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Energy Potential from *Areca Palm* through Direct Combustion and Pyrolysis in Indonesia: A review

Hendrix Yulis Setyawan[#], Sunaryo[#], Budi Waluyo[#], Merlya[#], Annisa'u Choirun[#], Addion Nizori[*], Sahrial[*]

[#] *Universitas Brawijaya, 1st Veteran Street, Malang, East Java 65145, Indonesia*
**Universitas Jambi, Jambi-Muara Bulian Street, Muaro Jambi, Jambi, 36361, Indonesia*

E-mail: hendrix@ub.a.c.id

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Abstract— **Global warming that occurs due to rapid population growth and increasing of energy consumption makes energy supply decreases. Energy source from non-renewable energy (fossil fuel) cause increasing greenhouse gas emission level and scarcity of natural resources. This paper reports that agricultural residues especially areca palm wastes had been widely used as an alternative energy source to reducing fossil fuel consumption. About 4,780,000 tones areca palm produced per year around the world and the shell was burned in open air or just thrown in the environment. This work aimed to investigate energy potential from areca palm shell using direct combustion and pyrolysis method also do analysis about this technology from environmental point of view and that contribution for sustainable uses.**

Keywords— **Areca palm; renewable energy; Areca palm empty-shell; alternative energy**

I. INTRODUCTION

Global warming due to emissions of greenhouse gas (GHGs), especially from the burning of fossil fuels, has harmed the environment along with a decrease in increased petroleum reserves [1]. Increasing population growth and consumption of goods and services imply that demand for energy and resources will continue [2]. In this perspective, cellulose, the most abundant biopolymer on earth, has attracted much attention. Several studies highlight the importance and potential application of cellulose in various fields [1,3]. In this case, the research study aims to obtain energy from available biomass, especially agricultural solid residues from Areca Palm. This residue can be used by direct combustion to produce energy or other advanced processes (eg, pyrolysis) to produce solid, liquid, and gas fuel products [4]. The use of cellulose fiber as an amplifier offers great potential for energy savings and reduction of environmental impacts [5].

If the results from agricultural residues, such as Areca Palm shells, are used to produce energy, it is necessary to carry out an integral assessment taking into account all stages and cycles and comparing them with the use of fossil fuels to identify conditions and their lower environmental impact.

The environmental analysis also needs to be carried out among the most commonly used technologies, such as pyrolysis or gasification. There is uncertainty about being more environmentally friendly during its life cycle, not only in the production process but also in the use of bioenergy. The purpose of this review is to examine the energy potential of agricultural residues, which are focused on the Areca Palm shells. A full description will be given from direct combustion and pyrolysis technology to convert Areca Palm shells into energy including its physical and chemical properties. Finally, this review carries out environmental analysis, using life cycle thinking perspectives as well as analysis of the results obtained in life cycle assessment studies available in the literature on the use of Areca Palm shells for energy purposes.

II. ARECA PALM

Areca Palm (*Areca catechu*) is a species of palm under family of Arecaceae which grows in tropical area such as Asia and parts of East Africa. About 4780.000 tones areca palm produced per year around the world [6]. The largest producers of area palm in the world is Sri Lanka, Malaysia, and Melanesia. Areca palm has many common names including areca nut palm, indian nut, betel palm, and pinang palm is the one of the abundant and low cost material that contain lignocellulostic fibres. Areca palm is widely used as a food ingredients and areca palm fruit (areca nut) as a constituent of medicinal herbs which has entered to WHO (World Health Organization) priority list. Quality of areca palm varies with locations and seasons. From this case, areca palm has potential being a highly profitable crop to developed because not only fruit that can be utilized but other parts like leaves and stems can also be utilized. The palm reaches 10 – 20 m (33 – 66 ft.) high with a trunk diameter about 25 – 40 cm (10 – 16 in). Flowers are unisexual that is male and female flower grow in the same inflorescence. Each terminal branch has a few numerous of female and male flower. Areca palm life cycle from sterile state until death about 40 years [7].

