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Techno-Economic Analysis of Biogas Production from Cow Manure

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ABSTRACT

Biogas has been considered as a renewable alternative energy produced by anaerobic digestion of cow manure. A process of anaerobic digestion of cow manure was simulated by Aspen Plus software to analyze the cost of production. The simulated project used cow manure wastes as a feedstock. From the study, economic analysis includes Net Present Value (NPV), Internal Rate of Return (IRR), Payback period (PBP), and B/C Ratio. The resulting BEP value is 539.20, the NPV is 6,414,566,421.98, the IRR is 249.84%, and the B/C ratio is 1.66. These values can be said that the business of cow dung which is processed into biogas is feasible to run.

***Keywords*:** Aspen, biogas, cow dung, energy, techno-economic analysis.

1. INTRODUCTION

Energy demand continues to increase with global population growth and increasing urbanization causing an increase in energy demand and the use of fossil energy which results in increased pollution throughout the world. One option that has been widely used and has been widely used is the production of biogas from waste rich in organic matter through the process of anaerobic digestion [1–6]. Biogas is the main energy source derived from biomass [7]. Previous studies have proven that biogas can have a significant effect on reducing global warming [8,9]. Waste can be used as a good energy source and can prevent the accumulation of waste. The amount of waste that increases every day can help to meet energy needs. Many countries have switched to using renewable energy [10,11]. Biogas renewable energy can be produced from organic materials with a biological process, namely anaerobic digestion. Another way to produce biogas is to use residue from the sugar-ethanol industry [12,13]. Organic waste in rural areas focuses on in-situ treatment such as cow manure and pig manure. The amount of food waste carbon annually contributes to greenhouse gas emissions by accumulating around 3.3 billion tons of CO_2 into the atmosphere. Anaerobic digestion can be made the right choice for effective organic waste management by the action of microorganisms originating from the rumen to lead to a circular economy. This will foster a transition from dependence on fossil fuels to sustainable energy production. Anaerobic digestion involves four stages, namely hydrolysis, acidogenesis, acetogenesis, and methanogenesis. The methane content and energy of the produced gas vary and depend on the physical and chemical properties of the substrate used. The biogas industry is identified as being able to address nine of the seventeen sustainable development goals (SDGs) [2,3,12].

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The hydrolysis stage of complex organic molecules is converted into monomer compounds by hydrolyzing bacteria, and the insoluble particles turn into water. During the hydrolysis stage of carbohydrates, lipids, proteins, lignin, and inorganic materials break down into simple molecules. The acidogenesis or fermentation stage, after the fermentation process, the primary molecules will become monomer compounds. Monomer compounds will turn into short chains. All the products produced will be left to the methanogenic bacteria. The acetogenic stage of the substrate decomposes and is converted into CO_2, H_2, and acetate by acetogenic bacteria. This stage will release hydrogen which has a toxic effect on this process. The last stage is the methanogenesis stage, at this stage methanogens produce methane by utilizing the previous products (CO_2, H_2, and acetate).

Table 1. Summary of biogas economic analysis

Feedstocks	Methods	Results	Ref.
Fruit and vegetable wastes	Anaerobic digestion by	• Total capital investment in excess of RM25 million • profit margin of 11 % • ROI 12 % • Payback time 8.2 years	[14]
Cow Manure	Mono-digestion	• NPV -5.54 Million MYR • ROI -1%	[15]
Cow Manure	Co-digestion	• NPV -2.90 Million MYR • ROI 3% • IRR -6%	[16]

Table 1 shows a summary of the economic analysis of biogas production using fruit or vegetable waste and cow manure as raw materials through various methods, including anaerobic digestion, mono-digestion, and co-digestion. Methane production process takes time with methanogenic bacteria within 3-50 days [17–20]. The purpose of this article is to determine the techno-economic feasibility of the proposed biogas. Techno-economic analysis is used to compare different process design methods, to find the main bottlenecks of the process, to direct research studies to avoid these bottlenecks, and to estimate the minimum cost involved [21].

