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Overview of the Potential of Bio-Succinic Acid Production from Oil Palm Fronds

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ABSTRACT: *The realisation on the environmental impact, depletion of fossil fuel and the importance of sustainable technology are among the driving forces for replacing petrochemical approaches with biological methods. Bio-succinic acid production in this regards was listed as one of the potential chemical building blocks to be commercially produced via biological approach by the United States Department of Energy in 2004. Bio-succinic acid production has a net zero carbon footprints and 30%–40% less energy consumption. Moreover, the economic potential has surpassed the conventional petrochemical approach. This had led to the commercialisation of bio-succinic acid around the world in the past three years. This mini review serves to investigate the potential of oil palm fronds for the production of bio-succinic acid. Different reported renewable carbon sources for the production of bio-succinic acid were compared with oil palm fronds in terms of cost and availability. There is approximately 250 million metric tonnes of oil palm fronds with 68.3% structural carbohydrate. It has an approximate potential capacity of producing as much as 30.8 million metric tonnes of bio-succinic acid per annum worldwide. Oil palm fronds turned out to be the cheapest biomass (lower than USD 20/tonne) as compared to the other 12 biomasses reported for the production of bio-succinic acid.*

Keywords: Bio-succinic acid, oil palm fronds, sustainable, carbon footprints, acid production

1. INTRODUCTION

The increasing price of oil and gas, the rising concern of sustainability, and environmental issues have led to research on environmental benign routes. The adverse consequences of petrochemical industries are becoming visible.[1] Petrochemical approach was more competitive due to the continuous optimisation and researches on the process for more than half of a century as compared to biological approach. However, this trend will soon be altered due to depleting fossil fuels and the optimisation of biological processes. Biochemical approach converting renewable resources into valuable chemical products is a growing multibillion dollar industry.[2,3]

Bio-succinic acid has a molecular formula of $C_4H_6O_4$, which is known as butanedioic or amber acid. It is conventionally produced by catalytic hydrogenation of maleic anhydride or malic acid which originated from petroleum.[4] Sustainable and cheaper bio-production allow bio-succinic acid to be competitive and become a rising alternative over conventional petrochemical approach.

Apart from sustainability, bio-succinic acid excels in environmental aspect too. The current bio-succinic acid production lowers the release of greenhouse gas (GHG) emissions by 50% as compared to the production of equivalent petrochemical products. Further development of this approach could potentially realise 80% of GHG emissions reduction.[6] In fact, a life cycle analysis by BioAmber showed that bio-succinic acid production had a net zero carbon footprint.[7] Moreover, a decrease of 60% total energy consumption was reported as compared to conventional petrochemical approach in their study.[7] Bio-production of bio-succinic acid is aligned with the mission of the United Nation Framework Convention on Climate Change (UNFCCC) to minimise the carbon footprint by using green technology in chemical production.[8]

2. BIO-SUCCINIC ACID CURRENT TREND

2.1 Market of Bio-Succinic Acid

Currently, petrol-based is the commonly used bio-succinic acid globally. The market for the same is estimated to decline by 2019. Due to the negative impact of the conventional succinic acid, emphasis is laid on production and consumption of bio-based succinic acid. Bio-based succinic acid is primarily preferred for pharmaceuticals and cosmetic applications as it is considerably less toxic, which has great advantages for the industry of personal care, home care and cosmetics.[9]

This four-carbon dicarboxylic acid, succinic acid, has been identified as one of the 12 chemical building blocks that can potentially be produced commercially through biological conversion, according to the US Department of Energy in 2004.[5]

Susanne Kleff, Senior Scientist for Michigan Biotechnology Institute, outlined three largest potential markets for bio-succinic acid. The primary potential opportunity is a replacement for petrochemical maleic anhydride, which currently serves 1.65 million tons of capacity annually. This is followed by global demand for polymers, currently derived from butane occupying a market capacity of more than GB 1.6 million per annum. The other potential capacity for bio-succinic acid is for pyrolidinones which are used in the production of eco-friendly chemicals and green solvents for water treatment, which currently serves a global market capacity of about GB 100 million annually.[25]

The applications of bio-succinic acid market vary from 1,4-butanediol (BDO), plasticiser, polybutylene succinate (PBS), food and beverages, pharmaceutical, solvents and lubricants, polyols, and other industrial applications. BDO is largest application that drove the global bio-succinic acid market with about 17% in year 2013. BDO is forecasted to increase with compounded annual growth rate (CAGR) of 35% in 2014–2020 by OMR Industry Analyst and Grand View Research.

