And., Intl.,J., Appl Sci., Eng., Tech, Vol 03, No 01, March 2023
e-ISSN: 2797-0442

Analysis of Potential Electric Energy Rice Husk using Gasification Process in West Sumatera

Maidi Rizki*), Refdinal Nazir

Department of Electrical Engineering, Engineering Faculty, Universitas Andalas, Padang, Indonesia
*Corresponding author, e-mail: maidi.rizki@gmail.com

Abstract— Currently, the use of fuel is increasing, it is feared that fossil fuels will run out in the near future and the national energy policy make the target of the new renewable energy to reach 23% in 2025, especially those most widely used for electricity fuel. Energy from vegetable waste is one of solution to produce new biomass energy an alternative energy to replace fossil fuels. The potential of biomass energy at Indonesian, especially in the West Sumatra area is very large, one of which is solid waste from rice husk agricultural products. In this article, use the rice husk gasification downdraft method to produce synthetic gas to internal combustion engine and coupled with electric generator. The results of rice production at West Sumatera in 2021, which is total of 1.361.769 tons of dry unhulled rice (GKG), will produce 272.353,8 tons of rice husks or about 20% of the total rice production, and mass syngas is 235.335,47 tons, the energy potential electrical 118.924,82 MWh per year. The generator can runs 216 days continuously and cost of fuel is $ 224.64/day vs $302.23/day a diesel engine. So fuel of biomass gasifier 34.5% more efficient compared with the diesel engine.

Keywords: Rice Husk, Gasification, Reneweble Energy.

This article *is licensed under the CC–BY-SA license.*

1. Introduction

Currently, the electrical energy that we often has increased to become a basic and that must be use. Broadly, electricity needs have been utilized by various forms of social economic activity in various household, industrial and government sectors in Indonesia [1]. The availability of electrical energy is one of the main points in improving welfare and national economic growth. Indonesia has several energy sources, one of which is fossil energy sources such as petroleum, which is one of the main ingredients in the production of electrical energy in Indonesian [2]. In 2018, the total production of fossil energy consisting of oil, gas, coal, and renewable energy reached 411.6 MTOE. Meanwhile, 43.2 MTOE Indonesia imports crude oil. In the last 10 years, oil production has shown a declining trend, from 346 million barrels in 2009 to 283 million barrels in 2018. The decline in production is due to the fact that the oil production wells are old, while the production of new wells is still limited. To meet the needs of refineries, Indonesia imports crude oil, one of which is from the Middle East so that the dependence on oil imports reaches approximately 35%[3].

On the other hand, the National Energy Policy mandates the primary energy mix target of New and Renewable Energy to reach 23% by 2025. The Indonesian government has officially submitted a commitment to contribute to post-2020 global emission reductions in the Intended Nationally Determined Contribution (INDC) to the United Nations Framework Convention on Climate Change (UNFCCC) for 29% of the Business as Usual (BAU) scenario in 2030. The facts above show the importance of the role of Renewable Energy (RE) as a solution to the electrification problem [4].

The use of fossil energy is getting bigger as demand increases, thus making fossil energy reserves dwindle. The shift from the use of fossil energy to New and Renewable Energy is something that is

Received: October 20, 2022, Revised: December 15, 2022, Accepted: January 01, 2023
https://doi.org/10.25077/aijaset.v3i01.63

absolutely done to maintain energy availability in the future [5]. To respond to these problems and reduce the use of petroleum, one solution is to utilize renewable energy in the form of biomass with the gasification method.

