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Overview on Bio-refinery Concept in Malaysia: Potential High Value Added Products from Palm Oil Biomass

(Gambaran Keseluruhan mengenai Konsep Penapisan Bio di Malaysia: Potensi Produk Penambahan Nilai Tinggi dari Biomas Minyak Sawit)

Nursia Hassan[a], Ani Idris*[a], Junaid Akhtar[b]
[a]*Institute of Bioproduct Development (IBD), Faculty of Chemical and Energy Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia*
[b]*School of Energy and Chemical Engineering, Ulsan National Institute of Science and Technology50 UNIST-gil, Ulji-gun, Ulsan, 44919, Republic of Korea*
**Corresponding author: ani@cheme.utm.my*

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ABSTRACT

This paper presents an overview of bio-refinery concept in Malaysia emphasing on diversifying and maximizing the value of palm oil biomass feedstock to produce bio-based chemicals that demonstrated strong market growth. The oil palm mills and plantations contributes to large amounts of biomasss such as oil palm fronds (OPF), oil palm trunks (OPT) and empty fruit bunches (EFB) which are sources of renewable energy. A majority of these lignocellulosic palm oil byproducts are not effectively utilized and some parts of the biomass are utilized as biofertilizers and solid biofuels. Thus, the potential of palm oil biomass should be explored by diversifying the consumption of these biomass to produce high value added chemicals and biofuels which can generate additional revenue for the country. A number of technologies; namely biochemical conversion, pyrolysis etc. have been established to convert such biomass into a wide spectrum of biobased commodities such as biodiesel, succinic acid, lactic acid, bioethanol and polyhydroxyalkanoates (PHA). This article comprehensively reviews the potential of high value added products generated from palm oil biomass via different bio-refinery approach with special attention on the biochemical conversion process followed by their development stage towards full commercial scale. Limitations and challenges in each process were also discussed in detail.

Keywords: palm oil biomass; biorefinery; biofuel; bioconversion; lignocellulosic biomass

ABSTRAK

Makalah ini membentangkan gambaran keseluruhan konsep bio-penulinan di Malaysia dengan tumpuan khas untuk mempelbagaikan dan memaksimumkan nilai bahan mentah biomas minyak kelapa sawit untuk menghasilkan bahan kimia berasaskan bio yang menunjukkan pertumbuhan pasaran yang kukuh. Perkebunan kelapa sawit dan kilang kelapa sawit terkenal dengan sumber tenaga diperbaharui dengan jumlah biomas yang besar seperti daun kelapa sawit, batang kelapa sawit dan tandan buah kosong. Sebilangan besar sisa kelapa sawit lignoselulosik ini tidak digunakan secara berkesan dan beberapa bahagian sisa digunakan sebagai biofertilizers dan biofuel padu. Oleh itu, potensi biojisim kelapa sawit perlu diterokai dengan mempelbagaikan penggunaan biomas ini untuk menghasilkan bahan kimia dan bahan api berasaskan bio yang dapat menghasilkan pendapatan tambahan bagi negara. Sejumlah teknologi; iaitu penukaran biokimia, pirolisis dan sebagainya telah dibangunkan untuk menukar biojisim kelapa sawit kepada spektrum produk berasaskan bio yang luas seperti biodiesel, asid succinic, asid laktik, bioethanol dan polyhydroxyalkanoates (PHA). Artikel ini mengkaji secara komprehensif potensi produk nilai tambah tinggi yang dihasilkan daripada biojisim kelapa sawit melalui pendekatan bio-penapisan yang berbeza dengan perhatian khusus pada proses penukaran biokimia diikuti oleh peringkat pembangunan mereka ke skala komersil. Kekangan dan cabaran dalam setiap proses juga dibincangkan secara terperinci

Kata kunci: Biojisim kelapa sawit; biorefinery; bahan api bio;penukaran bio; jsim lignocellulosa