BDO dominated the global market accounting for over 35% of the overall demand in 2013. Growing consumption of BDO in engineering plastics, cleaning products, pharmaceuticals, coatings, adhesives and sealants is expected to fuel market growth. Replacement of maleic anhydride (MAN) by bio-succinic acid is expected to drive its demand tremendously in BDO over the forecast period.

BDO is used industrially as a solvent and in the manufacture of some types of plastics, elastic fibres and polyurethanes. BDO is used for the synthesis of γ-butyrolactone (GBL). In the presence of phosphoric acid and high temperature, it dehydrates into the important solvent tetrahydrofuran.[10] At about 200°C in the presence of soluble ruthenium catalysts, the diol undergoes dehydrogenation to form butyrolactone.[10] It is also manufactured on an industrial scale from maleic anhydride in the Davy process, in which it is first converted to the methyl maleate ester, then hydrogenated. However, this market will be taken over by bio-succinic acid route which is more economic and environmental friendly.

Polyurethane is a polymer composed of a chain of organic units joined by carbamate (urethane) links. While most polyurethanes are thermosetting polymers that do not melt when heated, thermoplastic polyurethanes are also available. Polyurethane polymers are traditionally and most commonly formed by reacting a di- or polyisocyanate with a polyol. Both the isocyanates and polyols used to make polyurethanes contain on average two or more functional groups per molecule.

Some noteworthy recent efforts have been dedicated to minimising the use of isocyanates to synthesise polyurethanes, because the isocyanates raise severe toxicity issues. Non-isocyanate based polyurethanes (NIPUs) have recently been developed as a new class of polyurethane. Transparency market believes that the growing demand for plasticisers and polyurethanes will further boost the overall market. The upward trend in the demand for resins, coatings, dyes, and ink will help the global bio-succinic acid market grow, as bio-succinic acid is a major component in the manufacture of these products.[11]

Polyester polyols accounted for significant revenue share on account of growing polyurethanes demand. In addition, its growing use in molded foams, soles in footwear, automotive interiors, and as adhesives and sealants is likely to increase polyester polyols market share. PBS is expected to grow with fastest CAGR of 38.9% from 2014 to 2020 owing to excellent growth potential in packaging coupled with increasing demand for bio-plastics.[12] Figure 1 shows the global bio-succinic acid market by application in year 2013.

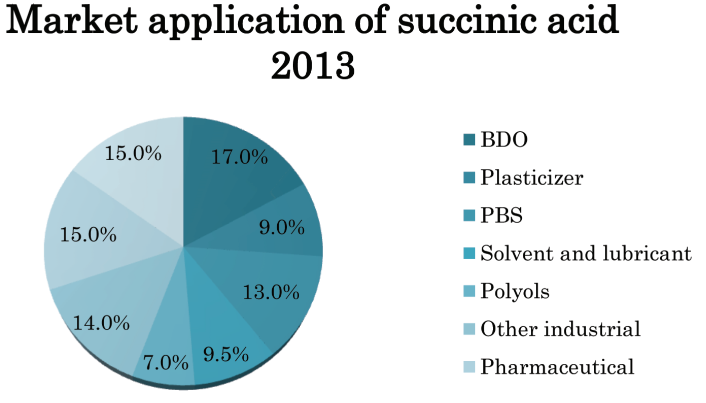

Figure 1: Global bio-succinic acid market by application in year 2013 (Source: OBRC Analysis[13]).

2.2 Supply of Bio-Succinic Acid

Over the past few years, several key players in bio-succinic acid production have started commercialising bio-based succinic acid production plants. Commercialised bio-based succinic acid production by several companies is summarised in Table 1. BASF, Purac, BioAmber, Mitsui and PTT MCC Biochem are among the early players of bio-succinic acid production, as shown in Table 1. Reverdia (joint venture between DSM and Rouquette) also joined this revolution by using yeast technology for bio-succinic acid production.[15] In addition, US-based Myriant was supported by the US Department of Energy in setting up a commercial-scale facility in Louisiana.[10] The development of this exciting technology can be a platform to develop other potential bio-based chemical building blocks. Global bio-succinic acid producers with different capacities were shown in Table 1.

Table 1: Bio-succinic acid production capacity.

