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Electricity Generation from Palm Oil Biomass Residues Incineration: Feasibility study with feedstock from governmental plantation sites in Sumatra Utara, Indonesia

A Master's Thesis submitted for the degree of
"Master of Science"

supervised by
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Vienna, August 9, 2015

Affidavit

I, **Jennifer Elisa MacDonald**, hereby declare

1. that I am the sole author of the present Master's Thesis, "Electricity Generation from Palm Oil Biomass Residues Incineration: Feasibility study with feedstock from governmental plantation sites in Sumatra Utara, Indonesia ", 53 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
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Abstract

This thesis investigates the feasibility of communal electricity generation from feedstock originating from government owned plantation sites throughout Sumatra Utara. This region was selected due to the high concentration of palm oil plantations in the area, currently occupying of 15% of total land territory in the region. The city of Medan, an urban area with 2.1 Mio inhabitants, and capital of Sumatra, Utara, has relatively high grid connectivity and is therefore an ideal site for a palm oil biomass residue plant. The calculations done show that with the amount of feedstock from palm oil biomass residues of the government owned plantations in Sumatra, Utara, available it would be possible to power about five plants of 60 MW thermal power respectively of 21 MW generated electricity each. Thus, electricity of 105 MW, or during a year about 840 GWh might be produced.

There are however limitations originating from the peculiarities of the fuel properties which impose difficulties for the operation of larger plants:

- The humidity of the fuel mix of palm fiber and palm kernel shell is highly variable which requires a management of the humidity level by seasoning or torrefaction.
- The palm oil biomass residues exhibit a relatively high nitrogen content, which may create high emissions of NO_x. The operation of a staged fluidized bed combustor might reduce the NO_x emission. If the NO_x emissions still remain too high, then de-NO_x systems involving ammonia injection will be necessary.
- The palm oil biomass residues exhibit a relatively high ash content, with high concentrations of Na, K, Ca and Si. The resulting ash upon combustion exhibits a high alkalinity and a low melting point promoting bed agglomeration and liquid slagging, making the boiler more difficult to operate. For fuel with low melting ash fluidized bed combustion is likewise the recommended technique.
- The high ash content requires increased efforts for limiting the emissions of fine particles. In order to meet fine particles emission standards for biomass power stations of the EU or US, in addition to cyclones either electrofilter or bag house filters will be required.
- However, the alkalinity of the fly ash creates absorption sites for SO_2, thereby reducing the emissions to a concentration below emissions standards.
- The ash from a 60 MWth power plant operated with POBR is in the order of 700 kg/h (17 t/day), requiring silo transports back to the plantation, or to a suitable dump site, where the ash gets deposited and processed in a solidified form. Handling has to be taken with care due to the alkaline (caustic) properties of the ash.
- Due to the many not completely resolved technical issues of POBR utilization for electricity generation a pilot plant of small size is recommended.
- For a sustainable utilization of the POBR for power generation stack gas emission standards are to be defined.

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List of abbreviations

ASEAN - Association of Southeast Asian Nations
BIGCC - Biomass integrated gasification combined cycle
BPP - Biomass power plant
BPS - Bandan Pusat Statistik
CHP - Combined heat and power
CO - Carbon monoxide
CO_2 - Carbon dioxide
CPKO - Crude palm kernel oil
CPO - Crude palm oil
EBTKE - New and Renewable Energy and Energy Conservation
EFB - Empty fruit bunches
EU - European Union
FBC - Fluidized bed combustion
FFB - Fresh fruit bunches
FS - Fiber-shell
G20 - Group of Twenty
GDP - Gross Domestic Product
GHG - Greenhouse Gas
GWh - Gigawatt hour
h - Hour
H_2O - Water
HC - Hydrocarbons
K - Kelvin
Kg - Kilogram
kPa - Kilopascal
kW - Kilowatt
kWh - Kilowatt hour
LCA - Life cycle assessment
LHV - Lower heat value
m - Meter
Mboe – Thousand barrels oil equivalent
MJ - Mega joule
MW - Megawatt
MW_{el} - Megawatt electric
MW_{th} - Megawatt thermal
N - Nitrogen
NCV - Net calorific value
NGOs - Non-Governmental Organizations
NO_x - Nitrogen oxides
PAH - Polycyclic aromatic hydrocarbons
PF - Palm fiber
PKC - Palm kernel cake
PKS - Palm kernel shell
PLN - Perusahaan Listrik Negara
PM - Particulate matter (2.5 or 10)
POBR - Palm oil biomass residues
POM - Palm oil mill
POME - Palm oil mill effluent
PTPN - PT Perkebunan
RE - Renewable energy
RET - Renewable energy technology
RSPO - Roundtable on Sustainable Palm Oil
SC - Sludge cake
SCR - Selective Catalytic Reduction System
SO_x - Sulfur oxides
VOC - Volatile organic compounds
µg - Microgram
µm - Micrometer

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1. Introduction

Indonesia is currently the fourth most populated country with 240 million people, spread across 17,000 different islands and ranks 13th globally for primary energy use at 893 one thousand barrels oil equivalents (Mboe) (Hasan et al., 2012). Indonesia is the only Association of Southeast Asian Nations (ASEAN) member who is part of the Group of Twenty (G20) and currently has the highest gross domestic product (GDP) in the ASEAN region. Most energy sources are located outside of Java, particularly in Sumatra, but the demand of energy is concentrated on the island of Java (Hasan et al., 2012). The concentration and development of infrastructure remains the highest in Java in comparison to other islands. Indonesia's rapid growth rate cumulates into rapid depletion in oil and natural gas reserves. Following the economic recession in 1998, Indonesian energy consumption increased with a growth rate of 7% annually (Hasan et al., 2012). While fossil fuel reserves in Indonesia are limited (e.g. oil, gas, and coal) but the dependency on this type of fuel is still high. Additionally, much of the extracted raw material resources are exported to neighboring countries. One solution is to focus on the development in renewable energy technologies (RET). An important Renewable energy Technology (RET) could potentially be biomass residues that are by-products from palm oil plantations.

Palm oil trees (Elaesis guineesis) are originally West African palm trees introduced to the South East Asian region in the 19th century. The palm oil industry in Indonesia, developed in the early 1920's under Dutch colonials, expanded rapidly between 1960-2000 in Asia that was coupled with the rapid increase in demand for the palm oil products. Palm oil is well known for its versatility and adaptability as food and cleaning product including oils, soaps, chocolate and other foodstuffs (Mahlia et al., 2001). Currently, the two largest producers of palm oil are Malaysia and Indonesia, accounting for approximately 85% of the world's palm oil production (Abdullah and Sulaiman 2013). As the global demand for food oil grows, so does the palm oil industry. Indonesia has moved to a more agrarian based culture in order to shift its economic downturn after the 1997 Asian Economic Crisis. Many palm oil plantations have been developed in ideal conditions located on the islands of Sumatra, Kalimantan and Sulawesi in which the misty environment and favorable soil conditions enable this agricultural product to thrive so well (Mahlia et al., 2001). In 2006, Indonesia overtook the Malaysian palm oil industry as the world's largest producer of crude palm oil (CPO) and crude palm kernel oil (CPKO) products. According to Indonesian government statistics, the palm oil crop consists of 10,586,500 ha worth of plantation area. This is nearly triple the area of the second largest planted agricultural goods, coconut at 3,787,300 ha, and triple rubber production currently at 3,555,800 ha (BPS 2013). Between 2012 and 2013, there was an expansion of 453,200 ha difference in palm oil plantation area from 2012 levels of 10,133,300 ha (BPS 2013). The palm oil industry is a rapidly expanding industry and Indonesia currently produces 21.6 million tons of palm oil annually. Palm oil exports are still in raw form, which makes it a low value-added industry, the products of which are produced at a low cost and high volume (Hasan et al., 2012). Palm oil products increase in value as the product moves from extraction of the raw materials to the final product. According to the World Bank, as of June 2015, the cost of oil palm per ton is at 607 USD in raw form (World Bank, 2015). Oil palm is the highest yielding oil crop yielding approximately a net of 4-5 tons of oil/ha/year (Sumathi et al., 2008). Today, approximately 90% of palm oil is currently used as food related products while the other 10% is used in soap and skin care products (Mahlia et al., 2001). Recently, an increasing use has been reported as a source of for biofuels, ideally from waste palm oil or oil residues (Mekhilef et al., 2011)

Due to this rapidly expanding industry, measures have been taken in order to improve the overall sustainability of the industry. The sustainability of the palm oil industry is regulated by the establishment of Roundtable on Sustainable Palm Oil (RSPO). According to RSPO Principles and Criteria, RSPO sets the standards and defines the production of palm oil crops as legal, economically viable, environmentally appropriate, and socially beneficial operations (Shuit et al., 2009). The Roundtable for Sustainable Palm Oil (RSPO) was established in recent years with support from a variety of stakeholders ranging from palm oil producers, processors, traders to non-governmental organizations (NGOs), and manufacturers (Abdullah and Sulaiman, 2013). This group is responsible to develop goals for a sustainable palm oil industry and production. These goals include a commitment to transparency, compliance with all (international, local, national, and ratified) regulations, adoption of sustainable cultivation practices, conservation of resources, biodiversity, and local community development (Abdullah and Sulaiman, 2013).

While there is much controversy surrounding the palm oil industry, namely negative publicity of its land use practices, deforestation, disruption of ecosystems, corruption and transboundary haze pollution, the industry is well established and will continue to operate on developed land. Due to the establishment of the RSPO, it is within the interest of palm oil industries to continue sustainable development of its industry and mitigate effects of their agricultural practices. While it is important to focus on many of the above listed issues associated with the palm oil industry, it is also important to maximize utility and sustainability of this already-existing industry in order to grow and sustain a potential renewable energy resource. A major focus should be drawn to electricity generation through controlled biomass incineration. This type of electricity generation is a pre-existing phenomenon that has mainly been limited to power many palm oil mills (POMs). Fibers and shells from the processing are mixed in an optimized ratio and utilized as alternative fuel for electricity generation within factories. Shell and fibers produced from palm oil extraction can supply considerably more steam and electricity than is internally required, thereby giving palm oil plantations the potential opportunity to export their electricity to surrounding settlements and cities (Lim et al., 2014).

The focus of this thesis is on the feasibility of electricity generation and supply by estimating the amount of feedstock and production of electricity in a hypothetical biomass plant located in the region of Sumatra Utara, the capitol of this area being Medan, Indonesia. The thesis will model potential energy supply from palm oil biomass residues from given palm oil plantation sites, which are relatively close to an urban area. Selection of this region is ideal in such a study since the city has a large electrical demand, a population of 2.1 million inhabitants, and in close proximity to large palm oil plantation sites. Utilizing shell and fiber can generate more than enough energy to meet the demand of the palm oil mill (Mahlia et al., 2001). Even though the feedstock of this biomass plant greatly surpasses its overall capacity, a pilot plant would be able to test the feasibility of an electrical plant utilizing this type of substance. Various studies conducted have shown that the chemical composition of these substances make the plant operation more complex, requiring close monitoring of plant incineration activities. While the benefits of CO_2 reduction using electricity via biomass residues is clear, it is important to also account other potential pollutants, such as particulate matter from the ash content and the nitrogen content of the fiber-shell feed mix.

A summary of Indonesia's current energy mix will be discussed and legislation that encourages the development of more renewable energy technologies. This will be followed by an introduction to palm oil production methods and technologies that are currently available and typically utilized in the region's palm oil mills (POMs). The ideal substances used for biomass incineration will then be discussed followed by their chemical composition, properties, and shortcomings during incineration. Mitigation efforts will be discussed by an account of filtration systems and pollution control options available to reduce pollutants in the off-gas. Finally a calculation estimate of a 60 megawatt (MW) plant, taking into account the amount of feedstock available from government owned palm oil plantations, will be employed to estimate whether or not a 60 MW plant could be feasible for the region. A final emission assessment based on the chemical composition of the byproducts will be related to EU emissions standards specifically which areas would need to be optimized to satisfy such standards and safely operate the plant and protect human health and life ("sustainable operation").

