Journal of Sustainable Development Studies
ISSN 2201-4268
Volume 5, Number 1, 2014, 100-115

Implementation of Bioenergy from Palm Oil Waste in Indonesia

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Abstract. Nowadays, the use of Renewable Energy (RE) has been proposed because the concerns with the price fluctuation of oil due to its high demand and its environmental benefits. In the field of RE, at present there is a continuously increasing interest concerning bioenergy from palm oil. Nevertheless, several studies point out the environmental impacts of bioenergy when compared to conventional energy and therefore question, if bioenergy in general is more environmentally friendly than conventional energy use, is still exist. Though researches have been carried out on different forms of bioenergy from palm oil waste, little is known about which part of palm oil waste and implementation are the most beneficial for the environment. There are few ways for that: pelletization, gasification, liquefaction and the latest been found, torrefaction, a low temperature at 200-300°C under an inert atmosphere which effective for improving the energy density and the shelf life of biomass. In this paper, it is aimed to analyze the implementation A to Z of waste utilization from palm oil cultivation through the torrefaction process towards its environmental impacts. This article uses palm oil real data from Indonesia as a potential country for biomass energy production given its equatorial climate. The result will be of use in modeling commercial production of bio-coal from palm oil waste regarding its impact to environment.

Keywords: Bioenergy, Palm Oil Wood, Torrefaction, Biomass, Bio-coal, Renewable Energy

1. Introduction

Nowadays, the concerns about the price fluctuation of oils, its high demand and climate change have been a hot issue on the international policy discussion. The use of Biomass as energy is often suggested as the promising renewable energy sources, and is utilized as solid, liquid and gas fuels. Biomass accounts for approximately 15% of global primary energy use and 38% of the primary energy use in developing countries. More than 80% of biomass energy is used by more than two billion consumers, many of whom have no access to modern energy services.

At present there is a continuous increasing interest concerning palm oil as a renewable energy resources for biomass. Biomass power potentials from palm oil were estimated at 820 TJ on 2010. Indonesia has very substantial potential for biomass energy utilization from palm oil given its equatorial climate that is ideal for dense tropical forest growth and agricultural vegetation. As of 2009, Indonesia was the largest producer of palm oil, surpassing Malaysia in 2006, producing more than 20.9 million tons. Indonesia aspires to become the world's top producer of palm oil. But at the end of 2010, 60 percent of the output was exported still in the form of Crude Palm Oil. FAO data show production increased by over 400% between 1994 and 2004, to over 8.66 million metric tons. In addition to providing traditional markets, Indonesia is trying to put more effort into producing biodiesel (Indonesian Palm Oil Advocacy Team 2010).

Along with the growing of palm oil industry in Indonesia, it also creates the availability of palm oil residue. However, in some agricultural industries, large concentrations of biomass waste can be utilized for power and heat production, thereby providing access to modern energy services. The types of residue generated by the palm oil industry include Empty Fruit Bunches (EFB), Palm Mesocarp Fiber (PMF) and Palm Kernel Shell (PKS) as a potential source of solid fuel. EFB, mesocarp fiber and kernel shell are generated at palm oil mills. EFB is the residue generated at the thresher, where fruits are removed from fresh fruit bunches. Mesocarp fiber is generated at the nut/fiber separator while kernel shell is generated from the shell/kernel separator. Because of its abundant availability, palm oil wastes are considered as a great potential to become alternative source of renewable energy.

In general, oil forms about 10% of the whole palm oil trees while the other 90% remains as biomass. Fresh fruit bunch contains only 21% palm oil, while the rest are 14-15% fiber, 6-7% palm kernel, 6-7% shell and 23% EFB which left as biomass. Nowadays, utilization of biomass has attracted interest of researchers because of its potential applications. One of the key technologies for utilizing biomass residues towards an efficient renewable energy supply in Indonesia is torrefaction. However, torrefaction technology is not yet fully developed and study about the environmental impacts of this technology alternatives within the process have yet to be made.