2. RESEARCH METHODS

2.1. PROCESS OVERVIEW

Indonesia has a population of nearly 223 million with a growth rate of around 1.01%/year, which is a potential for livestock market products. Judging from the existing potential, the Indonesian people have opened more livestock businesses which are also considered to be more promising. The development of the livestock industry has good prospects especially by utilizing existing natural resources. Land use is also one of the most important aspects of the livestock industry. The potential of land in Indonesia that has not been utilized is 32 million ha, 5.40 million ha of yards, and 11.50 ha of abandoned land [22]. One of the by-products of the livestock industry is livestock waste. Utilization of waste disposal so far has not been carried out properly by livestock industry owners. Waste in the form of leftover feed, urine and faeces is thrown into the river or left to accumulate. Even though most of the waste disposal is organic material, its utilization must be processed first so that it can be used again. One of the products from the utilization of livestock waste disposal is biogas from cow manure [23].

Table 2. Manures and gas product amount [24]

Type	Produce Gas/kg (m^3)
Human	0.020 – 0.028
Cow	0.023 – 0.040
Pig	0.040 – 0.059
Chicken	0.065 – 0.028

Each biogas production process from various raw materials such as human, cow, pig, and chicken waste produces different amounts of gas as shown in Table 2. The process of making biogas from cow dung includes anaerobic digestion and purification. The type of raw material and composition of cow dung has a significant impact on the design and economic value of the biogas production process. Nutrients are the most important thing in the content of cow dung because it can be reused as manure [2,3,25]. Cow dung contains 27.2% carbon dioxide, resulting in the highest biogas production with a methane content of 67.9% [26]. Cow manure contains 18.6% hemicellulose, 17% cellulose, 20.2% lignin, 1.67% nitrogen, 1.11% phosphate, and 0.56% potassium. The C/N ratio in cow dung is 16.6-25% with a C/N ratio range between 25-30 which is the optimum condition for the anaerobic decomposition process. If the C/N ratio is too high, nitrogen is very quickly consumed for protein needs by methanogenic bacteria and can no longer react with the remaining carbon which can affect low gas production. If the C/N ratio is too low, nitrogen can be free and gather in the form of NH_4OH [27].

If data is given in % form, the component composition is calculated to allow the simulation to be carried out on a kg/h basis. Table 3 shows the data used in the simulator. For hemicellulose, xylan, and arabinan both share the same stoichiometry therefore the mass composition is summed for use in the simulator. In order to be able to carry out the simulation the data source on cow manure was collected from previous literature (Food and Agriculture Organization of the United Nations) and is shown in Table 3.

The raw material for making biogas is pure cow manure in Indonesia. Mass and energy balances were estimated using Aspen Plus software. Then for the main equipment of the designed process and economic parameters also obtained through the Aspen Plus software.

Table 3. Content of cow manure [28]

Components	% in cow manure
Total solid	25.15
Glucose	19.63
Galactose	4.31
Xylose	5.41
Arabinosa	2.22
Sucrose	-
Asetic acid	-
Cellulose	17
Glucan	-
Galactan	-
Pectin	-
Hemicellulose	22
Xilan	-
Arabinan	-
Peptide	13.37

2.2. PROCESS SIMULATION

Experiments conducted at Aspen Plus used cow dung and water in a 1:1 ratio. There are 3 stages carried out namely mixing, fermentation, and separation. This aspen experiment is intended to determine the feasibility of small-scale biogas production.

The process simulation stages at Aspen Plus are shown in Figure 1. The expected output is pure methane as biogas. In addition, there are also solutes that are produced as fertilizer. Input and output components can be seen in Table 4 and Table 5. The main assumptions of this model are:

1. The process is operated in a continuous mode without any consideration of increase or decrease in performance
2. The components of cow dung will be fermented into methane gas for biogas
3. Components can be divided into 2 namely solids and gases
4. Equipment heat dissipation is neglected.