Company	Annual capacity (tonnes)	Plant location	Operational date
BASF-Purac JV	50,000	NA	NA
BASF-Purac JV	25,000	Barcelona, Spain	2013
BioAmber-ARD	3,000	Pomacle, France	Full capacity by Q2 2012
BioAmber Mitsui JV	65,000	US or Brazil	NA
BioAmber Misui JV	17,000 (initial), 34,000 (at full capacity)	Sarnia, Ontario, Canada	2013
BioAmber Mitsui JV	65,000	Thailand	2014
Myriant	13,600	Lake Providence, Louisiana	Q1 2013
Myriant-China National BlueStar	110,000	Nanjing, China	NA
Myriant	77,110	Lake Providence, Loisiana	Q1 2014
Myriant-Uhde (owner and operator)	500	Infraleuna sit, Germany	H1 2012
Reverdia (DSM-Rouquette)	10,000	Cassano Spinola, Italy	H2 2012
Total	1,008,000		

NA = Not available; Q1= first quarter of the year; H1= first half of the year; H2= second half of the year.
Sources: OBRC Analysis,[13] ICIS Chemical Business[14]

2.3 Market Demand of Bio-Succinic Acid

Several comprehensive studies had been carried out by renowned forecasting companies to predict the future prospect of bio-succinic acid market. The estimation of global market of succinic acid was proposed based on the studies carried out by these market forecasting companies. Each company had a different forecast on succinic acid market. In this study, the average market estimation that considers all nine market forecasting companies was acquired which would better reflect the reliable figures on the current and future market, as well as the CAGR of succinic acid. The market forecasting companies include Global Industry Analyst, Transparency Market, Allied Market Research, Grand View Research, Market and Market Research, Research and Market, Occams Business Research & Consulting and OMR Industry Report as shown in Table 2.

Table 2: Global market forecast for bio-succinic acid from nine companies.

Current demand	CAGR	Forecast market	Reference
–	–	USD 3.5 billion by 2020 (654kton)	16
USD 240 million in 2011	19.4% (2012–2018)	USD 836 million by 2018	11
USD 137 million in 2013	22.6% (2014–2019)	USD 486.7million by 2019	18
USD 115.2 million in 2013	45.6% (2013–2020)	USD 1.1 billion by 2020 (710kton)	19
USD 170.6 million in 2014	23.32% (2014–2022)	USD 912.91 million by 2022	9
USD 137 million in 2013 (47.5kton)	–	–	Grand View Research 2014
USD 400 million in 2014	20%	1000 by 2020	20
–	24% (2014–2020)	–	21
–	–	1280 by 2020 (711kton)	13
–	22% (2015–2020)	–	22

The average CAGR from all these nine market forecasting companies over the period from 2012–2022 was 25%. The base year was set at 2014 by using the 25% CAGR while the forecasting was set until year 2020. These figures were adjusted in Table 3 for a more accurate estimation of future bio-succinic acid market.

Table 3 shows the average CAGR for bio-succinic acid market that was used to forecast the market demand on 2020. The forecasted market demand of 1344 was used to back calculate the CAGR from 2014–2020 using the following formula:

$$\text{CAGR} = \left(\frac{\text{volume at the predicted year}}{\text{volume at the base year}}\right) \text{number of forecasting years} - 1$$

Both calculated and predicted values from nine market forecasting companies were averaged that resulted in a final CAGR of 27.8% from 2014 to 2020 while USD 1177 million/year market demand was forecasted in the year 2020.

Table 3: Adjusted figures for succinic acid market trend.

2014 capacity USD/annum	CAGR (%)	Forecast 2020 market capacity USD/annum	Reference
–	–	3500	16
469	19.4	1429	11
171	22.6	622	18
144	45.6	1100	19
171	23.32	477	9
400	20	1000	20
–	24	–	21
–	–	1280	13
–	22	–	22
271	25	1344	Average
271	27.8	1164	Adjusted average (to tally between CAGR and 2020 forecasted market)

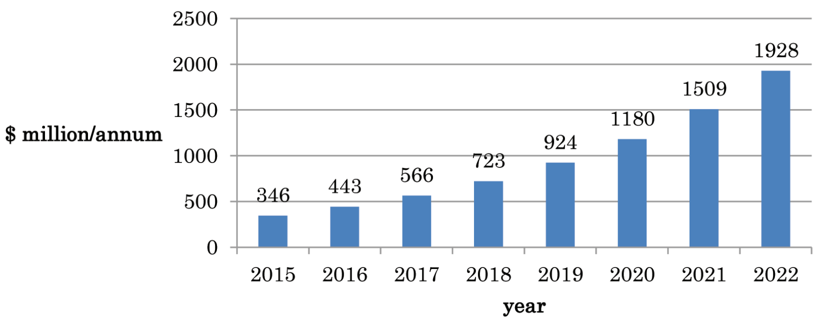

Figure 2: Market forecast from year 2015–2020.