Main advantage properties of torrefied biomass are the moisture is reduced which the energy density is increased; O/C ratio is reduced which increased the heating value; the strong fibrous of biomass become brittle, which improve grindability and reduces the cost and energy required for grinding. Although, torrefaction seems to be one of the pre-treatment for biomass, less attention had been paid to torrefaction palm biomass. Thus in this study, we focus on torrefaction of empty fruit bunches (EFB), mesocarp fiber and kernel shell of palm oil, which are typical agricultural wastes in Indonesia.

However, little is unknown about which palm oil residue and is torrefaction technique more environmental friendly in comparison to other options. In addition, it is important to conduct research in order to verify the comparison. Therefore, the purpose of this study is to discuss the best implementation of bioenergy production from palm oil residue in Indonesia and identify the most environmentally saving option.

2. Material and Methods

2.1 Overview of Indonesian Palm Oil Industry

Nowadays, Indonesia is one of the world's largest producers of palm oil. This industry has been the economy's most valuable agricultural export sector for recent years. The attractive gains, strong demand and high prices of palm oil in international market have strengthened investment in Indonesian palm oil industry, making significant rural economic development and poverty alleviation. Indonesian palm oil industry achieved significant growth in last decade. Indonesia become the world's second largest economic growth and emerged as the world's largest producer of palm oil, surpassing its neighbor Malaysia in 2006 with an annual production of 16mn tones. The annual growth rate of Indonesia's CPO production during the last ten years continued to increase by 12% and in 2009, the production of Indonesian CPO reached 20.5mn tones, representing nearly half of the world total. Many forecasters predict country's production will be double to 40mn tones by 2020, thanks to strong demand from India and China despite lingering economic uncertainty in the US and Europe.

In the past seven years, the world's palm oil consumption increased sharply by reaching 42mn tones in 2009 and the demand is expected to exceed 100mn tones in 2015 as shown in figure 1. The main driver is foodstuff producers in developed countries are increasingly using palm oil to replace saturated animal fats. Another reason is the rising consumption of palm oil in developing countries and their overall population growth. Indonesia itself is currently the main consumer of domestic CPO for biofuels. The growth in domestic demand remains solid with palm oil consumption of 6.7mn tones in 2011, up 23% y/y. This results with many residues from palm oil waste, i.e. 19.5mn tones of EFB, 12mn tones of mesocarp fibre, and 5.9mn tones of palm kernel shells. Seeing those abundant residues, people can see that there are a lot of potencies from palm oil waste as renewable energy.

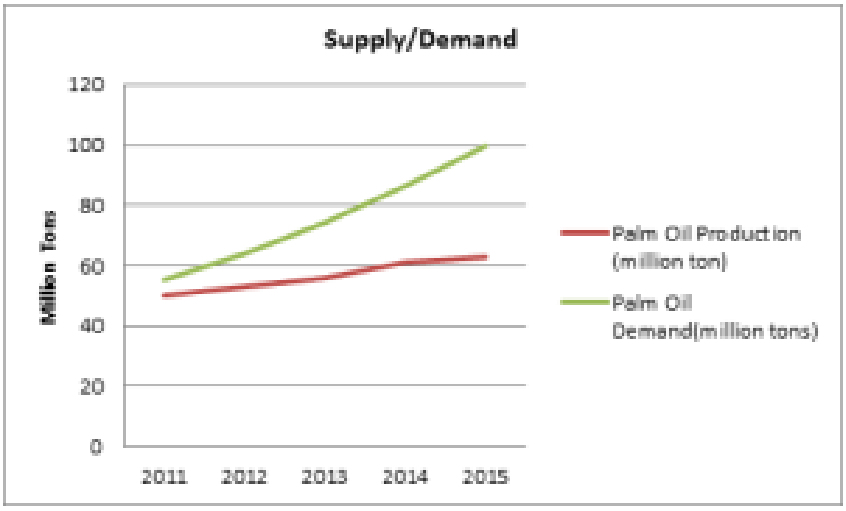

Fig. 1 shows world's palm oil supply/demand graph.

2.2 Best Practice

Palm oil industry in Indonesia consists of the following five stages: plantation, CPO mills, palm kernel oil mills (PKO mills), refinery factories and others.