The cultivation of areca palm has various crucial factors. Various factors that increase the suitability of areca palm are rainfall, soil characteristics, temperature, and sunlight intensity. The best condition for growth of areca palm is in 14 – 36°C temperature or in tropical regions. For best growth roots should be kept at 21 – 27°C with air temperatures up to 35°C. To get good quality of areca palm the soil must contain 1,5-2,5% dry weight of nitrogen,0,1-0,3% phosphorus, 0,7-2,0% potassium, 1,0-1,5% calcium, 0,3-0,6% magnesium, 10-60 parts per million (ppm) copper, 50-300 ppm manganese and iron and 25-200 ppm zinc [7]. Areca palms can tolerate low soil moisture but best growth is obtained if plants are not subjected to drought condition. The best condition of environment will have a good impact to support areca palm growth.

Fig. 1 Areca palm fruit and Areca Palm

A. The spread of Areca Palm in Indonesia

Areca palm is a new alternative herbal plant that is found in Indonesia, but areca palm plants grow widely or planted as yard crops, except on some regions in Sumatera especially in Province of Jambi have started cultivate in large area and its utilization is still limited. Areca palm found in many regions in Indonesia such as Sumatera (Aceh, North Sumatera, and West Sumatera), Kalimantan (South Kalimantan and West Kalimantan), Sulawesi (South Sulawesi and North Sulawesi), West Nusa Tenggara, East Nusa Tenggara, and Papua. Superior varieties of areca palm in Indonesia which are widely exported are “Betara Super” from Jambi, “Bulawan” from North Sulawesi, and areca nut from Aceh. In 2013, the total areca palm planted area in Indonesia reaches 151.750 ha [Agricultural Ministry of Indonesia, 2014].

B. Utilisation of Areca Palm

In generally, parts in areca palm can be used for many application. The nut (areca nut) has several beneficial effect such as anti-oxidant, anti-hypertension, anti-microbial, anti-depressant, antiviral, and as wound healer [8]. Areca nut is an astringent, stimulant herb that relieves hunger and weariness. It kills intestinal parasites and also has laxative effects. The nut is used to against anaemia, leprosy, obesity, and worms. Extract from areca nut could be used as a bioactive ingredient for functional food, nutraceutical, or cosmetic ingredients. The nut shell is used for industrial process to make hardboard, cushions, paperboard, and activated carbon. The nut also has potential to be developed into cytotoxic agent which can combine with chemotherapy agent so that can increase cancer cell sensitivity. The trunks are used for crude construction, the fallen fronds are used in alcohol making. The leaves are used as antifungal in wrapping and packing material. Areca leaf sheath is shed periodically and used for making plates/cups, fuel, and composting material [9]. In medical, the nuts, husks, buds, leaves, young shoots, and roots of the areca palm are used in various medicinal preparations. The stems are used as building materials in villages and also used in construction purposes.

The utilization of areca palm in Indonesia is popular used to be chewed. Usually areca nut consumed alone or as betel quid with other ingredients that closely related with alkaloid such as catechu, betel leaf, tobacco, lime, perfumes are responsible for stimulant effect. Kalimantan, Java, Sumatera, and Nusa Tenggara are regions which conduct chewing habit use areca palm. Chewing areca nut is thought to have stimulating effect for central nervous system, salivary stimulating and digestive properties. In Papua society, areca palm used as tooth brace material and medicine for shrinking the uterus after childbirth (astringent). Moreover, Areca nut boiled water is used to illness overcome such as eczema, diphtheria, dysentery, and ulcer. Aromatic areca nut also has antioxidant and anti-mutagenic effect.

