected to pretreatment which is followed by transesterification reaction of lipid fractions with alcohols. At this step, the addition of some catalyst is necessary. The substance obtained after this reaction is then purified and finally converted into biodiesel (Figure 3.9) (Voloshin et al., 2016).

3.3.3 Challenges for algal biofuel commercialization

Algal biomass has high growth rates, reasonable growth densities and high oil contents to invest significant capital for converting it into biofuels. But the major challenges restricting its commercialization include strain isolation, nutrient sourcing and utilization, harvesting, production management, fuel extraction, co-product development, refining and residual biomass utilization (Roberts and Upham, 2012).

The capital costs of algae production systems can be reduced through the use of cheaper materials and lower cost construction methods. Besides, improved automation of the whole process is required to ensure reliability and minimize labor costs (Darzins et al., 2010).

3.3.4 Advantages and disadvantages of third generation biofuels

Algae grow significantly faster than land crops and offer high biomass yields per acre of cultivation (Dahiya, 2012). It can be cultivated on marginal / non-arable land, so, there is no food and land competition. Besides, algal biomass production can be integrated with the treatment of industrial, municipal and agricultural wastewater (Doshi et al., 2016). It provides high value added products like lubricants, bio-plastics, animal feed and pharmaceuticals and consumes huge amounts of carbon dioxide (Liew et al., 2014). However, algal biofuel production technology is under development where harvesting and processing is costly, energy intensive and difficult (Doshi et al., 2016).

CHAPTER 4

PERFORMANCE OF BIOFUEL

4.1 Economy of Biofuel

As alternative energy source biofuels are becoming increasingly important (Karmee, 2015) and its production technologies have been achieved continuing improvements. But relatively high production cost is still considered as a critical barrier to commercial development (OECD/IEA, 2004). Overall production costs of biofuels vary as the prices of feedstocks are highly unstable. So, the production scale of biofuels has significant impact on cost. Nevertheless, biofuel competitiveness will continue since the prices for crude oil and other fossil sources increase. Today, the competitiveness of biofuel largely depends on the national legislative frameworks and subsidies (Rutz and Janssen, 2007).

Generally, biofuels are expected to have large socio-economic impacts especially for the local actors. Its production creates new market opportunities and income options for the farmers. So, it can be expected that agriculture will not only play a role in food production but also in energy provision in near future with the help of biofuel technology (Rutz and Janssen, 2007).

Although biofuels offer large economic advantages over fossil fuels, the direct cost comparisons are difficult. It has the potential to generate many positive externalities. It can reduce greenhouse gas emissions, decrease air pollution and create job opportunities (Rutz and Janssen, 2007). Additionally, production of biofuel can reduce dependency on petroleum fuel which may lower the cost of fossil fuels. Thus, it will also make countries energy independent which have a positive impact on economy since there will be less dependency on politically unstable fossil fuel rich nations (Karmee, 2015).

4.2 Benefits of Using Biofuel over Fossil Fuel

Fossil fuels cause greenhouse gas emissions where the gases trap the Sun's rays inside the Earth's atmosphere and cause global warming. On the other hand, biofuels are carbon neutral where all of the carbon contained in it has been already absorbed from the atmosphere. Thus, it helps to reduce greenhouse gas emissions (Table 4.1) (Roos, 2014).

Table 4.1 Average biodiesel emissions (%) compared to conventional diesel

Emission type	**Pure biodiesel**	**20% Biodiesel + 80% petrodiesel**
	B 100	**B 20**
Total unburned hydrocarbons (HC)	- 67	- 20
Carbon monoxide	- 48	- 12
Particulate matter	- 47	- 12
NO_x	+ 10	+ 2
Sulfates	- 100	- 20
Polycyclic aromatic hydrocarbons	- 80	- 13
Ozone potential of speciated HC	- 50	- 10

Source: Balat, 2008.

Many fossil fuels will no longer be available in the next few decades at convenient prices i.e. fossil fuels are non-renewable. On the other hand, biomass materials which generate biofuels can be produced continuously i.e. biofuels are renewable (Olabi, 2012).