Best agricultural practices are implemented in opening plantation, such as the usage of covering the crop to prevent erosion, constructing terrace and silt pits, correct placement of front piles, and mulching with empty fruit bunches to increase the organic matters in soil. Another method suggested by Jelsma et.al. [2009], is focusing on degraded land, evidenced by satellite imagery shots taken at 5-10 year intervals, using GIS system to monitor all agronomic and environmental issues, and ensuring the land acquired with the "free, prior and informed consent" of local people since landownership is a highly complex issue in Indonesia.

The next step in the production process is the transport of the fresh fruit bunches (FFBs) from the palm oil plantation to a CPO mill, in which CPO and biomass wastes are produced. Empty fruit bunch (EFB) and mesocarp fibre are the highest contributor of palm oil biomass, whereby about 19.5mn and 12mn tones, respectively have been produced per year. Palm oil fronds are available daily throughout the year when the palms are pruned during the harvesting of fresh fruit bunch for the production of oil. Palm oil trunk is obtained during the re-plantation of the palm oil trees. EFB, MF, shells are collected during the pressing of sterilized fruits.

Next process after CPO mill, kernel and CPO are transported to a kernel factory and a refinery factory where palm oil products are produced. In the process of palm oil product production, many kinds of residues are generated both on the plantations as well as in the palm oil factories. In plantations, felled palm trunks, palm fronds at felling and annual pruning cause the main source for residues. Empty fruit bunch (EPB), fibers and shells and palm oil mill effluent (POME) are generated in CPO mills. Parts of the fiber and shells are in some cases, utilized for mill boiler fuels. Because of this, recently palm oil has been given great attention as renewable energy resources and is being recognized as a candidate of potential project for the clean development mechanisms (CDM) under Kyoto protocol.

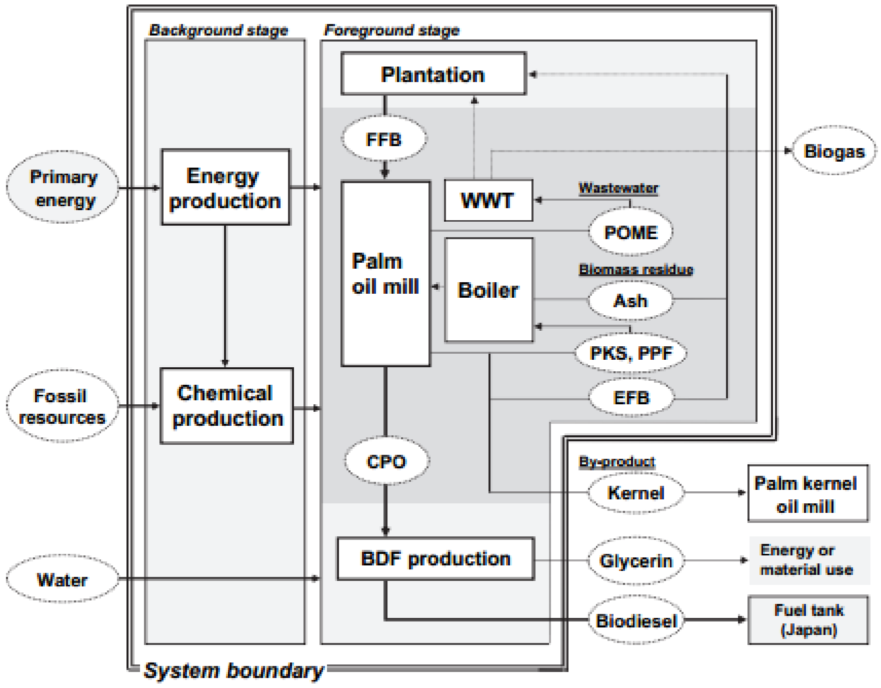

Fig. 2 shows palm oil plantation production system (FFB: Fresh fruit bunch, CPO: Crude palm oil, WWT: Wastewater treatment, POM: Palm oil mill effluent, PKS: Palm kernel shells, PPF: Palm press fiber, EFB: Empty fruit bunch.

2.3 Environmental Impact Study

This study will divide environmental impact of Palm oil process into six steps. In each step, possible impacts to the environment will be analyzed.

