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Original Research

Study of Potential Refuse Derived Fuels as Renewable Alternative Energy from a Jatibarang Landfill

Mochamad Arief Budihardjo[1]*, Eflita Yohana[2], Bimastyaji Surya Ramadan[1,3], Annisa Sila Puspita[4], Sheila Nurul Adhana[1], Julia Nur Rizkiana[1]

[1]Environmental Sustainability Research Group, Department of Environmental Engineering, Faculty of Engineering, Universitas Diponegoro, Semarang, Indonesia 50275
[2]Department of Mechanical Engineering, Faculty of Engineering, Universitas Diponegoro, Semarang, Indonesia 50275
[3]Department of Life and Environment Engineering, Faculty of Environmental Engineering, The University of Kitakyushu, Fukuoka, Japan 808-0135
[4]Master Program of Environmental Engineering, Department of Environmental Engineering, Faculty of Engineering, Universitas Diponegoro, Semarang, Indonesia 50275

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Abstract

Population growth is correlated with the increasing demand for resources, such as fuel. The utilization of landfill passive zone mines as raw material for refuse-derived fuels (RDF) can be an alternative to meet fuel needs. However, mining results are dominated by combustible waste so that the concentration of methane gas decreases below 40% and causes a decrease in the financial aspect. Therefore, this study aims to determine the existing conditions of passive zones one and two and analyze the technical, environmental, and financial feasibility aspects of the RDF plant carried out at the Jatibarang landfill. Data were taken via field sampling and interviews with experts. The treated waste can produce a calorific value of 2,980 kcal/kg. Besides, there is a reduction in the amount of waste that goes to the landfill by 30,300 tons per year. The net profit obtained after the loan period ends is Rp. 12,703,795,674. The RDF plant at the Jatibarang landfill is feasible to run in view of the technical, environmental, and financial aspects.

Keywords: environmental, financial, Jatibarang landfill, RDF

Introduction

The mining of waste in landfills has become the center of discussion. Refuse-derived fuel (RDF) is a waste processing technology that converts waste into more valuable materials, namely fuel. According to Cheremisinoff, what is meant by RDF is the result of separating solid waste between combustible and non-combustible fractions, such as metal and glass [1]. RDF is produced from dividing fractions with a high calorific value from the separation of municipal solid

*e-mail: m.budihardjo@ft.undip.ac.id

waste (MSW). The production of RDF aims to convert the bit of combustible waste from municipal solid waste to be used as fuel [2].

In the Jatibarang landfill of Semarang City, around 850 tons of waste per day is buried [3]. The Jatibarang landfill has four buried zones, where the first and second zones have been closed. In the closed zones, methane gas has been extracted as material for a waste-to-energy (WtE) power plant since 2019 and is expected to decline after 2021 [4]. This situation is reinforced by Nurhadi and Windarta's [5] research, examining the potential of combustible waste in the passive zone of the Jatibarang landfill as RDF raw material during the trial process with electricity buyers. The generator failed to meet the requirements because the gas volume decreased, and the concentration of methane gas was below 40% after four hours of operation. This result had a decreasing economic feasibility effect. The utilization of methane gas in passive zones one and two will leave a pile of waste. Therefore, the waste pile can be mined to be used as RDF since the waste has a calorific value that could potentially be used as fuel. RDF can reduce the number of waste piles and become co-combustion fuel, which is a secondary fuel for the cement, paper, and power generation industries. The combustible waste fraction is generally reduced in size and then dried to be used as fuel [6].

Hutabarat et al. examined that the waste taken comes from a depth of 0-1 m, 1-2 m, and 2-3 m. Further, the low calorific value varies for each waste depth, from 3.5 kcal/ton to 4.25 kcal/ton. These results indicate that the passive zone waste at the Jatibarang landfill has the potential to become raw material for RDF production because it exceeds the minimum calorific value limit as raw material for RDF, which is at least 2-2.5 kcal/ton [7]. Rotheut and Quicker have also carried out other research showing that decomposed waste could be used as RDF. However, because mining waste is dominated by non-combustible waste, it needs to be mixed with new waste in a ratio of 1:10 [8]. Thus, a solution is needed to overcome the decomposed waste in passive zones one and two at the Jatibarang landfill and the incoming waste pile by reusing it into RDF. Currently, RDF from waste from landfill mining has not been widely applied as an energy source. Therefore, a feasibility study is needed regarding the RDF plant by utilizing mining waste into fuel viewed from the technical, environmental, and financial aspects. This research must be done because no one has reviewed RDF using the integrated risk-based approach (IRBA) method with AHP.