INTRODUCTION

Malaysia is known for its palm oil industry and is one of the largest producers of palm oil products for the global market. Generally, Malaysia and Indonesia are the biggest suppliers for palm oil which supplied about 41% and 44.8% of the world's palm oil quantity respectively. However, the increasing growth of palm oil plantation and palm oil production has raised environmental concerns. The high demand for palm oil worldwide has increased its production in Malaysia and, has led to the accumulation of substantial amount of lignocellulosic agriculture wastes which have negative impact to environment but can be a potentially valuable resource. This is because the wastes produced take a long time to decay or decompose. Combustion of the palm oil waste contributes to the pollution crisis. In 2014, it was reported that 96,000 ktonnes of oil palm biomass were produced from oil palm plantations and this number is expected to increase per year. Mostly the wastes were from OPF, OPT and from EFB (Norshamsiana et al. 2017). In order to control the problem of excessive biomass produced by industries, proper management and procedures should be taken to prevent environmental pollution. Bestowing to the waste management order, it is essential to reduce the production of waste generated. If the reduction of the waste failed then, the waste must be reused or recycled for possible uses. When these options are unsuitable, then the waste must undergo for energy recovery before going through the last resort which is waste disposal. The potential of palm oil biomass as a renewable and sustainable source for the production of bio-based and energy related product has been envisaged by many scientists (Sitthikitpanya et al. 2018; Akhtar and Idris, 2017; Hassan and Idris, 2016; Kumneadklang et al. 2015; Zhang et al. 2013; Bari et al. 2009; Jahim et al. 2006). It is a lignocellulose material which comprised of cellulose and hemicellulose and is versatile as the entire palm oil biomass waste can be exploited into new commodities. Biorefinery is one of the technologies that convert biomass into valuable products and energy. Biorefinery can be a facility, a process, a plant or a cluster of facilities. Production of other valuable products or energy from biomass shall be under sustainability aspect which means the assessment of possible consequences such as competition for food or environmental impact should be taken into account. The concept of biorefinery is to produce biofuel or bio-based chemical from biomass through any type of conversion processes which include physical, chemical, biological and thermal process. Biomass which is categorised as a lignocellulose material can be converted into renewable energy sources as the agricultural waste could become a promising alternative energy sources. Plants are characterized as lignocellulose materials that comprised of cellulose, hemicellulose and lignin. These renewable sources can be used as feedstock for conversion to energy by using thermochemical conversion, biological conversion, chemical conversion, or physical conversion. According to Milbrandt et al. (2008), based on the report by APEC, it is a good platform for Malaysia to develop second generation bio-diesel since Malaysia has a high resource of biomass feedstock throughout the country. This article comprehensively highlights the biorefinery concept of lignocellulosic palm oil biomass as a carbon source in producing biobased value added and energy related products. Overview and development stages of different biochemical conversion technologies utilised to produce lactic acid, succinic acid, bioethanol and polyhydroxyalkanoates were also included in this review.

MALAYSIA PALM OIL INDUSTRY

Malaysia has established its name as a large producer and exporter of palm oil in the world, second only to Indonesia. Malaysia's oil palm industry spans to 5.81 million hectares of plantation and 453 palm oil mills, producing over 19.92 million tonnes of oil and almost 100 million tonnes of biomass (MPOB 2017) as shown in Table 1.

Malaysian palm oil industry has played a significant role in supplying the world demand of steady source of versatile, healthy and inexpensive source of oil and fats. Over the last 100 years, country such as Iran did not consider palm oil as edible oil. Most of the palm oil was only used in soap making and steel industry processes. Over the years through intensive research activities, palm oil was characterized and made popular as a major source of edible oil used for cooking oil and production of fats, margarine, shortenings and even chocolates. Started as an unknown and insignificant commodity, palm oil has been recognized in the global stage as an everyday commodity which eventually provides food security to the world population. Nowadays, palm oil industry has broadened its horizon as it has further expanded its applications in the oleo chemical and biodiesel sector. This is a great achievement of Malaysian palm oil industry in enhancing the value of palm oil which can further compliment the current economic needs. Large amounts of palm oil biomass wastes were simultaneously produced during palm oil extraction.

These palm oil biomass includes EFBs, mesocarp fibres, palm kernel shells and liquid effluents, OPT and OPF. A majority of these palm oil biomasses were used as commercial solid fuels as they have high calorific values (Chow et al. 2008). Besides that they are also potential feedstocks for biobased chemical, biofuel and bioplastics industries. Their abundance and availability throughout the year makes them appealing as resources for sustainable and renewable energy.

POTENTIAL OF OIL PALM BIOMASS IN BIOREFINERY

An advancement in oil palm industry has led to enormous accumulation of oil palm biomass in solid and liquid form during the replanting and processing of edible oil. The statistical data in Table 2 shows the massive lignocelluloses in OPT, PF and EFB accumulation in palm oil industries in Malaysia. Some parts of these wastes are being utilized as bio-fertilizer, however, most of the portion is disposed

TABLE 1. Land area used for oil palm plantations (Hectares) (MPOB 2017)

State	Matured	%	Immatured	%	Total	%
Johor	682,624	91.2	66,236	9	748,860	13
Kedah	82,421	94.2	5,117	6	87,538	2
Kelantan	118,090	74.6	40,220	25	158,310	3
Melaka	52,322	91.2	5,050	9	57,372	1
Negeri Sembilan	162,634	88.0	22,181	12	184,815	3
Pahang	641,876	86.6	99,619	13	741,495	13
Perak	360,501	88.7	45,968	11	406,469	7
Perlis	617	93.5	43	7	660	0
Pulau Pinang	12,870	94.9	693	5	13,563	0
Selangor	128,058	92.9	9,725	7	137,783	2
Terengganu	146,561	85.4	24,987	15	171,548	3
Peninsular Malaysia	2,388,574	88.2	319,839	12	2,708,413	47
Sabah	1,380,037	89.2	166,867	11	1,546,904	27
Sarawak	1,342,102	86.3	213,726	14	1,555,828	27
Sabah & Sarawak	2,722,139	87.7	380,593	12	3,102,732	53
Malaysia	5,110,713	87.9	700,432	12	5,811,145	100

TABLE 2. Palm oil biomass generated in Malaysia from 2001 to 2020 (Fazlena, 2012)

Biomass supply (tons/year)	2001-2003	2004-2006	2007-2010	2011-2013	2014-2016	2017-2020
OPT	3,933,442	4,020,852	3,234,164	4,283,082	3,583,803	2,971,934
PF	7,41,074	7,025,525	6,890,233	6,803,260	7,044,853	7,141,490
EFB	2,870,148	2,860,194	2,823,695	2,830,331	2,906,647	2,863,512

