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Oil palm biomass utilization as an energy source and its possibility use for polygeneration scenarios in Langsa City, Aceh Province, Indonesia

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Abstract. This article deals with the discussion on the recent status of oil palm biomass utilization as an energy source and its possibility use for polygeneration system. The discussion focused only on the energy viewpoint. At this point, many projects and research have been developed in order to utilize the oil palm biomass to meet the energy demand of industries and communities, especially in the largest producing countries: Indonesia and Malaysia; and a few in Thailand, Africa, Latin America and Europe. Through the simulation work in the case study, it is evident that the government of Langsa City can fulfill the fresh water to their community and electricity to Langsa Harbor only by using EFB and PKS from one POM with the generated power of 12 MW, while the desalination plant consumes about 7 MW of electricity. If all potency of biomass from all POMs in Aceh Timur and Aceh Tamiang, without the combination of other primary energy sources is used, Langsa City might earn surplus of energy. The use of the oil palm biomass for polygeneration scenarios is possible and feasible from the technical point of view.

1. Introduction

Indonesian oil palm industry (planting and milling) produces about 4.4 million tons of solid waste (biomass) per year (or 32,654 MWe), and Aceh Province produces about 116.5 thousand tons per year. This kind of biomass consists of empty fruit bunches (EFB), mesocarp fiber (MF), palm kernel shells (PKS), oil palm fronds (OPF), oil palm trunks (OPT), oil palm leaves (OPL) and oil palm stone (OPS). This biomass can be used as a source of energy to produce power [1-5] and heat [5-13]. Heat (thermal) and power are the only direct energy products resulted from biomass utilization.

Furthermore, most of the products from the oil palm biomass are categorized as fuel such as bio-oil [14-38], biofuel [39-41], syngas [42-47], hydrogen [48-55], biogas [56-57], biochar [58-63, briquette and pellet (in some cases biomass added as co-fuel) [64-74], etc.

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On the other hand, even though Indonesia has a lot of renewable energy sources (one of them is oil palm biomass), this country still faces the energy crisis problem until now. From 32,654 MWe of resources, it was only 1,717.1 MWe at a stage of installed capacity for power generation (1,626 MW off grid and 91.1 MW on grid), as was reported by Indonesia Energy Outlook 2016. In Aceh, the biomass-based energy projects can only be found generally in palm oil mills (POMs), and the use of this energy is still limited for their own needs, both for heating (steam) and generating power (electricity). Only a little was addressed to the independent power plant (IPP). Installed capacity for heat and power plants in the POMs is more or less 65 MW, whereas the capacity of IPP to the grid is about 10 MW. The main current energy issues in Indonesia appear due to the fact that fossil energy reserves depletion and limited access to energy, especially in remote and border areas. Another issue is that the investment for the renewable energy development is still high; however, the return rate and profitability are relatively long and uncertain.

This article deals with the discussion on the study of oil palm biomass uses in the last ten years; including some commercial scale implementations and/or pilot projects. The focus of this study is only limited in the scope of energy purpose. At the end of this article, the case study on the electricity generation fueled by the oil palm biomass in Langsa City and the possibility of its use on polygeneration technology implementation are presented.

2. Oil palm biomass utilization

Pattern of the oil palm biomass utilization is almost the same in all producing countries. PKS and MF are mostly served as boiler fuel to produce steam and electricity, while EFB is burned in the incinerator, and some of them are sent to the plantations for mulching. PKS is sometimes used as a conditioner for pathways within plantations [75] and exported to the target countries such as Japan. OPF and OPL (also OPT after replanting) are usually left in the field [76].

2.1. As a fuel in heat and power plants

Almost all POMs have their own heat and power plants with the capacity around 2.0 to 2.5 MW fueled by MF and PKS. The plants are operated as the utility units in POMs and some energy of the POMs are shifted to electricity for the staff dormitories or housing. In addition, as the fuel in power plants, the biomass is also used to generate the steam, which is consumed in processing fresh fruit bunches (FFBs). Nevertheless, only a little amount was addressed to the IPP. Table 1 lists some of the commercial projects on heat and power plants in Indonesia and Malaysia.

Table 1. Oil palm biomass-based heat and power plants in Indonesia and Malaysia.

Fuel	Capacity	Location	Owner
EFB, MF and PKS	14 MWe (cogeneration system)	Sabah, Malaysia	TSH Bio Energy Sdn Bhd
MF and PKS	2 MWe (cogeneration system)	Kedah, Malaysia	Kumpulan Guthrie Bhd
EFB	6 MWe	Perak, Malaysia	Bumibiopower Sdn Bhd
EFB	7 MWe	Sabah, Malaysia	Potensi Gaya Sdn Bhd
EFB	8 MWe	Sabah, Malaysia	Alaff Ekspresi Sdn Bhd
EFB	12 MWe	Johor, Malaysia	Naluri Ventures Sdn Bhd
EFB	11.5 MWe	Sabah, Malaysia	Seguntor Bioenergy Sdn Bhd
EFB	11.5 MWe	Sabah, Malaysia	Kina Biopower Sdn Bhd
PKS	10 MWe	Kalimantan Barat, Indonesia	PT Rezeki Perkasa Sejahtera Lestari
EFB, MF, PKS (and wood chip)	6 MWe	Bangka Barat, Indonesia	Kencana Agri Ltd
EFB, MF, PKS (and wood chip)	6 MWe	Belitung, Indonesia	Kencana Agri Ltd

Fuel	Capacity	Location	Owner
PKS	2 MWe	Kalimantan Tengah, Indonesia	PT Atman
EFB and PKS	2 x 10 MWe	Dumai, Indonesia	Wilmar Group
EFB and PKS	2 x 10 MWe	Kuala Tanjung, Indonesia	Wilmar Group
EFB and PKS	6 MWe	North Sumatra, Indonesia	PT Medan Sugar Industry
PKS	10 MT/hour of sat. steam at 71.4 kg/cm^2	North Sumatra, Indonesia	PT Multimas Nabati Asahan

Meanwhile, the laboratory and pilot scale studies have been conducted widely and intensively in these areas. A few numbers of the studies on this topic are tabulated in the following table 2.

Table 2. Study on oil palm biomass utilization for heat and power generations.