The value of 27.8% CAGR was used for the construction of market forecasting in year 2015–2020 as shown in Figure 2. Therefore, the final estimated market volume for bio-succinic acid in the year 2022 was USD 1.9 billion/annum. Cenan Ozmeral, Myriant's General Manager for speciality chemicals, forecast that the total penetration of the bio-based succinic acid market would hit USD 10 billion/annum.[23] Therefore, 1.9 billion market demand for bio-succinic acid was only 19% from the total potential of this industry.

2.4 Regional Market of Bio-Succinic Acid

Europe occupied the largest market of bio-succinic acid in year 2013, owing to the fast-growing personal care and pharmaceutical industries. The key consumer that drove this market is Germany. However, Asia Pacific (APAC) region has been identified as the most potential market for highest CAGR from 2015–2020 (all of the forecasts). This was due to the fast industrialisation of APAC countries particularly China and India that led to the increasing demand for bio-succinic acid. APAC was forecasted to turn the table and become the largest market demand for bio-succinic acid, surpassing Europe region. Allied Market Research has forecasted the rapid growth of bio-succinic acid market as high as 49.5% CAGR in APAC region while Global Industry Analyst forecasted 34.3%.[16,19] The average forecasted values from these companies gave 41.9% CAGR. OBRC analysis showed that APAC market capacity of bio-succinic acid in year 2013 was 24%.[13] This is equivalent to approximately USD 271 million × 24% = USD 65 million. Succinic acid market by region in year 2014 is shown in the Figure 3 below.

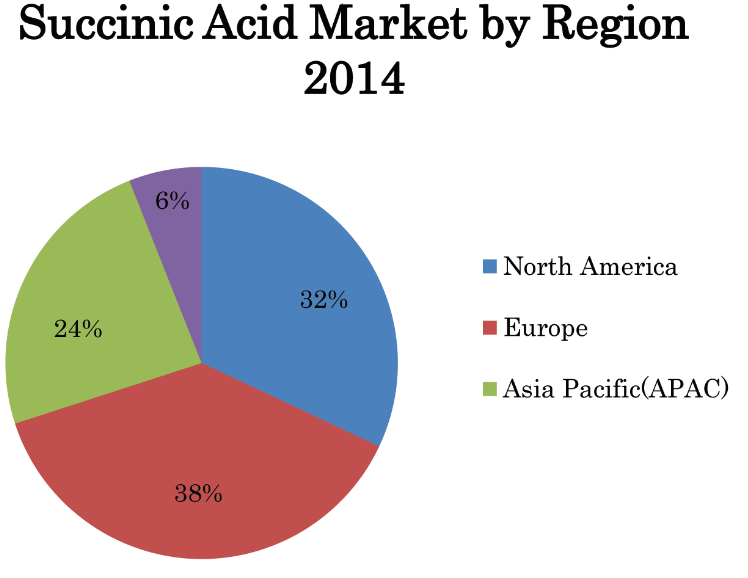

Figure 3: Succinic acid market by region 2014 (Source: OBRC Analysis).[13]

Therefore, by using the average CAGR for APAC region as 41.9% and the base year in 2014 as USD 65 million, the forecasted APAC market demand for bio-succinic acid in year 2022 was USD 1,070 million. The price of bio-succinic acid was approximately USD 2,500 per ton. This resulted in a market demand for bio-succinic acid of approximately 427 kilo tonnes in APAC region in 2022.

According to ICIS company report, the current market supply of bio-succinic acid in APAC was reported in Nanjing, China by a joint venture between Myriant and China Blue Star, which has one of the largest production capacities in the world with 110 kilo tonnes per annum. Another production plant was reported in Rayong, Thailand with an annual production capacity of 65 kilo tonnes, which was owned by BioAmber-Mitsui joint venture.[14] This has led to a total production capacity of 212 kilo tonnes of succinic acid in year 2022 in APAC region. APAC, being the fastest growing demand for succinic acid due to rapid industrialisation in the region, had a market vacancy of approximately 427 kilo tonnes – 212 kilo tonnes = 215 kilo tonnes of succinic acid in year 2022. Figure 4 shows the final market demand for succinic acid estimation for 2014–2022.