OPT – oil palm trunks, PF – pruned fronds, EFB – empty fruit bunch

or incinerated. Majority of the residues are not effectively utilized, and their presence is creating an environmental concern. Thus, the potential of OPB to be used as a substrate for numerous purposes must be explored due to its abundance. Generally, the plantations and milling process area are the great producers of oil palm biomass. Trunks and fronds are usually found in the plantations. Oil palm trunks can be collected during replanting while fronds can be obtained during pruning of the trees. Currently, most of the OPF are kept left on the ground as fertiliser. EFB, mesocarp fibres, palm kernel shells and palm oil mill effluent (POME) can be found in mills. These biomasses are more sustainable compared to oil palm trunks as they are produced daily. The origins and types of palm trees which are diverse can vary the chemical composition in oil palm biomass (OPB) (Chew and Bhatia 2008).

Table 3 depicts the chemical constituents of different OPB. Cellulose forms a major constituent of most OPB. Fermentable sugars can only be produced from cellulose and hemicellulose. The lignin reinforcing the lignocellulosic similar to that of other natural fibres need to be removed. Felled trunks are usually sold to interested party at cost ranging from RM8-RM18 (Wan asma et al. 2010). The problems encountered when dealing with OPTs are their heavy weight and large size which contribute to high transportation costs. Their moisture content is also high compared to woods (Yamada et al. 2010) causing a major problem as they cannot be stored for a long time because bacteria and fungus growth is promoted consuming the high sugar present. One trunk produces about 200 - 250 liters sap. However, studies in felled OPTs have revealed that high sugar was amassed with suitable storage time (Yamada et al. 2010). The hypothesis has successfully proved that the total sugar increased from 8.3% in fresh trunks to 15.3% while starch content decreased from 3.5% to 0.5% after 30 day storage. This method has effectively increased the sugar content of sap while the starch content in the trunk continued to reduce.

TECHNOLOGIES TO CONVERT PALM OIL BIOMASS TO VALUABLE PRODUCTS

The combustion technology is well established to transform the biomass to heat. There are also a number of technologies being actively pursued to transform this biomass into a more convenient liquid or gaseous fuel for more specific uses. These include pyrolysis, anaerobic process and bioconversion as shown in Figure 1. Some of these technologies are still in their early stages and evaluation is needed before it can be commercialized.

TABLE 3. Chemical content in common palm oil biomass feedstock

	Chemical constituents of various palm oil biomass				
Component	EFB	PF	OPT	OPMF	Kernel shell
Cellulose	38-70	40-50	22-44	39-42	13-28
Hemicellulose	10-35	23-38	12-41	9-24	21-22
Holocellulose	68-86	70-83	42-73	49-64	42-47
Lignin	13-37	18-32	18-36	21-33	44-52
Xylose	29-63	26-52	15-55	40-49	63-64
Glucose	23-66	20-67	18-32	23-29	21-22
Ash	1-6	2-8	2-4	3-9	1-2

Note: EFB - empty fruit bunch. PF - prunned fronds. OPT - oil palm trunk. OPMF - oil palm mesocarp fibre

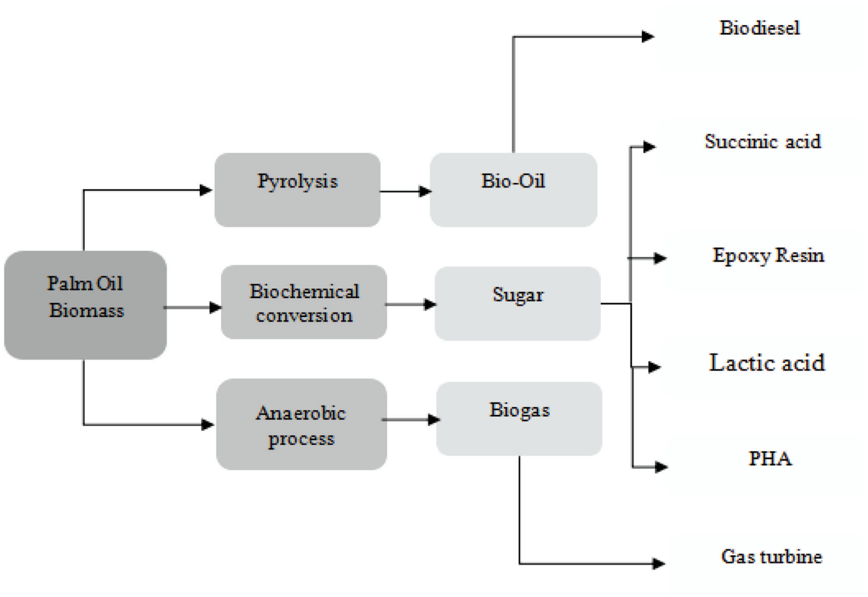

FIGURE 1. Conversion technologies of oil palm biomass

PYROLYSIS PROCESS

Pyrolysis occurs without the presence of oxygen at elevated temperature which results in decomposition of the biomass (Ro et al. 2018; Sukiran et al. 2014; Abnisa et al. 2013; Yin, 2012). The intermediate products which include biochar, bio-oil, and gases including carbon monoxide, hydrogen, methane, and carbon dioxide (Mabrouki et al. 2015; Sukiran et al. 2014; Amin et al. 2012; Mohammed et al. 2011) can be a promising biofuel product as an alternative to replace the petroleum-based fuel. Figure 2 illustrates the fundamental pyrolysis process diagram. Different temperature conditions will yield different types of products. During pyrolysis, products mainly biochar will be obtained at low temperatures (less than 450˚C), pyrolysis, while bio-oil is the main product at an intermediate temperature. Therefore, solid biomass can be converted into a liquid in pyrolysis which enable it to be stored and transported easily. Compared to pyrolysis, direct combustion will completely convert the biomass into heat which only offered just about 10 percent efficiency.