Table 4. Input components

Input components	Units (%)
Total solids	25.15
Glucose	19.63
Galactose	4.31
Xylose	5.41
Arabinose	2.22
Sucrose	-
Acetic acid	-
Amino acid	6
Peptide	13.37
Cellulose	17
Hemicelulose	22
Water	-
Hydrogen sulfide	-
Methane	-
Carbon dioxide	-
Ammonia	-

Table 5. Output components

Output components	Units (ton/h)
Amino acid	0.0000125
Peptide	0.0002421
Water	00115937
Methane	0.0051510
Carbon dioxide	0.0141302
Ammonia	0

Processing cow dung into biogas has several process stages, including anaerobic digestion and purification. The anaerobic digestion (AD) process is an alternative way of treating waste that is sustainable and has a complex processing process. AD changes the overall wet biomass of certain components biochemically. The general biochemical steps in the AD process include: (1) hydrolysis: the breakdown of macromolecules such as proteins, lipids, polysaccharides into simpler compounds such as amino acids, sugars, fatty acids and glycerol; (2) acidogenesis and acetogenesis: hydrolyzed molecules are converted into volatile fatty acids, especially acetate, hydrogen, and carbon dioxide; (3) methanogenesis: production of methane from acetate, hydrogen and carbon dioxide.

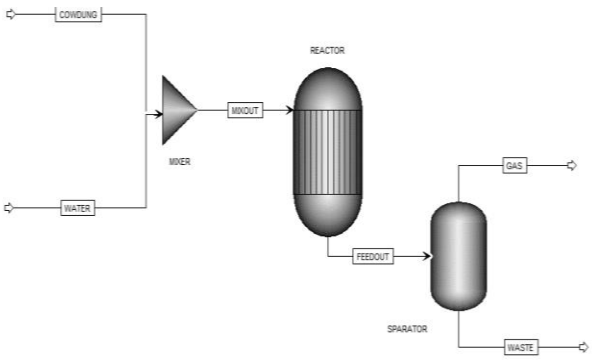

Figure 1. Process simulation using Aspen-Plus

The hydrolysis step plays an important role in determining the success of methane production. AD technology has been recognized as a powerful technology for converting biomass into bioenergy [29]. The AD process depends on interactions between microorganisms capable of carrying out all four stages. In a single stage batch reactor, all the waste is loaded simultaneously, and all four processes occur sequentially, whereby all the wastes are loaded together. Then the compost is emptied after the expiration of a certain retention period or the discontinuation of the biogas product.

The hydrolysis stage is the decomposition of soluble organic matter and the digestion of complex organic matter into simple ones. In this process, hydrolytic bacteria are capable of secreting extracellular enzymes that can convert carbohydrates, lipids, and proteins into sugars, long chain fatty acids (LCFA), and amino acids. After enzymatic cleavage, the products of hydrolysis can diffuse through the cell membrane of acidogenic microorganism [30]. However, for certain substrates such as lignin, cellulose, and hemicellulose, it will be difficult to degrade and cannot be accessed by microbes because of their complex structure, so enzymes are often added to increase the hydrolysis of these carbohydrates. In general, hydrolysis itself has an optimal temperature between 30-50◦C and an optimum pH of 5-7 [31,32]. Hydrolysis of cellulose $(C_6H_{10}O_5)$ through the addition of water H_2O to form glucose $C_6H_{12}O_6$ as the main product and release H_2.

The reaction is catalyzed by homogeneous or heterogeneous acids to produce a very useful fermentable monosaccharide, namely glucose ($C_6H_{12}O_6$) [33,34].

Acidogenesis is the fermentation stage, in which the soluble compounds formed during the hydrolysis stage are degraded and converted into CO_2 and H_2 through bacteria known as acidogenic bacteria (fermentative microorganisms). The acid used is acetic acid (CH_3COOH) because it is the most significant organic acid as a substrate for H_2-forming microorganisms. Acidogenic microorganisms are capable of producing intermediate volatile fats (VFA) by absorbing hydrolysis products through their cell membranes. The specific concentration of the intermediate produced at the acidogenesis stage depends on the conditions of the digester, where the VFA concentration can fluctuate significantly for digesters operating at different pH [33].

The acetogenesis waste product in H_2 gas is formed in the acidogenic stage of the AD process so this stage is also known as the dehydrogenation stage. This is because the metabolism of acetogenic bacteria is inhibited by the H_2 gas produced. Bacteria such as Methanobacterium suboxylans and Methanobacterium propisim are actually responsible for the decomposition of the acid phase products into acetate CH_3COO^- and H_2 which are released in the reaction showing toxic effects on microorganisms carrying out the process of acetogenesis.