Some fossil fuels extraction from the Earth is a dangerous process and oil spills have a serious effect on environment as they are not biodegradable. On the other hand, biofuels production by farming is highly safe where spills of biofuels can be broken down and absorbed naturally (Olabi, 2014).

Dependency on fossil fuels import negatively affects the economic growth and security. On the other hand, development of a biofuel industry decreases imports, creates more jobs and keeps the economy independent of international developments (Olabi, 2013).

4.3 Uses of Biofuel

Biofuel is mostly used as transportation fuel. Bioethanol and biodiesel are two most important biofuels that have gained much popularity in transportation sector due to environmental benefits, ease of use and available subsidies (Dale, 2003).

Conventional biofuels are likely to produce between 3.7 and 6.6% of the energy needed in road and rail transport while advanced biofuels could meet up to 4.3% of the world's renewable transport fuel target by 2020 (Demain, 2007).

The generation of electricity is the largest use of biofuel in the world. It is considered least damaging in terms of minimal pollutants produced, generating less carbon than any form of power generation (Dale, 2003). The United Kingdom is the largest market for biofuel to electricity generation that generate enough power for 350,000 households from landfill gas alone (Demain, 2007).

Most of the electricity produced from biofuel is the byproduct of fuel production for transportation. So, advanced research and technology is needed to enrich this stage (Dale, 2003).

Application of biofuel can also be seen as a heating fuel in domestic and commercial boilers. A blend of heating oil and standardized biofuel is used here. It is sometimes known as 'bio-heat' which is available in various blends; up to 20% (Dale, 2003).

4.4 Impacts of Biofuel

4.4.1 Positive impacts of Biofuel

4.4.1.1 Social impacts

Biofuel production technology ensures food nutrition security and develops proper land use planning. It ensures local prosperity through spreading poverty reduction strategy. Besides, it enhances energy security and renewability and opens new market for agricultural products (Tirado et al., 2010).

4.4.1.2 Economic impacts

Production of biofuels contributes to sustainability and secures fuel diversity through reducing the dependency on imported crude oil. It increases investments in plant and equipment and thus helps to earn foreign currency. It also creates employment and income generation opportunities (Demirbas, 2009).

4.4.1.3 Environmental impacts

Biofuel reduces greenhouse gas emissions and air pollution. It is biodegradable in nature. It helps in carbon sequestration as well as has higher combustion efficiency (Demirbas, 2009).

4.4.1.4 Political impacts

Biofuel policy is based firmly in the philosophy of freedom. So, today's policy decisions ensure a free market for biofuel where producers of all sizes are free to compete in this industry without farm subsidies, regulations and other interventions skewing the playing field (Demirbas, 2009).

4.4.2 Negative effects of biofuel

Biomass feedstock production requires land, water, fertilizers and other resources that may cause land use change and land competition. It may engender additional pressure on water resources i.e. pollution and over use. Besides, it may increase food prices and in certain scenarios, it may emit more greenhouse gases and consume more fossil energy on an energy-equivalent basis (EPA, 2014).

But these negative effects can be minimized through careful planning and technological advances.

4.5 Safety, Health and Environmental (SHE) Assessment of Biofuel Production

Technological and economic factors are often given higher priority than the other non-profitable factors i.e. Safety, Health and Environmental (SHE) aspect for the assessment on chemical production pathway (Liew et al., 2014). But due to the increasing cases of chemical accident e.g. Deep water horizon oil spill, Gulf of Mexico, 2010; Fertilizer plant explosion, Texas, 2013 etc., public has gradually aware that the SHE performance in chemical processes is actually one of the primary contributors to the protection and preservation of human and the environment (Hook, 1996). Thus, under the public and legal forces, chemical industries are prompted to improve the SHE performance (Liew et al., 2014). It is more effective to improve SHE performance by introducing inherent SHE principle in plant design (Kletz, 1984).

and water resources etc. (Liew et al., 2014). The evaluation results may vary due to different regions with varied economic (e.g. feedstock price, type of biofuels and raw materials), geographical (e.g. weather) factors and other uncertainties (e.g. product demand and timeframe of assessment) (Reno et al., 2011).