2. Palm Oil Products as an Energy Source

2.1 Indonesia's Energy Mix

Due to an expanding demand for energy, Indonesia has become a net energy importer. In 1962, Indonesia became a member of OPEC but later resigned in 2008 after becoming a net importer of oil in 2004. Indonesian oil reserves are estimated at 4.3 billion barrels with an additional 3.7 billion potential barrels, which have not yet been extracted nor explored. This makes up for approximately 0.3% of global oil demand (Hasan et al., 2012). Recently production has decreased sharply due to lack of investment for exploration and development. This is offset by the fact that Indonesia has the largest natural gas reserves in the Asia-Pacific region, 11th in the world consisting of approximately 107 trillion cubic feet (Hasan et al., 2012). Most of the gas supply; however, is exported to neighboring countries. Despite these vast reserves, the shift towards domestic use is hindered by poor natural gas transmission and network distribution throughout the island. Coal is and remains the cheapest and most abundant fossil fuel in Indonesia. Indonesia produced 232 million tons of coal in 2009, about 232% more than in 2000. Ninety-five percent of coal is extracted from surface mining operation (Hasan et al., 2012). Similar to its natural gas reserves, a majority of the mined coal is exported to other countries (e.g. Japan, Taiwan, China, India, South Korea, Hong Kong, Malaysia, Thailand, and the Philippines).

Oil, gas and coal contribute to 82% of electrical energy generation as new energy sources have not been optimized due to high production cost and the government's previous subsidy policy on fossil energy (ACE, 2013). The use of crude oil decreased from 45% in 1990 to 39% in 2009 but at the same time, coal use has increased from 4% in 1990 to 18% in 2009 (Hasan et al., 2012). When looking at Indonesia's overall energy mix (non-electrical), 76% come from non-renewable energies while the remaining 24% is renewable energy. Biomass is a strong source at 20%. However, when accounting for electricity generation, 82% comes from conventional fossil fuels, coal being the main fuel. Renewable energies play a minor role and only contribute 18% of the share of electricity generation, mostly hydropower and geothermal energies (ACE, 2013). Indonesia has a large untapped source of hydropower energy and geothermal energy due to the country's proximity to the equator. The country has been exploring these two energy sources as viable alternative to fossil fuels . Biomass, which fulfills primary energy demand from renewables, play no significant role for electricity generation. The use of biomass is utilized primarily for household consumption in rural areas (e.g. cooking and heat) (ACE, 2013).

Efficient utilization of renewable energies can be the best alternative to reduce energy poverty in rural areas. Within developing countries, energy poverty exacerbates overall quality of life thereby worsening the effects of overall poverty. In Indonesia, the high cost for electrical grid extension through difficult terrain (e.g. thick jungle areas), may make such projects economically unfeasible (Borhanazad et al., 2013). By 2011, Indonesia had 71% grid connectivity and has a goal by 2025 to reach 95% grid connectivity (ACE, 2013). Indonesia certainly has the capacity to utilize solar and biomass energy, but these resources are overall, massively under utilized. Photovoltaic systems, for example, can have a high potential due to (Indonesia's) equatorial location (Borhanazad et al., 2013). Common barriers to renewable energy (RE) development for electricity generation are: high cost of transmission, low electricity demand, low consumption, and dependence on donors. Issues of RE development fall into one of three categories: economic, legal and regulatory, financial and institutional issues. Today, after many legislative changes, various advantages of off-grid renewable energies are being taken into consideration (Borhanazad et al., 2013). The cost of RE technology for rural electricity supply is currently simply too costly for the Indonesian government to afford. Additional developmental subsidies from developmental funds would be required to further develop RET in the region.

The Indonesian government is cognizant of the potential for RE mix and have taken positive steps in that direction. Indonesia's 2007 Energy Law lists a primary goal to increase the country's share of renewables to 25.9% of the total primary energy consumption by 2025. On the supply side they have focused on energy conservation, intensification, reducing oil dependence, increasing energy supply from non-nonrenewable to renewable sources and electrification of rural areas (ACE, 2013). According to the ACE (2013), the current biomass potential stands at 50 GW but its utilization factor remains low. Recent utilization of biomass is estimated at 1600 MW or 3.25% of the existing potential (ACE, 2013). Installed capacity can be increased via the small-distributed power programs. New regulations established by the Indonesian government such as MEMR Regulation No. 4 encourages new energy companies to begin generating electricity, provided it is renewable. Since the regulation obligates the Indonesian government to purchase excess electricity, this offers the palm oil industries the opportunity to sell their excess energy. Most utilization of biomass in electricity generation is distributed power within commercial industries but not for feeding into the national grid. Even though Indonesia has a large biomass energy generating potential (inexpensive biomass feedstock and high electricity demand), development of biomass energy generation has been slow. In contrast to current, sluggish biomass energy development projects, Indonesia's Biomass energy policy, as in accordance with Presidential Regulation no. 5/2006 on National Energy Policy as a basis for biomass energy development, set the targets for an optimal mix in 2025, including a 5% biomass electrical energy threshold (ACE, 2013). The main task of EBTKE (New and Renewable Energy and Energy Conservation) is to formulate and implement policies and regulations regarding new and renewable energy conservation (ACE, 2013). Therefore, as Indonesia plans to significantly increase their share of renewable energies, it is within their best interest to focus on biomass residues.

Biomass is a natural energy source, derived from agriculture crops, residues, and forest wastes, commodities of plantation, and animal waste. Biomass is one of the only renewable energies that can be used to produce fuel that is in liquid, solid and gaseous forms (Hasan et al., 2012). Biomass production in Indonesia is around 147 million tons per year and is mostly used by rural areas and small industries to provide energy for cooking, heat, and electricity (Hasan et al., 2012). An industrial sized power plant with its main purpose of converting biomass products into electrical energy to power a grid seems promising because of the large amounts of biomass produced every year. Palm oil crops are the most dominant producers in biomass residue, with an estimated 100 million tons per year of biomass residue. In order to examine the potential of biomass electricity capabilities in Indonesia, it is first important to analyze the local distribution of palm oil industries vs. the availability of the PLN grid. 70% of palm oil mills are located in Sumatra where the electrical grid stands at a connectivity of approximately 75-90% depending on the area (Conrad and Prasetyaning, 2013). Energy production potential of sugar cane, rice paddy and palm oil residues have a potential of 43 TWH (Terawatt hours). Utilizing fibers and shell residues from palm oil production might contribute to nearly 66% of this electricity generation potential (Conrad and Prasetyaning, 2013). Availability of an electrical grid is the main barrier to the full bioenergy production potential in Indonesia. Were Indonesians were to utilize these resources, the country would meet their emission reduction target in the energy and transport sector, in accordance with the National Action Plan for Greenhouse Gas Reduction (RAN-GRK) (Conrad and Prasetyaning, 2013). Within Indonesia alone, greenhouse gas emission is expected to grow approximately 3-5% in annual CO_2 emission due to its economic expansion and population growth (Conrad and Prasetyaning, 2013). It is in the interest of Indonesia to increase their RE mix. Since palm oil production is a dominant industry in Indonesia, increase utilization of the biomass residues would be one way to promote a sustainable RE mix.

2.2 Palm Oil production

2.2.1 Palm oil tree planting

In a typical plantation there are approximately 148 oil palm trees planted per ha, in triangular groups of three, each tree representing one of the three points of a triangle (Lim, 2010). The distance from tree to tree is approximately 3 meters in length. This formation tends to maximize the yield of the crop, reducing competition for nutrients between the trees. The oil palm fruit is harvested after 3 years of initial planting, reaching a maximum yield at the $12\text{-}13^{th}$ year wherein productivity tends to decline at the end of the 25^{th} year. The average life expectancy of a palm oil tree is 35 years. After approximately 35 years, the tree groups, which have declining utility, are then cut down and the wood sold for lumber. Young trees are then replanted in large blocked areas. What is harvested from these trees are the fresh fruit bunches found below the palm fronts. Two of the products that are developed from these fruit bunches eventually produce crude palm oil (CPO) and crude palm kernel oil (CPKO). CPO originates from the pressing of the fruit and the CPKO originates from oil extraction from the inner seed of the fruit. CPO is from the mesocarp fibers, or the yellow oily flesh of the fruit, and CPKO is from the endosperm, the inner white flesh of the kernel seed (Figure 2-1). Each individual reddish fruit consists of a seed, surrounded by a soft oily pulp. The oil is extracted from the pulp of the fruit and can be then made into an edible oil. The kernel oil, or the oil found in the seed, is mainly used in soap and skin care products (Shuit et al., 2009). An average medium size palm oil mill processes about 30-60 tons of FFB per hour, approximately 1,440 tons per day. One mill can produce tremendous amounts of oil, which equates upwards of approximately 525,600 tons per year. Up to 5 tons of FFB are harvested per acre per year and the average growing area is 30,000 acres, totaling up to 50 trees/acre. Average distance from plantations to mills is about 30-50 km (Kittikun, et. al, 2000). The reddish fruit grows in large bunches that can weigh between 10-40 kg.

One palm tree occupies 0.0068 ha of land and each tree yields about 150 kg/year of FFB. The yield of FFB produced per palm tree for 23 years is 3.45 tons (Yusoff, 2006). One source of biomass residue is produced by pruning of fronds. This process is carried out in order to facilitate cutting of ripe fruit branches. The annual dry weight of fronds is 11.6 t/ha. Total dry weight of fronds per palm from pruning is 1.8 tons within the 23 productive period years (Yusoff, 2006). During all extraction, most of the palm oil tree biomass is wasted by open air burning, dumped in nearby areas, or used as fertilizer for palm oil plantation due to much of the residues' high nutrient content. An added waste problem occurs with palm tree trunks. Because of the tree trunk's high moisture content of 70%, a freshly chopped trunk cannot be burned immediately. Typically trunks are left for natural decomposition but this obstructs the re-plantation process. This encourages the practice of burning tree trunks in open fields (Abdullah and Sulaiman, 2013). Typically, the harvest of one palm tree contains on average 21% palm oil, 6-7% palm kernel, 14-15% fiber, 6-7% shell and 23% EFB (Husain et al., 2012). The overall breakdown from 100% FFB can be seen in Figure 2-2 below. This breakdown determines the biomass residue energy potential per hectare of the palm oil crop.

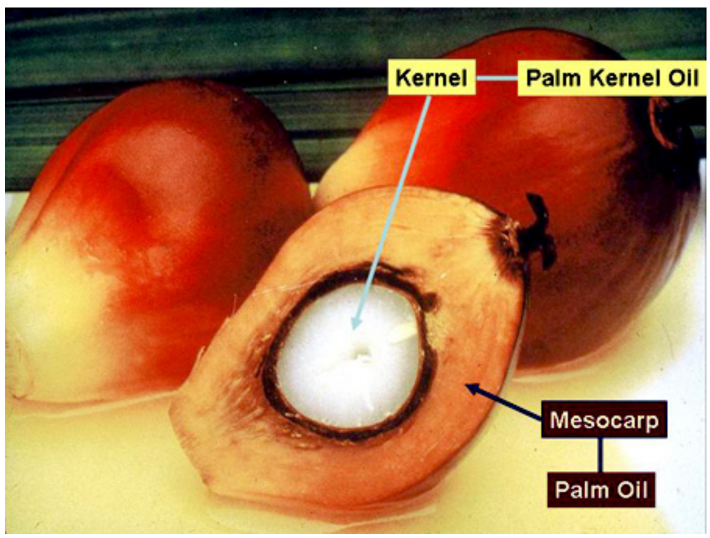

Figure 2-1: Oil Palm fresh fruit components (Malaysian Palm Oil Council, 2012)

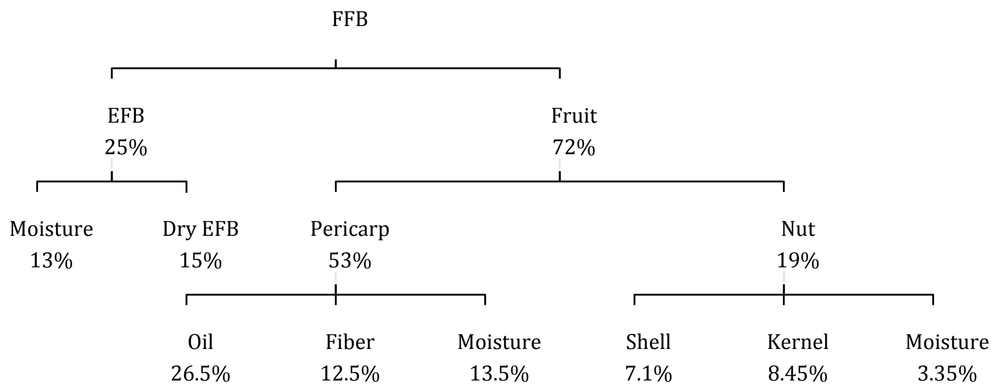

Figure 2-2: FFB components in %. Harvest averages obtained from Prasertan and Prasertan (1996).