III. ENERGY RECOVERY FROM ARECA PALM

Sustainability of energy sources are currently needed to meet the needs of life such as the sustainable energy for industry which requires cheap price, abundantly available, and a very high potential material. The thing that needs to be considered for energy sources in large industry is its effect on the industrial economy and surrounding area because of the gas disposal results from energy sources can effect on exhaust gas emissions which can cause air pollution [10]. Most sources of non-renewable energy are fossil fuels such as coal, gas, and oil. Over 70% of the energy used in industrial processes comes from non-renewable resources. Bad effect form non-renewable energy are cause environmental pollution, huge amounts of fuel reserves, public health issues because burning fossil fuels can lead to lung problem in humans, health risks to workers, and need much cost. Pollution from the earth’s natural resources for energy are now the major concern. If only 10% of the vehicles were electrically powered, petroleum consumption would be cut by 700 million barrels per year, the reduction of expenses would be 14 billion at \$20 per barrel, and CO_2 as an air pollution reduced until 1011 kg [11].

Biomass is organic material that can be alternative choice for renewable energy sources because its availability and cheap. Biomass comes from a variety sources such as agro-industrial waste, agricultural residues, and food processing wastes. Moreover, the use of the industrial and agricultural bio-residues as another valuable material contributes to solving waste disposal problems [1]. Many researchers have been investigating low-cost biomass which can be used as energy sources such as sawdust, rice husk, sago waste, areca husk, palm kernel fibre, groundnut shells, tree fern, etc. Areca palm is one of an abundance sources biomass in Indonesia which can be alternative energy sources. Areca Palm appears to be a promising materials because it abundantly available as the development of Areca Palm plantations around the world including in Indonesia [12].

A. Areca Palm Empty-shell Branch and Its Availability

Fig. 2 Areca palm shell

Areca palm fruit (Areca nut) in fresh fruit is green and has soft nut inside. The areca nut shell become yellow or orange when it's ripe. Areca nut can only sliced using certain knife or scissors when it is in the dried form because the nut inside become more solid. Areca palm shell contribute around 65–80% from the total weight and volume of the fresh fruit [13]. Areca nut empty-shell can be divided into three zones, the outer layer covered with cuticle, the middle layer contain enclosed fiber, and the last zone is the nut part that has hard and solid layer. Areca nut empty-shell contains lignin, hemicellulose, and cellulose [14]. Areca nut empty-shell is an agricultural residues which is a solid waste that generated from plantations and useless on the fields, causing a significant disposal problem. It can causes environmental issues because it has bad odor and other decay due to burning process of that waste in an open area. Areca palm empty-shell is one of waste product form has potential used as a fuel. Large expanse of cultivation of areca palm is observed mainly in Southeast Asia and parts of Africa.

TABLE I
THE PHYSICO-CHEMICAL PROPERTIES OF ARECA PALM EMPTY-SHELL BRANCH

Composition	[15]
pH	6.20 – 6.50
EC	1.68 – 1.88
Organic carbon (%)	62 – 65
Nitrogen (%)	0.60
C:N ration	110 – 120
Lignin (%)	43 – 44
Cellulose (%)	41 – 42
Hemicellulose (%)	17 – 18

Areca palm shell after being peeled for the collection of areca nut can be used as potential biomass sources for heat production and bio-oil [12]. Moreover, empty-nut shell also can be used as briquettes. Biomass briquette fuel technology is one of the major directions of biomass conversion technology. Briquetting is method with pressurizing loose of biomass in their natural form into a compacted fuel [16]. Success in processing and producing fuel from all areca parts will be able to reduce dependency on fuel obtain from non-renewable energy. Utilization of areca palm waste is used to make renewable fuel using several combination methods of potential biomass energy sources is one form of innovation in solid fuel products.