This study aims to determine and analyze the existing conditions of passive zone one and passive zone two and analyze the technical feasibility, environment, and finance of the RDF plant conducted at the Jatibarang landfill. A technical feasibility analysis was carried out on landfill mining with the aim of landfill rehabilitation, the number of raw materials for RDF from the first and second zones of Jatibarang landfill, and planning the technical concept of the RDF plant. Furthermore, the environmental feasibility analysis focuses on the environmental impact of mining the production zone and RDF use. The financial feasibility analysis focuses on the investment and operational costs of the RDF plant and financial analysis based on the NPV, payback period, IRR, and sensitivity analysis.

Research Methods

Field Sampling Technique

Sampling was not carried out in passive zones one and two because they were already covered with a geomembrane. Therefore, it was carried out in the intermediate area of the third zone, which has almost the same age as the first and second passive zone at a depth of 2-3 m. The sampling method of waste composition is carried out regarding SNI 19-3964-1994 as the national government standard. In this technique, the sample is flattened with a foot or shovel. The sample was divided into four parts (called the cone and quartering method), with the two opposite parts mixed and the other two parts discarded. The two composite parts are the samples used. After that, the waste from the coning and quartering samples was weighed. The weight was recorded and then sorted into several types and weighed again. It was compared to the total weight of the waste to find out the percentage of each type of waste. The density technique used refers to the government standard [9]. The waste sampled at this density is the last excavation at a depth of 2-3 m.

Interview and Document Review

The interview targets in this study were the Jatibarang landfill manager and the Semarang City Environmental Service. Additionally, a questionnaire was given to three respondents to select RDF drying technology to specialists considered experts in the field of solid waste, namely lecturers, the Jatibarang landfill manager, and the officers of the Environmental Services of Semarang City Government. The document review was used to find the current waste management of the Semarang City, a map of the Jatibarang landfill, the calorific value of waste in the landfill, the unit price of the building materials and wages of the Semarang City, and the specifications for the price of the equipment needed to build the RDF plant.

Data Analysis

Based on the data obtained, data analysis was carried out. In this study, the Jatibarang landfill's existing condition and waste facilities were analyzed better to understand the current waste management system. Then, the waste composition, volume, and characteristics of the waste were calculated using the formula (1). Meanwhile, the calorific value of the RDF was determined based on the study literature. The feasibility analysis included the technical, environmental, and financial feasibility aspects.

$$\text{Excavation volume} = \text{zone area x zone height} \quad (1)$$

In the analysis of the technical aspects, the appropriate mining method is used by the Regulation of the Minister of Public Works and Public Housing No. 3 of 2013. Furthermore, the integrated risk-based approach (IRBA) method is used to analyze the environmental aspects. If the assessment results show a value of 601-1,000, the landfill must be closed because it could potentially pollute the environment or even cause social problems. The value of 300-600 means that the landfills are feasible to be rehabilitated using the landfill mining technique or other rehabilitation methods. An IRBA that has a value of fewer than 300 means that the landfill cannot be mined since it is not feasible concerning the environmental value. Landfill mining can be carried out if the environmental risk index assessment results are in the range of 300-600. Finally, the financial feasibility analysis uses the payback period, present net value (NPV), and internal rate of return (IRR) methods with the formula below:

$$\text{Present value} = \frac{Net\ Cash\ Flow}{Factor\ PV} \quad (2)$$

$$\text{Payback period} = \text{Cash flow of the previous year} + \text{Cash flow for the current year} \quad (3)$$

The questionnaire results were then analyzed using the analytical hierarchy process (AHP) method.

Results and Discussion

Existing Condition of the Jatibarang Landfill

The Jatibarang landfill is the largest landfill in Central Java, located 12 km southwest of the center of Semarang City, which has been operating since 1992 with a total area of 46 Ha and the incoming waste generation is 850 tons/day [3]. The land used by the Jatibarang landfill is divided into six zones, namely the buried zone 1, 2 (passive), 3, 4 (active), composting zone, leachate processing facility zone, and the WtE zone. Passive zone one and two are zones that no longer accept waste and have used methane gas to generate energy since the end of 2019. The State Electricity Company purchases the electricity produced from the Jatibarang WtE with an eight-year contract. The Jatibarang landfill is also equipped with several basic facilities, environmental protection, and operational and supporting facilities as stipulated in the Regulation of the Minister of Public Works Number 3 of 2013 [10].