2.3.1 Impacts of the Plantation

Plantation development has many impacts to the environment. Site preparation contributes to the ecological impacts of the environment. If the plantation is located in an ecologically sensitive area, it may result in clearing and subsequently removal and extinction of ecologically important ecosystem and species. Aside ecological impact, plantation establishment also has impact on air due to the open burning of the biomass, and water due to the usage of agro-chemicals (i.e. fertilizers, pesticides, and fungicides). The biggest impact is on soil, which is mainly happened after forest clearing and plantation establishment. It is affecting soil quality by directly reducing nutrients and affecting soil properties such as infiltration rates.

2.3.2 Impacts of Cultivation and Transport

In this stage, Palm oil cultivation has significant impacts on water surface with the discharge of effluents and hydrocarbon contamination. Transportation of FFB as the result of cultivation process to the palm oil mills or port also has impact to the environment by generating dust, noise and air pollution with CO_2 emission.

As illustration, there are 608 units POM in Indonesia with capacity of total production reaches 34 tones FFB/hour in 2010, the annual requirement of FFB could, therefore, be in the region of some 212,160 tones (Ministry of Industry Republic of Indonesia 2011). This tonnage would require to be transported an average distance from various plantation collection points to the Palm Oil Mill. If we suppose that each truck carries about 5 tones of FFB at a time, the number of trips require to be made would be in the region of 42,432 and if the emission of the vehicles is say 250 gm of carbon dioxide per km (this is an estimated assumption which can vary considerably depending on the type, age, fuel used, condition and the design technology of the engine of the vehicle). If we had the distance traveled, we could estimate the amount of carbon dioxide gas that might be dumped into the atmosphere per annum from the vehicles supplying the Palm Oil Mill with FFB.

2.3.3 Impacts of the Mills

This stage has some impacts that can be summarized as follows:

a. The air and atmosphere as result of various exhaust gases from energy generating process that required for the extraction step.
b. The surface water through the discharge of untreated process effluent and other contaminated effluents.
c. Soil through hazardous substances spilled and bad “housekeeping” practices.
d. Pollution to the environment through the generation of solid waste.

Material balance and environmental impacts in plantation and CPO mill stages were illustrated in the Fig. 3 below through literature study.

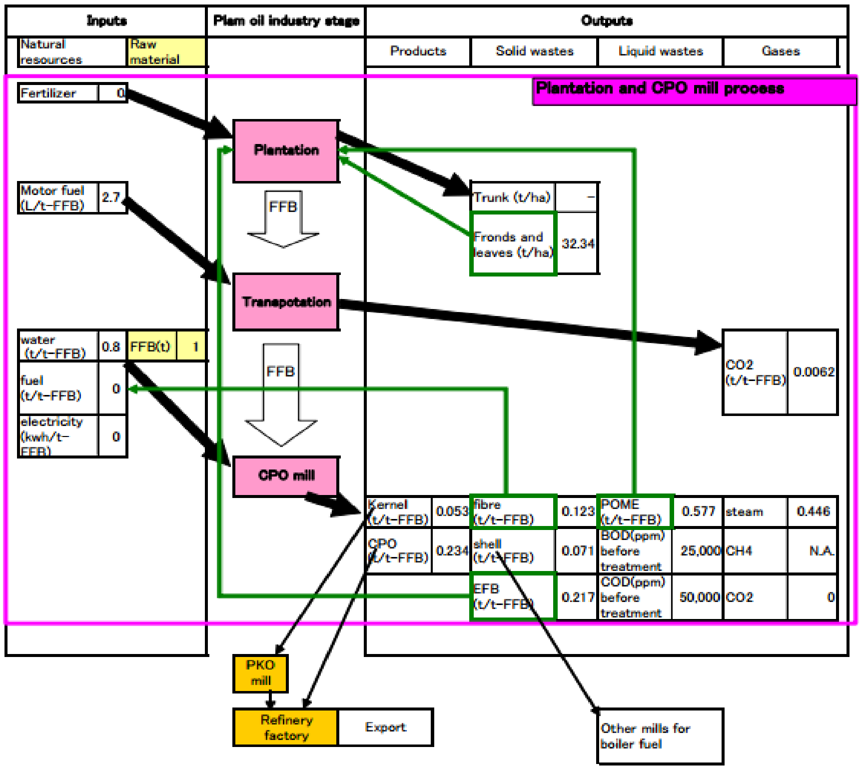

Fig. 3 shows material balance of typical palm oil plantation, transportation and CPO mil in Indonesia per one t-FFB basis [Hayashi Kiichiro, 2007]

2.3.4 Transport of Residues to Torrefaction Plant

Transportation of palm oil residues to the torrefaction plant is using truck. Overall transportation gives the same impact to environment which is traffic activities by generating dust, noise and air pollution with CO_2 emission.