B. Physical and chemical properties of Areca Palm

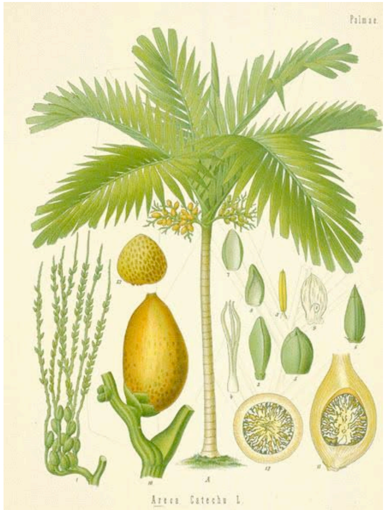

Fig. 3 All parts of areca palm (*Areca catechu*)

Areca palm occupies the fourth position as a psychoactive substance that is widely used globally after tobacco, alcohol, and caffeine. Areca consumption can produce psychostimulant effects such as well-being, can increased capacity to do daily activities, and increase euphoria effect. But, chronic consumption of areca nut can increase several diseases potential such as cancer, metabolic syndrome, and myocardial infection. Areca palm can grow until 20 m height with. Trees can commence bearing fruit in 6- 10 years from seed and fruit take 6 – 8 months to ripen. Areca palm can continue fruiting for 30 – 60 years. Trunks are vertical with crown shafted. Trunk diameter is about 25 – 40 cm (10 – 16 in). The trunks are smooth because there are no fibers. Ranging colour of the trunk is from green to yellow and if the trunks is exposed to sunlight there will develop a brown dark. Crown shaft colour is variable such as green, silver, white, and rarely yellow. Areca palm leaves is pinnate shaped with 1 to 1.5 meters length. Each areca leaf sheath weights around 200-300 gram. The leaf sheath contains the highest amount of α – cellulose. Besides α – cellulose, areca palm leaf sheath contains hemicellulose, lignin, aqueous extract, fatty and waxy matters, and pectic matters [17]. The chemical composition of areca leaf sheath is shown in **Table 2**.

TABLE II
THE CHEMICAL COMPOSITION OF ARECA PALM LEAF SHEATH

Composition	**%** [17]	**%** [1]
α- cellulose	66.08	72.27
Lignin	19.59	12.84
Hemicellulose	7.40	13.38
Fatty and waxy matters	5.06	
Pectic matters	1.15	1.51
Aqueous extract	0.72	


a) b)

Fig. 4 The trunk and leaves of areca palm

Areca nut is oval shaped with 3 type of maturity stages i.e. raw, ripe and matured fruits. The colour shell of raw areca nut is green with soft shell and nut. When ripe areca nut is orange until yellow in color, and the shell part is spongy and contains more juicy liquid than raw and matured stages of areca nut. Matured areca nut is when the ripe areca nut reached full of maturity and detached from the branch [18]. The physical difference between 3 types of areca nut is shown in **Fig. 5**.


a) b)

c)

Fig. 5 Areca nut of (a) raw, (b) ripe and (c) matured stages

The composition of Areca nut are carbohydrates (20%), polyphenols are mainly flavonoids and tannins (20%), fats (17%), alkaloids includes arecaidine, arecoline, guvacine, and guvacoline (5%), proteins, crude fiber, and mineral such as copper and calcium. Areca nut have a bitter taste because it has an alkaloid content. Arecoline is the major of additive alkaloid in areca nut and has been shown to modulate matrix metalloproteinase and lysyl oxidase. Arecoline also known has effect to inhibit p53 mRNA expression and DNA repair [19]. Gen p53 plays a role in regulation of cell cycle, apoptosis, and genomic stability, so that if arecoline consumed in excess it can be harmful to the human body. But arecoline acts as a stimulant of the nervous system and increases the levels of of noradrenaline and acetylcholine. Phytochemicals as phenolics and alkaloids in areca nut are mainly distributed in roots, fresh unripe fruits, and veins. The chemical composition of areca nut is shown in **Table 3** and the composition of areca palm shell is shown in **Table 4**.