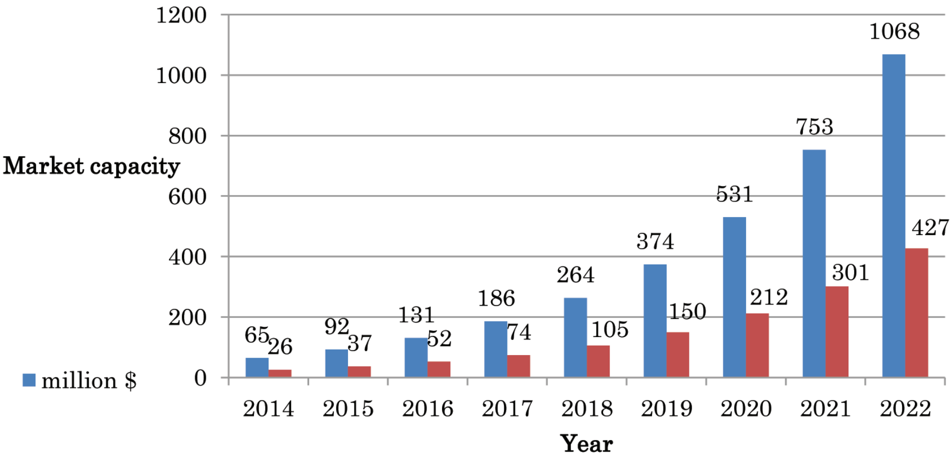

Figure 4: APAC market demand for succinic acid 2014–2022.

2.5 Price of Succinic Acid, by Product and Raw Material

Price of petroleum-based succinic acid in year 2011 is around USD 2,400 to USD 2,600 per metric tonnes while the bio-based succinic acid is approximately USD 2,860 to USD 3,000 per metric tonnes. The total market volume is about USD 63.2 million for year 2011. However, starting from year 2013 onwards, the bio-based succinic acid price is expected to go down to USD 2860 per metric tonnes.[24]

From the aspect of application, the production of 1,4 butanediol is predicted to occupy the largest consumption of the bio-succinic acid with more than 50% of the total market share. 1,4 butanediol is widely used as a solvent in industrial application and also for the manufacturing of plastics, elastic fibres, electronic chemicals and polyurethanes. The second largest application of production of PBS which is a thermoplastic polymer derived from succinic acid. It can be processed to be used as packaging material in the form of bags or boxes. Figure 5 shows the global succinic acid by application in year 2020.

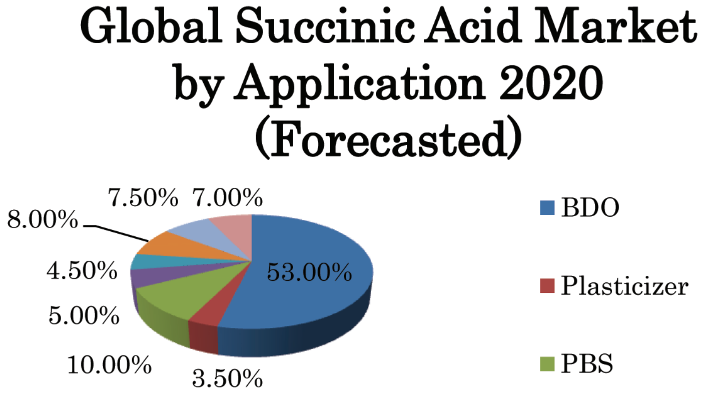

Figure 5: Forecasted global bio-succinic acid market by application in year 2020.[13]

Figure 5 shows that in 2020, the demand of bio-based succinic acid in APAC region is estimated at 427 kilo tonnes while the market can only supply 212 kilo tonnes of bio-succinic acid. This led to a market vacancy of about 215 kilo tonnes in the region. Therefore, the market vacancy for BDO is approximately 215 kilo tonnes × 0.53 = 114 kilo tonnes in APAC region in 2020.

3. PROSPECTS OF OIL PALM FRONDS

The major usage of palm oil is as cooking oil, but it is also used in detergent, biofuel, food products, cosmetics and more. More than 50% of all packaged products in the US contain palm oil including ice cream, soap, lipstick, detergent and others.[26] Palm oil is a remarkably highly efficient vegetable oil. Comparatively, palm oil requires a much lower production cost but produces a much higher yield. Besides, among the 10 major oilseeds in the world, palm oil accounts for 5.5% of the land use for cultivation worldwide, but produces 32% of the world's oils and fats.

Global demand for palm oil is 51.2 million tonnes in 2012.[15] Oil palm plantations are spreading across Africa, Asia and Latin America. Southeast Asia region has been reported to be the largest producer in the world. Indonesia and Malaysia are responsible for 85% of the world's supply of palm oil.[27] Hand in hand with the development of this industry is the mass production of oil palm wastes which is much less noteworthy in terms of economic value as compared to palm oil. Mesocarp fibres and shells are used as fuel in the mill boilers to generate steam for producing electricity which leads to the savings in fuel costs.[28] However, most of the biomass produced is still categorised as waste.