Fuel	Study	Result	Reference
EFB (and POME)	Simulation on integrated small-scale power generation of EFB gasification and POME digestion; gasification temperature: 800, 900 & 1000 ^{o}C; flow rate of wet EFB 10 tones/hour.	Total gasification yields: 68.24%, 80.05% & 91.7% at 800, 900 & 1000 ^{o}C, respectively; generated powers: 3.05 - 7.46 MW at 800 – 1000 ^{o}C; power generation efficiencies: 11.2, 16.3 & 24.6%.	[2]
EFB and MF	Assessment study based on the survey data analysis from 21 POMs in North Sumatera with capacity of 30 to 60 tones FFB/hour.	It was found that generated power in POM with capacity of 30 tons/hour ranges from 20 to 25 MW.	[4]
EFB, MF, PKS (and biogas)	Simulation study using ECLIPSE software in order to investigate and optimize power and heat generation (case study); the model was validated using the practical data of the CHP plant.	EFB and PKS fuel can generates 2.2 MW power; biogas can replace PKS to produce about 1.3 MW power; the highest power provided by fuel combination of EFB, PKS and biogas of 2.4 MW.	[5]
OPS	Burning of OPS in the pilot-scale fluidized bed combustor; bed material: sand (average size 850 μm); initial bed temperature was 950 ^{o}C; fuel rate was 1.2 kg/h.	Bed and bed's surface temperatures decrease when primary airflow rate increases; stable combustion was recorded at 950 ^{o}C.	[6]
EFB, MF and PKS	Oxidation was done in Thermo-gravimetric Analysis (TGA) at temperature ranges 25 – 1100 ^{o}C.	EFB and PKS have additional peak besides drying, devolatilization and char oxidation during combustion.	[12]
PKS	Combustion of PKS was done in a conical fluidized-bed combustor (FBC) at excess air of 20%, 40%, 60%, and 80%; fuel feed rate is 45 kg/h; superficial air velocity at the air distributor exit was varying from 5.2 to7.7 m/s.	Recommended excess air is 60% to get combustion efficiency up to 98.9%; alumina sand, dolomite, and limestone beds can be used to burn PKS safely in the FBC; Alumina bed lead for K_2O, SiO_2 and CaO formation.	[13]
EFB	Theoretical study for steam power plant by using wet EFB (60% moisture content).	Generated electricity is 418 kWh per tons wet EFB with the overall efficiency 20%.	[77]

2.2. As feedstock in fuel production
In this part, discussions will be put on the gasification, pyrolysis, liquefaction, carbonization, torrefaction, etc. A lot of studies have been established in order to convert the oil palm biomass to be the most useful and valuable fuels in the last ten years as cited in the introduction. Some of them are

presented in Table 3 as examples. There is no information about commercial or pilot plants scale on this field so far.

Table 3. Study on oil palm biomass for fuel source.

Feedstock	Study	Result	Reference
PKS	Torrefaction in batch reactor; temperature: 200 – 350 ^oC; retention time: 10 – 60 min; nitrogen flow rate: 100 – 1000 ml/min.	Maximum torrefied solid (semi-char) mass yielded is 73% found at temperature of 300 ^oC, retention time of 20 min and nitrogen flow rate of 300 ml/min.	[23]
PKS	Microwave assisted pyrolysis in nitrogen gas that applied the central composite design.	Yield of bio-oil is 32.34% at 45.0 5% carbon loading and 4.9 l/min nitrogen flow rate.	[31]
MF	Torrefaction using nitrogen and air at 300 ^oC.	Torrefied solid (semi-char) mass yields of 51.7% and 30.2% given by nitrogen and air carrier gases, respectively.	[32]
EFB	Pyrolysis in rotating cone reactor	Gas yield is about 51.4 wt% (mf).	[33]
PKS	Hydrothermal liquefaction using an 8.8 ml Inconel batch reactor placed in a reactor furnace; resident time of 1 h; temperatures: 330, 360 and 390 ^oC; pressures: 25, 30 and 35 MPa; biomass-to-water ratios: 0.20, 0.35 and 0.50.	Optimum conditions are obtained at 390 ^oC, 25 MPa and biomass-to-water ratio of 0.20 with bio-oil yield 15.55%.	[35]
MF dan OPF	Pyrolysis was done in a slow-heating (heating rate: 10 ^oC/min) fixed-bed reactor using N_2 gas at flow rate 100 - 300 ml/min; experimental temperature: 400 – 600 ^oC; reaction time: 15 min.	Highest bio-oil yield of 50 and 47 wt%, respectively for MF (at 550 ^oC) and OPF (at 600 ^oC) appear at N_2 gas flow rate of 200 ml/min; highest biochars for both biomass detect at 400 ^oC and the same N_2 gas flow rate of 40 wt% and 31 wt%, respectively.	[36]
MF	Thermo-liquefaction at range of temperature: 300 – 500 ^oC; heating rate: 10 – 30 ^oC/min; cracking time: 10 – 30 min; solvent: supercritical ethanol.	The greatest yield of bio-oil is 84% recorded at temperature of 500 ^oC, heating rate of 10 ^oC/min and cracking time of 10 min; gas yield is 11% and residual solid is 5%.	[37]
EFB	Metal oxide - catalytic super-critical hydrothermal liquefaction in Inconel batch reactor; catalysts content: 1 wt%; temperature: 360 – 450 ^oC; pressure: 25 MPa; reaction time: 15 – 960 min.	The highest bio-oil yield was observed at temperature of 390 ^oC, pressure of 25 MPa and reaction time of 60 min, in which relative yield (ratio of yield with catalyst to yield without catalyst) is about 1.4.	[38]
EFB	Supercritical water gasification to produce hydrogen at 380 ^oC and 240 bar for 8 min.	Reducing the carbon was occurred when loading of biomass increased from 0.05 to 0.5 gram.	[54]
OPF	Non-catalytic and catalytic supercritical water gasification (SCWG) at temperature of 380 ^oC and pressure about 22.1 Mpa for	Catalytic gasification provides higher yield of H_2 than non-catalytic one.	[55]

Feedstock	Study	Result	Reference
	hydrogen production.		