Table 1. The composition of the passive zone waste.

Composition	Percentage (%)	
	Active Waste*	Passive Zone Waste
Organic	61.34	-
Fine material	-	56
Cans	0.1	-
Aluminium	0.02	-
Glass cup	0.44	0.1
Plastic	16.34	32
Paper	10.31	0.67
Logam	0.15	2
Wood	-	3.3
Rubber/Leather	-	2
Fabric	1.97	2.67
Others	9.32	1.3
Total	100	1.3

Waste Composition

Data on the Jatibarang landfill waste composition, which will be processed into RDF, consists of the composition of the waste entering the landfill and the passive zone waste, as shown in Table 1.

Waste Density

The density of active waste that enters the Jatibarang Landfill is 154 kg/m^3 [11]. In contrast, the density of passive waste is obtained by sampling in the intermediate zone, which has almost the same age as passive zones one and two. Waste sampling was carried out at three points. At the first point, 20 weightings were carried out to weigh the entire sample taken with an excavator. Meanwhile, the second and third points were only weighed four times due to weather constraints. For the volume of the waste, it takes 20 sacks of rice husks to fill the dug hole as deep as 1 m from the bottom of the hole, where the volume of rice husks is known from the size of the cardboard. Based on the sampling results, the solid waste density value for passive zones one and two is 738.05 kg/m^3.

After analyzing the calculation by looking for the standard deviation, the second- and third-point solid waste density values were obtained by multiplying five times without significant differences. Therefore, weighing four times was considered sufficient. According to Damanhuri and Padmi [12], the density of the waste piles in landfills is 600-1,000 kg/m^3. Therefore, the results of the passive zone solid waste density sampling are acceptable.

Table 2. Calorific value of waste entering Jatibarang landfill.

Parameters	Unit	Waste Test Result
Total moisture	%	66. 63
High Heating Value (HHV)	kcal/kg	4.915
Low Heating Value (LHV)	kcal/kg	1.220

The Calorific Value

The data on the calorific value of the Jatibarang landfill waste is divided into the calorific value of waste entering the landfill and the calorific value of passive zone waste. The calorific value of active waste entering the Jatibarang landfill is known based on data from the Jatibarang landfill UPT presented in Tables 2 and 3. At the same time, the calorific value of waste in the passive zone refers to the research results conducted by Hutabarat and Priyambada [7].

Raw Materials for RDF in Jatibarang Landfill

Waste that can be used as raw material for RDF comes from active waste. Meanwhile, waste from passive zones one and two are combustible waste types, such as paper, wood, cloth, leather/rubber, and plastic. Non-combustible waste cannot be used as raw material for RDF and must be removed, such as metal, glass, or construction waste (e.g., stone). The obtained weight is 243.27 tons/day with a volume of 1,579.68 m^3, which is the amount of waste that goes to the landfill for RDF raw materials every day. Additionally, the number of passive zone waste excavations for RDF raw materials has a weight of 733.268 tons and a volume of 993.526 m^3.

Feasibility Study of Refuse Derived Fuel (RDF) Plant

There are three aspects in this study that will be discussed: the technical, environmental, and financial aspects. Based on the environmental risk index value data, Table 4 shows that the risk index value of the Jatibarang landfill is 582. This value belongs to the medium-level hazard evaluation, and the recommended action is that the landfill is continued and rehabilitated into controlled landfills in stages. Additionally, according to the Regulation of the Minister of Public Works No. 3 of 2013 [13], the cliff-type landfill becomes a landfill with a priority scale for immediate mining to overcome the danger of landslides. Thus, backfill mining at the Jatibarang landfill can be conducted as a stage of landfill rehabilitation and to overcome the threat of landslides.

Technical Aspect

Processing Capacity Plan

The planned capacity for processing waste into RDF at the Jatibarang landfill is 250 tons/day and has met the minimum amount as stipulated in the Regulation of the Minister of Public Works No. 3 of 2013 [10], where the minimum amount of waste as RDF material is 100 tons/day. The composition of the processed waste consists of a mixture of waste from mining in passive zones one and two (from now on referred to as passive waste) with active waste. Mixing passive and active waste is done to utilize passive landfill waste and reduce active waste entering landfills.