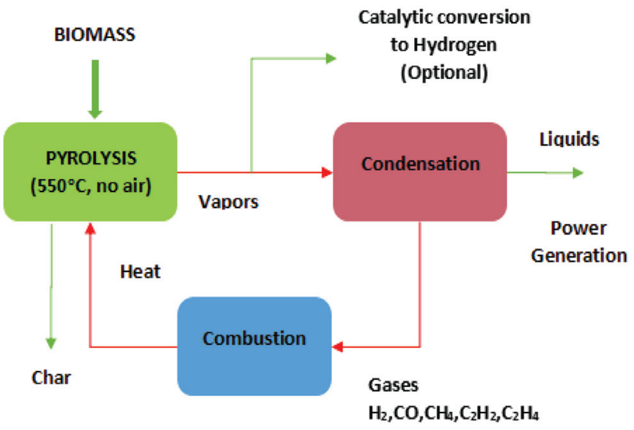

FIGURE 2. Biomass liquefaction via pyrolysis process (Bioenergyconsult 2018)

BIOCHEMICAL PROCESS

The biochemical conversion of cellulosic biomass consists of five main steps which starts with feedstock preparation, followed by pre-treatment to release increase accessibility to cellulose, saccharification to convert the hemicellulose and cellulose to simple sugars called glucose and xylose. The simple sugars were then fermented using specific microorganisms to bioethanol or other products, and improve the purity of the product through distillation as shown in Figure 3.

FIGURE 3. Five major steps in biochemical process

FEEDSTOCK PREPARATION

Initially, the feedstock will be washed to ensure inorganic substances were separated from the biomass. After that, the biomass will be cut into smaller sizes depending on the desired size range of pretreatment technology to be used. Existing forestry or agricultural techniques can be used to chop and ground cellulosic feedstock. In processing of EFB, several processes are involved including shredding, separating, refining and drying. No chemicals are involved in the production of palm oil fibres (Shamsudin et al. 2012; Lau et al. 2010; Hassan and Idris, 2016).

High quality palm oil fibres must have several criteria such as clean, toxic- free and meet specifications. The major components in the process of producing EFB fiber are the shredder, dryer and bailing machines. The system starts with EFB pressing unit where EFB need to be pressed to remove the water and moisture. EFB is then shredded by machines to turn the bunch into fibre form. Generally, hammer mill is used to produce fibres according to specific length. EFB fiber is subjected to the steam dryer to maintain the mosture content at lower level. Bailing is done to facilitate transporting of the EFB fibres. The average cost to produce EFB fibre is estimated at around USD 90-120/ton (Abas et al. 2011). In producing OPT and OPF fibers, the trunks from the felled trees were normally collected during replanting and cut into several sections to facilitate easy handling process (Jung et al. 2012; Goh et al. 2010). As mentioned earlier, high moisture content, size and weight of OPT are major problems that need to be dealt with. The OPTs need to be chopped and then squeezed so as to remove the juice. The remaining biomass in the form of OPT bagasse is subsequently subjected to grinding and drying process. The juice was also known as oil palm trunk sap can be used directly to produce biobased product through fermentation process as it contains high sugar content and mineral ions (Shahirah et al. 2015; Yamada et al. 2010; Kosugi et al. 2010).

PRETREATMENT

The purpose of preforming pretreatment process is to destroy the lignocellulosic structure thus allowing enzymatic digestion to occur. Pretreatment processes are made arduous due to the intricate structure of lignocellulosic biomass where celluloses, hemicelluloses and lignin are entangled and intimately attached to each other (Kim and Kim 2013). Enhancing the efficiency of lignocellulosic pretreatment can increase the amounts of cellulose and hemicellulose released from lignocellulosic biomass which are ultimately converted into fermentable sugars at higher yield. Figure 4 depicts the effect of lignocellulosic biomass pretreatment. Pre-treatment processes can be classified as physical, chemical or biological method and sometimes both of these effects are incorporated (Nomanbhay et al. 2013; Lau et al. 2010; Ariffin et al. 2008).