Gasification is a process of changing from a flammable solid material and can be processed into gas fuel by a thermochemical process, where the air required is less than the air that is processed in the combustion process[6]. The gas produced from the gasification process is carbon monoxide (CO), hydrogen (H_2), methane (CH_4), carbon dioxide (CO_2), and ethane called synthesis gas (syngas) [2]. This gas can be used as an alternative fuel for the combustion process in generators/generators. The gasification process consists of 4 main stages, namely: heating or drying, pyrolysis, oxidation and combustion processes[7]. The 4 stages are carried out in a reactor (gasifier). The reactor in the gasification process is divided into several types. That is, Updraft Gasifier, Downdraft Gasifier, and Crossdraft Gasifier. In the Updraft Gasifier reactor, air enters from the bottom of the gasifier through the grate. Meanwhile, the fuel enters through the top of the gasifier and the ash from the combustion passes through the bottom stream of the gasifier. The advantages of this Updraft Gasifier are the simple manufacturing mechanism, charcoal can be burned out in the gasifier, the temperature of the gas produced is low, and the efficiency is quite high. While the drawback is the high amount of tar vapor present in the output gas, the ability of the gas to carry a load is quite low, there can be an uneven distribution of heat in the gasifier so that it can reduce its efficiency. For the Downdraft Gasifier type reactor, air is introduced into the fuel flow above the oxidation zone, this flow is in the same direction as the fuel flow that enters the gasifier from above. The steam and tar produced are melted into gas and charcoal, so they can maintain the temperature in the combustion chamber. The gas produced will flow towards the bottom of the gasifier. The advantages of the Downdraft Gasifier are the possibility of producing tar-free gas and can reduce environmental problems caused by the tar, the recovery of tar and oil is 10% smaller than the Updraft Gasifier type, the time required for ignition and system operation at optimal conditions is about 20-30 minutes. , faster than the Updraft Gasifier type. The drawbacks are the low heat exchange in the gasifier, resulting in low efficiency, difficulty handling humidity and high ash content [8]. The Downdraft Gasifier produces relatively clean syngas and the content of tar and particles is low enough that it is suitable for boiler and turbine combustion engines [9].

One of the users of biomass is in solid waste from agricultural products, is a rice, because the processing process is flexible and is always available quite large from day to day. The opportunity for its utilization lies in the waste in the form of rice husk which is considered to have the potential to contain a fuel source because it has a high silica content to be used for various purposes [10]. The following is the general content of rice husks per kilogram.

Table 1. Content and calorific value of rice husk per kg

Biomass Content	Value
C	55.4%
H	20.1%
N	11.3%
O	13.2%
CH4	1.8%
HHV	5,059.23 KJ/Kg
LHV	1,819.23 KJ/Kg
Density	617 kg/m^3
Carbon Conversion	62%

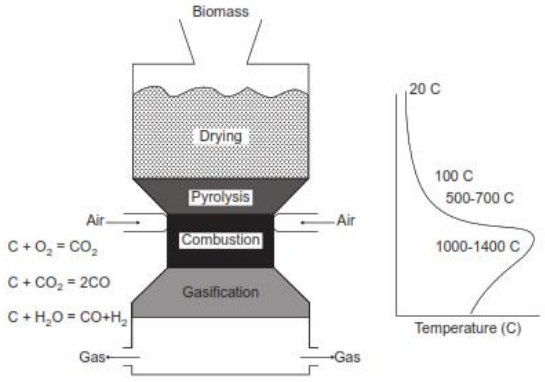
Due to some of the conditions above, this article will present an Analysis Potential Electrical Energy in Rice Husk through the Downdraft Gasification process in the West Sumatra Region. It is hoped that this article can be applied in an applicable manner, especially in the West Sumatra Region, which annually produces quite large processed rice as well as rice husk waste, so that the supply of New Renewable Energy from rice husk waste can replace fossil fuels in the future. Quite a lot of potential for

the area of West Sumatra in particular and in the future can spur local economic growth.