2.2.2. How is Crude Palm Oil (CPO) extracted?

Fresh Fruit Bunches (FFB) undergo processing to obtain the palm oil. CPO processing is both physical and mechanical. Currently there is no chemical utilization of products in the CPO production. Self-regulated environmental management tools such as life cycle assessment (LCAs) have been used by palm oil industries where pollution prevention strategies have been addressed (Yusoff, 2006). Main concerns for pollution within the industry are the by-products of production, such as empty fruit bunches (EFBs), palm oil mill effluent (POME), sterilizer condensate, palm fiber (PF) and palm kernel shell (PKS). One ton of fresh fruit bunches (FFB) consists of about 230-250 kg of EFB, 130-150 kg of PF, 60-65 kg of PKS, and 160-200kg of CPO. The typical state of EFB, without a drying process, exhibits a lower heating value (LHV) because of the high moisture content (Sing and Aris, 2013). High noise levels, water consumption, generation of high organic content wastewater, generation of large quantities of solids and air pollution are major issues that typically need to be mediated. Many CPO mills involved in self-sustaining electrical generation, are insufficient for full regulatory combustion, fly ash, and energy conservation requirements in neighboring Malaysia (Lim, 2010). As stated previously, the annual production volume of biomass residues exceeds the amount required for the conversion process. This surplus is discarded in open areas or burnt, generating biomass smoke with pollutant particles and volatile hydrocarbons. POME ponds emit methane gas estimated to be 24 times as detrimental to climate change in compared to CO_2.

Crude Palm Oil (CPO) production is as follows: (Figure 2-3)

1) Transportation: Fresh fruit bunches reach the processing plant soon after harvesting to avoid fatty acid production by natural enzymes in the mesocarp. They are then unloaded on a ramp and placed into containers approximately 2.5-3.0 tons in size.
2) Sterilization: Batches of 20-30 tons of FFB capacity (approximately 7-10 containers) are exposed to steam (120-130˚C) and pressure (2.5-3.2kg/cm^2) for 1 hour.
3) Stripping process: Sterilized bunches are emptied into a thresher where fruits are separated from the bunch. A rotating divesting machine separates sterilized oil palm fruit from the sterilized stocks. This produces the EFB consisting of 230-250 kg/t of FFB.
4) Empty fruit bunch (EFB) incineration: EFB fall into a collector, incinerated, and waste products used as fuel and ash for crop fertilizer.
5) Digester: separated fruits are carried on and mechanically treated and 80˚C water is added.
6) Pressing: A screw-type press is employed and extracted oil is collected and collected for further purification.
7) Purification: Consist of many processes including screening, settlement, treatment of settlement tank, centrifuging, drying and cooling.

(Kittikun et al., 2000)

2.2.3. What are the Biomass products formed in CPO and CPKO production? What is done with these products?

Biomass products are derived from forestry, purpose-grown agricultural crops, trees, organic waste, and effluent products that are of agricultural, agro-industrial, and domestic origin. According to Figure 2-3, the varying biomass wastes from palm oil mills include: EFB, PF, palm kernel cake (PKC), PKS, sludge cake (SC), and palm oil mill effluent (POME) (Figure 2-3). Palm cake waste is a mixture of nuts and fiber. The cake is then fed into a separator wherein the waste fiber and shells are transported to the boiler and utilized as fuel. The kernels are sold to kernel oil mills. PKS are the residues remaining from the outer layer of the nut that remain at the CPO mill site. Therefore the biomass which can be potentially utilized from FFB processing consists of: PF, PKS, EFB, and POME. Awareness of these waste components provides a better understanding of current electricity generation practices of POMs. It is important to note that biomass products can be used to generate electricity through their incineration.

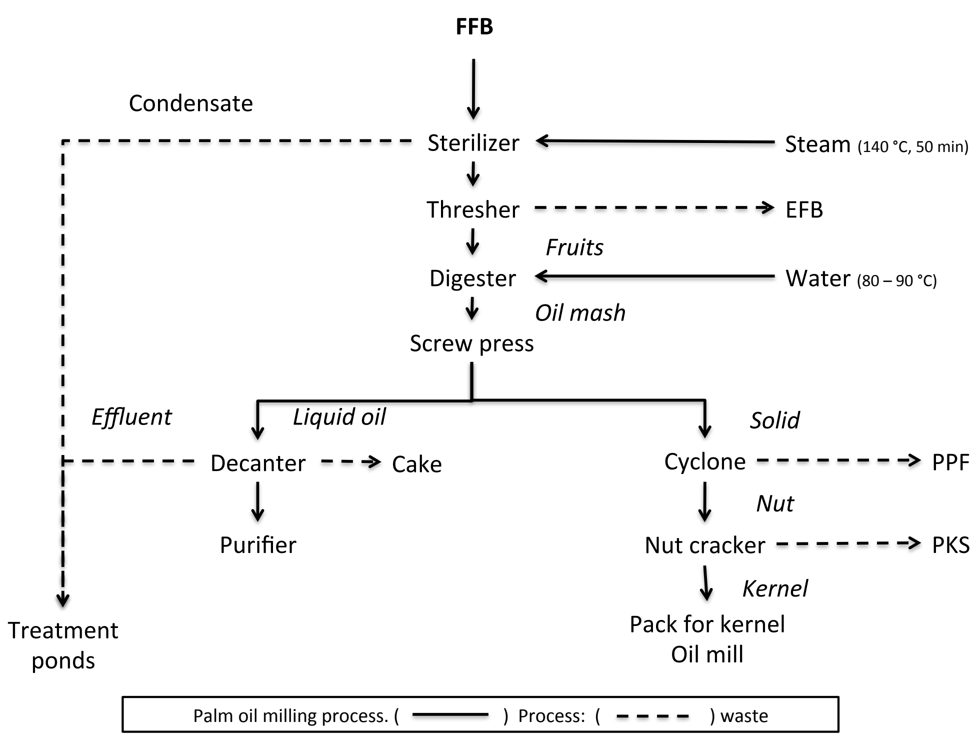

Figure 2-3: Biomass residues produced from the milling process. Processing obtained from Prasertan and Prasertan (1996).

A brief description of each component during the processing of Empty Fruit Bunches follows:

Empty Fruit Bunches (EFB)

During the FFB sterilization process, the EFB results in a moisture content of 60% (Prasertsan and Prasertsan, 1996) thus an unsuitable fuel for electricity generation. Some POME effluent may be used as organic fertilizer. Since disposal of EFB causes a high land-fill disposal cost, the EFB is incinerated. Resultant particulates and gas emitted can cause air pollution in nearby communities. The burning of 1 ton EFB produces 4 kg of ash. This ash makes for very good fertilizer. However, because of this high moisture content of the material, it tends to emit 'white smoke' upon burning and pollution. This can be mediated by the EFB undergoing a shredding and dehydration process to reduce the moisture content below 50%. The heat value standing at approximately 8.2 MJ/kg at 50% moisture. Empty Fruit Bunches can be used as fertilizer to improve foliar nutrient levels and has been shown to increase yields by 8-23% (Yusoff, 2006). Moreover, when using EFB as fertilizer, approximately 683 MJ per palm tree is saved from the production of chemical fertilizers when using palm residues as a replacement (Yusoff, 2006).

Palm Fiber (PF)

PFs are the fibrous interior of the palm oil fruit that has been squeezed for the production of CPO. It is the yellow interior of the fruit that is dried out after pressing occurs (Figure 2-1). PF has a high moisture content, ranging from 10-40% water content. It is not as high as EFB but before incineration, PF needs to have pre-treatment to reduce the water. When PF is removed from processing, the moisture content can be upwards of 40%+ creating a lower heat value due to its moisture content. What has been found is that PF, after pre-treatment, is a good combustible material. The lower heating value without drying and a moisture content of 65% a heating value of 5MJ/kg. Drying the PF increases the heating value to 18MJ/Kg (Yusoff 2006). When electricity is not produced within the POM plant, only about 30% of this residue material is used commercially. Therefore, factories consider 70% of PF a waste product (Kittikun et al. 2000). In fact, PF has a high potential as feedstock for biomass electricity production.

Palm Kernel Shell (PKS)

PKS are what remains of the shell once the inner nut has been removed to produce CPKO. PKS is an energy intensive substance. The lower heating value of the dry shell is 21 MJ/kg (Husain et al., 2003) and a lower ash content is in PKS compared to PF. Proper mixing of PF and PKS is essential because incineration of PKS alone may lead to incomplete burning and results in black smoke if the boiler is operated at lean flame conditions or too low temperatures respectively (Sing et al., 2013). Similar to PF, PKS also has a high potential to be used as feedstock for electricity generation.

Palm Oil Mill Effluent (POME)

POME is the wastewater that results from the milling process and produced during the sterilization stage of FFB milling. There are three major sources of POME wastewater, all of which are byproducts derived from the sterilization process, namely sterilizer condensate (17%), decanter or separator sludge (75%) and hydrocyclone water (8%). The POME is treated via anaerobic digestion in a series of ponds and is anaerobic due to the sheer amount of sludge (Kittikun et al., 2000). The most common usage for this substance, after effluent treatment is fertilizer agricultural water supply. Substances derived from a drying process of POME wastewater can be used for animal feed. (Prasertsan and Prasertsan, 1996)

Research is currently being conducted on POME treatment, pyrolysis of oil palm shells, re-use of chars from oil palm waste, solid biofuel production from biowastes, briquetting of palm PF and PKS, POME as a source of bioenergy, and ethanol fermentation from oil palm trunk (Abdullah and Sulaiman, 2013). While the manufacturing process of palm oil produces a large quantity of solid and liquid waste (including: EFB, PF, PKS and POME), currently PKS and PF wastes are used as fuel for steam production to generate electricity. These biomass residues are used to generate electricity in palm-oil mills itself and in some cases to power local settlements associated with POMs. EFBs also have a potential for power generation but are not typically used due to the white smoke that it produces upon combustion (Abdullah and Sulaiman, 2013). CPO mills achieve their energy demand, using low-pressure boilers. The PF and PKS extracted from 60 FFB tons per hour mill within a 10,000 ha plantation can generate enough energy to be self-sustaining and supply a surplus of electricity. Almost all palm oil mills generate their own heat and power through a co-generation system (Abdullah and Sulaiman, 2013). High-pressure steam enters through a backpressure steam turbine to generate the electricity necessary for mill consumption. Typically PF and PKS are mixed in a 60% PKS and 40% FB creating the optimal ratio for solid combustible fuel. Other ratios are also used depending on the system as well as the availability of this resource. One ton of FFB/h, produces 140 kg of fiber and 60 kg of shell per hour. Typically 30 tons of FFB/h in one mill can produce 4200 kg of fiber/h and 1800 kg of shell/h (Mahlia et al., 2001). These numbers would fall into the range of what has been reported (Prasertan and Prasertan 1996) and observed (Figure 2-2). Additional research has been done on the production of briquettes from PF and PKS as fuel for domestic stoves. These briquettes were mixed in a 60% PKS and 40% FB ratio, and pressed with a binder for solid fuel production from biomass residues (Sing and Aris, 2013).