The ratio between passive waste and active waste used is 2:1, and this ratio requires 167 tons of passive waste and 83 tons of active waste. With passive waste mining as much as 167 tons per day, the passive landfill will run out within 30 years. The water content in the waste affects the weight of the waste. The water content of the mixed waste with a ratio of 2:1 is 42.15%. The calorific value of RDF resulting from the ratio of passive and active waste is 2.98 kcal/ton. According to Damanhuri and Padmi, the calorific value of 2-2.5 kcal/ton has met the minimum material value of fuel [12]. The results of the recapitulation are presented in Table 5.

RDF Plant Jatibarang Landfill

The planned RDF plant facility can process 250 tons of waste per day, with 75 tons of RDF produced every day. Waste processing into RDF consists of several processes, with the type of RDF planned, namely RDF-3 or RDF fluff. In this RDF plant, the waste will go through several processes until it becomes a co-combustion of coal. Waste processed into RDF consists of combustible waste, such as plastic, paper,

Table 3. Calorific value of waste in the Jatibarang landfill passive zone.

Sample	High Heating Value (HHV)	Low Heating Value (LHV)	Total Moisture
	kcal/kg	kcal/kg	%
Depth 0-1 m	5.250	3.499	32.85
Depth 1-2 m	5.760	3.856	24.41
Depth 2-3 m	6.317	4.246	30.09
Average	5.775	3.867	29.12

Table 4. Jatibarang Landfill Environmental Risk Assessment Index.

No	Parameter	Weight	Landfill Data	Sensitivity Index Value	Score
I. Landfill Criteria					
1	Distance to the nearest water source	69	120	1	69
2	Waste filling depth (m)	64	29	0.75	48
3	Landfill area (Ha)	61	46.018	0.75	45.75
4	Groundwater depth (m)	54	>20	0.1	5.4
5	Soil permeability (1 x 10^{-6} cm/second)	54	6.161 x 10^{-6}	0.25	13.5
6	Ground water quality	50	Can be drunk if there is no alternative	0.6	30
7	Distance to habitat / wetland (km)	46	8.3	0.65	29.9
8	Distance to nearest airport (km)	46	11.6	0.55	25.3
9	Distance to surface water (m)	41	120	0.85	34.85
10	Type of subgrade (% clay)	41	73	0,1	4.1
11	Age of location for future use (years)	36	<5	0.1	3.6
12	Type of waste (urban / residential waste)	30	50/50	0.75	22.5
13	Total amount of waste disposed (tonnes)	30	292.555	0.5	15
14	Amount of waste disposed per day (tonnes/day)	24	850	0.65	15.6
15	Distance to nearest settlement in dominant wind direction (m)	21	400	0.6	12.6
16	Flood return period (years)	16	25	0.65	10.4
17	Annual rainfall (cm/year)	11	208.7	0.6	6.6
18	Distance to city (km)	7	12.7	0.3	2.1
19	Community acceptance	7	Doesn't get people's attention	0.1	0.7
20	CH_4 ambient air quality (%)	3	0.1	0.75	2.25
II. Characteristics of Waste in Landfill					
21	Hazardous material content in waste	71	2.00%	0.1	7.1
22	Fraction of biodegradable waste (%)	66	71.65%	1	66
23	Waste filling life (years)	58	10 - 20	0.5	29
24	Humidity of waste in landfill (%)	26	66.63	1	26
III. Characteristics of Leachate					
25	BOD of leachate (mg/L)	36	468.1	1	36
26	COD of leachate (mg/L)	19	2390	1	19
27	TDS of leachate (mg/L)	13	774	0.1	1.3
JATIBARANG LANDFILL RISK INDEX					**582**

cloth, and rubber/leather. Types of metal waste will be recovered and resold. Meanwhile, fine material from the decomposition of organic waste can be reused as landfill cover. At the landfill, there are problems such as the leaching of harmful substances, the production of methane gas, the loss of soil, and natural resources, such as groundwater, soil, and minerals. That is a challenge in this project.

The RDF plant Jatibarang landfill consists of the main building and supporting buildings. The main building contains waste processing units into RDF, starting from passive zone waste reception, a passive waste sifting area, active waste sorting, a heavy separation area, a metal separation area, an enumeration area, a drying area, a compaction and packaging area, RDF storage, and a garage. Meanwhile, supporting

Table 5. Processing capacity plan.