2.3.5 Impacts of Torrefaction process

Most of the factories in Indonesia are already implementing concept of zero waste emission, for example, all bio-wastes are utilized as fertilizer and materials for energy generation. One example of technology that can generate energy from bio-wastes is torrefaction. Torrefaction is a thermo-chemical treatment process for carbonaceous feedstock such as biomass. It takes place under atmospheric conditions and within a temperature range of approximately 200 to 300°C. The process parameter is similar with the coffee beans roasting, and its effect can be categorized as mild pyrolysis. (IEA 2012).

Currently, biomass torrefaction is taken full attention as an important pre-processing step to improve biomass quality in physical properties and chemical composition. However, biomass torrefaction is also resulting environmental impacts which should be taken into consideration. The environmental impacts from the process are mostly emissions to the air. The output of torrefaction process contains organic acids, gaseous volatiles and primary tars. After capturing the liquid and gaseous products from the process, the rest of emissions consist only CO_2, H_2O, NO_X and SO_X. NO_X emissions can be ignored because of low temperature and SO_X emissions can also be negligible due to small amount of sulfur content in lignocellulosic biomass. The major concern which should be taken seriously in torrefaction biomass process is condensed tars. As the temperature rises during the process, the tar content also increases exponentially. Besides that, ash, chlorine, sulfur and alkaline production should also be addressed very carefully.

2.3.6 Impacts of final Transport

Crude palm oil and its derivatives product are transported from Sumatera Island or Kalimantan Island to other provinces for domestic needs or to the seaport for export needs. With the huge amount of CPO movement, either for domestic or export need, final transportation is also considered giving significant contribution to the environmental impact since it uses truck and ocean tanker that uses fossil-based diesel. Fossil-based diesel results in huge amount of CO2 emission.

According to Ministry of Industry Republic of Indonesia (2011), total export of Indonesia CPO and derivatives in 2010 is 16mn tones so the amount of carbon dioxide gas that might be dumped into the atmosphere per annum from the vehicles supplying CPO to the seaport for export needs to be taken seriously into consideration.

3. Results and Discussion

3.1 Overview: Torrefaction

3.1.1 Torrefaction definition

Torrefaction can be defined as a mild pyrolysis, which is simply the first step of thermo-chemical conversion of biomass under an inert atmosphere to the temperature within the scope of 200 to 300 C with the absence of oxygen. Torrefaction is commonly used as one of technology to upgrade biomass to a higher quality solid biofuel. It produces mainly three products: a solid product with high-dense energy referred as "bio-coal"; a condensable liquid containing mostly water, acid, and other oxygenate; and non-condensable gases-like CO_2, CO and small amounts of methane. The last two products are categorized as volatiles. During torrefaction, the raw material loses most of its moistures and other volatiles which have a low heat value. The type and amount of gas that is released during the process is depending on the material type and torrefaction process conditions, including temperature and time. At the end, torrefaction process produces a solid uniform product with lower moisture content and higher energy content than raw biomass. In conclusion, the primary goal of torrefaction technology is to refine raw biomass to an upgraded solid fuel with better qualities and enhanced combustible properties compared to fossil coal.

3.1.2 Technology and alternatives

Nowadays, there are four types of conversion technology currently existing, each techniques fits for specific biomass types, giving specific energy products:

a. *Thermal conversion*: Direct combustion, Pelletization and Pyrolysis.
b. *Thermochemical conversion*: Gasification, Liquefaction and Torrefaction
c. *Biochemical conversion*: Help of enzymes, bacteria and other organisms.
d. *Chemical conversion*: Involves use of chemical agents.

Combustion

Combustion is a chemical reaction that occurs between a fuel and an oxidizing agent that produces energy, usually in the form of heat and light. Considering the biofuels' composition of hydrocarbons exclusively, the products of complete combustion are carbon dioxide, water and the release of thermal energy.