2.3 Current technologies in use

Analysis of an oil palm tree's products, through a 35 year productive era, the tree produces mostly biomass wastes. A 1998 study of 90 million tons of oil palm fruit produced, 43-45% is waste in the form of EFB, shell, and fiber; corresponds to 40 million tons of waste biomass composed of EFB, shell, and fiber (Abdullah and Sulaiman, 2013). This abundant waste biomass has the potential to be used for renewable energies and value added products. The current levels of biomass is underutilized with the potential to produce electricity, heat, and biofuels. Using oil palm biomass as an alternative to replace in the form of bio-fuels (ethanol, methanol, bio-oil, and bio-diesel) can replace fossil fuels. Such thermochemical processes using palm oil tree derived biomass include: direct combustion utilizing excess air, biomass combined heat and power (CHP), biomass co-firing, pyrolysis using no air, gasification using partial air, biomass integrated gasification combined cycle (BIGCC), liquefaction, and co-firing using a biomass/coal mix (Conrad and Prasetyaning, 2013). When transitioning into biomass combustion systems, co-firing, or replacing part of fossil fuel supplied to a power station provides renewable alternatives. This is particularly relevant for supplementing coal-fired plants. Nevertheless, biomass typically should not exceed 10% in these co-firing systems or operational requirements will not be met (Conrad and Prasetyaning, 2013). Due to Indonesia's abundant coal supply, this mixing could be a feasible and more sustainable option to utilize waste biomass to reduce both coal consumption and the environmental impact of strip mining.

Current research has determined that the use of biomass in electrical generation mitigates the impact of anthropogenic emissions from using fossil fuels. Comparing CO_2 emissions from electrical power plants using coal or oil to generate electricity, average electrical production using fossil fuels produces around 1100g of CO_2 per kWh whereas sustainable grown biomass produces 16g of CO_2 per kWh (Yusoff, 2006). Approximately 15 million tons/year of useable biomass for electrical generation is theoretically available from the palm oil industry in Indonesia. The feedstock amounts to approximately 29,475 GWh/year, 25% of generation potential of the Indonesian plantations (Conrad and Prasetyaning, 2013). As has been stated, the highest combustion potential stems from fiber and shell due to their high calorific values. The electricity potential from the palm oil industry is higher than any other agroindustry in

Indonesia. The power generation potential from PKS and PF (the most useable of the two materials for a biomass on-grid plant) is equivalent to 14,748GWh/year (Conrad and Prasetyaning, 2013).

Oil palm biomass: EFB, PF, and PKS can be used to produce steam for processing activities and for generating electricity. Normally EFB is used for fertilizers and, while EFB have a potential for electricity generation, it is a demanding substance to work with due to the higher ash content after combustion, as well as its high moisture content that results a white smoke disruptive to surrounding areas. Hence, the high moisture content of fresh EFB, consisting of over 60% humidity, without an additional drying process, makes the substance a poor fuel. This would explain why the shells and dryer parts of the biomass fibers are used for boilers, a cheaper, better energy source for POMs (Abdullah and Sulaiman, 2013). Most components, especially EFB, must be pretreated before incineration. One example includes shredding and a process that reduces moisture content. In Malaysia alone there are over 300 palm oil mills operating with self-generated electricity from biomass (Shuit et al., 2009). Typically 60 tons FFB (fresh fruit bunches) are processed per hour in a mill with normal operation at 20 hours a day. While PKS amounts to 6%-7% of residue, only 30% of the total PKS, or 1 ton/h, of which is dry enough for boiler fuel and 14% of PF or 8.4 ton/h. Power requirement for a mill is 15-20 kW per ton FFB or 1020 kW for 60 tons FFB per hour mill. The size of the generator is typically 1.2 MW (Yusoff, 2006). For each kg of palm oil produced, electricity consumption amounts to 0.075-0.1 kWh and steam demand is 2.5 kg. Steam to electricity is a ratio of 20 to 1 and could be met by burning 0.3-0.4 kg of waste, with a boiler efficiency at 70% (Abdullah and Sulaiman, 2013).

Larger POMs already produce energy from renewable oil palm wastes to avoid the additional costs of fossil fuel (Conrad and Prasetyaning, 2013). Shells and fibers can supply a surplus of energy to meet the mill's requirements while using low pressure in addition to inefficient boilers (Abdullah and Sulaiman, 2013). Maximization of this process could potentially allow these POMs to increase energy efficiency and subsequently reduce costs. The system typically requires a combustion system (boiler and furnace) in addition to a steam turbine and generator (Shruit et al., 2009). According to various studies, all palm oil mills in Malaysia and Indonesia utilize a small water tube boiler (standard D-Type boiler). These boilers can processes 30-60 tons FFB/h (Mahlia et al., 2001). As shown in figure 2-4, direct-fired systems require burning of feedstock to produce steam that is then captured by turbines, spins a generator, and eventually creates electricity. Diesel fuel is utilized as back up systems in low peak feed-in periods, such as low yield harvesting periods in the off-season. PKS and PF are used in the process in existing oil palm factories by direct burning or combustion, then captured to spin an electric generator. PF and PKS contains small quantities of oil and are therefore used as boiler fuel to generate steam for the mill (Sumathi et al., 2008).

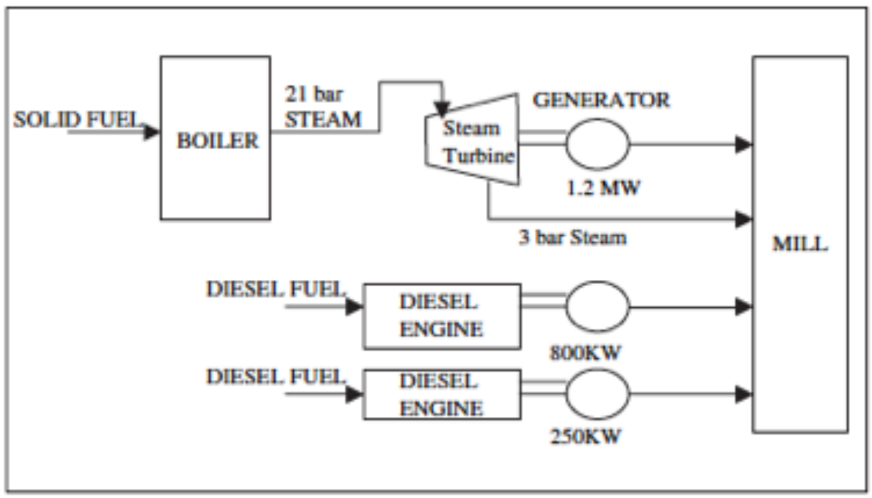

Figure 2-4: Diagram of powerhouse typically found in a palm oil mill (Yusoff, 2006)

While increasing electrical efficiency and biomass feedstock handling, it would be no surprise that many POMs could make a transition from generating electricity to power themselves to powering a nearby settlement thereby feeding onto the grid and increasing the proportion of RE used in these settlements. This option is to be determined by distance of the mill to the medium voltage grid. Indonesia's government-owned electricity corporation, Perusahaan Listrik Negara (PLN), currently has a monopoly on electricity distribution in Indonesia and is currently open for negotiations to bear the cost of grid connection. According to the Minister of Energy and Mineral Resources, MEMR Regulation No. 4 (2012), PT PLN has an obligation to purchase electricity from small to medium scale renewable energy independent power producers (IPPs) with up to 10 MW in capacity. It is also required to purchase excess electricity generally produced (e.g. state electricity enterprises, private enterprises, etc.) (ACE, 2013). As mentioned earlier, this would encourage palm oil companies to begin selling excess energy produced within the mill during processing.

Although this is a good sound approach maximize excess electricity production, POM located in remote locations require a provision for the electrical connection. Additionally, the size and processing capabilities of the POM's are important and relevant to the potential of electricity generation and export. In order to achieve export levels, a typical POM should process a minimum of 30 tons FFB/hour in order to generate its own electricity. This should be no problem as currently only 3-14% of POMs have a capacity lower than 30 tons FFB/h (Conrad and Prasetyaning, 2013). However, the smaller the size of the plant, the more waste is produced proportional to the harvest yields of the plantations. Luckily, most Indonesian mills have a capacity on the upper limit, 60 tons FFB/h, meaning that these POMs have the capability to produce electricity excess utilizing biomass produced from the milling process. Electricity generation via POMs pose as good opportunities for development because POMs, out of necessity, had to establish localized grid connections and are experienced with biomass combustion and cogeneration. The typical capacity of a plant without exporting additional electricity is up to 5 MW but feeding surplus power to the electrical grid is limited due to the remoteness of many POMs (ACE, 2013). All the same, as biomass is burned to produce electricity via steam turbines, these turbines can have a typical size ranging from 1 to 100 MW (Conrad and Prasetyaning, 2013). Plant efficiency of electrical production typically ranges between 30-34% and potentially up to 40%. These factors, of course, depend on feedstock quality, as well as the size of the power plant (Conrad and Prasetyaning, 2013). A good solution to the remoteness of these POMs would be to have large storage facilities that would not only facilitate the processing of substances with higher moisture contents, such as PF and PKS, but also allowing transport of the biomass residues to a biomass plant near an urban area with high grid connectivity. Storage facilities could be coupled with drying capacities, thereby increasing heating values of the feedstock available for biomass plants.

2.4 Chemical composition of biomass feedstock

2.4.1 Chemical composition of biomass substances and associated problems

The most commonly used substances for POM electricity generation are PF and PKS. These two substances are used for steam boilers. Sole incineration of PKS is problematic and can include dark smoke and the transference of partially carbonized fibrous particulates from incomplete combustion. The palm oil milling process does not utilize excess chemicals in processing. Products and by-products originate directly from oil palm trees in which facilitates chemical analysis of the substances themselves rather than external factors typically found in other crops (e.g. chemical fertilizer use) (Kittikun et al., 2000). The molar balance used in the chemical analysis is related to carbon, hydrogen, sulfur, oxygen, and nitrogen, and non-combustible ash elements. In the combustion of palm oil wastes, the chemical composition of the substances are very much relevant to not only the amount of energy produced through incineration but to the behavior of the substances during combustion and to the pollutants that are formed in the off gas and ash. The carbon, hydrogen, and oxygen content of Palm Oil Biomass Residues (POBR) is relatively similar to firewood from spruce and beech trees, but with considerably higher nitrogen and ash contents, as demonstrated in Table 2-1.

Table 2-1: Overall chemical analysis of PF, PKS, spruce trees, and beech trees. Chart data from from Mahlia et al. (2001), Permatasari et al. (N.D.), Harimi et al. (2005), Thai case study (Wittmayer, 2004), and Lasselsberger (2001)

	Mahlia		Permatasari		Harimi et al.		Thai case study		Lasselsberger		Average 4 papers*		
Component (wt %)	Fiber waf	Shell waf	Fiber waf	Shell waf	Fiber waf	Shell waf	Fiber waf	Shell waf	Spruce	Beech	Fiber waf	Shell waf	60/40 FS Mix
H	6.6	6.5	6.2	5.5	6.5	6.6	7.9	5.9	5.4	5.3	6.8	6.1	6.5
C	51.5	54.1	50.1	47.9	51.5	54.1	31.9	52.6	50.7	49.7	46.3	52.2	48.6
S	0.3	0.2	0.13	0.04	0.3	0.2	0.04	0.02			0.2	0.1	0.2
N	1.5	0.6	2.4	0.71	1.5	0.6	0.1	0.3	0.1	0.22	1.4	0.6	1.1
O	40.1	38.5	41.2	45.8	40.1	38.6	59.9	41.1	43.5	44.4	45.3	41.0	43.6
Sum	100	100	100	100	100	100	100.00	99.98	100	100	100.0	100.0	100
Ash	8.4	3.2	3.6	1.9	5.3	2.7	6.13	3.52	0.3	0.5	5.9	2.8	4.6
Moisture			14.0	12.2	36.4	16.4	20	12	15-20	15-20	23.5	13.5	19.5

* Average includes Mahlia, Permatasari, Harimi et at. and the Thai case study

What can also be observed in Table 2-1 is that PF has a higher nitrogen content than PKS, which is most commonly found in fruit and bark. PKS, as seen in the overall average column in Table 2-1, has a higher carbon and lower oxygen content than PF. This data is based on water and ash free results, the sum of elements totaling to 100%. The higher carbon and lower oxygen contents for shell than fiber is indicative of a higher calorific value. The exception of this observation being the Permatisari et al. (N.D.) data wherein PKS has a lower carbon content than PF, which appears to be quite unusual. Table 2-2 demonstrates the various mixes of PKS and PF utilized in seven different POMs. In plant 7 in particular, where the mix is at 50/50, PF to PKS ratio, PKS is shown to have nearly double the calorific value of PF. This can be explained by the high humidity in PF. The observable ash content is typically higher in fiber than in shell that creates issues with the presence of $PM_{2.5}$ and PM_{10} in the off gas during incineration. Additionally, PF has a higher and quite variable moisture content that would potentially produce white smoke and additionally reduce the potential energy production of the substance itself.