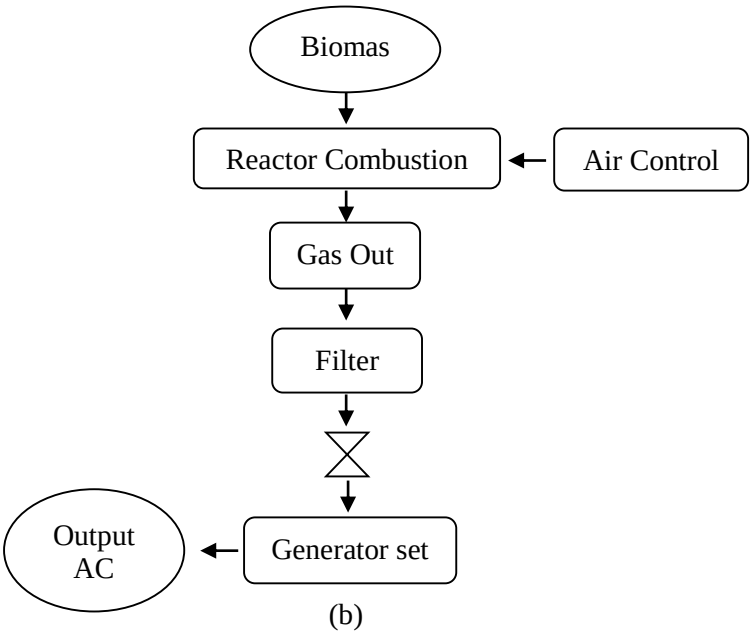
2. Method

Based on the data obtained by the Central Statistics Agency (BPS indonesian), Indonesian can produce rice husks of 20 – 30% rice yields [11]. Therefore, the presence of waste in the form of rice husks gives hope for the creation of renewable energy that can be used as fuel for power plants which of course can produce electrical energy in every area where there is rice processing through Biomass Power Plants. By applying the gasification method in processing rice husk waste, electrical energy can be generated.

2.1 Gasification Technology Design



(a)



(b)

Figure 1. (a) Downdraft gasification reaction, (b) Diagram of biomass generator set

The gasification process is a process of forming gaseous fuels (H_2, CO, and Methane (CH_4)) from chemical reactions of solid materials that have Carboneseos and Cellulose properties, such as wood, rice husks, coal and agricultural and forestry wastes [12]. The stages of the gasification process are as follows:

- Dryer, the stage of drying the raw material from the Oxidation reaction
- Pyrolysis, the raw material that is burned is heated at a higher temperature causing the raw material to split into charcoal, tar, oil, gas and other pyrolysis products.
- Oxidation, raw materials from the pyrolysis stage will be oxidized by oxygen from the air. The heat generated from this reaction is used for drying, pyrolysis and other endothermic reactions.
- Reduction, raw materials that are processed after the oxidation stage will occur a reduction reaction, a reaction that has calorific value and gas.

2.2 Downdraft gasifier reactor process

The reactor gasifier is designed to carry out the fuel combustion process. Basically it starts from the drying room and automatically feeds into the pyrolysis zone during stable operation which produces flammable charcoal (Fig. 1(a)). Charcoal produced in the pyrolysis zone will move down by gravity to continue and maintain the process. Start-up large-sized charcoal should be placed on the gasifier grate bed. Then, the charcoal provides the initial heat source. Once the temperature in the combustion zone reaches more than 800 °C, the raw material begins to be feed back. The heat from combustion removes moisture from the biomass as well as other particles in the pyrolysis zone. Combustion air is injected to reach the required temperature for combustion in the reduction zone. As a result, the high temperature reached during combustion and the reduction zone allows tar (800 °C) to form. However, it is important to note that the temperature must reach ±1100 °C in the reactor which will produce producer gas (syngas) with low LHV [13]. After the combustion-reduction zone, the remaining ash and charcoal are removed from the bottom of the reactor. Finally, the producer gas exits the gasifier and is cooled and filtered before entering the gas engine[14].

Tabel 2. Technical parameter downdraft gasifier reactor

Specification	**Description**
Model	"ANKUR" FBG-120
Mode of Operation	Cold and Ultra Clean Gas
Gasifier Type	Downdraft
Volume Gas Flow Rated	300 nm^3/h
Thermal Output	310,000 kcal/h
Biomass Consumption	± 144 kg/h
Biomass Fuel Type	Rice Husk

2.3 Generator Gas Engine

The clean gas produced by gasification is burned in the internal combustion engine ICE (spark ignition), this paper uses the reference Generator set model 100GFLS and Engine model TNJD-6160Q1 (By Powermax Gas Power Generation Product). Under normal conditions, this system is capable of producing 100 kWe. The technical parameters of the generator set and engine can be seen in Table 3.

The producer gas is mixed (in the carburetor) with clean outside air and compressed to the maximum compression ratio. Thus, the gas and air mixture results in a simple thermodynamic cycle in which the combustion phase is the only gas engine process. In this phase, the compressed mixture is ignited by the spark plug according to the oxidation reaction.

The gas engine is coupled with a generator set that produces mechanical torque in the rotor which is connected to an electric generator on the same shaft. Electricity can be generated normally when the generator reaches synchronization with the grid frequency (50 Hz). The regulation of gas flow entering

the Engine is adjusted according to load conditions automatically, so it is important to emphasize that reduced gas flow leads to reduced biomass consumption [14].