On the other hand, in some studies it was found that the cultivation of biofuel could potentially cause adverse environmental impacts due to the usage of pesticides and fertilizer that might introduce acidification, eutrophication and ozone depletion (Requena et al., 2011). As the advantages of biofuel over fossil fuel are many; so, it is thought that those effects can be resolved by the development of advanced knowledge and technology to ensure better and healthy environment.

CHAPTER 5

PRODUCTION, TRENDS AND PROSPECTS OF BIOFUELS

5.1 Current Biofuel Production and Trends in the World

According to the International Energy Agency, biofuels have the potential to meet more than a quarter of world demand for transportation fuels by 2050 because its production rate is increasing gradually (Figure 5.1) (World Agroforestry Centre, 2009). Besides, most countries in the world support various forms of biofuel production (Table 5.1) (Kocar and Civas, 2013). In 2015, worldwide biofuel production reached 130.7 billion liters, increasing by 0.9% from 2014 (Table 5.2) and provided 4% of the world's fuels for road transport, a contribution largely made up of ethanol and biodiesel (BP Statistical Review of World Energy, 2016).

Table 5.1 Biofuels' targets of several countries

Countries	Years	Target	Feedstock
U. S. A	2012	28 Billion ethanol	Corn, soybean oil, sorghum, cellulosic sources in the future
	2013	1 Billion liters of cellulosic ethanol	
	2020	25% Ethanol	
Brazil	2012	25% Ethanol and B2	Soybean, sugarcane, palm oil
	2013	B5 (2.4 billion biodiesel)	
	2020	B20	
EU	2005	2%	Rapeseed, sunflower, wheat sugar beet, barley
	2010	5.75%	
	2020	10%	
China	2010	1.5–2 Million biodiesel	Corn, cassava, sweet potato, rice, jatropha
	2020	10% Ethanol (8.5 million tons)	
		10.6–12 million biodiesel	
Thailand	2012	10% Biodiesel	Cassava, molasses, sugarcane, soybean, coconut, jatropha
Canada	2010	5% Ethanol	Corn, wheat
	2012	2% Biodiesel	
India	2012	5% Biofuel	Molasses, sugarcane in the future, jatropha
	2017	10% Biofuel	
Australia	2012	10% Ethanol and 10% biodiesel	Wheat, sugarcane, molasses, palm oil, cotton oil
	2017	20% Ethanol and 20% biodiesel	

Source: TEPGE, 2012.