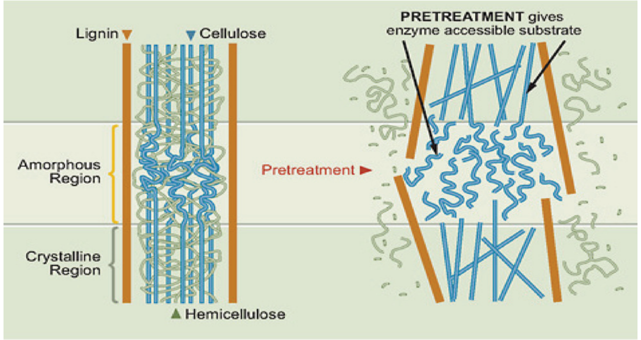

FIGURE 4. Pretreatment process on biomass structure (Mosier et al. 2005)

There are many pre-treatment methods but only a handful can be applied on an industrial scale due to high cost and environmental issues. Most of these methods involved the utilization of acids or alkalis in high temperature reactions and in some instances steam explosion was used. Thus, the pursuit for a cheaper, efficient and environmental friendly pre-treatment process is vital to commercialise enzymatic hydrolysis of lignocelluloses biomass. Comparison and evaluation of the pretreatment methods are challenging as they are influenced by many factors such as capital cost, downstream and upstream processes cost, waste treatment systems and chemical recycling (Jeoh et al. 2007). However, the challenge still remains in the technology vagueness of the process stage where the oil palm biomass need to be broken down to single sugars which subsequently will be fermented into the bio based products.

In recent years, an Australian company Leaf Resources had develop a new emerging technology in pretreatment of lignocellulosic biomass called Glycell^{TM} which uses glycerine to economically produce cellulosic sugars (leafresources, 2017). This process involves the usage of glycerol as a reagent in order to breakdown plant biomass into lignin, cellulose and hemicellulose at lower temperature. This process has the ability to liberate up to 90% of digestible cellulose within 24 hours. Glycell^{TM} is a real economic breakthrough. According to Leaf Resources, the production cost of cellulosic sugars using Glycell process was below $50/ton including the co-product. Low cost cellulosic sugar production through Glycell process is obvious when compared to the rival processes such as sugar production from sugar cane and raw sugars which was at $220/ton and $280/ton respectively. By dramatically reducing the cost of intermediate sugar for bio based chemicals, plastics and biofuels processing, the Glycell™ process has the potential to change the future direction of renewable bio-based industry and turn biorefinery concept into realization.

SACCHARIFICATION

In this stage, hydrolysis process was used to break down the cellulose polymers chain into individual sugars such as xylose and glucose. The sugars were then fermented into final product. There are three different groups of cellulolytic enzymes used for hydrolysis which are cellobiohydrolases, beta-glucosidases, and endoglucanases (Ahktar and Idris 2017; Lai and Idris 2016).

FERMENTATION

Fermentation process was carried out to convert glucose obtained from saccharification process to bioethanol and other biobased chemicals with the presence of microorganisms. Fermentation using lignocellulose materials can be performed either by these two established methods; separate hydrolysis and fermentation (SHF) or simultaneous saccharification and fermentation (SSF). Both of these methods have their advantages and disadvantages. Basically, SHF is performed in 4 different steps requiring 4 different reactors. The process involves i) production of cellulase ii) enzymatic hydrolysis of lignocellulose materials iii) fermentation of five carbons C5 sugars iv) fermentation of six carbon C6 sugars. Each process is carried out in separate reactors. The temperature for hydrolysis process can be optimized as the hydrolysis and fermentation were performed in different reactors (Zhang et al. 2013). However, SHF has its limitation in terms of economic view and practicality. Accumulation of high sugar concentration in hydrolysis step results in an inhibitor effect which then leads to low yield of lactic acid during the fermentation (Zhang et al. 2013). High sugar content in the hydrolysis process makes the process easy to be contaminated by microorganisms. The use of 4 reactors make SHF process not attractive as it involves high capital cost.

However, the yield obtained in SHF is much higher than SSF. Enzymatic hydrolysis of cellulose and hemicellulose to sugars, and the conversion of fermentable sugars to lactic acid occurred simultaneously in the same vessel in SSF (Figure 5). One of the advantages of SSF is to provide a solution in enzymatic hydrolysis by reducing enzyme loading thus decrease production cost. The main problem of this technique is to determine the suitable or optimum temperature for SSF as the optimum temperature for enzymatic hydrolysis of cellulose is different from temperature used in the lactic acid fermentation (Hassan and Idris 2016).

NEW BUSINESS POTENTIAL OF PALM OIL BIOMASS

The amount of biomass generated from the palm oil industry is tremendous in quantity that it would be a waste if they are not utilised. The following subsection describes the possible utilization of palm oil biomass. High value added products such as bio-based value added products and bio-fuel for power generation can be produced from palm oil biomass. Production of high value added and energy related product from palm oil biomass is summarised in Table 4.

BIO-BASED VALUE ADDED PRODUCTS

SUCCINIC ACID

Succinic acid ($C_4H_6O_4$), a dicarboxylic acid, also known as amber acid or butanedioic acid. Succinate acid has been widely used as feedstock for several industrial products such as 1,4- butanediol, aliphatic esters, adipic acid, and tetrahydrofuran. Due to the high price of petroleum, the bio-based succinic production by microorganisms may be an alternative to currently used petroleum-based succinic acid. Annual worldwide demand of succinic acid reaches to 30 million (Akhtar et al. 2014). Currently succinic acid can be produced using either maleic acid, refine sugar and petroleum based substrate. Chemical synthesis of succinic acid using petroleum based substrates apparently generates large amounts of chemical wastes during the process and has caused environmental concerns while the use of maleic acid or refine sugar as a starting material to produce succinic acid is viewed as not economical as the main components; maleic acid and sugar are expensive. This will affect the production cost of succinic acid. Succinic acid selling price depends on the substrate used and its purity. The current price of succinic acid from maleic acid was US$ 5.9 to 9.0 per kilogram and US$ 2.26 per kilogram from refine sugars (Efe et al. 2013). Thus, the use of carbon sources from agricultural waste such as EFB can significantly reduce the cost of feedstock. In the fermentation of succinic acid, EFB was used as a substrate to produce succinic acid through SSF method with *Actinobacillus succinogenes* ATCC 55618 (Akhtar and Idris, 2017). Succinic acid production via SHF and SSF from EFB is depicted in Figure 6. The maximum concentration of succinic acid 39.14 g/L was obtained.