Table 3. Technical parameter generator 100 GFLS and gas engine TNJD-6160Q1

Generator	
Model	100GFLS
Rated Power (kW)	100
Rated Voltage (kV)	0.4
Rated Current (A)	180
Rated Frequency (Hz)	50
Power Factor	0.8 Lagging
Engine	
Model	TNJD-6160Q1
Ignition Mode	Spark-Ignited
Volume Gas Consumption (Nm^3/h)	250-300
Arrangement of Cylinder	L-6 4-Stroke-Cycle
Cylinder Diameter	160
Displacement (L)	27
Rated Power (kW)	110
Speed (r/min)	1000

2.4 Rice Production in West Sumatra

Based on data from the Central Statistics Agency (BPS) of West Sumatra Province No. 57/11/13/Th.XXIV, November 1, 2021, the rice harvested area is estimated at 258,474 hectares with a production of 1,361,769 tons of GKG originating from several districts/cities.

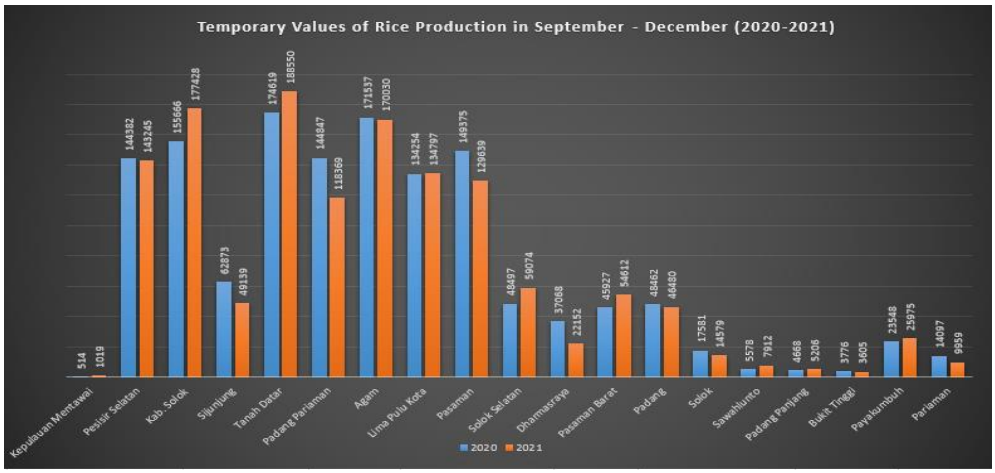


Figure 2. Development of rice production in West Sumatera (Thousand Tons – GKG), 2020-2021

It can be seen from the graph above that a relatively large increase in rice production in 2021 will

occur in Tanah Datar, Solok, and South Solok districts. Meanwhile, a relatively large decline in rice production occurred in Padang Pariaman, Pasaman and Dharmasraya districts.



Figure 3. Map of the distribution of rice production in West Sumatra

The distribution of the highest rice-producing districts in West Sumatra can be seen in Figure 3 above. With the potential of the scattered area, it can be a criterion for consideration in determining the electrical energy that will be produced by Biomass Power Plant.

The heat content in rice husks is the largest place of heat compared to other parts of other rice plants [15].

Table 4. Calorific value of rice agricultural biomass waste

Biomass Waste		Calorific Value
Rice Husk	3,300 kCal/kg	13.86 x 10^6 J/kg
Straw	2,800 kCal/kg	11.76 x 10^6 J/kg
Moan	3,200 kCal/kg	13.44 x 10^6 J/kg

Rice husk is also known to have a water content of 0% which can trigger the amount of heat energy contained in rice husk. Based on the calorimeter, the High Heating Value (HHV) potential value of burning rice husk is ranked third after sawdust and charcoal, thus providing more value for rice husk as a renewable energy fuel [16].

2.5 Data retrieval for analysis

There are several important parameters in calculating the analysis of a Biomass Power Plant by the equation [12] :

- Fuel Consumption Rate (FCR)

  It is the level of fuel consumption which the process is carried out in the combustion chamber, the fuel that is burned is Rice Husk to produce H_2CO gas with the equation:

$$\text{FCR} = \frac{massa}{waktu} \quad \text{(kg/h)} \tag{1}$$

- Density of Chemical Mixture

  Is the density of the chemical substances contained in rice husk:

$$\rho Mix = (\rho C\ x\ \%C) + (\rho H\ x\ \%H) + (\rho N\ x\ \%N) + (\rho CH4\ x\ CH4) \quad \text{(kg)} \tag{2}$$