Oil palm frond (OPF) in this regard turns out to be the largest residue from palm oil industry (70%)[29] which amounts to approximately 83 million metric tonnes per annum in Malaysia.[30] The world production of OPF is approximated to be 250 million tonnes (wet weight). This is estimated from the ratio of the cultivation land in Malaysia (4.49 million hectares)[31] to the world cultivation land of oil palm (13.46 million hectares).[32] OPF is available daily during pruning for harvesting fresh fruit bunch. Pruned frond is left at the oil palm estate for nutrient recycling and soil conservation.[33,34] However, OPF consists of a large amount of carbohydrates.[30] The carbohydrate is in structural form in the bagasse part while readily fermentable sugars are available in the juice of the fronds. In order to optimise OPF usage, the petiole part of the frond should be acquired from the lower half nearer to the trunk while the leaflet should be left in the estate for nutrient recycling and erosion prevention.

Biomass Technology Centre (BTC) was set up by Malaysia Palm Oil Board (MPOB) in 2001 to research ways in producing high value added products from oil palm biomass and promote the image of oil palm industry as an environmental friendly industry through zero waste approach.[35] Bio-production of succinic acid using oil palm biomass in this regard, is in line with the mission of BTC. Moreover, Malaysia's Prime Minister has made a pledge at the 15th Conference of Parties of the United Nations Framework Convention on Climate Change in Copenhagen to reduce the GHG emissions intensity per Gross Domestic Product (GDP) by 40% by 2020,[35] which is another driving incentive for using oil palm biomass as bio-succinic acid production feedstock.

4. CARBOHYDRATE CONTENT AND THE PRE-TREATMENT OF OPF

There were three reports on the characterisation of oil palm frond, carried out by Zahari et al. using TAPPI method,[30] Ofori-Boateng and Lee via National Renewable Energy Laboratories (NREL) procedures,[36] and Lai and Ani that used ADF, NDF and ADL.[37] The average from these three reports showed high total carbohydrate percentage which is 68.3% in oil palm frond. This is perfect as a feedstock for bio-succinic acid production. The composition of OPF was tabulated in Table 4.

Table 4: Composition of OPF.

Reference	30	36	37	Average
Glucan vs Cellulose (C6)	41.7	41.9	35.3	39.6
Xylan+Arabinan vs hemicellulose (C5)	16.4	33.6	36.1	28.7
Total structural carbohydrate %	58.1	75.5	71.4	68.3
Lignin	15.5	20.65	29	21.7

The structural carbohydrate content in OPF however, requires pre-treatment to recover the sugars from lignocellulosic biomass before it can be used in fermentation. The recalcitrance (resistance of plant cell walls to destruction) is due to the highly crystalline structure of cellulose which is embedded in a matrix of polymers-lignin and hemicellulose.[38] The prime objective of pre-treatment is to overcome the recalcitrance, to separate the cellulose from the matrix polymers, and to make it more accessible for enzymatic hydrolysis. Pre-treatment methodologies can basically be divided into four categories which are chemical, physical, physiochemical and biological pre-treatment.[38]

Physical pre-treatment includes extrusion, milling, freezing and microwave, resulting in reduction in the degree of polymerisation and crystallisation of biomass. This category of pre-treatment is normally targeted to increase the surface area and reduce the particle size of lignocellulosic materials.[38] Apart from physical pre-treatment, there are chemical pre-treatment that includes ionic liquid, organosolv, alkaline, acid and ozonolysis pre-treatment; physiochemical pre-treatment that includes ammonia fibre explosion (AFEX), steam explosion, liquid hot water (LHW), carbon dioxide explosion and wet oxidation (WO); and biological pre-treatment (enzymatic pre-treatment), which are among the established approaches in harvesting fermentable sugars from complex carbohydrate (cellulose, hemicellulose and lignin) in lignocellulosic biomass.[38]

Recovering fermentable sugars from lignocellulosic oil palm biomass is one of the research focuses in Malaysia. Several institutes in Malaysia had come out with different pre-treatment methods for OPF to extract the sugars from complex carbohydrate into a more readily fermentable form. Table 5 shows several pre-treatment methods for OPF. These studies serve to increase the recovery of fermentable sugars in OPF that would be helpful for bio-succinic acid fermentation.

Several technologies tried on the pre-treatment of OPF include hot compressed water (HCW), autohydrolysis, ionic liquid, ethanolic hot compressed water (EHCW) and SOP/H2O2 as shown in Table 3. Among these pre-treatment methods, ionic liquid gave the most promising pre-treatment method that could recover 100% of glucose structural carbohydrate in OPF. The establishment of this pre-treatment method allows the efficient recovery of fermentable sugars from structural carbohydrate in OPF.