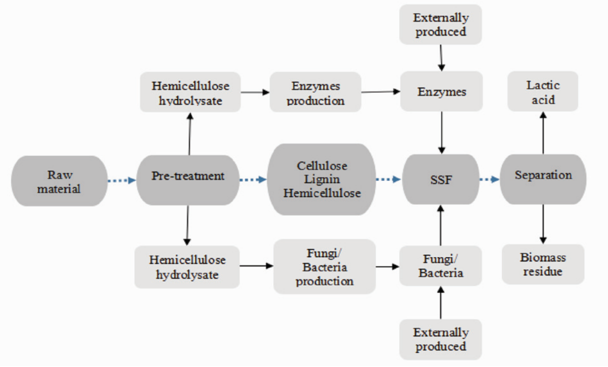

FIGURE 5. Simultaneous saccharification and fermentation process diagram

TABLE 4. High value added and energy related products from palm oil biomass

Types of palm oil biomass	Biorefinery approach	Biobased/energy related product	Yield/production rate	References
EFB	Solid state fermentation using *Aspergillus niger* IBO-103MNB	Citric Acid	367.4 g/kg of dry EFB	Alam et al. (2011)
EFB	SHF using *Saccharomyces cerevisiae*	Ethanol	0.40 g /g glucose	Pangsang et al. (2019)
EFB	SHF using by *Bacillus coagulans* JI12	Ethanol	80.6 g/L of lactic acid; Productivity of 3.4 g/L/h	Ye at al. (2014)
EFB	SSF using pretreated OPEFB as substrate by *C. acetobutylicum* ATCC 824n	acetone–ethanol–butanol (ABE)	0.18 g/g	Ibrahim et al. (2015)
EFB	Acid hydrolysis	levulinic acid	10.77 g/L (53.93 %) of levulinic acid	Chin et al. (2015)
EFB	SSF using *Actinobacillus succinogenes* ATCC 55618	Succinic acid	33.4 g/L, Productivity 0.69 g/ L/ h	Akhtar and Idris (2017)
EFB	Submerged fermentation of EFB with *Trichoderma viride*	Humic acid	64.7 g/L	Motta and Santana (2013)
EFB	Acid hydrolysis	Furfural	57 g/kg dry EFB	Raman and Gnansounou (2015)
EFB	Pyrolysis	Bio-oil	27 %	Sembiring et al. (2015)
EFB	SHF using *Bacillus megaterium* R11	Polyhydroxybutyrate	9.32 g/L, for an overall OPEFB	Zhang et al. (2013) sugar concentration of 45 g/L
EFB	SSF using *Rhizpus Oryzae*	Lactic acid	12 g/L	Hassan and Idris (2016)
OPT	SSF	bio-hydrogen and methane	60.22 mL H_2/g-OPT	Sitthikitpanya et al. (2018)
OPT	SHF using *Clostridium spp.*	biobutanol	10.0 g/L; 0.41 g/g	Komonkiat and Cheirsip (2013)
OPT	solid-state fermentation using *Aspergillus fumigatus* SK1	cellulases and xylanase	Activities; 418.70 U/g substrates for xylanase	Ang et al. (2013)
OPT sap	Fermentation using *Saccharomyces cerevisiae*	Bioethanol	81.89%	Shahirah et al. (2015)
OPT sap	Fermentation using *Lactobacillus lactis* ATCC19435	Ethanol and lactic acid	94.2%, 89.9%.	Kosugi et al. (2010)
OPF	SSF using TISTR5048	Bioethanol	17.2 g/L	Kumneadklang et al. (2015)
OPF juice	Fed batch fermentation using *Cupriavidus necator*	poly(3-hydroxybutyrate)	30.5 g/l	Zahari et al. (2014)

LACTIC ACID

Recently, lactic acid has also been characterized as a chemical commodity due to its rapid increase in market demand. The world demand of lactic acid is stimulated due to its wide application in industries such as food additives, pharmaceutical and biopolymers. It is mainly used as a food additive (acts as an acidulant and a preservative). It is also used to make stearoyl-2-lactylates for the baking industry. Recently, in its polymeric form, it can be polymerised to poly-lactic acid, which in turn can be used to make biodegradable plastics, controlled release agrochemical formulations, as well as for medical applications such as biodegradable sutures and biocompatible prosthetic devices.

Lactic acid can be obtained either via synthetic or a fermentation route. However, it was estimated that 90% of world's production of lactic acid are using microbial fermentation process. This was driven by the recent upsurge in demand for naturally produced lactic acid (Panesar et al. 2010). In biological production of lactic acid, glucose or sucrose was used as feedstock. Generally, bioconversion of carbohydrate to lactic acid is a time consuming process. In contrast, the lactic acid produced via chemical synthesis route originated from fuel product is in racemic form and needs to undergo some extra purification steps to produce high purity lactic acid. Thus, fermentation process is viewed as the preferred technology to produce high purity lactic acid in large scale.