TABLE III
THE CHEMICAL COMPOSITION OF ARECA NUT IN DIFFERENT FORMS [19]

Areca nut form	**Total Carbohydrate (%)**	**Total Arecoline (%)**	**Total Alkaloids (%)**	**Total Protein (%)**	**Total Tannin (%)**	**Total Copper (weight)**
Riped	1.66	0.06	0.14	0.08	6.57	3.31
Unriped	1.29	0.05	0.06	0.04	2.93	2.07
Dried	1.86	0.04	0.06	0.03	0.28	3.63
Roasted	0.76	0.05	0.07	0.05	3.57	3.30

TABLE IV
THE CHEMICAL COMPOSITION OF ARECA PALM SHELL IN DIFFERENT FORMS [20]

Areca palm shell form	**Total Cellulose (%)**	**Total Hemicelluose (%)**	**Total Lignin (%)**	**Total Ash (%)**
Unriped	43.49	17.71	26.85	1.69
Riped	43.99	12.07	26.88	3.13
Matured	50.21	13.16	29.34	3.48

C. Technology to Obtain Energy from Areca

Direct combustion

Direct combustion is the oldest method to convert biomass resources into power. Biomass burnt to generate exhaust gas which used directly to provide heat or fed for industrial process or space heating to generate electricity [21]. Direct combustion is a thermochemical method in which the biomass is burned in little bit excess air or open air at a temperature about 800 – 1000°C. Costs required in the direct combustion are slightly higher compared to pyrolysis or gasification [10]. During combustion, an oxygen play a role as oxidizing agent. But, direct combustion of biomass is ineffective method because the combustion will produces lot of fly ash which can increase release of unburnt carbon to the atmosphere [12].

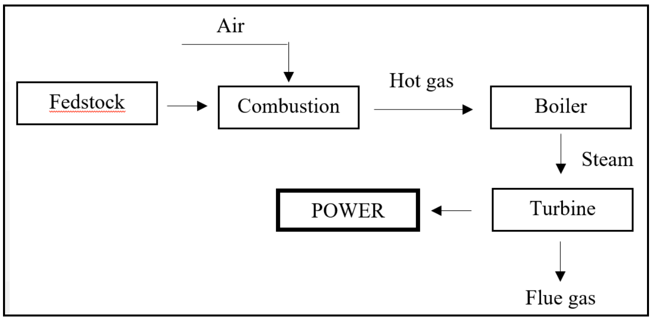

Fig. 6 Direct Combustion Flow Diagram

The combustion of lignocellulosic fuels starts when the volatile gaseous products from the thermal degradation ignite in the surrounding air. In general, material that contain lignocellulose are more reactive and have higher volatile compound than coal from fossil fuels [22]. The combustion such as ignition temperature, reactivity index, and peak temperature are known as thermal parameters which can be defined from thermogravimetric (TG) and derivative thermogravimetric (TG). Ignition temperature (T_i) is the lowest temperature when start the ignition. Reactivity index (R_c) is used to assess combustible material. Whereas, peak temperature (T_{max}) is the maximum temperature that have maximum degradation rate loss. According to the literature, areca palm empty-shell branch characteristics compared with moj and bon bogori. The result is shown in **Table 5**.

TABLE V
COMBUSTION CHARACTERISTICS OF BIOMASSES [22]

Atmosphere Characteristics	Air		
	Areca empty-shell	Moj	Bon bogori
Ignition temperature/ T_i	526.38	521.41	498.08
Reactivity index/ R_c	0.21	0.17	0.14
Peak temperature/ T_{max}	554.68	597.91	571.47

Pyrolysis

Pyrolysis Combustion is thermal decomposition process that uses organic material (biomass) such as lignocellulosic compound through a heating process using little bit or without oxygen so that material will undergo chemical structure breakdown into a gas phase [23]. The energy from biomass or other organic component is converted to combustible gas (mixture of carbon monoxide, methane, and hydrogen). Pyrolysis produces the end products in the form of charcoal, liquid smoke and gas. Charcoal from this process can be used as a fuel and active carbon. The liquid smoke can be used as additive substance or preservatives in certain food. While the gas produced can be burned directly [2]. The major types of pyrolysis are slow, intermediate, and fast pyrolysis which depend on several factors such as residence time, reaction temperature, feed rate, heating rate, and other parameters. The temperature for slow and intermediate pyrolysis is about 500°C, when fast pyrolysis is about 700°C [24].

