



Energy Performance Indicator of a Gold Mining Industry in Indonesia

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ABSTRACT– Energy Audit follows ISO 50002 standard had been done on one of gold mining industry in North Maluku, Indonesia that has operations involving two underground mining. As part of the energy audit report, this paper present energy sources and energy consumption, specific energy consumption cum energy intensity of the plant. Energy audit methods include energy audit planning, opening meeting, data collection, measurement plant, siti visit, data analysis, energy audit reporting and closing audit. Most electricity data were collected from the SCADA system which the company use to monitor and control maximum electricity demand. Arithmetic mean, energy intensity equation and visual graphic methods had been employed to investigate energy profile and energy performance indicator of this gold mining. As the site located far away from the national grid then four Diesel powerhouses generates the electricity. Fuel consumption for four unit mainly electricity generation, transportation, heavy duty and supporting are investigated thoroughly. Since Diesel powerhouse occupy more than 80 % fuel consumption then the Diesel power houses is the Significant energy users (SEU). Further study SEC and on heat rate of the powerhouse is carried out and benchmarked with the IEA. It shows that the powerhouses have excellent performance as SEC and heat rate is lower than typical powerhouses. The powerhouse distributed electricity to four different unit, Kencana Underground Mining, Toguraci underground mining, Mill and Merrill Crowe Processes and Supporting Unit. Among these units, Togurachi under ground mining with its uniqueness become the highest electricity end user as expected. It covers more than 40 % electricity consumption resulting quite high total energy intensity by ore milled which is approximately 475 kWh/ton (1710 MJ/ton) and energy intensity by Dore bullion is 1,420 kWh/ounce (5108 MJ/oz).

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Introduction

Gold is a treasurable metal that used for jewelry, finance and investing, dentistry and medicine, structure ornament, electronic circuits, recognition, etc [1]. In 2023, gold production has overtaken other competitors in the metal category [2]. This is sustained by high geopolitical insecurity, and strong requirement from central banks in their efforts to increase gold reserves. Based on the World Gold Council, central banks of all countries have enhanced around 800 tonnes of gold during 2023, a new record that 14% more than in 2022. Due to the ongoing economic turmoil and Middle East escalation, Black Sea instability and the risk of Russian-style sanctions by US and European hegemony resulting central bank has become an ardent gold buyer. Moreover, the gold price increase sharply since the Covid-19 pandemic a total of 1,136 tonnes purchased in 2022, up from 450 tonnes in 2021 [3], [4].

Meanwhile in Indonesia, according to the Directorate General of Mineral and Coal of the Ministry of Energy and Mineral Resources Republic Indonesia, the realization of

domestic mineral commodity production did not achieve the target in 2023. This happened to the commodities of gold, silver, tin and nickel (matte nickel and ferronickel). Throughout 2023, Indonesia's actual gold production is only 83 tons from the target of 106 tons as it is shown on Figure 1 [5].



Figure 1. Target and realization of Indonesian Mineral Production 2023

The gold mining industry encounter a growing pressure to reduce its energy consumption cum environmental impact. Studies estimate that mineral mining consumes a significant portion of global energy, ranging from 4% to 12 % [6] and for gold mining about 1 % [7]. This high energy demand instigates to substantial greenhouse gas emissions and contributes to climate change. Electricity demand for gold production itself increase due to many factors such as the type of ore, the lower ore head grades, the supply of water to the mines and source of ore [8], [9], [10], [11]. Research of the effect of ore grade decline on energy consumption during the processing of metal has been conveyed using historical data and LCA analyses [12], [13]. In other paper another approach using a computational model was developed with specialized software i.e HSC Chemistry, to analyze the relationship of ore grade declining to energy consumption [14]. It was confirmed that both specific energy and associated environmental impact would have exponential growth as ore grade in the mine decreases.

In recent years, many mining companies have many programs to reduce their specific energy requirements in the ore processing, in that way improving their competitiveness. Some of the programs are complex and involve, for example, the closure of unprofitable mines, technological improvements such as modern grinding processes or improved energy management [9], [15], [16], [17]. Government issued a national policy of energy conservation as the counterpart of the programs to plunge the energy consumption in industrial sector. As a national energy policy, energy conservation programs have strong legal basis mainly the Law of Indonesian Government No. 30/2007 about energy, which then follow up by Government Regulation No. 70/2009 about energy conservation which requires user energy above 6000 TOE to carry out energy conservation program. Furthermore, as a continuation of the government regulation, it has been reintroducing Government Regulation no. 33 /2023 about energy conservation that set the implementation of energy management system for industrial energy users above 4000 TOE [18].