- Mass of Gasified Gas (Msyngas)

  Msyngas is the mass of gas that has been heated and multiplied by the density of the mixture to adjust the chemical content before and after the gasification process:

$$\text{Msyngas} = \rho Mix\ x\ Rice\ Husk \quad \text{(ton)} \tag{3}$$

- Calor Rice Husk Heat (Q)

$$Q = Msyngas\ x\ LHV \quad \text{(MJ)} \tag{4}$$

- Gasification Efficiency
  It is the efficiency level based on the LHV and HHV of the content contained in the rice husk, each of which is added to the total mass of Syngas and the total mass of Biomass used.

$$\eta g = \frac{Massa\ Syngas\ x\ LHV}{Massa\ Biomassa\ x\ HHV}\ x\ 100\% \tag{5}$$

- Energy potenstial

  By using a similar energy equation, we can calculate the potential utilization of Biomass into electrical energy:

$$W = P \text{ x } t \tag{6}$$

  Where ;

  W = Electric Energy (Joule), P = Power (W), t = Time (s)

  1 kWh = 3.6 x 10^6 Joule

- Raw materials gasifier generator engine
  Assumed power generator output is constant (100 kW) on 300 nm^3/h volume gas consumptions with raw materials of rice husk 144 kg/h. If generator running constant 24 hours/day, so raw materials consumed is 3456 kg/d.

$$\text{Generator operation time (days)} : \frac{\text{Rice husk production } \left(\frac{kg}{d}\right)}{\text{Raw materials consummed } \left(\frac{\text{kg}}{\text{d}}\right)} \tag{7}$$

- Economic Analysis
  The economic feasibility of the gasifier / generator engine of the operation time we can calculate cost of fuel gas engine with biomass vs diesel engine with the generator same of capacity.

$$FC = Diesel\ Fuel/l - Rice\ husk/kg \tag{8}$$

  Efficiency cost of fuel

$$\eta c = \frac{FC}{Rice\ Husk\ Cost} x\ 100\% \tag{9}$$

2.6 Workflow Analysis

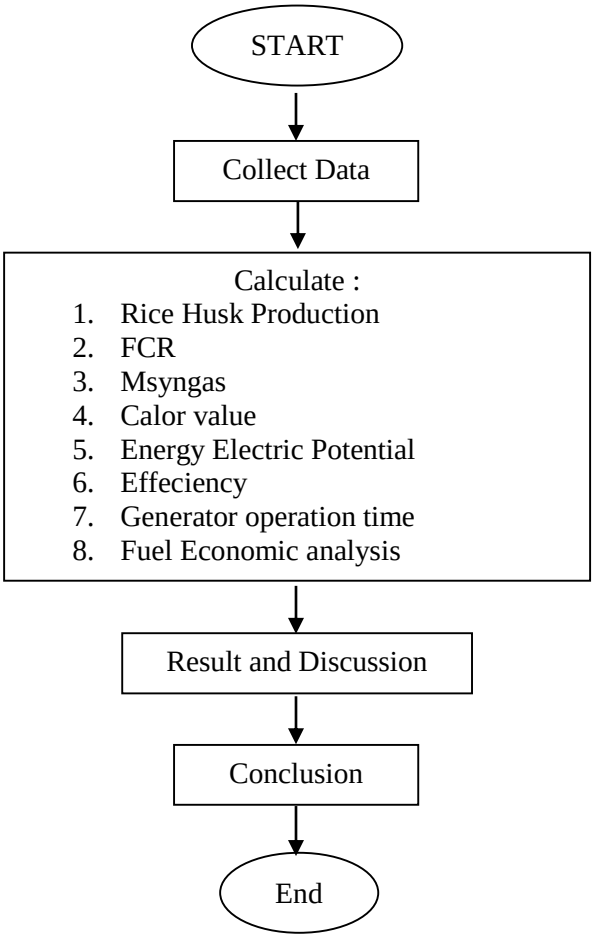


Figure 4. Workflow Process Analysis

3. Result and Discussion

Through the process of observation and research carried out using case examples of data collection from rice production in the province of West Sumatra, manual calculations were carried out which aimed to describe the energy potential of rice husk biomass that can be converted into electrical energy. For example, the capacity of a rice milling machine in one area in West Sumatra is 5 tons/day, in 1 day the milling machine works for 8 hours, producing an average of 20% rice husks of about 1 ton/day, so the calculation of fuel consumption for The gasification is as follows, the FCR = 125 kg/h.