Table 5.2 *Current biofuel production in the World from 2005 - 2015*

Thousand tons oil equivalent	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**Change 2015 over 2014**
US	7478	9746	13456	19149	21697	25568	28518	27270	28462	30118	**30983**	2.90%
Canada	133	160	461	501	721	741	851	1001	972	1104	**1059**	- 4.10%
Mexico	–	–	4	4	4	13	12	14	53	53	**53**	–
Total North America	7612	9906	13922	19654	22422	26322	29381	28285	29487	31275	**32095**	2.60%
Argentina	9	29	172	632	1049	1663	2224	2285	2005	2577	**1961**	-23.90%
Brazil	7835	8729	11323	14137	13964	15440	13210	13518	15687	16517	**17636**	6.80%
Colombia	14	131	141	145	303	439	554	608	629	654	**670**	2.40%
Other S. & Cent. America	185	469	546	736	585	316	470	453	567	599	**599**	–
Total S. & Cent. America	8043	9358	12182	15650	15900	17859	16459	16863	18888	20348	**20867**	2.60%
Austria	70	105	220	263	354	375	370	370	354	310	**360**	16.40%
Belgium	1	21	140	278	473	582	623	520	505	530	**514**	-3.10%
Finland	6	11	51	96	267	363	207	179	52	52	**65**	25.50%
France	439	665	1122	2012	2312	2269	1859	2071	2220	2603	**2592**	-0.40%
Germany	1525	2488	3181	2727	2728	2888	2825	2888	2632	3371	**3130**	-7.10%
Italy	340	585	443	617	758	670	479	292	447	571	**621**	8.70%
Netherlands	3	22	80	77	241	384	651	1250	1445	1749	**1749**	–
Poland	109	144	96	279	393	421	398	631	674	731	**882**	20.50%
Portugal	1	70	162	149	226	284	330	276	274	301	**315**	4.60%
Spain	282	251	352	359	958	1267	809	586	709	988	**1005**	1.70%
Sweden	48	88	146	178	246	276	330	398	543	774	**701**	-9.50%
United Kingdom	39	219	359	276	220	304	251	287	482	359	**359**	–
Other Europe & Eurasia	293	391	489	929	1150	1207	1252	1390	1440	1472	**1434**	-2.60%
Total Europe & Eurasia	3156	5061	6840	8241	10325	11291	10385	11136	11778	13811	**13726**	-0.60%
Total Middle East	–	–	–	–	–	4	4	4	4	4	**4**	–
Total Africa	6	6	6	11	17	32	25	27	32	54	**69**	28.10%
Australia	20	54	70	111	165	200	217	189	188	178	**205**	14.80%
China	622	846	901	1096	1124	1479	1673	1929	2101	2207	**2430**	10.10%
India	114	134	136	155	70	113	192	208	248	320	**362**	13.10%
Indonesia	9	44	216	528	464	718	1104	1388	1740	2532	**1344**	-46.90%
Thailand	52	80	138	495	619	661	721	994	1251	1402	**1508**	7.50%
Other Asia Pacific	10	137	217	373	455	435	693	983	1233	1753	**1863**	6.20%
Total Asia Pacific	834	1335	1752	2899	3241	4097	4909	5963	7070	8716	**8086**	-7.20%
Total World	19651	25666	34702	46454	51905	59605	61163	62278	67260	74208	**74847**	0.90%

Source: BP Statistical Review of World Energy, 2016

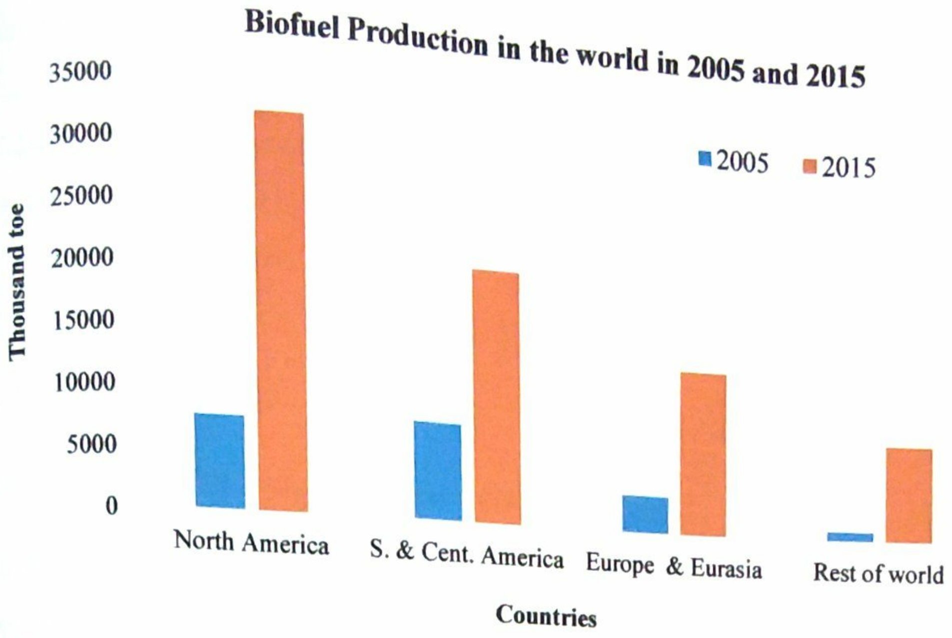

Figure 5.1. Biofuel production in the world in 2005 and 2015 (After BP Statistical Review of World Energy, 2016)

United States and Brazil are the two dominant producers and users of biofuel (Figure 5.2). In 2015, the production of biofuel of these two countries were 4.8 billion liters and 4.1 billion liters respectively and approximately 87.5% of the world's biofuel production is carried out by them (BP Statistical Review of World Energy, 2016).