Methanogenesis marks the final stage of anaerobic digestion, in which accessible intermediates are consumed by methanogenic microorganisms to produce methane. Methane-producing bacteria can be divided into two groups: acetophilic and hydrogenophilic; the first is in the production of CH_4 by acetate decarboxylation while the second is in the production of CH_4 by reduction of H_2/CO_2 There are six main pathways in the methanogenesis stage [33].

The purification process is a process of minimizing the content of elements in biogas that are deemed unnecessary or even detrimental when biogas is used as fuel [35]. Generally, the purification process in biogas is to reduce the content in the elements carbon dioxide (CO_2), hydrogen sulfide (H_2S), and hydroxide (H_2O) to improve the quality of the biogas produced. Gas purification or purification can be carried out by absorption technique using water, NaOH solution, and zeolite/silica gel [36]. One method of purifying biogas can be done with a water scrubber system which aims to reduce H_2S levels and reduce particulate matter contained in biogas. The purification method with a wet scrubber can be carried out because H_2S has a high solubility of 3.5 g of gas per kg of water at room temperature, while the solubility of CH_4 by water is very low, which is around 0.02 g of gas per kg of water at room temperature [37].

The proposed types of adsorbents used are zeolite and activated charcoal, where zeolite is hydrophilic and polar which is able to bind oxygen, while activated charcoal is hydrophobic and nonpolar which is able to bind carbon. Selection of the type of adsorbent is important in the adsorption process. The most frequently used adsorbent is activated carbon because it has a large surface area so that its adsorption power is greater than other adsorbents [38]. Several studies have been carried out on gas purification such as those carried out [38] researching the biogas purification process using activated carbon and the use of CO_2 scrubbers can improve the quality and quantity of biogas. The addition of activated carbon in the raw material, namely in the form of cow dung, functions to increase the C/N ratio, which can improve the anaerobic digestion process and obtain optimum conditions for producing methane gas. In the research conducted by Li *et al.* [39], testing the optimization of the methane content of cow dung biogas using various types of adsorbents.

Methane content testing was carried out to determine the effect of various adsorbents used on changes in methane content as measured using Gas Chromatography. The adsorbent and natural zeolite used are varied so that the optimum ratio can be identified. From the results of the gas testing shown in Table 6 using gas chromatography it can be seen that passing or interacting with the biogas with the adsorbent will cause the methane content to tend to increase and the carbon dioxide content to decrease. This is in accordance with the properties of charcoal which is able to bind carbon dioxide in biogas [40].

Table 6. Methane and carbon dioxide content

Adsorbent type	Content of Methane (CH_4) (ppm)	Carbon dioxide (CO_2) content (ppm)
Without adsorbent	9808.56	64470.54
Activated Charcoal: Natural Zeolite (30:70)	61735.80	1551.65
Activated Charcoal: Natural Zeolite (50:50)	89590.40	6283.32
Activated Charcoal: Natural Zeolite (70:30)	36594.39	819.355

3. RESULTS AND DISCUSSION

3.1. ANAEROBIC PARAMETERS

Process parameters greatly affect the quality and quantity of biogas production. Several important parameters of the Anaerobic Digestion (AD) process with growth kinetics and environmental factors that must be controlled to optimize the process. These parameters include pH, temperature, Hydraulic Retention Time (HRT), and carbon-nitrogen ratio (C/N) along with their broad description.

a. pH

pH greatly affects the function of microorganisms, if the pH is too low then methanogens cannot convert acid into methane. Methanogens are very sensitive to changes in pH and are generally optimal at a pH close to 7. A pH below 6.3 or above 7.8 can adversely affect methanogenesis with a tendency for process failure. However, unlike methanogenesis, other process steps such as hydrolysis and acidogenesis are capable of optimizing between pH 5.5 - 6.5 [41].

b. Temperature

Temperature is another limiting parameter for biohythane synthesis. The microorganisms responsible for the production of hydrogen and methane are present over a different temperature range including psychrophilic (0-20°C), mesophilic (20-42°C), and thermophilic (42-75°C) and the selection of microorganisms also determines the operating temperature of reactor [42]. Large-scale processes are generally designed to operate at mesophilic or thermophilic temperatures with a constant operating temperature achieved by insulation and heat transfer [43].

c. Hydraulic Retention Time (HRT)