TABLE VI
PYROLYSIS REACTION AT SEVERAL TEMPERATURE [24]

Temperature	Type of Reaction	End Products
Less than 350°C	Moisture loss, free radical generation, and depolymerization	Carbonyl and carboxyl group, CO and CO_2 gas, also biochar formation
350 – 450°C	Substitution for glycoside chain breaker of polysaccharide	Production of tar contain levoglucosan, anhydrates and oligosaccharides
Around 450°C	Dehydration, rearrangement and fission of sugar units	Production of acetaldehyde, glyoxalin and acrolein
Around 500°C	A mixture of all temperature mentioned	A mixture of all end products mentioned
Condensation	Unsaturated products condense and cleave to the char	A highly reactive char residue containing trapped free radicals

Pyrolysis is a promising step to process areca palm waste become an alternative energy application. According to the literature, the pyrolysis behavior of areca palm empty-shell has been investigated using thermogravitimetric analysis. Rapid decomposition of areca palm empty-shell was found in the temperature about 220 – 370°C whereas the activation energy ranged from 87.5 to 514.08 kJ/mol with 230.707 kJ/mol in average. Range in activation energy values indicates the existence of a complex mechanism during the thermal decomposition of areca palm empty-shell. The properties parameters revealed that areca palm empty-shell branch could be potential residue for pyrolysis [2].

IV. Environmental analysis of using Areca palm for energy recovery

A. Availability and Resource Depletion

Conventional heat or steam energy can be obtained from fossil fuels such as gasoline or diesel. This fossil fuel may be used up over time due to increasing demand [25]. Biomass application is one of the renewable energy sources which is an alternative to get energy. The most studied technology for obtaining energy from Areca palm is direct combustion and pyrolysis [26]. This technology uses different resources such as energy, nitrogen gas, and Areca husk, as discussed in **Fig. 7**. In this technology, what is needed and at that time is needed the energy needed to dry or condense Areca husk to get briquettes. Energy consumed can be obtained from renewable or non-renewable resources. As shown in **Fig. 7**, it will need another resource for transformation into heat or steam. After that, it is necessary to identify their availability and consumption for the various systems analyzed.

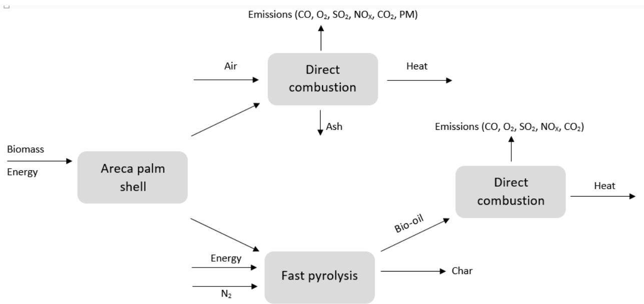

Fig. 7 Input and output scheme of direct combustion and pyrolysis technology in the areca palm

B. Transformation Process Emission

Using fossil fuels to obtain thermal or thermal energy can produce toxic gas emissions such as CO, SO_2, cyanide compounds, benzene, inorganic deposits, mercury compounds, methanol or NO_x. Fossil fuels are a major cause of global warming, which has contributed to 60% of GHG [24]. Regarding Areca husk waste, farmers or the company itself generally burns Areca husk in the open air landfilled in open fields and left alone. This general practice results in uncontrolled emissions such as particles, GHG or polycyclic aromatic hydrocarbons (PAHs), causing serious impacts on the environment and risks to human health [27]. Particulate emissions can cause acute respiratory disease and asthma [24].