Figure 1 describes a pathway of the oil palm biomass conversion processes that comprise three main processes: physical, thermo-chemical and biological processes. It can be seen that the only possible way to directly generate the heat and power is through the thermo-chemical process (direct combustion or co-combustion). This is a very simple way to generate heat and power. Additionally, all the commercial heat and power plants listed in Table 1 are run through this way. In differ to the heat and power; all the fuels might be produced by all other processing ways. However, effort on the fuel production is mostly still in the investigation stage, only a few is already in commercial level such as densification and gasification.

3. Possibility use of oil palm biomass for polygeneration scenarios in Aceh Province

The term of polygeneration is usually adopted to identify an energy supply system which simultaneously delivers more than one form of energy to the final user, for example: electricity, heat and cold, and in many cases it also uses one or a combination of primary energy sources such as several fossil fuels (oil, natural gas, coal, etc.) and primary renewable energy sources (solar energy, biomass, biogas, bio-oil, biofuel, syngas, geothermal, wind energy, fuel cell, etc.).

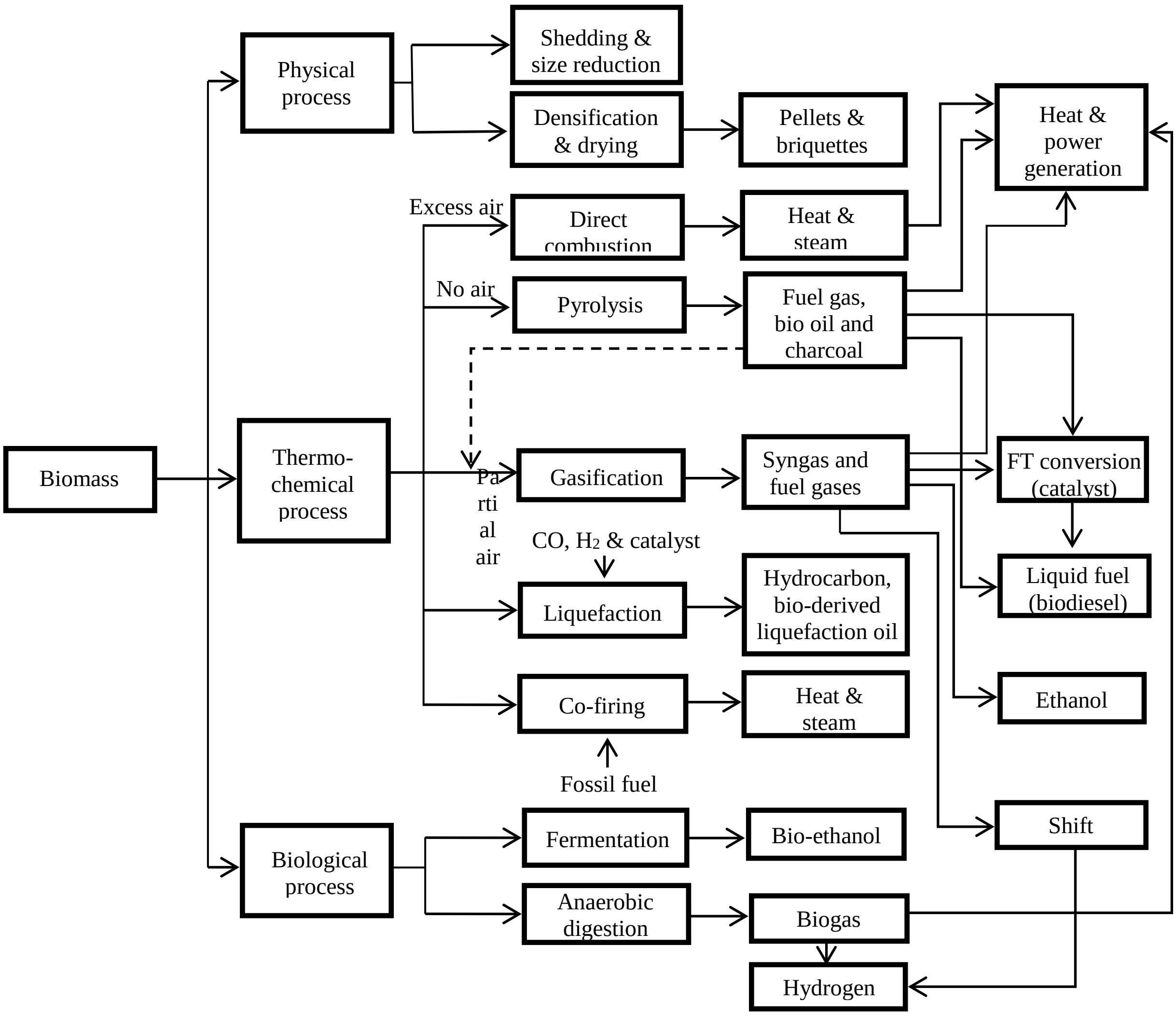

Figure 1. Pathway of oil palm biomass utilization [Source: Ref. 78].

Table 4. Potency of the oil palm biomass in Aceh Tamiang.

Type of oil palm biomass	POM Tj. Seumantoh (capacity 45 ton FFB/hour)	POM Pulo Tiga (capacity 30 ton FFB/hour)	Total (ton/year)
EFB	41,623.00	31,455.00	73,078.00
MF	24,450.00	18,476.00	42,927.00
PKS	11,763.00	8,889.00	20,652.00

Since direct combustion is simple and commonly used to convert biomass to heat and power, this method is applied in this case study. Langsa City has been chosen for the case study area. The oil palm biomass is available in Aceh Timur and Aceh Tamiang districts, a neighborhood of Langsa City. The potency of EFB, MF and PKS in two POMs of PTPN 1 (a state company) operated in Aceh Tamiang is listed in Table 4 and the proximate and ultimate data of the biomass is shown in Table 5. It is clear that the proximate, ultimate and calorific value data for all selected biomass exhibit the similarity. By this reason, in this preliminary study, two of them (EFB and PKS) are chosen and burned in the simulation works to generate the electricity (for the desalination plant and Langsa Harbor) (Figures 2 and 3). So far, a two-feedstock model only gives the reasonable results on the simulation.