Pelletization

Though pelletization is the cheapest option, there are some disadvantages relates with the result; quality deterioration by moisture (mass growth and bioorganic decomposition) and lower heat value.

Liquefaction

The main purpose of this technique is the production of liquid energy carriers, like pyrolysis oil or methanol. In most cases, this is achieved by combining some other thermo chemical treatment like gasification, pyrolysis or combustion.

Those three techniques together with torrefaction are in use currently or being developed for the future. Since this paper will focus more on torrefaction, other techniques are another future task to be studied. During the torrefaction process, the input biomass will lose about 30% of its mass, but only 10% of its energy. It is because of the moisture loss and de-gassing process of low energy volatile compounds, resulting in higher energy density of the biomass roughly 30% more energy per mass unit. Bioechemical torrefaction mechanisms are also changing biomasss' structure, leading to new properties that make the handling of the final product will be much easier, especially for being transported.

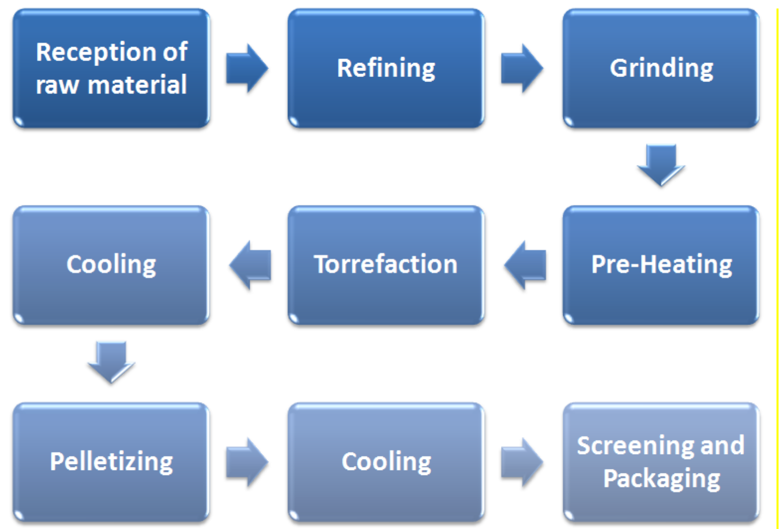

Fig. 4 shows Basic process of biomass torrefaction

Above figure shows basic process of operations in a biomass via torrefaction. From the storage of biomass, the material has to be refined first for purity and ground to smaller particles of a required size. After that, the material is heated actively. This is one important operation during the process, since the drying requires big amounts of heat. Then torrefaction step afterwards will roast the biomass with the temperature of 200-300 C and without oxygen. Next step, the material must be cooled down, since it may explode when it gets in contact with the oxygen. Next step is pelletizing process to improve the qualities and increase the volumetric energy density of the solid product. Then another cooling process to prevent high reactive fine matter with the oxygen. Final step is screening process to check the product quality and packaging the solid product for further handling and delivery process.

3.2 Palm Oil Waste

3.2.1 Palm oil waste potentials – by residues type

From study literature, there are 5 types of biomass produced by the palm oil industry: empty fruit bunches (EFB), mesocarp fiber, kernel shells, fronds and trunks. EFB, mesocarp fiber and kernel shells are discarded at palm oil mills, while frond and trunks are discarded at the plantations.

In general, oil is made from about 10% of the whole palm oil trees while the other 90% will be used as biomass. Fresh fruit bunch or FFB contains only 27% palm oil, while the rest are 19-21% fiber, 10-11% palm kernel, 10-11% shell and 30% EFB left as biomass source. Since the growth of palm oil consumption in Indonesia is increasing, the potency of palm oil residue as renewable energy in Indonesia is also growing. As illustration, domestic demand of palm oil in Indonesia in 2011 remains solid with 6.7mn tones. These results with many residues from palm oil waste: 19.5mn tones of EFB, 12mn tones of mesocarp fibre, and 5.9mn tones of palm kernel shells. All those amount of palm oil biomasses can be transformed into three types of biomass energies; bio-products, bio-fuels, and bio-power.