3.1 Technical Analysis

Perform calculations to determine the mass of syngas produced, first use equation (2) and data from Table 1 to determine the density of chemical substances in rice husks. $\rho Mix = 0{,}86408\ kg$

Use equation (3) to produce syngas mass with data from BPS West Sumatra in 2021 with a known rice production yield of 1,361,769 Tons GKG, resulting in a mass of rice husks of around 272,353.8 tons or about 20%. By knowing the mass of rice husks, the mass of syngas can be calculated as follows:

Msyngas 2021 = 235.335,47 ton

After knowing the mass value of syngas, the calorific value of the combustion of rice husk biomass can be calculated using equation (4), Q 2021 = 428.129.349,82 MJ.

With the mass value in the syngas and the heat energy produced, so that the energy electric power potential generated with equation (6) in West Sumatra is P $2021 = 118.924{,}82$ MWh / year

If each district / city in the province of West Sumatra is calculated to determine the potential for electrical energy produced by rice husk biomass using data from the BPS West Sumatra in 2020 and 2021, the results can be seen in Table 5 below:

Table 5. Potential electrical energy produced in West Sumatra per year

District / City Sumatera Barat	Rice Production (ton GKG)		Rice Husk Production (ton)		Mass Syngas (ton)		Calorific Value (MJ)		Energy potential power per year (MWh)	
	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021
Kepulauan Mentawai	514	1019	102.80	203.80	88.83	176.10	161,597.51	320,365.50	0.04	0.09
Pesisir Selatan	144382	143245	28,876.4	28,649.00	24,951.52	24,755.03	45,392,553.21	45,035,089.44	12.61	12.51
Solok	155666	177428	31,133.2	35,485.60	26,901.58	30,662.40	48,940,153.12	55,781,952.95	13.59	15.49
Sijunjung	62873	49139	12,574.6	9,827.80	10,865.46	8,492.01	19,766,771.47	15,448,911.03	5.49	4.29
Tanah Datar	174619	188550	34,923.8	37,710.00	30,176.96	32,584.46	54,898,825.67	59,278,621.34	15.25	16.47
Padang Pariaman	144847	118369	28,969.4	23,673.80	25,031.88	20,456.06	45,538,745.51	37,214,272.77	12.65	10.34
Agam	171537	170030	34,307.4	34,006.00	29,644.34	29,383.90	53,929,869.37	53,456,080.55	14.98	14.85
Lima Pulu Kota	134254	134797	26,850.8	26,959.40	23,201.24	23,295.08	42,208,390.51	42,379,105.39	11.72	11.77
Pasaman	149375	129639	29,875.0	25,927.80	25,814.39	22,403.69	46,962,312.72	40,757,471.19	13.05	11.32
Solok Selatan	48497	59074	9,699.40	11,814.80	8,381.06	10,208.93	15,247,071.33	18,572,396.06	4.24	5.16
Dharmasraya	37068	22152	7,413.60	4,430.40	6,405.94	3,828.22	11,653,884.57	6,964,412.73	3.24	1.93
Pasaman Barat	45927	54612	9,185.40	10,922.40	7,936.92	9,437.83	14,439,083.76	17,169,578.73	4.01	4.77
Padang	48462	46480	9,692.40	9,296.00	8,375.01	8,032.49	15,236,067.61	14,612,942.56	4.23	4.06
Solok	17581	14579	3,516.20	2,915.80	3,038.28	2,519.48	5,527,326.66	4,583,521.72	1.54	1.27
Sawahlunto	5578	7912	1,115.60	1,582.40	963.97	1,367.32	1,753,678.86	2,487,469.91	0.49	0.69
Padang Panjang	4668	5206	933.60	1,041.20	806.71	899.68	1,467,582.10	1,636,725.02	0.41	0.45
Bukit Tinggi	3776	3605	755.20	721.00	652.55	623.00	1,187,144.39	1,133,383.35	0.33	0.31
Payakumbuh	23548	25975	4,709.60	5,195.00	4,069.47	4,488.90	7,403,304.03	8,166,333.54	2.06	2.27
Pariaman	14097	9959	2,819.40	1,991.80	2,436.19	1,721.07	4,431,984.75	3,131,030.44	1.23	0.87
Sumatera Barat	1,387,269	1,361,769	277,453.80	272,353.8	239,742.27	235,335.47	436,146,347.14	428,129,349.82	121,1517	118,924,82

With the results obtained in Table 5, the efficiency value of the gasification results from rice husks can be calculated using equation (5) with HHV and LHV data from Table 1, is $\eta g\ 2021 = 31.07\ \%$.