Because the primary energy source is only biomass and the energy delivery is only electricity, the polygeneration scenario might not be achieved yet in the case study. The polygeneration scenario (as briefly discussed in part 3.2) will be further examined in the future investigation in detail. Observation in that part is limited to cost of energy (COE) as initial description only.

Table 5. Proximate and ultimate analysis data of EFB, MF and PKS used the study.

Parameter (dry sample)	Type of biomass			Unit	Basis	Reference
	EFB	MF	PKS			
Proximate						
Moisture in air (M)	9.38	9.35	9.76	%	adb	ASTM D.3173
Ash (A)	5.38	3.87	1.19	%	adb	ASTM D.3174
Volatile Matter (VM)	68.47	71.47	69.95	%	adb	ISO D.562
Fixed Carbon (FC)	16.77	15.31	19.10	%	adb	ASTM D.3172
Calorific Value	4,469	4,278	4,515	Cal/gr	adb	ASTM D.5865
Ultimate						
Carbon (C)	46.50	44.97	45.74	%	adb	ASTM D.3178
Hydrogen (H)	7.13	6.99	5.54	%	adb	ASTM D. 3179
Nitrogen (N)	0.89	0.45	0.25	%	adb	ASTM D. 3179
Total Sulphur (S)	0.21	0.14	0.09	%	adb	ASTM D. 3177
Oxygen (O)	39.89	43.58	47.19	%	adb	ASTM D. 3176

3.1. Case study

The area of Langsa City is about 262.4 square kilometers with the population of 165.890 people. Water consumption for people in this city is supplied by the district government company, PDAM Tirta Keumuneng. The company has their own water treatment plant (WTP) to treat the raw water from Alur Gampu River with debit about 160 liter/second. Unfortunately, the company has the capability to serve only approximately 30% of the water needs in the city. It is predicted that about 23 thousand households in Langsa are not connected to the government pipeline system. Most of them consume water directly from well and river. A future challenge that the Langsa City Government will face is how to solve the problems on limitation of water resources. One of the possible raw water resources is seawater. In this article, the simulation was done on the seawater desalination using membrane technology (figure 4).

Figure 2. Langsa City and Kuala Langsa location.

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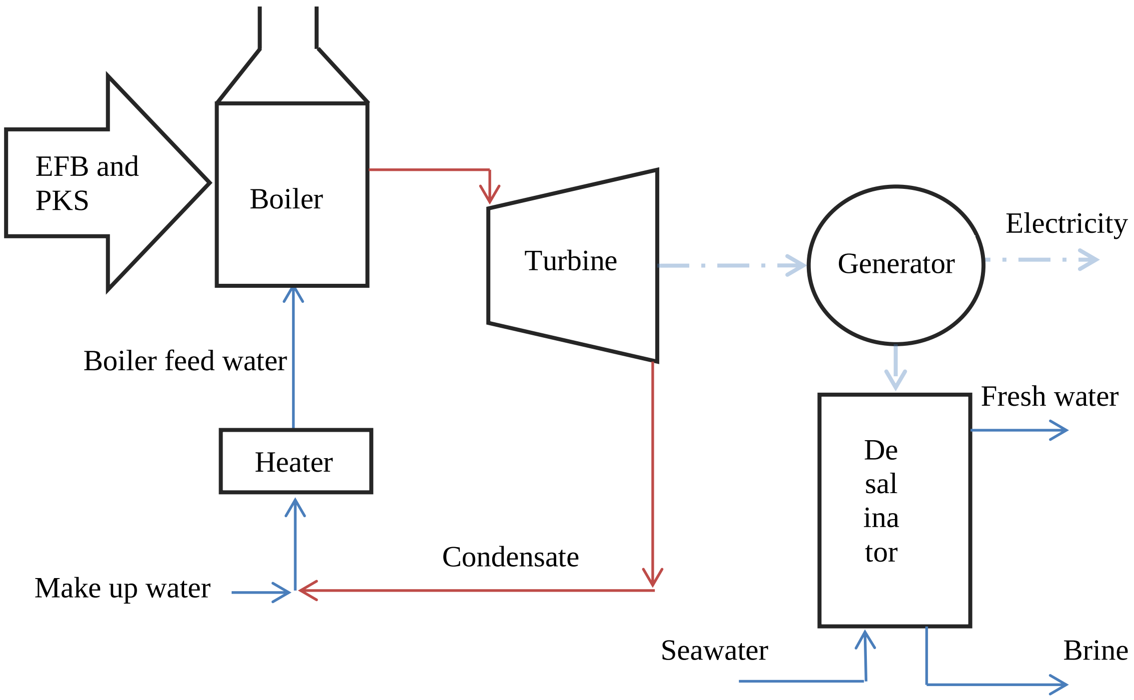

Figure 3. Oil palm biomass utilization for electricity generation and seawater desalination.

Fan et al. [79] said that water consumption for the city household is plus minus 116 m^3 per household per year. Thereafter, to cover the water for 23 thousand households, PDAM Tirta Keumuneng has to produce about 2.7 million m^3 water per year or 7,300 m^3 water per day. In the simulation, the reverse osmosis (RO) system (one type of the membrane technology) is applied to meet the Republic of Indonesia Government Regulation No. 82 year 2001 (read as PPRI No. 82/2001) on the water quality management and pollution control. Figure 4 presents the RO system developed by Oh et al. [80]; the system consists of high-pressure (HP) pump, booster pump, RO unit and energy recovery device. Seawater is pumped to reach a pressure of > 50 bar and is passed through RO unit to produce a fresh water (permeate) and brine. Due to the fact that the rejected brine has a relatively high pressure and temperature, an energy recovery device is attached to the system to recover the energy from the braine to lower the power consumption. The characteristics of seawater for the desalination feed are tabulated in Table 6.