Table 2-2: Analysis of seven POMs, the ratio of PF and PKS used in biomass mix, and their respective calorific values used for incineration – F and S individual data in kJ/kg, sum in MJ/kg (Husain et al., 2003)

Calorific value of biomass waste

Mill no.	Proportional weight (%)	Calorific value ($MJ\ kg^{-1}$)
1	F 64	7368
	S 36	6943 = 14.311
2	F 60	6076
	S 40	7714 = 13.790
3	F 67	7713
	S 33	6364 = 14.077
4	F 70	8058
	S 30	5786 = 13.844
5	F 60	6076
	S 40	7714 = 13.790
6	F 50	5756
	S 50	9202 = 14.958
7	F 50	5756
	S 50	9292 = 14.958

F—Fibre, S—Shell. Calorific value of Fiber = 19.188 $MJ\ kg^{-1}$, Shell = 21.430 $MJ\ kg^{-1}$, Moisture content (x) in: Fiber = 40%, Shell = 10%.

While utilization of POBR in RET can lead to significant decreases in greenhouse gases (GHGs), most notably CO_2 emissions. Incomplete combustion of biomass as seen in experiments produces dioxins and bio-accumulative chemicals (persistent organic pollutants, POPs) (Hosseini and Mazlan, 2014). The dioxins are formed in boilers and open burning and reduced effectively by avoiding lean, oxygen deficient combustion conditions possible in fluidized bed combustion.

Another problem for POBR combustion is the high ash content of the fuel and the chemical composition of the ash containing high levels of alkaline and earth-alkaline elements (K, Ca) and silicon (Ninduangdee and Kuprianov, 2015). The ash content of POBR is up to a factor of 10 higher than woody biomass from forestry (Table 2-1). According to Hosseini and Mazlan (2014) slagging and bed agglomeration emerges in the fluidized bed combustors when temperatures increase above 575˚C. To determine the use of POBR in boilers, chemical characteristics must be taken into consideration not only to determine potential energy utilization but also to undertake proper pollution mitigating measures. Primary pollutants formed in combustion are particulate matter (PM), nitrogen oxides (NO_x), sulfur oxides (SO_x), hydrocarbons (HC) and carbon monoxide (CO). During incomplete POBR combustion at lower temperatures or under oxygen deficient conditions, carbon monoxide, volatile organic compounds (VOC), and polycyclic aromatic hydrocarbons (PAH) are generated. In addition, a fluctuating lower heat value (LHV), or net calorific value (NCV) of POBR, creates problems with flame stability and formation of these compounds (CO, VOC, and PAH). What has been done in various experiments was that blending POBR with fossil fuels, most notably coal can effectively reduce many of the flame stability and pollutant problems.

In addition to the emissions formed, the chemical properties of POBR off gas and ash may also cause issues of fouling, slagging, and corrosion. The incineration of POBR also produces residues and ash that is found on the surface of heat transfer equipment known as slagging. This is molted or partially fused deposit on chamber walls and often occurs when the soften ash is not cooled down to solid form. Sodium and potassium content in POBR may decrease the melting point of ash, thus creating more ash deposition and fouling of the boiling tube. This phenomenon is known as bed agglomeration typically found in fluidized bed combustion (FBC). Bed agglomeration is a major problem when burning biomass fuels with high alkali metal contents in fluidized-bed combustion systems. When combined with sulphur, chlorine, silica and phosphorus, low-melting compounds or mixtures are formed and are deposited on the ash particles forming a sticky glue bonding the particles together (Ninduangdee and Kuprianov, 2015). Therefore in biomass conversion, the agglomeration is related to a higher potassium, chlorine, and sulfur content in fuels that enhance the potential for bed agglomeration. Another physical process that typically occurring in the incineration of POBR is corrosion, or metallic deterioration due to its interaction with its incineration environment. Molten phase corrosion, solid phase corrosion, and gas particle corrosion are the common issues with POBR boilers that have been frequently observed (Hosseini and Mazlan, 2014).

The products of combustion are related to these elements and important especially in terms of the temperature and excess air used during incineration. According to most experimental incineration tests, what is most relevant is the operating temperature in an incinerator. Operating flame temperature is determined under adiabatic or near-adiabatic conditions, namely an assumption that combustion is taking place with minimal heat loss to the surrounding environment (Harimi, 2005). There is a strong dependence on excess air requirement and the lower heat value of the waste. Knowledge of these incineration characteristics allows preventative measures to be undertaken to reducing pollutants in the off-gas, as well as bed agglomeration and corrosion of equipment.

2.4.2 Preventative pollutant measures

For the use of palm oil biomass residues for electricity generation for communal electricity generation, a range of issues have to be considered.

- Physical issues, such as methods of storage, handling, transport, humidity content control, and size requirements (e.g. chipping of the chunks) all play a role in the thoroughness of combustion.

  While PKS has low moisture content, PF material can contain moisture from approximately 10-40% thereby decreasing overall energy output of the substance and issues during incineration, emitting environmentally harmful a white smoke. The high moisture content of POBR makes the collection and transport of this product very expensive. If not given the right attention, the conservation process could be deleterious to this viable biomass. Improper on-field storage results in material loss and increase moisture of the substances cannot be controlled. Additional concerns are the formation of spores and fungus that can spoil the material further reducing its overall utility. Storage of POBR can increase the cost up to 10-20% (Hosseini and Mazlan, 2014). Therefore storage facilities should be in close proximity to biomass power plants in order to mitigate transportation costs. The drying process can be facilitated by trapping waste heat and reduce decomposition from spore and fungal formation. What is recommended is an initial drying of the PF substance before mixed with PKS. It is important to remember that energy facilities located near palm oil mills provides huge amounts of low-cost POBR.

- Incomplete combustion may lead to emissions of soot and associated pollutants, such including polycyclic aromatic hydrocarbons, dioxins, phenols and gaseous indicators of incomplete combustion (e.g. CO, VOC, and aldehydes).

  To ensure complete combustion, incineration systems that are recommended are fluidized bed combustion (FBC) systems and staged combustion systems. Typically a FBC system is dependent on a variety of operating conditions, including but not limited to: temperature, excess air, staged air, fuel feed rate, and fuel properties. It utilizes a continuous stream of air to create turbulence in a mixed bed of fuel, generally consisting of inert materials and coarse fuel ash particles. Temperatures of operations range between 800-900˚C. This mixture ensures complete combustion of substances (Permatasari et al. N.D.). FBC is ideal in situations where POBR has a high moisture content and the fuel flow is relatively high. Temperature profiles decrease with FBC height. CO emissions are lower for staged air combustion rather than for the non-staged air combustion (Permatasari et al. N.D.). In FBC, emission formation as well as fluidization of ash formulates a serious issue. Increasing secondary air decreases distributions along FBC. This effectively reduces the flame temperature and resistance impacting the air velocity that allows particles to carry-over. It was found that palm shell emission decreases 30% and fiber at 20% at secondary air combustion (Permatasari et al. N.D.). Increasing air staging also increases the combustion efficiency and effectively reduces CO emission from FBC (Permatasari et al. N.D.).

- Physico-Chemical issues originating from the alkaline ash-constituents causing low melting points with effects of slagging and bed agglomeration at higher combustion temperatures. The chemical properties of POBR off gas and ash may also cause issues of fouling and corrosion.

With respect to a controlled fuel feeding system, with careful utilization of selective bed materials, bed agglomeration may be prevented. Typically, bed materials exhibit time-domain changes in physical and chemical properties (Ninduangdee and Kuprianov, 2015). Removal of slag may be done by leaching the fuel with water thereby decreasing volatilization at temperatures higher than 575˚C. Higher calcium and magnesium contents in biomass fuel can mitigate bed agglomeration. Additives such as limestone bauxite, magnesium oxide, and kaolinite generate high melting points for alkali compounds. Hosseini and Mazlan (2014) found that additionally using ferric oxide and dolomite can also be effective in the use of alternative bed materials. This results in an overall decrease of deposit formation. Typically after a few hours of operation, an ash layer of potassium develops and agglomerates are formed. A presence of low-temperature-melting of phosphorous and potassium or silica from calcium and sand are formed (Hosseini and Mazlan, 2014). It is recommended to implement an early agglomeration recognition system (EARS) to predict these phenomena 30-60 minutes in advance; however, a boiler with a co-combustion system can effectively eliminate the agglomeration.

- The sulfur, nitrogen, and ash content of the fuel may lead to elevated emissions of SO_2, NOx and fine particles.

When referring to NO_x, HC, and CO emission mitigation, a staged FBC system is most ideal. SO_2 emissions become negligible due to the high alkalinity of POBR. POBR burning at higher excess air resulted in lower peaks of CO and HC. A secondary reaction creates a catalytic reduction of NO_x and CO of the particles and homogeneous reactions of NO_x with light hydrocarbon radicals, resulting in a reduction of formed NO_x thereby forming relatively low NO_x emission from combustion (Ninduangdee and Kuprianov, 2015). NO_x emissions exhibit opposite effects with excess air. This relates to the role of CO and HC to NO_x reduction. To reduce NO_x emissions, excess air of combustion can be controlled at a minimum possible value, but also ensuring that CO emissions at a level above national emission limit for pollutant. According to laboratory experiments conducted by Ninduangdee and Kuprianov (2015), highest levels of CO and HC emissions are at peak at 20% excess air thereafter decreasing with increased air input. When using the materials, 60% excess air is ideal for dolomite and limestone and 40% is optimal when using aluminum (Ninduangdee and Kuprianov, 2015). Increasing air in a specified range, combustion-related heat loss also decreases significantly. FBC can be operated with high efficiency with acceptable emissions of both CO and NO_x while at the same time maintaining HCs at appropriate levels (Ninduangdee and Kuprianov, 2015). During experiments utilizing dolomite/limestone, a generation of fine bed particles carried over from the combustor. A continuous substitution of bed particles is required. Eventually, multi-cyclone dust collectors are necessary to trap particulates that carry over from the combustor.

3. Electricity Generation Model Study

3.1 Considerations for model feasibility

Biomass incineration has the potential to reduce fossil carbon emissions via the use of POBR as compared to the use of fossil fuels. This is a key to help prevent further global warming (Shuit et al., 2009). There are three major factors that must first be taken into consideration before considering the model calculations:

- Theoretical biomass feedstock (biomass available)
- Electricity generation potential and closeness to grid
- Technical capacity (technology used/available, feedstock type-chemical composition)

The theoretical biomass and potential electricity generation can both be calculated together as they do have an interlinked relationship between biomass feedstock availability and amount of energy produced by incineration of the feedstock. Technical capacity will have to be considered based on the chemical composition of the feedstock and its behavior during incineration including the technologies necessary to mitigate pollution, agglomeration, and machinery depreciation. Specialization will also have to be considered as operations of a boiler, specifically a fluidized bed combustor, can pose challenges due to POBRs chemical and physical consistency.

Much research has been done in Malaysia on POBR electricity generation. Just as Indonesian palm oil plantations, Malaysia utilizes POBR for their POMs' own electricity production and consumption on plantations. They also calculate feasibility of biomass usage to power nearby settlements and urban areas. In Sabah, a region of Malaysia, which has a high concentration of palm oil plantations and other agricultural industries, the total electricity generated using biomass waste is 3,300 GWh per year. Only 5% of the total available POBR are used for the electricity generation. The 95% that is not utilized is generally scattered around the palm oil plantation (Lim et al., 2014). In Malaysia the cost of transporting biomass waste from plantations to power plants is relatively high, indicated by Lim et al. (2014) from the Malaysian Industrial Development Authority (2005) at RM0.20 per ton per kilometer, or 0.5 Euros. Consequently, locations must be determined that are close enough to POMs to receive and process biomass feedstock for usage in power facilities and keep transportation cost to a minimum. Potential capacity of biomass power plants due to the plantations high feed availability of POBR alone, is estimated at nearly 500 MW in Sabah (Lim et al., 2014). Additionally, a grid connection is essential in determining the viability of power plants. POBR plants must have the ability to feed the electricity produced onto an electrical grid.