With the results of rice husk production (Table 5) it can be calculated using equation (7) how long the consumption of gas generator sets with the biomass gasification method in West Sumatra in operating ; Generator operation time : $746{,}174.79/(3{,}456) = 216$ day operation, that's equal to 7 months of generator running until the rice husks are produced again. For the each district/city can see in the Table 6. below:

Table 6. Calculated of estimation generator production time

District / City Sumatera Barat	Produksi Sekam Padi (ton)		Estimated generator 100kVA running continuously (day)	
	2020	2021	2020	2021
Kepulauan Mentawai	102.80	203.80	0	0
Pesisir Selatan	28,876.40	28,649.00	23	23
Kab. Solok	31,133.20	35,485.60	25	28
Sijunjung	12,574.60	9,827.80	10	8

District / City Sumatera Barat	Produksi Sekam Padi (ton)		Estimated generator 100kVA running continuously (day)	
	2020	2021	2020	2021
Tanah Datar	34,923.80	37,710.00	28	30
Padang Pariaman	28,969.40	23,673.80	23	19
Agam	34,307.40	34,006.00	27	27
Lima Pulu Kota	26,850.80	26,959.40	21	21

Pasaman	29,875.00	25,927.80	24	21
Solok Selatan	9,699.40	11,814.80	8	9
Dharmasraya	7,413.60	4,430.40	6	4
Pasaman Barat	9,185.40	10,922.40	7	9
Padang	9,692.40	9,296.00	8	7
Solok	3,516.20	2,915.80	3	2
Sawahlunto	1,115.60	1,582.40	1	1
Padang Panjang	933.60	1,041.20	1	1
Bukit Tinggi	755.20	721.00	1	1
Payakumbuh	4,709.60	5,195.00	4	4
Pariaman	2,819.40	1,991.80	2	2
Sumatera Barat	277,453.80	272,353.80	220	216

3.2 Economic Analysis

From an economic point of view using equation (8-9), it is assumed that the cost of purchasing rice husks in West Sumatra is around $ 0.065/kg so that the cost of using rice husk fuel during the operation of the gasifier generator in 24 hours/day is around $ 224.64/d (exchange rate is 0.000065 usd/rupiah, access 14 October 2022), Meanwhile, when compared to the cost of purchasing diesel fuel at $ 0.44 /liter, (access website for Pertamina West Sumatra Province 14 October 2022) for the diesel generator model (APD125C-6, by Cummins) the use of fuel per day with full load (100 kW) then the spend cost for fuel is $ 302.33/d. From the above calculation, the difference in fuel use can be calculated: $ 77.69 or 34.5%. So that the use of biomass gasifier fuel is 34.5% more efficient than of the diesel engines.

4. Conclusion

The large potential of biomass energy from rice husks in West Sumatra can be used as renewable alternative energy for replaced fossil fuels in the future, so that they no longer depend on fossil energy. From the energy calculations that have been carried out, the output of electrical energy that can be generated in West Sumatra is 118,924.82 MWh per years, and the efficiency is 31.07%. From the technical analysis of the production of rice husks, 272353.80 tons/year in 2021, that is the resulting generator runs 216 days continuously with a fuel cost of $ 224.64/day and vs $ 302.23/day from a diesel engine (fossil fuels). So that the use of fuel from rice husks biomass energy is 34.5% more efficient compared with the fossil fuels.

References

[1] D. Mulyani and D. Hartono, “Pengaruh Efisiensi Energi Listrik pada Sektor Industri dan Komersial terhadap Permintaan Listrik di Indonesia,” *J. Ekon. Kuantitatif Terap.*, p. 1, 2018, doi: 10.24843/jekt.2018.v11.i01.p01.

[2] A. Suardi, N. Chairat, V. Antono, and R. Nurhasanah, “Rancang Bangun Gasifier Tanpa Blower Berbahan Bakar Arang Limbah Perkebunan Kelapa Sawit,” vol. 9, no. 2, pp. 208–216, 2020.