Conventional fermentation process of lactic acid apparently, used high volume of refine sugars as a substrate and usually used bacteria producing lactic acid. Technically, this process should be very economical as the purification steps become easier and thus separation cost can be reduced. Unfortunately, the widely use of expensive refined sugar as a feedstock for lactic acid production, result in an increase in production cost (Probst et al. 2015). Moreover, this technique also needs more nutrient supplement as they used fastidious lactic acid producing bacteria to ensure the growth of the cells. Thus, in order to ensure viability and reduce the production cost, it is important to find cheaper feed stocks because polymer suppliers and other industrial producers usually required lactic acid in large bulk quantities at comparatively low prices. Many of industrial producers of lactic acid are facing some disappointing margins due to the high production cost. Consequently, they have to hike the market price for lactic acid for several times in the past few years in a bid to pass the rising cost of production to consumers (Abdel Rahman et al. 2011).

Recently attention was diverted to synthesize lactic acid and ethanol from various lignocellulosic feedstocks in order to replace expensive glucose. Production of lactic acid from lignocellulosic of palm oil biomass (EFB, OPT and OPF) was reported by several researchers (Hassan and Idris, 2016; Hamzah et al. 2011; Lai and Idris 2016). The process scheme for lactic acid production from EFB has some similarity to that of bioethanol production from cellulosic biomass. Both these processes utilize simultaneous sacchariffication and fermentation (SSF) technique. It is an art in bioprocess engineering that can transform lignocellulosic carbohydrate to end product in a single process. In SSF, the EFB, cellulase enzyme and the *Rhizopus oryzae* pellet are introduced into one reactor (Hassan et al. 2017; Hassan and Idris, 2016). The enzymes break the cellulose chains into cellobiose and glucose during the saccharification process. By introducing microorganisms along with cellulase, glucose can be consumed by the microorganisms as soon as it is formed and produces lactic acid as its product metabolites. As a result, the enzymatic hydrolysis reaction is pulled in the forward direction and the rate of glucose production is significantly enhanced. Therefore, SSF proceeds under glucose limitation and the inhibition of glucose on enzymes is completely eliminated.

In order to achieve desired final concentration of lactic acid after fermentation, it is necessary to use high gravity substrates which contains more sugar or water insoluble contents, most importantly, cellulose and hemicelluloses. When high gravity substrate is employed the viscosity of the reaction broth is increased and normally more inhibitors are brought into the system. The increase in viscosity will require harsh operating conditions such as powerful mixing, more base/acid to adjust the pH and limited mass/heat transfer thus resulting in more stress to the fermenting microorganisms (Koppram and Olsson, 2014). The toxic substances released from the pretreatment of raw materials are another major cause for cell stresses. They can be classified into three groups: furan aldehydes, weal acids and phenolics (Wang et al. 2014). The stress microorganisms present declined viability and lactic acid productivity. To minimize these negative effects, process configurations have to be modified; by applying proper feeding strategies, keeping the viscosity or inhibitor concentration at acceptable levels. For example, in a feed batch simultaneous saccharification and fermentation (SSF), the substrate feeding is controlled to be slower than or equal to the consumption rate (Hu et al. 2015). In this way, incoming substrate can be liquefied very quickly and the viscosity of the reaction broth can be maintained at a similar value.

POLYHYDROXYALKANOATES (PHA)

EFBs can be used as the subsrate to produce bioplastic such as polylactate (PLA) or polyhydroxyalkanoates (PHAs). PHA biodegradable thermoplastics with similar mechanical properties to those of polypropylene are produced from bioresources such as fatty acid and sugars (Mumtaz et al, 2010). PHAs can be amassed in various microorganisms as carbon and/or energy storage material. Mumtaz et al, (2010) have identified 150 different hydroxyalkanoic acid monomers in PHA. PHA subunits can be broadly subdivided into short-chain lengths which consist of 3-5 carbon atoms. They can also be in medium-chain length with 6-14 carbon atoms monomers existing mostly as 3-hydroxy-substituted fatty acids (Madison and Huisman, 1999). During production of PHA, EFB and lactic acid producing bacteria/fungi were introduced in the same fermentation vessel. The enzymes