Hydraulic Retention Time (HRT) is defined as the ratio between reactor volume and feed flow rate, representing the average time the cell and substrate are in the reactor [44]. Hydraulic Retention Time (HRT) is a very important parameter for the production of hydrogen and methane in continuous mode. This parameter is related to the specific and different growth rates of hydrogen and methane producing bacteria. When the Hydraulic Retention Time (HRT) is low, it supports the breakdown of methanogens, and guarantees survival of hydrogen producers. Thus a low Hydraulic Retention Time (HRT) and slightly acidic pH (6.0-6.5) is the best condition for hydrogen production. Meanwhile, an increase in Hydraulic Retention Time (HRT) means that the pattern of hydrogen fermentation can change to be methanogenic [42].

d. Ratio of C/N

The C/N ratio represents the amount of carbon and nitrogen in the feedstock and is an important process parameter for high solids AD. Carbon and nitrogen are essential for the growth and function of microbial cells. Nitrogen present in raw materials facilitates the synthesis of amino acids, proteins and nucleic acids, while carbon acts as a structural unit as well as a source of energy for microbes. Proper C/N ratios in the digester can be achieved by digesting carbon-rich raw materials, such as crop residues, and nitrogen-rich feedstocks such as animal manure, urine, and abattoir waste [2].

Techno-Economic Analysis (TEA) is principally a cost-benefit comparison of various alternative techniques. TEA is usually based on process specifications, material and energy requirements, equipment, services, prices, production and investment costs [45]. Economic analysis determines the economic feasibility of an industry. Economic feasibility is an important factor for the final decision whether it can be implemented or not. Economic analysis is carried out using a discounted cash flow (DCF) approach in which projected future cash flows are discounted along with the net present value (NPV) or available value. The analysis investigates the impact of various gas prices on project viability to provide investment guidance with typical factors for estimating the cost of fixed capital as shown in Table 7 [46].

Table 7. Typical factors for estimating the cost of fixed capital

Factor	Value
Piping	0.30
Instrumentation	0.15
Electrical	0.10
Dev. Process	0.10
Storage	0.10
Contractor	0.05
	Not needed for small factories
Contingencies	0.05

Process simulators such as Aspen Plus enable evaluation of the entire process chain based on plant upgrades, advanced technology, and price quotes. Target cost is a market-oriented method, which means a target selling price is set for cost evaluation based on market value and people's needs. The target price for the final product cost of each step of the supply process will be estimated with an allowance for costs, which is key in process design. Target costs can be integrated with value engineering in cost management activities, so that cost allowances and cost targets can be reconciled [47]. Aspen Plus is a chemical process simulator that includes unit operations for building process models to simulate complex calculations for integrated batch and continuous processes [1].

The goal of investing in any project is to get a profit in return. Thus, several key economic parameters are applied to measure the economic attractiveness of a project at the initial stage. These parameters include Net Present Value (NPV), Internal Rate of Return (IRR), Break Event Point (BEP), and Net Benefit Cost Ratio (Net B/C) [48].

a. *Net Present Value* (NPV)

NPV provides the cumulative net cash flow of a project calculated over the life of the project which can be a future value. It measures the project's revenue after paying back the total initial capital investment, NPV > 0 and NPV < 0 respectively denote profit and loss

b. *Internal Rate of Return* (IRR)

The IRR is the discount rate that will make the NPV zero at the end of the project's operational period. This can measure the maximum interest rate that the project will sustain in order to reach the break even point.

c. *Break Event Point* (BEP)

Break Even Point (BEP) is an analysis carried out to find the amount of goods or services that must be sold to consumers to cover costs incurred and get a profit/at a certain price.

d. *Net Benefit Cost Ratio* (Net B/C)

Net B/C is the ratio between the positive NPV and negative NPV. This Net B/C shows an illustration of how many times the benefits will be obtained from the costs incurred.

A business is feasible to run if the NPV value is > 0, meaning that it is financially feasible to run the business because the benefits are greater than the costs. If the NPV < 0 the benefits obtained are smaller than the costs incurred. The value of the Net benefit Cost Ratio (Net B/C) must be > 1 so that the business is feasible. If the BEP value < selling price, then the business is profitable and can be run. If the IRR is greater than the prevailing bank interest rate, the business is feasible, and vice versa, if the IRR is less than the applicable interest rate, the business is not feasible. Net benefit is the result of sales minus expenses. The NPV value is known by multiplying the Net Benefit value by the annual deficit. So that these values are obtained for BEP, IRR, total NPV, and Net benefit Cost Ratio (Net B/C) to determine whether this business is feasible or not [49] .