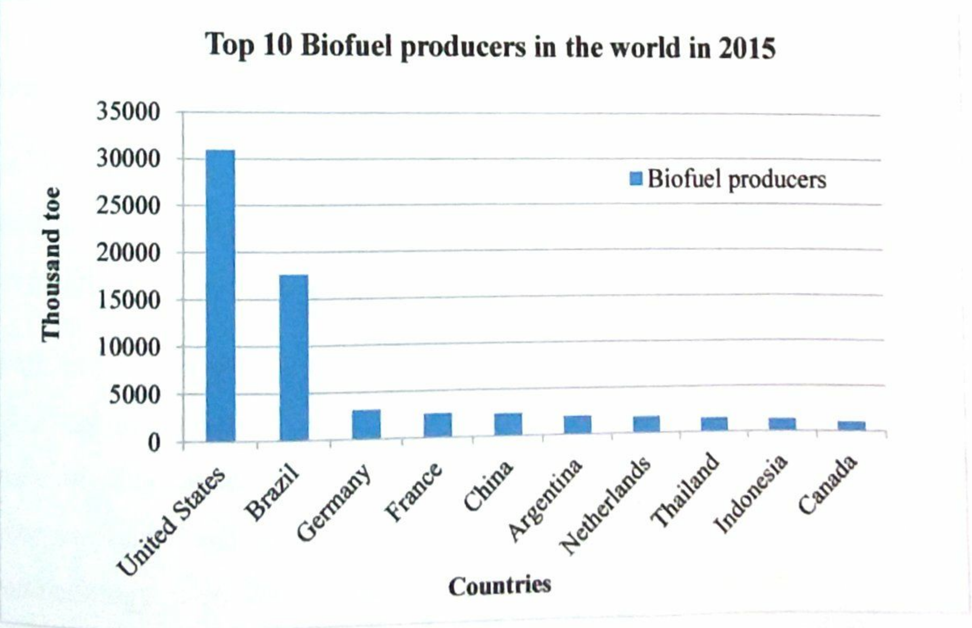

Figure 5.2. Top 10 biofuel producers in the world in 2015 (After BP Statistical Review of World Energy, 2016)

About 1 billion gallons of biodiesel and more than 22 billion gallons of fuel ethanol are produced each year in the world. The USA has allocated a significant portion of its highly productive agricultural areas to corn production in order to produce low-cost bioethanol whereas Brazil uses sugarcane as a raw material for bioethanol production. The foreign-owned bioethanol market in Brazil is the largest exporter with a share of 25%. The second exporter of bioethanol is the US followed by France and the United Kingdom (Kocar and Civas, 2013).

5.2 Prospects of Biofuels

5.2.1 Prospects of biofuels all over the world

Biofuel is regarded as potential substitute to fossil fuel due to the facts that it is generated from biological sources, able to resolve the environmental issues and promote social development particularly in rural areas (Liew et al., 2014). It is evident that the global consumption of biofuel is increasing under the influence of present renewable energy and climate change policies. Bio-power, lignocellulosic bioethanol (Second Generation) and biogas will be the most prosperous bio-energy and renewable sectors with highest growing market potential in the short term. Moreover, there is a strong indication by the World Energy Council that biofuels will meet 30% of the whole world's energy demand by 2050 (Guo et al., 2015).

If the rapid development that biofuels have enjoyed over the last decade is to be sustained, the challenges they meet will have to be overcome (Moschini et al., 2012).

Despite the unique advantages of biofuel, it is apparent that present patterns in biofuel use and their future potential as fossil carbon substitutes are fraught with uncertainty and remain controversial in many quarters (Murphy, 2008).

The high production cost is still preventing it from vast commercialization. From the results of techno-economic analysis, it is found that the main economic barriers of biofuel commercialization are attributed to the total capital cost, feedstock cost and other factors like process yield, fossil oil price, plant capacity and availability. So, it is suggested that the methodology used for biofuel production pathway should be standardized and extendable. Therefore, more researches and concerted efforts in biofuel production, development and assessment are needed to improve its competitiveness and ensure the sustainability in overall aspects that would be beneficial particularly to human and environment in the long run (Liew et al., 2014).