[3] Tim Sekretaris Jenderal Dewan Energi Nasional, “Indonesia Energy Out Look 2019,” *J. Chem. Inf. Model.*, vol. 53, no. 9, pp. 1689–1699, 2019, [Online]. Available: https://www.esdm.go.id/assets/media/content/content-outlook-energi-indonesia-2019-bahasa-indonesia.pdf.

[4] A. M. Fatimah, F. S. Ragina, N. Siahaan, and H. Batik, “Gasifikasi Biomassa: Studi Kasus Proyek di Desa Munduk, Buleleng, Bali,” *J. Integr. Proses*, vol. 8, no. 1, pp. 1–15, 2016, [Online]. Available:

https://www.esdm.go.id/assets/media/content/FIX2_Jurnal_Energi_Edisi_2_17112016(1).pdf%0Ahttps://halshs.archives-ouvertes.fr/halshs-01100209/document.

[5] Humas EBTKE, "Direktorat Jenderal EBTKE - Kementerian ESDM," *Kementerian ESDM*, 2019. https://ebtke.esdm.go.id/post/2020/10/22/2667/menteri.arifin.transisi.energi.mutlak.diperlukan?lang=en (accessed Oct. 18, 2021).

[6] A. Rizkal and B. Sudarmanta, "Karakterisasi Unjuk Kerja Diesel Engine Generator Set Sistem Dual Fuel Solar-Syngas Hasil Gasifikasi Briket Municipal Solid Waste (MSW) Secara Langsung," *J. Tek. ITS*, vol. 5, no. 2, 2017, doi: 10.12962/j23373539.v5i2.20017.

[7] Y. A. Situmorang, Z. Zhao, A. Yoshida, A. Abudula, and G. Guan, "Small-scale biomass gasification systems for power generation (<200 kW class): A review," *Renewable and Sustainable Energy Reviews*, vol. 117. Elsevier Ltd, Jan. 01, 2020, doi: 10.1016/j.rser.2019.109486.

[8] F. Tricahyandaru, "Bab ii dasar teori 2.1," *Pengaruh Perlakuan Panas Dan Penuaan*, pp. 5–18, 1998.

[9] R. Manurung, "Gasification and pyrolytic conversion of agricultural and forestry wastes," *RENEW. ENERGY REV. J.*, vol. 3, no. 1, pp. 1–21, Apr. 1981, Accessed: Oct. 18, 2021. [Online]. Available: http://www.rericjournal.ait.ac.th/index.php/reric/article/view/1641.

[10] S. Herodian, "Peluang Dan Tantangan Lndustrl Berbasls Hasil Samping Pengolaxan," *Peluang Dan Tantangan Lndustrl Berbasls Has. Samping Pengolaxan Padi*.

[11] "Berita Resmi Statistik N0.57/11/13/Th.XXIV, 1 November 2021." Faizal A. SE, M.Si, Sumatra Barat, [Online]. Available: http://sumbar.bps.go.id.

[12] U. F. Al-afifi, Erdin Syam, and Elvin Piter, "Perhitungan Potensi Energi Listrik Pada Sekam Padi Melalui Metode Gasifikasi," *SainETIn*, vol. 4, no. 2, pp. 48–56, 2021, doi: 10.31849/sainetin.v4i2.4329.

[13] M. Simone, F. Barontini, C. Nicolella, and L. Tognotti, "Gasification of pelletized biomass in a pilot scale downdraft gasifier," *Bioresour. Technol.*, vol. 116, pp. 403–412, 2012, doi: 10.1016/j.biortech.2012.03.119.

[14] D. Vera, F. Jurado, N. K. Margaritis, and P. Grammelis, "Experimental and economic study of a gasification plant fuelled with olive industry wastes," *Energy Sustain. Dev.*, vol. 23, pp. 247–257, 2014, doi: 10.1016/j.esd.2014.09.011.

[15] H. Z. G. Grassi, A. Collina, *Biomass for Energy, Industry and Environment*, vol. 1, no. 1. 1991.

[16] S. Widiyanto, "Analisis Nilai Kalor Pengujian Bahan Bakar Biomassa Terhadap Korelasi HHV(High Heating Value)," *Jur. Tek. Mesin Fak. Tek. Univ. Muhammadiyah Surakarta*, 2017, [Online]. Available: https://core.ac.uk/download/pdf/148617279.pdf.