Researchers show that agricultural residues have a smaller impact than fossil fuels because biomass has zero net CO_2 emissions to the environment through the process of photosynthesis [4]. In other words, CO_2 captured at the stage of plant growth is released at the stage of use as an energy source. Therefore, using Areca Husk as an energy source is a good choice for reducing environmental impacts through various technologies [28]. Several studies have reported ratios of GHG emissions for combustion of various fuels and HV of each fuel, as shown in the first and second columns respectively in **Table 7**. The amount of CO_2eq per MJ of fuel is estimated by dividing the ratio of GHG emissions per type fuel with the appropriate HV, as shown in the third column in **Table 7**.

TABLE VII
COMPARISON OF SEVERAL FUELS DERIVED FROM BIOMASS

No	Sample	Yearly production (ton)	Renewable Energy (Ton of Oil Equivalent)	Mitigation (Ton CO_2eq)
1	Corncob	8,120	4,539	18,036
2	Areca nut fiber	9,380	4,653	18,491

The direct combustion and pyrolysis process uses Areca husk to obtain energy, but they also release pollutants that need to be identified. Direct combustion emissions are particles (PM), nitrogen oxides (NO, NO_2, N_2O) and sulfur oxides (SO_x). Acid gases, such as HCl (condensed in the fine ash fraction or gas phase), can also be output ([29]. On the other hand, if combustion is carried out at low temperatures with inadequate mixing of fuel and combustion air, and very short residence times of flammable gases in the combustion zone, the following contaminants will be emitted: CO, HC, tar, Polycyclic aromatic, PAHs, CH_4, and charcoal particles [29,30]. Operational variables that affect pollutant emissions are: fuel feed rate (eg, Areca husk), air inlet speed, excess air, and equilibrium temperature. Therefore, proper handling of these variables will be sought to achieve combustion not only to reduce environmental impact, but also to be more efficient.

C. Waste Treatments and Disposal

Both direct combustion and pyrolysis of Areca husk waste can produce pollution, which requires treatment. The direct combustion process produces ash with high SiO_2 content and different studies have identified that Areca husk ash has properties that are suitable for components of construction materials, such as cement or ceramics [24]. Therefore, this waste can be reused in other processes to reduce environmental impacts. Regarding emissions, this can be treated with a gas treatment system that can work together with combustion equipment. In addition, fly ash and ash cause problems in direct combustion of equipment such as corrosion (due to deposition of ash species or gas phase), fouling (ash layer on the surface) and slagging, due to deposits on the walls and surfaces of the furnace which are exposed to radiant heat [4]. To reduce agglomeration and slagging by coating sand particles, different additives such as kaolin, dolomite limestone, limestone, and alumina can be used. However, efficiency, subsequent problems, and application of these materials clearly limit their use [4].

The fast pyrolysis process produces gas and biochar that cannot be condensed. This can be burned to meet the heat demand of the fast pyrolysis process, and circulated back to the reactor to smooth out the sand bed [31]. On the other hand, fast pyrolysis is generally focused on recovering bio-oil. However, the gas produced may be useful if the proportion of

CO, H_2 and carbon components (C1-C40s) is high [32]. To date, environmental analysis of these technologies is more qualitative than quantitative, increasing uncertainty about which of them are more environmentally friendly during their life cycle, and not only in the production and use of bioenergy.

V. Conclusion

Areca palm shell contribute around 65–80% from the total weight which can cause a significant disposal problem. Using direct combustion and pyrolysis method, characteristic of areca palm shell (biomass sources) through thermogravitimetric analysis has great potential as energy alternative such as bio-oil and briquettes to reduce fossil fuel consumption. Furthermore, the energy production using this method is environmentally friendly.

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