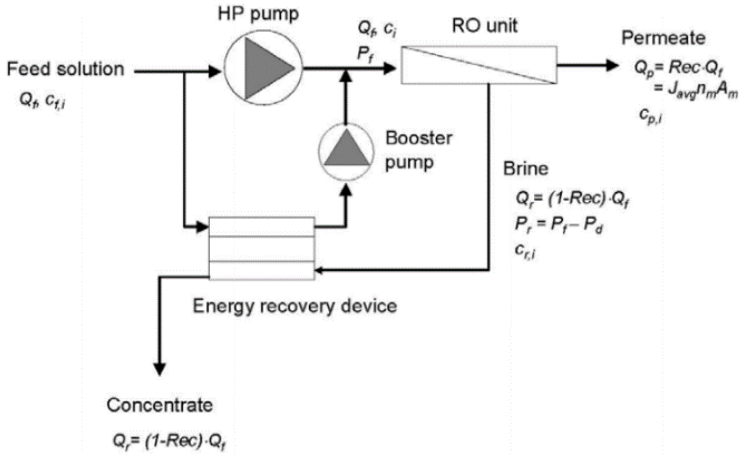

Figure 4. Schematic diagram of RO desalination process.

Table 6. Mineral content in seawater for desalination feed.

Constituent	Content (mg/l)	Constituent	Content (mg/l)
Ammonium ($NH4^+ + NH_3$)	-	Nitrate (NO_3)	0.50
Potassium (K)	390.00	Chloride (Cl)	19,700.00
Sodium (Na)	10,900.00	Fluoride (F)	1.40
Magnesium (Mg)	1,310.00	Sulphate (SO_4)	2,740.00
Calcium (Ca)	410.00	Silica (SiO_2)	0.05
Strontium (Sr)	13.00	Boron (B)	3.44
Barium (Ba)	0.05	TDS	35,661.50
Carbonate (CO_3)	24.88	pH	8.10
Bicarbonate (HCO_3)	152.00		

Source: Government Fishery Agency, Langsa City (2016)

At the first step of the simulation task, the performance of the desalination unit and its energy need is predicted by using ROSA 9.0 software. The second step is the optimization of the energy generating system based on the oil palm biomass firing both for the energy in desalination process and electricity in Langsa Harbor using System Advisor Model (SAM) software. The desalination system is analyzed to meet the fresh water product with RO permeate silt density index (SDI) < 1 and type of membrane module of SW30XHR-440i. The specifications of feed are shown in Table 7.

The results of this simulation are presented in the below part of Table 7. It is obvious that the permeate flow reaches a point of ≅300 m^3/h or 7,300 m^3 per day as expected by PDAM Tirta Keumuneng. In addition, the permeate TDS is 40.02 mg/l, lower than the limit issued in PPRI No. 82 (50 mg/l for water class I and II). Furthermore, it is found that the energy consumption for the desalination plant is 6,960.83 kW or ≅7 MW, with the specific energy consumption of 23.2 kWh/m^3 fresh water.

The final step (the second step) is the simulation for power plant in the SAM simulator. The simulation starts by feedstock specification, including mass flow rate; moisture, carbon, hydrogen and nitrogen contents both for feedstock 1 (EFB) and feedstock 2 (PKS). Calculation of higher heating value (HHV) proceeds based on the input data. Finally, combustion process is conducted in the Fluidized Bed Boiler (FBB) and continued with the optimization as well.

The results show that the FBB can generate a superheated steam of 600 psig (40.82 bar) and 750 ºF

(398.9 ^{o}C) with the boiler efficiency of 84.2%. The output power is 19,644 kW (19.6 MW). Because the desalination plant consumes the energy of 7.0 MW, the remaining of 12.6 MW is then transmitted to Langsa Harbor in Kuala Langsa. It is such an interesting fact that, the number of energy is already enough to run the desalination plant and to supply 12.6 MW to the harbor by considering only two of biomass sources.

Table 7. Simulation result of RO desalination process.

Parameter	Value/type	Unit
Feed specification		
Flow rate	2000	m^3/h
Flow factor	0.85	-
TDS	35,661.50	mg/l
Type of membrane module	SW30XHR-440i	-
Result		
Feed pressure	100.22	bar
Total active area	8,502.21	M^2
Number of module	208	#PV
Permeate flow	299.98	m^3/h
Recovery	15	%
Permeated TDS	40.02	mg/l
Power	6,960.83	kW
Specific energy	23.20	kWh/m^3

3.2. Polygeneration scenarios

In order to achieve the Indonesian government goal in energy mix by 2025 share of renewable energy (bio-oil, biofuel, geothermal, biomass, wind energy, solar cell, hydropower, etc.) is expected 17%. Currently, the utilization of the energy sources (both renewable and non-renewable) as a fuel is only achieved through the single processing or co-processing system, such as combustion or co-combustion, gasification or co-gasification, etc. Generally, these processing systems have low efficiency. To improve the disadvantages of those technologies, energy hybrid is one of the interesting topics to be paid attention from the research institutions and energy industries. Polygeneration (hybrid of energy sources as a part of technology) is known as an energy-efficient technology, which plays a key role in the sustainable energy system (SES). The additional target from the polygeneration technology is eliminating/reducing CO_2 emissions [81-82]. Therefore, in the future work, the primary energy source will be combined with wind energy and solar cell. Moreover, the source of biomass itself will also be extended to four kinds (EFB, MF, PKS and OPF). The following Figures 5 and 6 describe the polygeneration scenarios for the next investigation on the biomass hybrid with solar cell and biomass hybrid with wind energy and solar cell, respectively.

Sahoo et al. [83] have developed an innovative polygeneration process in hybrid solar and biomass system for combined power, cooling and desalination. They did the thermodynamics evaluation (energy and exergy) and optimization by a simulation. Thereafter, Edwin and Sekhar [84] have also simulated a combination of biomass, biogas and solar energies to run the milk chilling units in remote villages. Finally, hybrid of biomass and wind energy to produce power, heat, cold and synthetic natural gas have been attempted in Aspen Plus, a commercial simulator, by Rudra et al. [85]. Different from the past studies, our simulation on the polygeneration scenarios is pointed in the COE, as one of parameter consideration for the future examination.