Utility maximization considerations that arise in Malaysia are certainly transferable to the Indonesian palm oil industry. Because Indonesia is the world's leading producer in palm oil, its overall total level of production is greater than Malaysia implying that POBR potentials are also at higher levels. Indonesia's RET research and development is emerging and new information on feasibility of POBR potential installation capacity is gaining significance because of the country's motivation to increase their share of RET. Indonesia's national energy policy, announced in October 2014, will increase RE in the national energy mix to at least 23% by 2025 and 31% by 2050. Climate change has adversely affected the palm oil crop growth in important agricultural regions such as Sumatra. Agricultural yields have also been decreasing due to frequented El Niño and La Nina events, exacerbating both drying and flooding trends in the region.

Other major research studies biomass produced from other agricultural goods such as sugar cane, rice paddy, and other notable crops such as corn, rubber, and cassava. According to Indonesia's government statistics, Bandan Pusat Statistik (BPS), palm oil (of FFB origin) consists of nearly 41% of the total agricultural commodities produced in Indonesia, a demonstration of the sheer importance of the crop to the country as well as its biomass potential for RET (Conrad and Prasetyaning, 2013). With this new emerging interest in RE, Indonesia is open to new measures that would not only enable the country to increase market competitiveness in energy production, but also use cleaner and more sustainable technologies to mitigate the effects of GHG issues.

Since more than 70% of CPO production is located in Sumatra, a well interconnected grid is available in the region. In general, the electrical grid is concentrated in urban areas such as in the city of Medan, the location of Northern Sumatra (Sumatra Utara). Hence, a pilot plant appears to be the most ideal location to begin such a POBR pilot plant (Conrad and Prasetyaning, 2013). There are three options for the size of biomass plants, a small plant, approximately <5 MW_{el} generation capacity, a medium sized plant between 5-19 MW_{el}, and finally a large sized plant with a capacity of >20 MW_{el}. The following considerations will be performed for a larger biomass power plant (BPP) of around a 60 thermal megawatt (MW_{th}) capacity or about a 21 electrical megawatt (MW_{el}) capacity, assuming an efficiency of 35%. This would equate to a larger biomass power plant in the EU, there is technological know-how and experience with plants of this size, and a large amount of POBR potentially available in the Sumatra Utara region. Assuming that the model only takes into account the use of PF and PKS materials and not a co-firing plant, it is important to appreciate that the total feedstock may exceed the feedstock capacity amount of the BPP, a smaller pilot plant would ensure a safer investment that would improve on shortcomings and provide a model of operating procedures for future larger potential plants.

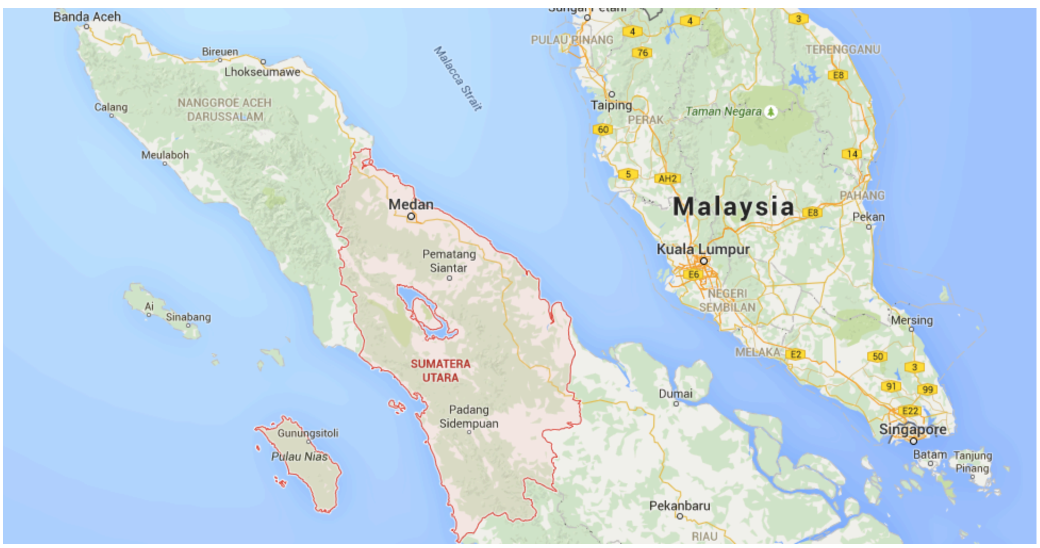

Figure 3-1: Sumatera Utara region (Google Maps 2015).

Although the MW potential is significantly higher due to the large abundance of feedstock, many developed countries have BPP to generate electricity for households (e.g. Francescato et al., 2008). An additional potential is to export these materials to other countries interested in POBR incineration. Indonesia may have this same capacity to use POBR at a larger, commercial scale to produce steam for electricity generation. As regional technological know-how develops, a heat to cooling system can be implemented to provide cooling in the region as well. The ideal maximization of efficiency of biomass electricity generation is typically found in a heat and power co-generation (CHP) system. With minimal use of household and district heating in tropical areas such as Indonesia, wherein temperatures rarely fall below 25˚C, for now we will consider solely electricity generation. As such, efficiency stands at a maximum of 30-40% utility of electricity generating potential from POBR. As POMs already utilize the residues for their own processing, many of these plants are not only already energy self-sufficient, but demonstrates that these POMs have the technological know-how and experience of dealing with POBR during incineration and subsequent electrical generation process. In order to determine how much surplus a POM produces, the subtracted total amount of energy necessary for the POM or the plantation itself from the total amount of electrical energy produced determines the remaining surplus energy that could be transported onto a grid to a nearby city or settlement.

For the model itself, the amount of biomass feedstock availability will be estimated utilizing data provided by PT Perkebunan Nusantara (PTPN IV). PTPN IV is a government owned palm oil plantation company established at the beginning of the Asian economic crisis as part of the state owned enterprise restructuration measures. The selection of a community-owned palm oil plantation company facilitates the transport of electricity onto the state-owned grid (PLN), it provides the government with the opportunity to improve their own systems, and supports RE measures. From the determination of this feed stock quantity, the amount of PF and PKS produced will be determined followed by the energy potential of this substance and how much feedstock is available vs. how much is needed for a 60 MW_{th} power plant. The model will assume that PF and PKS substances have been dried to operable conditions, most importantly that there is a lower moisture content. The amount of energy needed for POM operations will be subtracted from the total energy amount thereby providing the amount available to feed onto the grid.

3.2 Calculation of biomass feed stock availability

Sumatra plays an important role in the development of oil palm industry, approximately 1,000,000 hectares (ha) worth, an area equivalent to 15.7% of the total area of the region (CAREPI, 2009). Private plantations consist of 377,337 ha, community plantations 367,741 ha, and government owned plantations (PTPN IV) 278,272 ha (CAREPI, 2009). The model's focus is based on government-owned plantations in the region, namely the PTPN IV plantation area total, 278,272 ha will be considered for the model. According to Hosseini and Mazlan (2014), the approximate number of mature vs. immature trees fall into an estimated, average ratio of 85% mature to 15% immature trees on a palm oil plantation, meaning that about 85% of the trees are ready and able to be harvested for their FFB fruits. We determine 85% of the 278,272 ha as harvesting potential.

$$278{,}272 \text{ ha} (* 0.85) = 236{,}531 \text{ ha}$$

There are approximately 236,531 ha of harvestable land on the PTPN IV owned plantations.

Figure 3-2: Immature oil palm trees (MacDonald 2015).

From this we determine the amount of fresh fruit bunches produced per year. According to Yusoff (2006), one tree occupies an estimated 0,0068 ha of land and each tree produces about 150 kg of FFB per year. We can determine the amount of FFB bunches produced by dividing the total harvestable area by the area a typical palm oil tree occupies to obtain the approximate number of the estimated total number of trees in the plantation, and multiply that number by the amount of FFB produced per tree per year.

$$236{,}531\ \text{ha} \times \frac{150\text{kg/yr (FBB)}}{0.0068\text{ha}} \times \frac{1\ \text{ton}}{1000\ \text{kg}} \approx 5{,}217{,}600\ \text{t FFB/yr}$$

Idealistically speaking a more accurate account of the exact number of trees would be best, however, considering that this data is not readily available to the public, we have determined that 5,217,600 tons of FFB are produced per year on the PTPN IV government plantations. After the processing of FFB, the amount of PF and PKS residue waste that is typically remaining after production, as determined by Prasertan and Prasertan (1996) and seen in Figure 2-2, is about 12.5% PF and 7.1% PKS. We multiply the total amount of FFB potentially harvested in a year by these percentages to note the feedstock yield from production. Two separate calculations will be done to show the approximate mix of the two residues.

$$0.125(5{,}217{,}598\ \text{t FFB/yr}) \approx 652{,}110\ \text{t PF/yr}$$

$$0.071\left(5{,}217{,}598\ \text{t}\frac{\text{FFB}}{\text{yr}}\right) \approx 370{,}449\ \text{t PKS/yr}$$

Even though the amount of fiber and shell produced per year has been determined, the processing mill potential limits the amount of feedstock produced on an hourly basis. According to Mahlia et al. (2001), a typical medium-sized mill can process 30-60 t of FFB per hour. Assuming that operation hours are at 7300 h/yr, (about 20 h/day operation) the production output of one mill can be up to 220,000-440,000 t of FFB per year. This time also accounts for the time if machinery malfunctions and requires replacement. With this in mind, it is important to determine the amount of potential feedstock available per hour to determine how many mills it would take to process the FFBs available. Assuming that the mill would be at the larger end of production, the capacity level will be assumed to be at 60 t/h. Therefore we determine this by dividing the tons of FFB harvested per year by the processing capacity in tons per year. We can then determine the number of mills required to process the sheer number of FFB.

$$\frac{5{,}217{,}598 \text{ t FFB/yr}}{440{,}000 \text{ t FFB/yr}} \approx 12 \text{ mills}$$

To accommodate the amount of FFB produced annually, 12 mills would need to process 5,217,598 t/yr for 7300 hr/yr, or when dividing the total number of FFB by the hours per year we estimate that approximately 715 tons of FFB per hour will be processed. Of this 715 t/h level, about 12.5% of this overall amount is PF and 7.1% consists of PKS. Summing up the two percentages of PF and PKS we will determine the amount of fiber-shell (FS) feedstock which is available per hour from the amount of FFB produced in a year. This does not account for the evaporative drying energy of PF, for this model we assume that the substance will dry at the plantation site or at a separate facility prior to the transport. Due to the sheer quantities of POBR, the feedstock must be stored in a holding location, such as a warehouse with close proximity to the plant, before being incinerated. These holding locations not only store the substances for future incineration but can also play a role in drying the substances. According to Kittikun et al. (2000), about 30% of the feedstock produced will be subtracted to account as fuel for the mills and utilizing the substance as fertilizer. Other plantations may use EFB's for fertilizers The current study assumes that if electricity generation is not produced directly on the POM, 70% of FS substance will be considered waste by the POM. We therefore assume a 70% usability level.

$$0.125(715 \text{ t/h}) \approx 89 \text{ t PF/h}$$

$$0.071(715 \text{ t/h}) \approx 51 \text{ t PKS/h}$$

$$89 \text{ t PF/h} + 51 \text{ t PKS/h} = 140 \text{ t FS/h}$$

With a 30% use assumption, 30% subtracted from 140 t FS/h, the total feedstock available per hour stands at around *98 t FS/h*.