Processing Capacity Plan		
Waste management plan (in)	250	tons/day
The minimum calorific value of material into fuel	2-2.5	kcal/ton
Comparison of passive and new waste	2:1	
The calorific value of RDF produced	2.98	kcal/ton
The water content of mixed waste 2:1	42.15	%
Moisture content after drying (25% reduction in moisture content)	17.15	%
Passive waste is used	167	ton/day
Active waste used	83	ton/day
Mining process duration (asset time)	30	years

buildings are established to support the operation of the RDF plant, including offices, control rooms, and clean water facilities.

Environmental Aspects

Based on the environmental risk index value (integrated risk-based approach), the Jatibarang landfill is classified as a moderate hazard evaluation, where it is possible to be mined. The methane gas content of passive zones one and two are being extracted and used for electricity. After the extraction is complete, the waste decomposition process in the landfill will stop, and it can be mined. The results of passive waste mining are recommended to be used as compost, cover soil for landfill operations, or processed into fuel or RDF. If the waste is used as RDF with a capacity of 250 tons per day, as much as 167 tons of passive waste will be mined every day and run out for 30 years. After its completion, zones one and two of the Jatibarang landfill can be reused as new zones. Beyond waste from the passive zone, the composition of the Jatibarang landfill RDF uses a mixture of waste that goes to the landfill. The amount of incoming waste used is 83 tons per day. This means that RDF production can reduce the amount of waste that goes into landfills by 30,300 tons per year.

The sustainability of RDF production can be ensured by gradually using passive waste from other zones. Plastic, one of RDF's compositions, harms the environment because one of the constituent elements of plastic is chlorine [14]. Chlorine burning at imperfect temperatures (less than 800) will produce dioxin compounds [15]. Because RDF must pass through complete combustion, it is not recommended for the home industry. The target market for the Jatibarang landfill RDF is directed to the cement industry. In the cement kiln, combustion occurs at a very high flame temperature of about 1.450 and has a relatively long residence time. This condition is favorable for the use of RDF in the cement industry [16].

Financial Aspects

On the feasibility of the financial aspect in RDF development, financial projections are carried out for the next 30 years with supporting data in the form of the rupiah exchange rate, tax rates, basic credit interest rates, fuel prices increases, electricity cost increases, and data on the effect of the rainy season on production. According to Reza et al., financial analysis is fundamental for assessing economic performance to avoid the associated uncertainty [17]. Additionally, NPV can be adopted to understand the financial feasibility of the project [17]. The recapitulation of the supporting data for the financial analysis of the Jatibarang RDF plant can be seen in Table 6.

Table 6. Recapitulation of supporting data for financial analysis of the Jatibarang RDF plant.

Component	Quantity
Operational capacity	250 ton/day
Capital	100%
Operational day	365 day
- Rainy season	275 day
- Dry season	90 day
Operating hours	8 hours
Land rental fee (R.P./Year)	580,000,000
Rupiah exchange rate	14.086
Business entity tax	25%
Basic Loan Interest Rate (SBDK)	10%
Increase in electricity costs	0.10%
Increase in solar costs	7.60%
Employee salary increase **	2%

Source: *Semarang City government land rental fees follow the costs incurred by PT. Narpati,
**Ummatin et al., 2019

Table 7. Investment cost recapitulation.

No	Job Description	Total Fee
1.	RDF plant Jatibarang complex building	IDR 6,978,747,593
2.	Procurement of goods	IDR 6,978,747,593
Total		IDR 12,376,244,232
Rounding off		IDR 12,376,245,000
VAT 10%		IDR 1,237,624,500
Total		IDR 13,613,869,500

Table 8. Financial feasibility analysis indicator.

Indicator	Calculation Result	Indicator
NPV	IDR 225,965,118.970	NPV > 0 (decent)
PP (Year)	6	< asset life (received)
IRR	24 %	> discounted rate set at 2% (decent)

Investment Cost

Investment costs incurred in the construction of the Jatibarang RDF plant are for the main building of the RDF complex and office, RDF production (excavator, bulldozer, forklift, dump truck, trommel, belt conveyor, bend belt conveyor, ballistic separator, magnetic separator, shredder, rotary dryer, automatic horizontal bale, residue box, transformer and generator set), and supporting facilities. The total investment cost for the construction of the Jatibarang RDF plant refers to the Regulation of the Mayor of Semarang Number 35 of 2019, as shown in Table 7. This is in the scenario of 80% own capital and 20% loan.