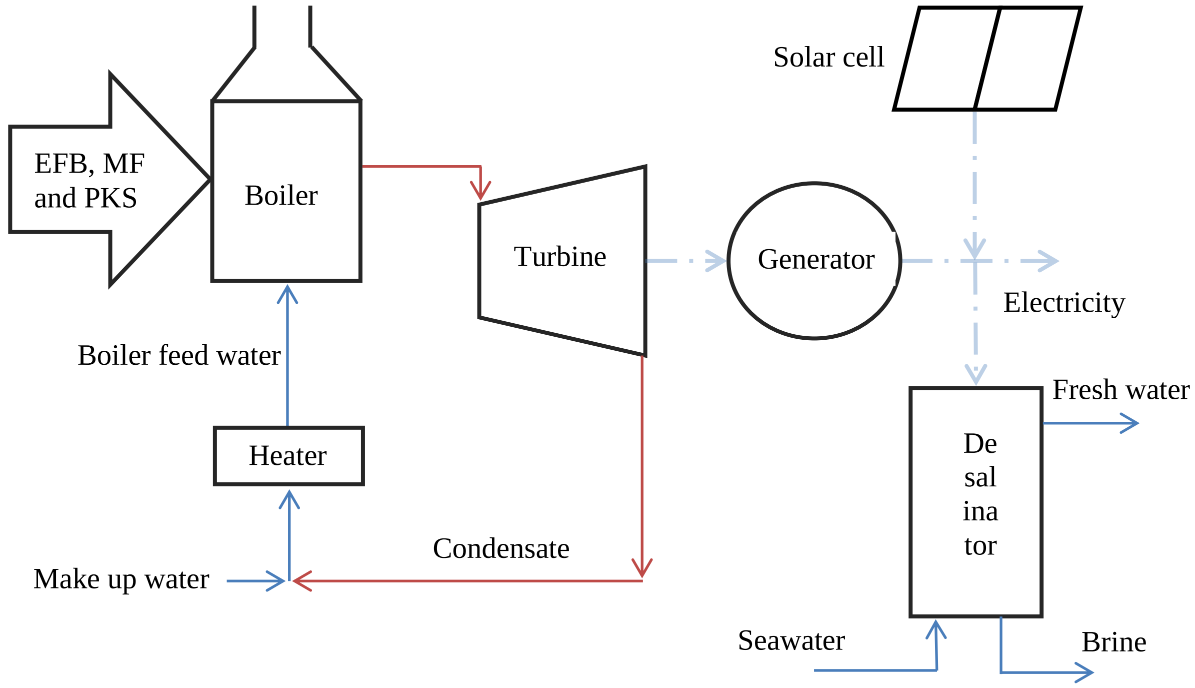

Figure 5. Scenario-1: a combination of primary energy sources, biomass hybrid with solar cell.

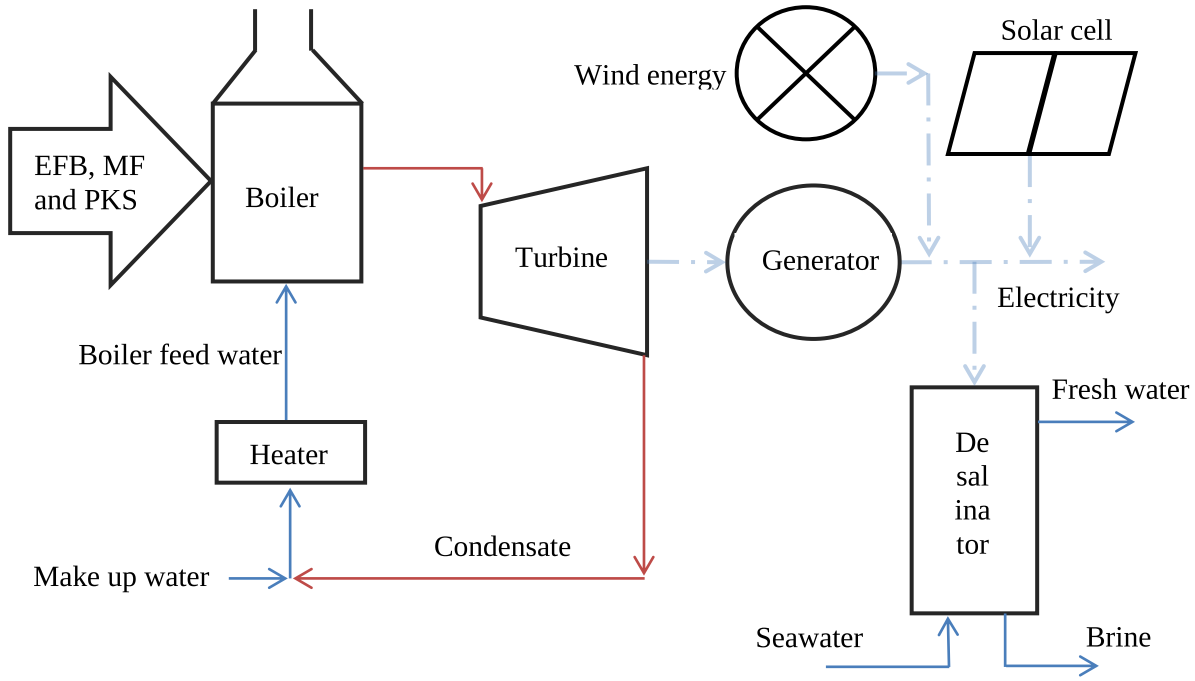

Figure 6. Scenario-2: a combination of primary energy sources, biomass hybrid with wind energy and solar cell.

For COE estimation process, the work starts with the prediction of daily electricity consumption in the Langsa Harbor. It is obtained that total power consumption is 3,172 kW daily, in which the daily electricity used is 1,600 kWh. Afterwards, it was recorded by the Surface Meteorology and Solar

Energy-NASA that the monthly average solar radiation ranges from 3.82 kWh/m^2/day and 5.22 kWh/m^2/day, and the annual average solar radiation is 4.55 kWh/m^2 /day. Meanwhile, the annual average wind speed at 50 m above the earth surface of Langsa is about 2.95 m/s. The lowest wind speed and the highest are 2.13 m/s and 3.83 m/s, respectively.

The configuration of the hybrid system in HOMER software (the type of software applied in the study) consists of PV arrays, wind turbines, biomass gasifier, battery banks and inverters. The economic data inputs in HOMER include capital, maintenance and replacement costs of components. The project life fixes for 25 years and the annual real interest rate is 6%.