5.2.2 Prospects of biofuel in Bangladesh

Though Bangladesh is a developing country, its economy is growing upwards as the energy consumption increased sharply in recent years. The energy sector of Bangladesh largely depends on natural gas and petroleum oil but the reserves are inadequate to meet the energy demand for long term economic growth (Saifullah et al., 2016). For this reason, Bangladesh annually imports about 3.5 million tons of different fuel oils; of them, 1.3 million tons are crude oil, 1.45 million tons diesel, 380 tons kerosene, 215 tons jet fuel and 155,000 tons petrol and octane (Energy and Power, 2003). So, it is clear that the country is heavily dependent on import of fossil fuel and coal. But the dependency makes the country's economy more vulnerable as the price of fuel in the international market has been showing rising trend since last few years. So, the search for alternatives of fossil fuels is a major environmental and political challenge now-a-days (Haque et al., 2009).

Biodiesel and bioethanol are considered as promising alternative source of fossil fuels though they are still in their infancy in Bangladesh (Saifullah et al., 2016).

Accurate data is unavailable about oil-bearing plant families and their production and utilization in Bangladesh. But there are some native plants which grow well in the fallow lands and can play a major role for getting the non-edible oil which could be possible to convert biodiesel or directly used as a source of alternative fossil fuel in Bangladesh. Some of the well-known non-edible oil seed producing plants are Jatropha (*Jatropha curcas*), Karanja (*Pongamia pinnata*), Castor (*Ricinus communis*) and Rubber (*Hevea brasiliensis*) seeds. There are many other indigenous plant seeds available in Bangladesh which should be investigated for their potentiality to produce oil (Haque et al., 2009).

In Bangladesh, Khwaja Agri-Horticultural Research Centre (KAHRC) is the first organization to produce biodiesel from Jatropha seeds at the Bangladesh Ansar and VDP Academy, Gazipur. Bangladesh environmental condition is favorable for Jatropha plantation as it can grow in dry subtropical region to tropical rain forest. Besides, castor grows almost everywhere in Bangladesh because it can grow in stony, sandy and saline lands, live for many years, produce huge amount of seeds every year and seeds contain 67.7% oil (Saifullah et al., 2016).

On the other hand, microalgae are another promising feedstock for biofuel production. Bangladesh has huge natural water resources suitable for easy algae cultivation. In addition, marginal land, brackish and waste water sources can also be utilized that will not compete with agriculture for land and water resources. Thus, large scale cultivation of algae holds the potential to alleviate energy crisis, CO_2 emission and environmental issues (Muhit et al., 2014).

Considering these potential sources, Bangladesh can set up small or medium size biodiesel industry to meet the energy demand, decrease heavy dependence on imported oil as well as ensure economic and social development. It is believed that with the modification of relevant laws and regulations and close co-operation among scientific researchers, institutes and enterprises; advanced technologies would be put into large scale application in the near future that will be imperative for both sustainable development and environmental protection (Saifullah et al., 2016).

CHAPTER 6

CONCLUSION

The use of liquid fossil fuel as an energy source has long been considered unsustainable and most importantly this fuel will be diminished by the middle of this century. So, governments, policymakers, scientists and researchers have been forced to find alternative energy sources to overcome recent challenges such as rapid depletion of fossil fuel reserves, global climate change, rising crude oil price and environmental degradation (Alam et al., 2015). Biofuels that are generated from biological material have emerged as one of the most strategically important sustainable fuel sources due to their renewability, biodegradability and emitting lower emissions of exhaust gases (Singh et al., 2011). First generation biofuels produced from edible feedstocks are not so promising due to the conflict with food security. So, a lot of hope has been placed on second generation biofuels that are produced from non-edible lignocellulosic feedstocks. Though this generation has been attained much popularity, the researchers focused on third generation biofuel which is derived from algal biomass. To cope with the increased worldwide demand and ensure the sustainability and reliability of biofuel, its production technology should not rely on one generation but should be a combination of the three generations (Alam et al., 2015).

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