Table 5: Several pre-treatment methods for fermentable sugars recovery from OPF.

Pre-treatment method	Conditions	Total solids (%)	Glucose (%)	Xylose (%)	Reference
Hot compressed water (HCW)	175°C 15.5 min	–	84	–	39
Auto hydrolysis	121°C 60 min	75	–	27	40
Ionic liquid	92°C 24.1 min	–	100	–	41
Ethanolic hot compressed water (EHCW)	180°C 42 min	–	88	–	42
SOP/H_2O_2	80°C 70 min	45	86	61	36

Apart from the lignocellulosic bagasse, OPF can be pressed to extract the juice. The juice was reported to contain 76.09 g/l of total sugars.[30] On the bio-succinic acid fermentation side, the maximum glucose concentration for the highest bio-succinic acid yield was at 70 g/l of glucose concentration via *Actinobacillus* succinogenes.[43] This was the concentration of total sugar reported in OPF juice. This phenomenon supports OPF as a practical carbon source for the bio-production of succinic acid. Apart from that, Zahari et al.[30] reported that the total amino acids in the OPF juice were 174.1 µg/g, with serine (111.0 µg/g), glutamic acid (22.7 µg/g) and proline (27.1 µg/g) as the major amino acids[30] which is almost similar to that oil palm trunk sap reported by Kosugi et al.[44] The presence of this amino nitrogen further accredits OPF as the carbon source for bio-succinic acid since it can reduce the reliance on external nitrogen source for microbial fermentation process.

5. ECONOMIC POTENTIAL OF BIO-SUCCINIC ACID FROM OPF

In order to elevate the potential of bio-production of succinic acid, the cost of bio-production must be made competitive compared with the petrochemical method. The cost of the raw feedstock (carbon source) in this case contributes directly to the total production cost. This issue is becoming increasingly vital due to the increasing sugar prices. It has become one of the hottest topics for the researchers around the world. Approximately 12 other biomasses had been introduced to replace the costly sugar as the carbon source for bio-succinic acid fermentation as compiled in Table 6. OPF in this regard has the potential to serve as the cheapest feedstock for fermentation. Apart from cost, availability of the biomass is another important parameter to ensure a large and continuous supply of carbon source for production of bio-succinic acid.

Table 6: Cost comparison of raw materials (waste biomass) and their availability.

Rank	Types of biomass	Cost of biomass (USD $tonne^{-1}$)	Availability (mmt/annum)
1	OPF	19.4	250
2	Sugarcane bagasse	23	74
3	Rice straw	29	800
4	Cotton straw	38	107
5	Corn core/cob	40	84
6	Corn straw	40.5	1015
7	Wheat straw	60	915
8	Waste bread	60	0.8 (UK)
9	Sugarcane molasses	140	56
10	Wheat	261	704
11	Rapeseed meal	324	31
12	Soybean meal	506	152
13	Whey	795	2.5

Figure 6 shows the potential bio-succinic acid capacity that can be generated from OPF in the global scale. This could give an overview which covers the loss in every stage of the operation from the recovery of fermentable sugars from structural carbohydrate until the final stage of recovering bio-succinic acid from the fermentation.

As mentioned earlier, the world production of OPF is estimated to be 250 million tonnes (wet weight) from the ratio of the cultivation land in Malaysia (4.49 million hectares),[41] to the world cultivation land of oil palm (13.46 million hectares).[21] 24% of juice can be extracted from raw OPF which splits the OPF into roughly 60 MMT of juice and 190 MMT of OPF bagasse.[47] Bagasse contains approximately 60% moisture content in the bagasse, leaving about 76 MMT of dry OPF bagasse. 68.3% of the dried bagasse is 52 MMT of structural carbohydrate (from the average calculated in Table 2). Taking an estimation of 90% recovery from the pre-treatment, 47 MMT of fermentable sugars can be recovered from the dried bagasse.[38] The sugar utilisation is estimated to be 95%,[46] which led to 44 MMT of sugars fermented in the fermentation process. Taking 80% succinate yield from the