A large loan was obtained of Rp. 2,722,773,900 with five-year installments and a 10% interest [18] with the net profit obtained after the loan period expires IDR 12,703,795,674.

Investment Feasibility Indicators for the Jatibarang RDF Plant

The investment feasibility indicators used for this feasibility study are NPV (net present value), PP (payback period), and IRR (internal rate of return). The results of the recapitulation of each financial feasibility analysis indicator are shown in Table 8.

NPV is the net profit that will be obtained in the future. The resulting NPV value is >0. Therefore, the project is feasible to run. The payback period is an indicator of the investment feasibility concerning the payback period of the Jatibarang RDF plant, which is six years. This project is feasible because the payback period is less than the asset's lifetime. IRR is the profit used to pay off the amount of money borrowed. The IRR value of the Jatibarang RDF plant is 24%, where the value is greater than the discounted rate so that the project is feasible to run. Based on the results of the calculations of each investment feasibility indicator, the RDF plant project is feasible to run.

Sensitivity Analysis

Sensitivity analysis is applied to assess the project's feasibility due to changes that affect the planned project. According to Esguerra, the factor-based method with the development of exploratory scenarios and global sensitivity analysis is presented as an approach to conduct generic and learning-oriented studies [19]. A recapitulation of the sensitivity analysis of the Jatibarang RDF plant is presented in Table 9.

Table 9 shows that if the interest rate increases, it will affect the NPV value obtained. However, in this condition, the project is still feasible to run. If the proportion of the cost sources is changed, it will affect the NPV, the cost recovery duration, and the IRR, but the condition is still feasible. In scenario three,

Table 9. Sensitivity analysis of the Jatibarang RDF plant.

	Initial Condition	Scenario 1	Scenario 2	Scenario 3
Investment	IDR 13,613,869,500	IDR 13,613,869,500	IDR 13,613,869,500	IDR 13,613,869,500
Proportion of cost source	80% Own Capital	80% Own Capital	60% Own Capital	60% Own Capital
	20% Loan	20% Loan	40% Loan	40% Loan
Basic Loan Interest Rate (SBDK)	10%	12%	10%	12%
Eligibility Indicator				
NPV (IDR)	IDR 225,965,118,970	IDR 225,966,372,080	IDR 223,368,183,614	IDR 223,368,183,614
PP (years)	6	6	7	7
IRR	24%	24%	22%	22%
Eligibility	Decent	Decent	Decent	Decent

if the proportion of cost sources is changed and the interest is also changed, the NPV, the duration of cost recovery, and IRR are affected. However, the project condition is still feasible to run. Therefore, it can be concluded that financial changes are influenced by the proportion of cost sources and the basic loan interest rate. The results of this study can complement the shortcomings of research that Hutabarat and Nurhadi have carried out concerning how the RDF plant is feasible to be implemented at the Jatibarang TPA from technical, environmental, and financial aspects [7, 8].

Conclusions

Based on the description above, it can be concluded that the RDF plant at the Jatibarang is feasible to run from the technical, environmental, and financial aspects. It is planned to process 250 tons of waste/day and produce 75 tons of RDF/day from the technical aspect. RDF is produced by mixing passive and active waste with a ratio of 2:1 and produces a calorific value of 2,980 kcal/kg. Meanwhile, from the environmental aspect, it is concluded that processing waste into RDF with a capacity of 250 tons per day consisting of passive zone waste and active waste can rehabilitate the passive zone after 30 years of mining and reduce waste that goes to the landfill by 30.300 tons per year. The negative impact of RDF on the environment is the dioxin from plastic waste formed during incomplete combustion with a temperature of less than 800. Therefore, the target market for RDF in this feasibility study is aimed at the cement industry, where the combustion process in cement kilns occurs at a temperature of around 1,450. From the financial aspect, it was found that the implementation of the Jatibarang RDF plant with an economic value of 30 years of investment and an interest rate of 10%, the average net profit obtained after the loan period expired was Rp. 12,703,795,674, with an NPV of Rp. 225,965,118,970, the payback period for six years, and an IRR value of 24%. The sensitivity analysis found that financial feasibility is affected by the proportion of cost sources and the basic loan interest rate.

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Conflict of Interest

The authors declare no conflict of interest.

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