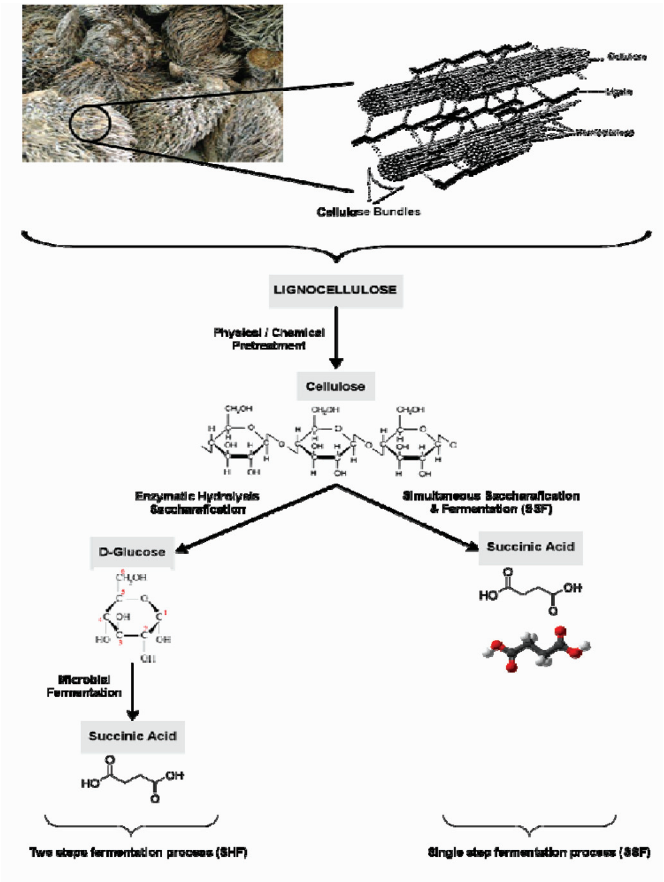

FIGURE 6. Succinic acid production via SHF and SSF from EFB (Akhtar et al. 2014)

will hydrolyse the cellulose into fermentable sugars and subsequently the microbes will utilize the sugar to produce PHA. Figure 7 illustrates the processes involved in the production of PHA through microbial fermentation. PHA can also be produced from OPF juice as it contains high sugar and starch. During fermentation, bacteria producing PHA used the sugar from OPF or OPT juice as a carbon source simultaneously amassing PHAs inside the cell wall of *Ralstonia eutropha* under limiting conditions of nutrient supply such as nitrogen, sulphur and phosporous (Hassan and Syirai, 2003). Current price of PHA is about US$ 6-10 per kilogram which is expensive. To be commercially viable, the price of PHA should be around US $ 3-5 per kilogram (Hassan & Syirai 2003). Thus the use of cheap carbon sources of palm oil biomass (EFB/OPT/OPF) could reduce the price of bioplastics.

ENERGY RELATED PRODUCTS

BIOETHANOL

Bioethanol is an alternative fuel to reduce world's consumption on non-renewable resources. Bioethanol can be synthesized from cellulose and hemicelluloses that originated from many sources of biomass. The use of yeast cells enables the breakdown of starch and water to produce bioethanol and carbon dioxide (Ceng et al. 2007). Currently, corn grain (starch) and sugar cane (sucrose) are the main substrates for production of ethanol. However, both corn grain and sugar cane are considered as food competitive materials and can negatively affect the pricing of food supply system.

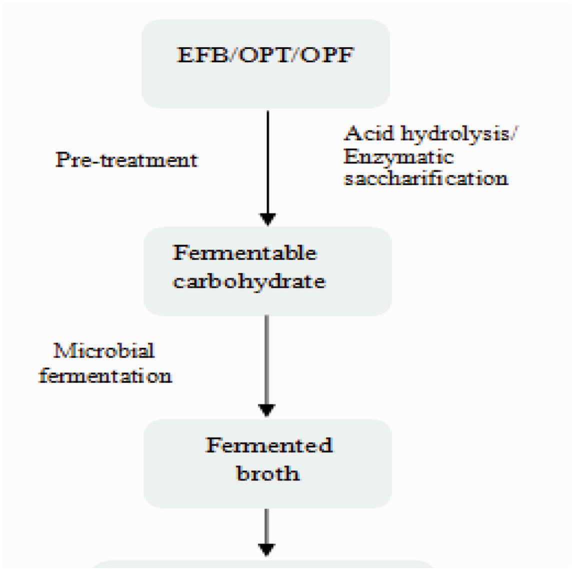

FIGURE 7. Schematic diagram of PHA production using lignocellulosic oil palm biomass (Hassan et al. 2013)

BIO-OIL

The composition bio-oil is similar to biomass but it is a dark brown liquid (Lu et al. 2009, Islam and Ani, 2000). It is an organic compound mixture consisting mainly of ketones, alcohols, acids, esters, aldehydes, phenols, and lignin-derived oligomers. The ease of transportation and storage made bio-oil an attractive renewable liquid fuel which can be used as fuel oil or diesel in various appliances such furnaces, boilers, engines, and turbines for electricity generation (Xiu and Shahbazi 2012).

CONCLUSIONS

The abundance of biomass resources in Malaysia can be converted into wide spectrum of high value added products. Realizing the benefits of utilizing the renewable energy resources of oil palm biomass residue, Malaysia is now promoting the use of the biomass as a source for both energy and also for high end products. This is obviously strategically viable as it can ensure the sustainability of energy supply at the same time minimizing the environment pollution. Indirectly these measures can also help in extending the fossil fuel reserves. However, to make the biorefinery concept into a reality, advances in technologies for converting biomass to biobased chemicals efficiently and economically is required. Thus, this review has successfully provided an insight on the potential high value added products that can be generated from pretreated palm oil biomass via current biorefinery technologies.

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Nursia Hassan, Ani Idris*,
Institute of Bioproduct Development (IBD),
Faculty of Chemical and Energy Engineering,
Universiti Teknologi Malaysia,
81310 UTM Johor Bahru, Johor, Malaysia

Junaid Akhtar
School of Energy and Chemical Engineering,
Ulsan National Institute of Science and Technology 50
UNIST-gil, Ulji-gun, Ulsan, 44919, Republic of Korea

*Corresponding author: ani@cheme.utm.my