As a result, HOMER shows as the top ranked system configurations according to total net present cost (NPC) and HOMER defines the enhanced cost of energy (COE) as the average cost per kWh of the useful electrical energy produced by the system. Two best scenarios resulted from the simulations are showed in Table 8.

Table 8. Simulation result on hybrid system.

	PV (kW)	Wind (kW)	Generator Biomass (kW)	Battery H3000	Converter (kW)	Total NPC ($)	COE ($/kW)
Scenario-1	240	-	200	119	99	3,818,947	1,320
Scenario-2	150	250	200	115	122	3,684,119	1,086

1. Hybrid PV-biomass power system composed of 240 kW PV panels, 200 kW biomass generator, 119 battery banks and 99 kW converter.
2. Hybrid PV-wind-biomass power system composed of 150 kW PV panels, a 250 kW wind turbine, 200 kW biomass generator, 115 battery banks and 122 kW converter.

References

[1] Bazmi A A, Zahedi G and Hashim H 2011 *Renew. Sustain. Energy Rev.* **15** 574–83
[2] Aziz M, Kurniawan T, Oda T and Kashiwagi T 2017 *Appl. Thermal Eng.* **114** 1378–86
[3] Rahman N A, Atan M F, Low C M, Baini R and Mat Nfc Salleh S F 2013 *Eur. Int. J. Sci. Technol.* **2** 111–18
[4] Nasution M A, Herawan T and Rivani M 2014 *Energy Proc.* **47** 166–72
[5] Wu Q, Qiang T C, Zeng G, Zhang H, Huang Y and Wang Y 2017 *Int. J. Hydrogen Energy* ***XXX*** 1–7 (article in press)
[6] Razuan R, Chen Q, Finney K N, Russell N V, Sharifi V N and Swithenbank J 2011 *Fuel Process. Technol.* **92** 2219–25
[7] Uemura Y, Saadon S, Osman N, Mansor N and Tanoue K I 2015 *Fuel* **144** 171–179
[8] Uemura Y, Omar W, Othman N A, Yusup S and Tsutsui T 2013 *Fuel* **103** 156–60
[9] Uemura Y, Omar W N, Tsutsui T and Yusup S B 2011 *Fuel* **90** 2585–91
[10] Aziz M, Prawisudha P, Prabowo B and Budiman BA 2015 *Appl. Energy* **139** 188–95
[11] Guangul F M, Sulaiman S A and Ramli A 2012 *Biores. Technol.* **126** 224–32
[12] Idris SS, Rahman NA and Ismail K 2012 *Biores. Technol.* **123** 581–91
[13] Ninduangdee P and Kuprianov VI 2015 *Biores. Technol.* **182** 272–81
[14] Mazaheri H, Lee KT, Bhatia S and Mohamed A R 2010 *Biores. Technol.* **101** 7641–47
[15] Mazaheri H, Lee K T, Bhatia S and Mohamed A R 2010 *Biores. Technol.* **101** 745–51
[16] Mazaheri H, Lee KT, Bhatia S and Mohamed A R 2010 *Biores. Technol.* **101** 9335–41
[17] Abnisa F, Daud WMAW, Husin WNW and Sahu JN 2011 *Biomass Bioenergy* **35** 1863–72
[18] Abnisa F, Arami-Niya A, Daud W W, Sahu J and Noor I 2013 *Energy Convers Manage.* **76** 1073–82
[19] Salema A A and Ani F N 2011 *Biores. Technol.* **102** 3388–95

[20] Salema A A and Ani F N 2012 *J. Anal. Appl. Pyrolysis* **96** 162–72
[21] Aziz M A, Sabil K M, Uemura Y and Ismail L 2012 *J. Appl. Sci.* **12** 1130–35
[22] Asadullah M, Ab Rasid N S, Kadir Sas A and Azdarpour A 2013 *Biomass Bioenerg.* **59** 316–24
[23] Asadullah M, Adi A M, Suhada N, Malek N H, Saringat M I and Azdarpour A 2014 *Energy Convers. Manage.* **88** 1086–93
[24] Ja'afar M M, Rahman A A and Shamsuddin A 2013 *IOP Conf. Ser. Earth Environ. Sci.* 16
[25] Sabil K M, Aziz M A, Lal B and Uemura Y 2013a *Biomass Bioenerg.* **56** 351–60
[26] Sabil K M, Aziz M A, Lal B and Uemura Y 2013b *Appl. Energy* **111** 821–26
[27] Sing C Y and Aris M S 2013 *Asian J. Sci. Res.* **6** 537–45
[28] Kim S W, Koo B S and Lee D H 2014 *Biores. Technol.* **167** 425–32
[29] Lim, Xiaoyien, Sanna A and Andrésen J M 2014 *Fuel* **119** 259–65
[30] Saadon S, Uemura Y and Mansor N 2014 *Proc. Chem.* **9** 194–201
[31] Mushtaq, Faisal, Abdullah T A T, Mat R and Ani F N 2015 *Biores. Technol*. **190** 442–50
[32] Lu K-M, Lee W-J, Chen W-H, Liu S-H and Lin T-C 2012 *Biores. Technol.* **123** 98–105
[33] Venderbosch Brh, Gansekoele E, Florijn J F and Assink D 2016 *PyNe Newsl Issue* 19 n.d. 2–4
[34] Sulaiman M H, Uemura Y and Azizan M T 2016 *Proc. Eng.* **148** 573–79
[35] Chan Y H, Quitain A T, Yusup S, Uemura Y, Sasaki M and Kida T 2017 *J. The Energy Inst.* 1-12
[36] Kabir G, Mohd Din A T and Hameed B H 2017 *Biores. Technol*. **241** 563–72
[37] Oliveira, A L P C, Almeida P S, Campos M C V, Franceschi E, Dariva C and Borges G R 2017 *Biores. Technol*. **230** 1–7
[38] Yim S C, Quitain A T, Yusup S, Sasaki M, Uemura Y and Kida T 2017 *The J. Supercritical Fluids* **120** 384–94
[39] Abdullah N, Gerhauser H and Sulaiman F 2010 *Fuel* **89** 2166–2169
[40] Chin K L, Hng P S, Go W Z, Wong W Z, Lim T W and Maminski M 2013a. *Ind. Crops Prod.* **49** 768–74
[41] Matali S, Rahman N A, Idris S S, Yaacob N and Alias A B 2016 *Proc. Eng*. **148** 671–78
[42] Lahijani P and Zainal Z A 2011 *Biores. Technol.* **102**(2) 2068–76
[43] Nipattummakul N, Ahmed II N, Kerdsuwan S and Gupta A K 2012 *Appl. Energy* **92** 778–82
[44] Atnaw S M, Sulaiman SA and Yusup S 2013 *Energy* **61** 491–501
[45] Ogi T, Nakanishi M, Fukuda Y and Matsumoto K 2013 *Fuel* **104** 28–35
[46] Guangul F M, Sulaiman S A and Ramli A 2014 *Renew. Energy* **72** 271–83
[47] Moghadam R A, Yusup S, Uemura Y, Chin B L F, Lam H L and Al Shoaibi A 2014 *Energy* **75** 40–4
[48] Akhtar J, Kuang SK and Amin N S 2010 *Renew. Energy* **35** 1220–7
[49] Fan S P, Zakaria S, Chia C H, Jamaluddin F, Nabihah S and Liew T K 2011 *Biores. Technol* **102** 3521–6
[50] Mohammed M A A, Salmiaton A, Wan Azlina W A K G, Amran M S M, Fakhru'l-R A and Taufiq-Yap YH 2011 *Renew. Sustain. Energy Rev.* **15**(2) 1258–70
[51] Ismail K, Yarmo M A, Taufiq Yap Y H and Ahmad A 2012 *Int. J. Hydrog. Energy* **3**(7) 3639–44
[52] Taufiq-Yap Y H, Sivasangar S and Salmiaton A 2012 *Energy* **47**(1) 158–65
[53] Khan Z, Yusup S, Ahmad M M and Chin B L F 2014 *Energy Convers. Manage.* **87** 1224–30
[54] Sivasangar, Zainal, Salmiaton and Taufiq-Yap Y 2015 *Fuel* **143** 563–9
[55] Mastuli M S, Kamarulzaman N, Kasim M F and Sivasangar S 2017 *Int. J. Hydrogen Energy* **42**(16) 11215–28
[56] Chin M J, Poh P E, Tey B T, Chan E S and Chin K L 2013b *Renew. Sustain. Energy Rev.* **26**717–26
[57] Chaikitkaew S, Kongjan P and Sompong O-T 2015 *Energy Proc.* **79** 838–44
[58] Sulaiman F and Abdullah N 2011 *Energy* **36** 2352–59