3.3 POM Electrical need and feedstock sufficiency of a 60 MW_{th} plant

There are further losses of POBR as POMs also require some of this biomass feedstock to power their own facilities, mainly using the energy in FFB processing to power machinery and to generate heat to boil the sanitizing water. According to Mahlia et al. (2001), in a typical medium-sized mill, about 20 kWh are needed to process 1 ton of FFB in the mill. Kittikun et al. (2000) measures the energy demand to be slightly lower at around 17 kWh, but assuming higher levels of energy would be more sufficient to account for losses. In order to determine exactly how much feedstock of the FS mix is necessary, the lower heat value (LHV) of the substance must be determined, taking into account the approximate, optimized ratio of the feedstock composition. The heating value is defined as the amount of heat produced by complete combustion of fuel that is typically measured as a unit of energy per unit mass or volume. In this case the LHV, or the net calorific value (NCV), is expressed as MJ/kg. We assume that after combustion, the moisture content present in the substance will be then in vapor form. The LHV is determined by subtracting the water vapor from the higher heating value, which assumes that after combustion the water present in the substance will continue existing in a liquid phase after combustion, in other words, the energy required to vaporize the water is presumed to not be recovered as heat. As the average POBR ratio used for optimized incineration properties stands at approximately a 60 fiber and 40 shell ratio within the feed. However, since this ratio is an estimated value we will assume an average value of the various mixes, which Husain et al. (2003) has recorded as an average net calorific value. Table 3-1 demonstrates the average heat values for 7 different POMs based on the various PF and PKS ratios utilized at different mills (referred to Table 2-2). The net calorific value for these various mixes is determined at 14.26 MJ/kg.

Table 3-1: Averages of net calorific values, extraction rate, boiler and turbine efficiency, utilization factor for 7 different POMs (Husain et al., 2003)

Values	1	2	3	4	5	6	7	Average values
Calorific value (MJ kg^{-1})	14.31	13.79	14.07	13.84	13.79	14.95	14.95	14.26
Extraction rate	0.23	0.20	0.16	0.18	0.21	0.14	0.20	0.188
Boiler efficiency (%)	81	73.2	83.4	61.4	70.0	65.3	77.0	73
Turbine efficiency (%)	83.7	85.7	90	53.0	44.6	65.5	57.4	68.5
Utilization factor	72	65	71.7	55	77	54	65	65.6
Heat/power ratio	16.6	12.9	17.2	21	19.6	17.2	20.8	17.9
Rate of steam consumption kg (kWh^{-1})	28.5	22.2	30	28.6	23.3	37.5	27.5	28.2
Increase in power (condensing) (%)	65.9	60	67.7	61.1	51.6	60.4	59.2	60.8
Electrical energy/tonn of FFB	60	17.4	24.0	34.9	33.5	37.9	3.87	30.2

First, a determination of how much feedstock, PF and PKS substance, is needed as internal energy for operating a mill is calculated.. This is done by using the net calorific value of a kilogram of the substance (MJ/kg), as determined by Husain et al. (2003), converting it to kWs and dividing this by the number of seconds in an hour (3600) to determine the amount of kWh of energy this can generate. Following this step is determining the amount of substance needed (kg) to run the mill. For the following calculation, we will assume the amount of feedstock required for 1 t of FFB.

$$\text{Energy of 1 kg fuel} = 14.26\ \text{MJ/kg}$$
$$14.26\ \text{MJ/kg} = 14.26\ \text{MWs/kg}$$
$$14.260\ \text{kWs/kg}/3600\text{s/h} = 3.9\ \text{kWh/kg} \approx 4\text{kWh/kg}$$
$$20\text{kWh/ton}\ /(4\text{kWh/kg}) = 5\text{kg FS per 1 ton FFB}$$

Since we have calculated the energy value in kWh of 1 kg of the FS mixture, this being at around 4 kWh/kg, we were then able to determine we need at least 5 times the amount of substance to generate 20 kWh of electricity. Therefore, 5 kg of PF and PKS are needed for 20 kWh of power to process 1 t of FFB. The amount of PF and PKS that is produced for 1 t of FFB processed in a mill is calculated by multiplying 1 ton of FFB by the relative fractions of PF and PKS, e.g.: 1 ton of FFB yields 19.6% POBR (PF and PKS), considering that 12.5% consists of fiber residue and 7.1% of shell residue. From this amount, the 5 kg FS mixture amount as required by the POM can then be subtracted from the total amount of the FS mixture produced from 1 ton of FFB to determine the remaining feedstock for use in the BPP.

$$1\ \text{ton FFB} = 1000\ \text{kg FFB}$$
$$0.196 * (1000\ \text{kg}) = 196\ \text{kg FS}$$
$$196\ \text{kg FS} - 5\ \text{kg FS} = 191\ \text{kg FS}$$
$$0.674 * (191\ \text{kg FS}) = 128.7\ \text{kg FS}$$

An estimated 191 kg of FS remains from the production of 1 ton of FFB after taking into account the 5 kg required to run the POM, or 2.6% of the total amount of POBR (=FS) is consumed for the processing of the palm oil products. An additional 30% is utilized for fertilizing, thus we assume a 32.6% usage and a 67.4% availability of the POBR can be theoretically utilized for external energy production, or about 128.7 kg FS.

Above it was defined that 715 t FFB/h are processed in the various mills (12 mills in total) to satisfy the amount produced in the plantation sites, with a total production of 140 t/h POBR. Accounting for 30% fertilizer use and 2.6% use for FFB processing, means that about 94.4 *t/h* POBR (FS) are available for external use. This is calculated by subtracting 32.6% of used FFB from the total 140 t/h of POBR produced. In order to determine whether or not this excess feedstock is sufficient to power a larger BPP, an estimation for the amount of feedstock to power a 60 MW_{th} pilot plant needs to be calculated in order to ensure whether or not that the amount of feedstock is sufficient to power such a BPP. Considering the 60 MW_{th} and then dividing this number by the net calorific value over the amount of seconds in an hour (3600), which would to determine the MWh/kg in the denominator, we can then determine the feedstock required in tons per hour (t/h). We can conclude whether or not there is enough POBR feedstock to power the BPP.

$$\frac{60\ \text{MW}_{\text{th}}}{14.3\text{MJ/kg}/3600\text{s}} = 15.1\ \text{t/h fuel}$$

In order to operate a 60 MW_{th} plant the amount of biomass feedstock of POBR required would be 15.1 t/h of fuel. Currently the POBR of PF and PKS stands at 94.4 t/h, after subtracting the amount required by POMs to operate FFB processing and assuming based on Kittikun et al. (2000) that 30% is the total use of feedstock for fertilization and 2,6% for self-power generation, there is a remaining of about 79,3 t/h of feedstock that could be utilized for additional electricity generation (this is obtained by subtracting 94,4 t/h-15,1 t/h). This would be an equivalent amount to generate an additional five were 60 MW_{th} power plants.

3.4 Emissions considerations

The European emission limits will be used as a basis for the analysis of a 60 MW_{th} biomass plant located in Indonesia. This is presuming that the technology and the know-how originate from the European Union (EU). The BPP should be assessed via EU standards as European emissions limits are quite stringent with respect to emissions from biomass incineration. Therefore the assessment will be made will have a basis in the EU emissions limits for combustion plants using biomass. These standards are legal requirements that limit the concentrations of pollutants in the flue gas emitted into the atmosphere from specific point sources. In the US standard the emission flow over the course of a certain time period or related to an energy unit is defined. The standards are established to achieve certain ambient air quality standards that would ensure the protection of human health and the environment. If a plant above a certain size is to be commissioned, then emission standards have to be considered and also a dispersion model is to be operated to demonstrate, that for the plant operations ambient air quality standards in the surrounding environment are met. The maximum limited concentration values in the flue gas after treatment in the stack are seen in Table 3-2 (EU standards). Considering the net calorific value of 14.3 MJ/kg of the biomass fuel for running a 60 MW_{th} power station, the net fuel consumption is 15.1 t/h. The emission considerations are according to the typical composition of fuel according to Table 2-1. Using this information, typical composition of the flue gas (wet and dry) is indicated in Table 3-2.

Table 3-2: EU Emission limits for combustion plants using biomass (Emission limits from EU Directive 2010/75/EU)

	MWth	**EU mg/m³**
SO_2	50-100	**200**
	100-300	200
	>300	150
NOx	50-100	**250***
	100-300	200
	>300	150
CO		Not regulated
Dust	50-300	**20**
	>300	20
NH_3	If DeNOx operating	**10****

*Calculated as NO2 ** 0% reference O2

Table 3-3: Typical maximum composition of flue gas - wet and dry of the 60 MWth power plant, based on the average composition data of Table 2.1 and a LHV of 14.26 MJ/kg – Table 3.1. Derived by flue gas emission calculations.

	Vol % wet	**Vol% dry**	**ppm**	**mg/m³**
CO2	12.1	14.1		
SO2	0.019	0.02	190	543
NOx	0.234	0.27	2700	5545
H2O	14.0			
N2	68.5	79.7		
O2	5.2	6.0		
Sum	100	100		
Fly Ash				7980

Flue Gas Flow m³/h STP	
wet	86050
dry	74000

3.4.1 SO_2 and NO_x emissions

The EU emission limits are for dry flue gas conditions at 6% O_2. Emission limit values shall be calculated at standard temperature and pressure (STP) involving a temperature of 273.15 K and a pressure of 101.3 kPa. As the water content of PF is quite variable, respective fluctuations, namely of the humidity content of the flue gas, are to be expected.

The SO_2 emission concentration of around 190 ppm, or 543 mg/m^3, is the concentration formed during the combustion process. This number is significantly higher than the maximum threshold values for a 50-100 MW_{th} biomass power plant, as found in EU Directive 2010/75/EU. Since both PF and PKS are both high in alkalinity and thus a presence of a large excess of alkaline fine particles during incineration, the SO_2 becomes scavenged by the alkaline material and the actual emission concentrations are low. Therefore, the emissions of SO_2 is not expected to exceed the EU limit of 200mg/m^3 (70 ppm) in the actual operation of the plant (EU, 2010).

When discussing the total emissions levels of NO_x, the maximum emissions levels from the fuel nitrogen are estimated at around 5545mg/m^3. These numbers are significantly higher than the set directive threshold amount at 250 mg/m^3. The assumed calculation for NO_x is for a 100% conversion of the fuel from nitrogen to NO_x. In the European experience of biomass incineration for woody biomass, nitrogen contents are at around 0.2-0.3% levels (Francescato et al., 2008). For levels at 0.25% N, the observed maximum emission of NO_x would amount to levels of 150-250 mg/m^3 (which is 10-15% of the maximum expected level from the fuel nitrogen) at around the threshold maximum amount of directive emissions levels. Thus for combustion of biomass with 0.2-0.3% N reduction measures are usually not required, however more recently provisions for ammonia based reduction systems are considered (Francescato et al., 2008). For the N content of about 1%, as observed in table 2-1, the POBR mix, a higher than expected NO_x emission level depending on the combustion technology. If a staged FBC system is not implemented, it will be required in a pilot power station to take provisions for an NO_x reduction system. Generally speaking, in a staged combustion process, only a small fraction of the calculated value is formed during the combustion process. Staged combustion adds secondary air during combustion. It has two main functions, it cools the flames and increases the complete combustion. Through this process there is an overall reduction in NO_x production. Therefore, if POBR incinerated to this sum, operates under these same conditions, NO_x is relatively low in FBC. In Europe, reduction measures take in cetratin cases place by adding ammonia. However, for the POBR combustion to meet the EU limit of 250 μg/m^3 (122 ppm), reduction systems most likely have to be applied. Currently it is not clear, whether staged combustion systems for POBR will lead to NOx emissions meeting the EU standard. Selective Catalytic Reduction system (SCR) is an example of a process that would work well for POBR incineration, as the catalyst reaction takes place between a temperature of 220-500˚C, around the temperature at which POBR is incinerated:

$$4\ NO + 4\ NH_3 + O_2 \rightarrow 4\ N_2 + 6\ H_2O$$
$$6\ NO_2 + 8\ NH_3 + O_2 \rightarrow 7\ N_2 + 12\ H_2O$$

What is shown in the reaction is the NO_x reacts with the ammonia compound within the presence of a catalyst. Two compounds that are typically formed in SCR de-NO_x system are nitrogen, N_2, and water, H_2O. Overall, an SCR system contains a reactor, tank for storage, an injection system and catalyst. These additional pieces of machinery will increase the overall cost to the POBR plant if the plant cannot meet emissions threshold requirements solely via staged combustion. The POBR plant would require additional substances such as limestone and dolomite and may need to utilize de-NO_x equipment.