As stated in the introduction, in this study we focus on empty fruit bunches (EFB), mesocarp fiber and kernel shell of palm oil, which are typical agricultural wastes in Indonesia. The effect of torrefaction on the mass and energy yields were investigated for those three types of biomass waste via study literature.

Yoshimitsue Uemura et.al. (2011) in his study measured the moisture content, calorific value, and elementary content for the three types of palm residues. The moisture content is measured as follows: a prescribed amount of sample was weighed in a crucible and placed in an electric oven maintained at 105°C. After 24 hours of drying, the sample was weighed every one hour until the decrease in weight became negligibly small.

The calorific value is measured using a bomb calorimeter. The calorific value is the high heat value (HHV) from bomb calorimeter, which includes the latent heat of the vapor resulted from the specimen. Values of HHV obtained are converted to the low heat value (LHV) using Eq.(1). We use LHV because it is more realistic than HHV. LHV does not have any contribution from the latent heat of the vapor.

$$LHV = HHV - (21.987\ Wh + 2.443\ Ww) \quad (1)$$

LHV and HHV are in MJ/kg; Wh is the hydrogen mass fraction of the specimen; Ww the free water fraction.

The elementary content together with ash content are measured as follows; a prescribed amount of sample (1 gram) was weighed in a crucible, and placed in an electric furnace with the temperature raised to 700°C. Then after 3 hours, the furnace was turned off and left to be cool down. Finally, the crucible containing the ash was weighed.

Results of mass measurement are summarized in Table 1. Calorific value and elementary composition are summarized in Table 2. The important result from the study is that the energy yield of mesocarp fiber and kernel shell could get to 93%-100%, whereas EFB showed rather lower values of 56%-83%. From this finding, we could conclude that mesocarp fiber or kernel shell is preferable as a feedstock for torrefaction.

Waste Type	Treatment	Mass before treatment (g)	Mass after treatment (g)	Mass yield (%)	Average mass yield (%)
EFB	Dried	2.8082	1.2014	42.78	-
	Torrefied at 220 °C	3.4110	1.3487	39.54	43.16
	Torrefied at 250 °C	6.4128	2.2603	35.25	36.98
	Torrefied at 300 °C	6.3099	1.4542	23.05	24.18
Mesocarp Fiber	Dried	6.4749	4.0638	62.76	-
	Torrefied at 220 °C	3.4517	2.1025	60.91	63.08
	Torrefied at 250 °C	5.2471	3.2563	62.06	60.04
	Torrefied at 300 °C	3.4237	1.8285	53.41	52.45
Kernel Shell	Dried	3.5679	2.8056	78.63	-
	Torrefied at 220 °C	8.7237	6.4597	74.05	77.44
	Torrefied at 250 °C	10.2515	7.787	75.96	73.83
	Torrefied at 300 °C	9.9687	7.2555	72.78	71.27

Tab. 1 Result of mass measurement

No.	Waste Type	Moisture	Calorific Value (MJ/kg)				Elementary and Ash Analysis (%)					
			Wet (HHV)	Wet (LHV)	Dry (HHV)	Dry (LHV)	C	H	N	S	O	Ash (Deform °C)
1	EFB	57.2	10.57	8.40	17.02	15.82	45.53	5.46	0.45	0.044	43.40	5.12
2	Mesocarp Fibre	37.2	13.33	11.48	19.61	18.31	46.92	5.89	1.12	0.089	42.66	3.32
3	Kernel Shell	21.4	16.14	14.55	19.78	18.49	46.08	5.86	1.01	0.06	42.01	4.38 (1070 °C)

Tab. 2 Biomass samples used and their physical properties

3.3 Transportation

3.3.1 In Indonesia

Palm oil product in Indonesia is used for domestic need and export need. For domestic need, palm oil products will be stringently inspected before loading, and then delivery to customers by using either high standard tanker trucks for mass consumption as industrial usages or different types of truck which suite for each customer size. For export market, the products will be supply as bulk shipment by using vessel with loading capacity either 1,000 tonnes or 2,000 tonnes upon requests. Currently there are six public active seaports for CPO in Indonesia, there are two CPO export ports namely Port of Belawan, located in the North Sumatera province and Dumai Port, located in Riau province.