[59] Sulaiman F, Abdullah N, Gerhauser H and Shariff A 2011 *Biomass Bioenerg.* **35** 3775–86
[60] Harsono SS, Grundman P, Lau L H, Hansen A, Mam S and Meyer A A 2013 *Resour. Conserv. Recycl.* **77** 108–15
[61] Sulaiman F, Abdullah N and Rahman A A 2013 *Am. Inst. Phys.* **248** 248–53
[62] Idris J, Shirai Y, Andou Y, Ali A A M, Othman M R, Ibrahim I and Hassan M A 2015 *J. Cleaner Prod.* **89** 257–61
[63] Idris J, Shirai Y, Andou Y, Ali A A M, Othman M R, Ibrahim I and Hassan M A 2015 *J. Cleaner Prod.* **104** 475–79
[64] Chaiyaomporn K and Chavalparit O 2010 *Environ. Asia* **3** 103–10
[65] Nasrin AB, Ma Ah, Ng An, May C Y, Mohd B W, Li J and Sew M 2010 *MPOB Inf. Ser.* **456** 3–6
[66] Nasrin A B, Choo Y M, Lim W S, Joseph L, Michael S and Rohaya M H 2011a. *J. Eng. Appl. Sci.* **6** 446–51
[67] Nasrin A B, Ravi N, Lim W S, Choo Y M and Fadzil AM 2011b. *J. Eng. Appl. Sci*. **6** 433–439
[68] Jaafar A and Ahmad M 2011 *World Acad Sci. Eng. Technol*. **60** 554–57
[69] Forero N C A, Jochum J and Forero V F E 2012 *Biotechnol*. **8** 67–76
[70] Kavalek M, Havrland B and Pecen J 2012 *Eng. Rural Dev.* **24** 468–74
[71] Lai Z Y, Chua H B and Goh S M 2013 *J. Mater. Sci.* **48** 1448–56
[72] Na B-I, Kim Y-H, Lim W-S, Lee S-M, Lee H-W and Lee J-W 2013 *Biomass Bioener.* **52** 159–65
[73] Salomon M, Gómez M F, Erlich C and Martin A 2013 *Biomass Convers. Biorefin.* **3** 213–29
[74] Mahidin, Gani A, Muslim A, Husin H, Hani M R, Syukur M, Hamdani, Khairil and Rizal S 2016 *J. Eng. Technol. Sci.* **48** (4) 465-81
[75] Er A C, Nor A R M and Rostam K 2011 *Am. J. Appl. Sci.* **8** 436–40
[76] Umar M S, Jennings P and Urmee T 2013 *Renew. Energy* **60** 107–15
[77] Wijono A 2014 *Simposium Nasional RAPI XIII* ISSN 1412-9612
[78] Samiran N A, Jaafar M N M, NgSu J H and Chong S L C T 2016 *Renew. Sustain. Energy Rev.* **62** 1047–62
[79] Fan L, Lingtong Gai T, Tong Y and Li R 2017 *J. Cleaner Prod.* **166** 124-33
[80] Oh H J, Hwang T M and Lee S 2009 *Desalination* **238** 128–39
[81] Rong A and Lahdelma R 2016 *Renew. Sustain. Energy Rev.* **53** 363–72
[82] Salkuyeh Y K, Elkamel A, Thé J and Fowler M 2016 *Energy* **113** 861–74
[83] Sahoo U, Kumar R, Pant P C and Chaudhary R 2017 *Applied Thermal Eng.* **120** 560-67
[84] Edwin M and Sekhar S J 2015 *Energy* **91** 842–51
[85] Rudra S, Rosendahl L and Blarke M B 2015 *Energy Convers. Manage.* **106** 1276–85