Table 8 shows the cash flow analysis of the biogas business from cow dung. Biogas sales are assumed to be IDR 4,680,000,000.00 per year. Tools and machines were obtained from Aspen Plus in the amount of IDR 691,953,215.00 and facilities were assumed to be IDR 100,000.00 per year, so the total investment was IDR 692,953,215.00. Operational costs are IDR 2,609,477,366.00, variable costs are IDR 2,600,243,066.00 and fixed costs are assumed to be IDR 9,234,300.00. From the cash flow analysis, the Net benefit, PV, and NPV values are obtained in the analysis of Table 9.

The results of the analysis include Net Present Value (NPV), Internal Rate of Return (IRR), Payback Period (PBP), and B/C Ratio. The resulting BEP value is 539.20, the NPV is 6,414,566,421.98, the IRR is 249.84%, and the B/C ratio is 1.66. This result is linear with a similar study conducted by Imeni *et al.* [50], states that the value of NPV> 0, IRR> 9%, and ROI 11 years. Similar research was also conducted by Tan *et al.* [51], which states that biogas with a closed digestate storage integration system has a good environmental impact and is economical, with a value of MYR 1.28 million NPV, 14% IRR, and 15% ROI, and a payback period of 6.56 years with an OPEX of MYR 3491, 82/MWh. So that these values can be said that the business of cow dung which is processed into biogas is feasible to run.

Table 8. Cash flow analysis

Parameter	Y-0	Y-1	Y-2	Y-3	Y-4	Y-5
Selling						
Biogas		4,680,000,000	4,680,000,500	4,680,001,000	4,680,001,500	4,680,002,000
Total Selling		4,680,000,000	4,680,000,500	4,680,001,000	4,680,001,000	4,680,001,000
Investment						
Tools and Machines	691,953,215					
facilities	100,000					
Total Investment	692,053,215					
Operating costs		2,609,477,366	2,609,477,366	2,609,477,366	2,609,477,366	2,609,477,366
Fixed cost		9,234,300	9,234,300	9,234,300	9,234,300	9,234,300
Variable costs		2,600,243,066	2,600,243,566	2,600,244,066	2,600,244,566	2,600,245,066
Surplus (Deficit)	-692,053,215	2,070,522,634	2,070,523,134	2,070,523,634	2,070,523,634	2,070,523,634

Table 9. Analysis for the feasibility study

Year	Net Benefit	NPV	PV (B)	PV (C)
0	(692,053,215.00)	(692,053,215.00)	-	692,053,215.00
1	2,070,040,739.00	1,815,825,209.65	4,105,263,157.89	2,289,437,948.25
2	2,070,041,239.00	1,592,829,516.00	3,601,108,417.97	2,008,278,901.97
3	2,070,041,739.00	1,397,219,211.17	3,158,867,370.80	1,761,648,159.62
4	2,070,041,739.00	1,225,630,886.99	2,770,936,290.17	1,545,305,403.18
5	2,070,041,739.00	1,075,114,813.15	2,430,645,868.57	1,355,531,055.42
Total	9,658,153,980	6,414,566,422	16,066,821,105	9,652,254,683

4. CONCLUSION

This article discusses the utilization of cow dung using the Aspen-Plus simulation for biogas production on an industrial scale. The method used for biogas production is Anaerobic Digestion (AD) because it can increase the quality and quantity of biogas. This is influenced by parameters which include pH, temperature, Hydraulic Retention Time (HRT), and carbon-nitrogen ratio (C/N). Process economics can be performed using Aspen Plus for evaluation of the entire process chain based on plant upgrades, state-of-the-art technology, and price quotes. Economic analysis determines the economic feasibility of an industry. These feasibility parameters include Net Present Value (NPV), Internal Rate of Return (IRR), Payback period (PBP), and B/C Ratio. The resulting BEP value is 539.20, the NPV is 6,414,566,421.98, the IRR is 249.84%, and the B/C ratio is 1.66. These values can be said that the business of cow dung which is processed into biogas is feasible to run.

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