3.3.2 In Europe

Sea ports in northwest Europe have a crucial role in imports of solid biomass and further hinterland transport to end-users. This is especially true for many intra-European trade routes and biomass imported from non-EU regions that require inter-continental shipping. Especially after 2014, it is predicted that overseas biomass imports in Rotterdam may rise to 6 to 7 million tons annually.

4. Conclusions

Global energy demand is expected to increase significantly especially in Indonesia with its energy sector is still dependant on fossil fuel as energy source. However, fossil fuel is decreasing gradually in all around the world, so renewable energy has been seen as the best solution. Indonesia, which is located in equatorial, has abundant renewable energy sources, i.e. solar, hydro, wind and the most practical source Biomass. Derivation of energy from biomass has been planned to be fully developed in Indonesia because of its richness in biomass. One of biomass that has great potential to be used in generating energy is Palm oil. Indonesia as the biggest producer of palm oil can use palm oil waste to produce bio-based commercial products, synthetic bio-fuels and also for power generation. Among all available conversion technologies, torrefaction is considered as the best technology because of its ability to improve physical properties (grindability and pelletability), composition by increasing carbon content and calorific value as well as decreasing moisture and oxygen content, and also biochemical composition by decomposing hemicelluloses, resulting in better binding during pelletization.

Hence, efforts, researches, and resources are needed to develop this technique so that it can be commercialized and also environmental-friendly. This paper studied about the implementation of palm oil and its potential of being made as bioenergy via torrefaction technique. Environmental impact of torrefaction for palm oil biomass and other technologies are also discussed in this study. In the end, it concludes that mesocarp fiber or kernel shell is preferable as a feedstock for torrefaction from quality point of view. With many projects and researches related to the utilization of palm oil waste in Indonesia, it shows that Indonesia has potential to be one of the major contributors of renewable energy sources in the world with its palm oil biomass.

Acknowledgements

Many thanks to Christian Wolf for the guidance provided for this study.

References

[1] Amzul Rifin (2011) The role of palm oil industry in Indonesian economy and its export competitiveness. Japan. Univesity of Tokyo.

[2] Bear B. (2013) Market View – Palm oil Sector. Thecitytrader. USA. http://www.thecitrytrader.wordpress.com. Accessed on 15.05.13

[3] Euroelectric Renewables Action Plan (2011) Biomass 2020: Opportunities, challenges and solutions. EU. Euroelectric

[4] Hayashi Kiichiro (2007) Environmental impact of palm oil industry in Indonesia. Proceedings of International Symposium on EcoTopia Science 2007. ISETS07

[5] Indonesian Palm Oil Board (2007) Sustainable oil palm plantation. Indonesia. Indonesian Palm Oil Board

[6] Indonesian Palm Oil Advocacy Team (2010). Facts of Indonesian Oil Palm. Indonesian. Indonesian Palm Oil Board

[7] Jelsma I., Giller K., Fairhurst T. (2009) Guidelines for setting up a smallholder oil palm plantation. Netherland. Wageningen Univesity

[8] Kamahara H., Hasanudin U., Widiyanto A., Tachibana R., Atsuta Y., Goto N., Daimon H., Fujie K. (2010) Improvement potential for net energy balance of biodiesel derived from palm oil: A case study from Indonesian practice. Biomass and Bioenergy 34:1818-1824. doi: 10.1016/j.biombioe.2010.07.014

[9] Levin Joshua (2012) Profitability and sustainability in palm oil production. WWF Report. http://wwf.panda.org. Accessed on 24.03.13

[10] PWC (2011) Overview of palm oil industry landscape in Indonesia. PWC Indonesia. Indonesia. http://www.pwc.com/id. Accessed on 20.03.13

[11] Sri Dato T. (2011) Palm Oil and Related Topics. The Chinese Chamber. Malaysia. http://www.chinesechamber.org.my. Accessed on 07.05.13

[12] Uemura Y., Omar W.N., Tsutsui T., Yusup S.B. (2011) Torrefaction of oil palm wastes. Fuel 90:2585-2591. doi: 10.1016/j.fuel.2011.03.021

[13] Williams Carol (2010) Bioenergy conversion technologies. Wisconsin Grasslands Bioenergy Network. USA. http://www.wgbn.wisc.edu. Accessed on 28.03.13