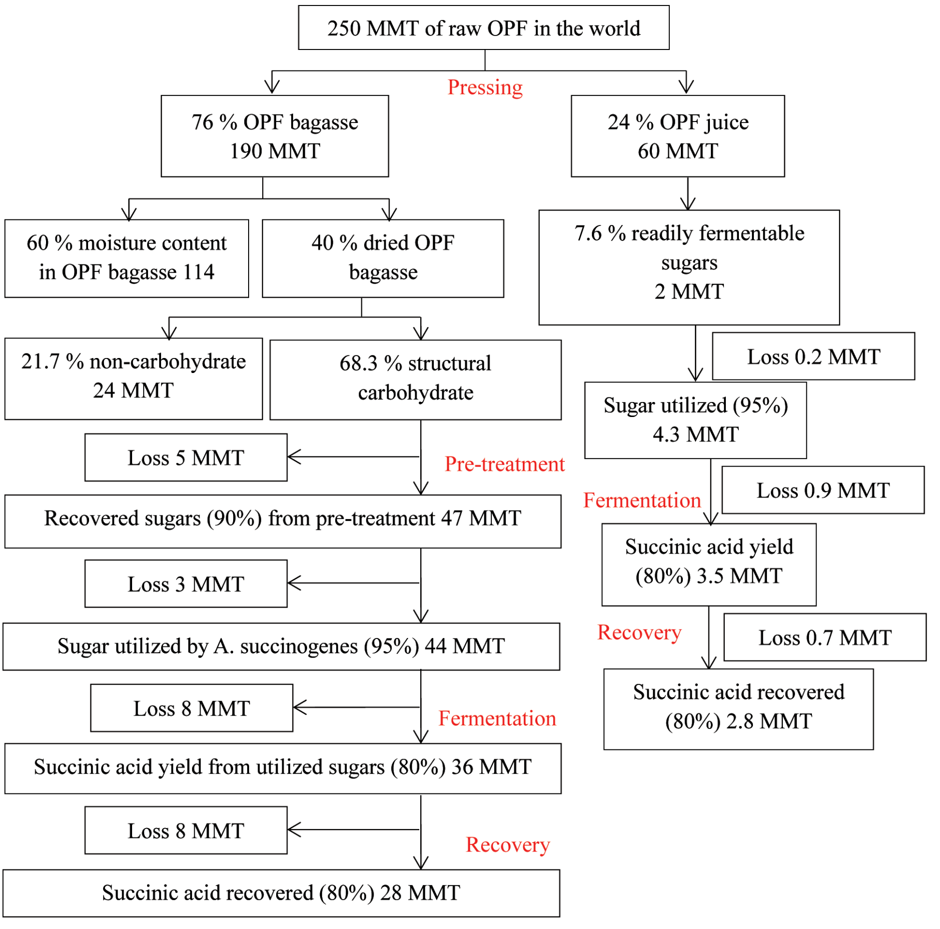

Figure 6: Potential world production capacity for bio-succinic acid from OPF.

used sugars, 36 MMT of bio-succinic acid is assumed in the fermentation broth at the end of the bio-succinic acid fermentation.

Finally, by approximating the bio-succinic acid recovery of 80%, 28 MMT of ready-to-sell bio-succinic acid can be obtained from the OPF bagasse. OPF juice on the other hand, was estimated to be 60 MMT around the world. The readily fermentable sugars in the juice were reported to be 76 g/l (7.6% w/w). Assuming 95% sugar utilisation, 80% yield and 80% bio-succinic acid recovery, 2.8 MMT of bio-succinic acid can be obtained from the OPF juice fermentation. Therefore, the total potential production capacity of bio-succinic acid from OPF is 28 MMT from the OPF bagasse, together with 2.8 MMT from the OPF juice will be 30.8 MMT per annum. The price of the bio-succinic acid is about \$6000–\$9000/tonne.[6]

6. CONCLUSION

OPF is one of the most sustainable renewable resources for bio-succinic acid production due to the stability of oil palm plantation industry in Malaysia. Judging from its availability at a large amount, consistency in supply, low cost, high content of reducing sugar, composition of nitrogen source, polices of the Malaysia Palm Oil Council and the support of Malaysia government, OPF should be considered as one of the best carbon sources for bio-succinic acid production. This exciting technology and facilities being developed for succinate production from OPF can be used as a platform for the development of other high potential bio-based building blocks molecules to fill the needs of local chemical demands. Malaysian National Biomass Strategy 2020 also proposed that the best use of oil palm biomass is for higher value-added downstream activities, e.g., generating bioethanol and bio-based chemicals rather than those business-as-usual uses of wood products, animal feed, energy, and using biomass directly on the field as fertilisers. The biggest long-term opportunity for Malaysia is in bio-based chemicals, with a forecasted global market size of RM 110–175 billion by 2020. Likewise, producing biofuel and bio-based chemicals from oil palm biomass will increase wealth and open up new and better jobs.

7. ACKNOWLEDGEMENTS

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