3.4.2 Fly Ash emissions

According to table 2-1, the percent by weight of ash stands at 4.6% of the POBR. As approximately 15.1 tons of POBR is incinerated per hour, about 694.6 kg ash i produced per hour. This means that the total ash that needs to be transported via silo transport is about 600 kg/h fly ash, and 100 kg/h of bottom ash. Fly ash would consist of 600 kg/h. The fine fly ash, assuming levels that are at 10% would not to be retained in the cyclones, would add up to about 59 kg/h fine fly ash. These levels are far above the EU emission levels of 20 mg/m³, or 1,5 kg/h, the emission being about 39 times the amount of allowed fly ash emissions. The most stringent emission concentration limit is for fine particles as these particles are detrimental to the health of human beings. PM is not only an irritant to eyes, nose, and mouth, but also can seep into the circulatory system of humans via the lung alveoli. In the EU the emissions limits are at 20 mg/m^3, which require highly efficient filtration systems, e.g. baghouse filters. According to the emissions analysis, fly ash emissions from POBR incineration far exceed the 20mg/m^3 levels as they are estimated to be at approximately 7980 $\mu g/m^3$ (before the cyclone). The emissions of fine particles from biomass incineration are typically very fine (<2.5 µm). From the European experience it is concluded that reduction systems based solely on cyclones may not reduce the emissions below 50-100 mg/m^3. It is for sure that efficient filters are required for lowering the PM10 or PM2.5, depending on the legal situation. In the EU this would require the emission of a plant to be below 20 mg/m^3 (EU standard, PM10) or an equivalent of 13 mg/m³ for US biomass plants. The fine particle emission standard in US for dry flue gas is 0.03 lb/MMBtu (at 3% oxygen) for plants ≥ 30 MMBtu/h, and 1 megawatt [MW] = 3.41 MMBtu (IT)/hour [MMBtu/h]

For a gas flow of about 74000 m^3/h the emission concentration can be calculated:

>30 MMBtu/h is equivalent to > approx.. 10 MW (exactly > 8.8 MW)

0.03 lb/MMBtu 3% oxygen 0.03 pound = 13.6 gram

For 30 MMBtu/ 0.03 lb/h = 30*13.6 = 408 g/h

For 21 MW el (71.6 MMBtu) the allowed emission would be
21*3.41*13.6 g = 973 g/h (about 1 kg/h)

Flue Gas is about 74000m^3/h then the limit for the emission concentration would be
973/74000 = 0.013 g/m^3 or **13 mg/m³** (3% O2)

Note : This is lower compared to the EU limit of 20 mg/m^3 (6%O2) = equivalent
to 24 mg/m^3 (3% O2)

The first reduction of the coarser part of the fly ash occurs in a cyclone or a system of cyclones (multi-cyclones). The fraction caught in the cyclones has to be determined in a pilot study. However, even if the collection efficiency of the cyclones were at very high levels, between 90-95%, the emissions of PM would still be quite high at around 400-800 mg/m^3. Even with efficient cyclones, a high amount of fine fly ash would still be emitted therefore not complying to EU standards of emissions. The further reduction requires an electro filter or bag house filter. A bag house filter operates by the dust entering into the baghouse compartment. Electro-filtration operates via the use of an electric field. As dust particles travel through these electrical fields, they ionize and attach to the positively or negatively charged plates organizing themselves according to the opposite charge. Harmful particles are localized and collected. The benefits of electro-filtration is the filter's ability to clear very fine dust, such as <1 µm in size. Soot and smoke are also cleared. Similar or higher collection efficiencies are expected for baghouse filters. A baghouse filter consists of a series of filters made of a woven or felted fabric that expedites dust cake formation on the fabrics' surface. It effectively creates a very effective filtration system by the use of ash that accumulates on these surfaces. Lowest emission levels are obtained from bag houses (e.g. below 1 mg/m^3 in the Vienna biomass plant).

4. Conclusions

Millions of tons of agricultural biomass residues are produced every year from Indonesia's palm oil industry. With Indonesia's interest in renewable energies and willingness to reduce consumption of and reliance on fossil fuels, most prominent being oil, gas, and coal, POBR biomass can be a good, sustainable source of energy. This energy cannot only power small local settlements, but larger urban areas as well. There is much controversy surrounding the palm oil industry, ranging from transboundary haze pollution to severe deforestation and subsequent biodiversity destruction. Without slowing down worlds demands for the two oil products themselves (CPO and CPKO), found in a large variety of products ranging from food to cleaning and skin care products and more recently biofuels, the palm oil industry will continue to thrive in Southeast Asia. A solution to reducing the utilization of palm oil products would be to reduce consumption and/or find alternative substances that could effectively replace palm oil and can be used in these products, thereby providing a satisfactory product to the consumer. As the palm oil industry is in fact a large and growing industry, it is advised, at the present time, to look into making the industry more sustainable which can be beneficial to RET development in Southeast Asia.

Meanwhile, the palm oil industries, whether large industries or small shareholders, should maximize their sustainability potential by using POBR to generate electricity, feeding excess electricity onto the grid to create a renewable energy niche to effectively power settlements and larger urban areas. Two commonly used POBR feedstock to generate power and run processing activities in POMs are PF and PKS. PF is the fibrous interior of the palm oil fruit that has been squeezed for the production of CPO. PKS is the outer shell layer of the seed of the oil palm fruit. It is removed when extracting the interior seed to produce CPKO. These two components, when incinerated separately, can create a multitude of issues. Optimizing incineration of the two POBR is useful as it creates a more stable fuel. Incinerating PF alone can create issues with flame stability as PF has a higher and fluctuating moisture content and a lower net calorific value. Burning PF result in a white smoke that can be harmful to the surrounding environment. On the other hand, PKS has a very high net calorific value due to its higher carbon content, but PKS incineration alone can create black smoke harmful to surrounding communities and ecological life. In the mills the two products are combined in an optimal ratio, of 60% fiber and 40% shell to achieve flame stability. For utilizing the biomass residues in a communal power station a pre-treatment of the biomass residues seems to be necessary; such as, seasoning or drying to reduce moisture.

Overall, POBR is a very underexploited potential source of energy. A majority of the time, excess residues are either scattered around plantations to be used as fertilizer, thrown into waste pits, or burned in open fields. Only very little of the biomass residues are used or even needed to power POMs. If electricity for external supply is not generated via these biomass residues, plantations would consider about 70% of these residues waste products. Many POMs, however, do use POBR as feedstock to generate electricity to run operations in FFB processing, showing that these processing plants have the technical experience and know-how necessary to utilize POBR as well as operate machinery associated with POBR incineration and electrical energy production. Although true, very little POBR is used or needed to generate electricity within the plant in comparison to the sheer number of POBR produced on an hourly basis in the region. In order to process 1 ton of FFB, only approximately 20 kWh are required, this is equivalent to 5 kg of FS. For the model, it was established that a typical mill can process 60 tons of FFB per hour in order to satisfy the sheer number of FFB harvest in the Sumatra Utara region. This region was selected due to the high concentration of palm oil plantations in the region and ideal agricultural conditions for the oil palm trees. Additionally, a connected grid is available in this region due to the location of the city of Medan, consisting of a population of 2.1 million in total. Government-run plantation sites were selected in order to facilitate the transferal of biomass product to electrical generation capacity and use of State supported electrical power grids.

One government organization, PTPN IV, operating with another government-operated organization, PLN, facilitates the process to sell and buy electricity respectively. Due to the high amount of FFB produced in these government-run plantation sites, a total 12 mills need to operate in order to process the amount of FFB harvested on an hourly basis. Each of these mills could generate 129 kg/h of FS out of 1 ton of FFB produced that could be used for electricity generation. This number takes into consideration the 30% of PF and PKS residues used for fertilizer on the field as well as the additional 2.6% required in the mill to produce energy. It was determined that this amount of feedstock is more than sufficient to power a 60 MW_{th} power plant. The total amount of feedstock required, taking into account the net calorific value as well as the output capacity of the power plant, was about 15.1 t/h. Thus for the 94.4 t/h produced a total of 5-6 power plants of this generation capacity could be fuelled.

While this seems a very promising prospect to begin POBR powered plants in Northern Sumatra, there are a range of additional external considerations that influence the operation such a plant:

- Drying locations and methodologies need be considered and accounted for. Due to the high moisture content of both PF and PKS and the large quantities of POBR, it is necessary to pre-treat the substances before incineration.
- Transportation costs and methods also need to be considered. Wien Energie reports that Austrian biomass plants have trucks able to support upwards of 24 tons of biomass per hour, transporting feedstock from the feedstock source to the outskirts of Vienna. Transportation is an incurred cost for a POBR power station in Northern Sumatra. According to PTPN IV RSPO report papers, mills of PTPN IV range from 2-6 hours away from the city, the closest distance at 140 km away and the farthest distance at 620 km away in distance (Putra, 2010). According to Lim et al. (2014), transportation of POBR in Malaysia costs 0.047 Euros per ton per kilometer. This means that the cost of transportation would range between 100 Euros-440 Euros if the shipments were at 15 t FS/h. Therefore, the remote locations of mills in Sumatra Utara would be optimized by producing the electricity on site, then transferring the energy on to power lines that could be constructed by the company or with government support.

In addition to external considerations, power station planning considerations need to be accounted for:

- The power station should be located near a water supply for cooling.
- When close to city, the plant must consider more stringent emissions standards.
- To ameliorate fine particle emissions, in addition to commonly used cyclones, e-filter or a baghouse filter is required (as for maintaining EU Emission standards). The ash content in FS feedstock is quite high and is a major cause for concern. Since potential fly ash emissions far exceeds thresholds established by the EU, it would be necessary to have filtration technologies to mitigate the amount of ash that would be produced by POBR incineration.

- Due to the high content of ash in POBR, the transport and disposal of collected ash needs to be considered.
- The potential ash problems during incineration (fouling, slagging, bed agglomeration) must be ameliorated during operation.
- There are relatively high NO_x emissions (de-NO_x possibly required). Emissions originating from this type of feedstock are a matter of concern especially with respect to NO_x and ash emissions. Nitrogen concentrations in FS feedstock are far higher than that of some trees such as beech and spruce trees that have similar chemical compositions as FS feedstock. While incinerating beech and spruce trees just meet the NO_x standard as set in EU Directive 2010/75/EU, estimated NO_x emissions from FS would be higher. If staged FBC combustion does not mediate this emission issue, then de-NO_x mitigating technologies would have to be implemented and applied onto the BPP to avoid high concentration of NO_x. Nevertheless some research has found that a staged combustion while applying materials such as dolomite and limestone actually reduces the NO_x emissions to acceptable levels. A pilot plant such as this 60 MW_{th} plant would have to determine the amount of NO_x produced after placing mitigating technologies. Operators would then need to see if these measures are sufficient or if more measures are in fact necessary to continue plant operational activities.
- There is no problem with SO_2 emissions due to alkaline fly ash.

Overall, this type of renewable technology, specifically utilizing POBR, and the feasibility of running a 60 MW_{th}, in the region seems feasible based solely on the sheer amount of feedstock that is available. This abundant amount of feedstock ensures powering of not just one plant but up to an additional 5-6 power plants in the region. The aforementioned emission considerations need to be taken into account. While utilizing these biomass technologies can help mitigate CO_2 emission levels, these other types of emission sources from POBR feedstock, most notably NO_x and ash, need to be seriously considered. Simply incinerating these biomass residues without any emission mediation technologies may negate the positive CO_2 mediation effects of incinerating biomass feedstock. Further planning and exploration into the costs of implementing and constructing such a plant needs to be accomplished. Drying and storage facilities are major obstacles to implementation because of the large amount of feedstock that is produced per hour. As such, the equipment needed to establish such a plant will be quite costly because of the additional filtration and drying measures necessary. Once these considerations are accounted for, energy generation from POBR seems to be a very promising prospect that promotes sustainable practices and provides a new niche for RET in Northern Sumatra.

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