This paper will focus on the energy review particularly the Energy Performance Indicator (EnPI) of gold mining in North Maluku, Indonesia, PT Nusa Halmahera Minerals (NHM) include the energy sources, energy consumption, energy intensity or specific energy consumption of gold production which are the part of energy audit report. An energy audit had been completed. The purpose of energy audit is to identify and analysis the energy production and consumption and to investigate the potential for energy efficiency program. Implementation of those program can hopefully improve the efficiency of energy utilization and finally to increase competitiveness of the gold in the global market. Despite of old mining, this site has two underground mining: Kencana and Toguraci. Operation in Toguraci underground mining required more energy due to the unique condition. There is a natural hot spring water inside and this made Toguraci the only underground mining with hot water sources in the world. These instigate the increase of both energy use and production cost. Meanwhile volatility of oil

price drives the industry to pursue methods to maintain the business cost-effective, therefore all operational aspects are revisited to identify cost saving opportunities. Energy-related cost is recognized as the most significant component of the whole operations. As a result, energy efficiency method in this gold mining is crucial [10], [19].

Energy Performance Indicator for gold mining represent in energy consumption, energy intensity or Specific Energy Consumption (SEC). Energy intensity or SEC is defined as ratio of energy consumption to the mass of product. This term can be used to find out the structural differences between industries and more broadly in national, regional and international level with regard to the performance of energy efficiency [20], [21], [22], [23].

The advantages of introducing energy performance indicator in this case energy intensity or specific energy consumption are:

- Indicators based on physical ratio related to measurement of technical efficiency from an industry so that it can be associated with the performance of the technology. Moreover, it can be used to recognize the potential for increasing efficiency through new technology.
- This indicator does not affect the price or the financial factor of the industry as on indicators that use merely the added value. Therefore, it does not relate to the disruption of economic fluctuations.
- Energy performance on a specific process in an industry can be analyzed separately and the difference in product distribution between countries and time can be calculated more easily. The impact of changes in the product distribution can be considered separately from the increasing efficiency because the driving factor may be changed at any time.

In term of environmental point of view, gold that is produced by mining are perilous for enabling the global transition to low-carbon infrastructure. Without any action, energy use in mining itself tend to become higher in the coming years as the gold demand increases according to the World Gold Council report and attributable to lower ore grade [3], [14]. The report suggests there are technologies that could make a significant difference. For example, it said comminution that include crushing and grinding processes is the single biggest user of energy at mine sites, typically accounting for 25% of mining's final energy consumption. Comminution is a natural target for the most impactful energy savings opportunities [24], [25].

All results of energy audit activities are required for completing the energy review document of energy management system, quality management system and as the basic data for Life Cycle Assessment.

Methods

Energy audit activities were carried out following ISO Standard 50002. Energy audit activities were carried out following ISO Standard 50002. The definition of an energy audit according to PP 33/2023 is the process of evaluating energy utilization and identifying energy saving opportunities and recommendations for increasing efficiency in energy source users and energy users in the context of energy conservation. The results of the energy audit include determining the energy baseline before energy efficiency is carried out; checking and measuring energy efficiency; analyzing energy consumption and costs; calculating detailed and systematic costs to determine the investment value required in implementing energy efficiency projects.

The energy audit flow was begun with the kickoff meeting which was attended by management and staff from the plant engineering. Kick off meeting discussed goals and purpose of energy audit and work plan and implementation of field survey.

Data collection and information such as primary data and secondary data are important activities of field survey. The data and information required for the purposes of analysis to find out the portrait of energy use and energy saving opportunities at PT. NHM. Secondary data were collected from the areas of power generating facility, underground mining, mill production, Dry Stack Tailing (DST) plant and Supporting facility area. Fuel consumption and electricity production in the power plant, electricity consumption in milling unit is extracted from the real time monitoring of the SCADA system. Arithmetic means for every data are carried out and presented in visual graphics. Energy intensities are presented in several ratio which are fuel consumption to ounce of product or Dore Bullion, fuel consumption to ton of ore, electricity consumption to ton of ore, each and in every unit.

A historical approach to the use of energy consumption is carried out to find out the pattern of energy use from a specific period until the last or present condition. It can be seen from the tendency of energy usage either increased or decreased or may have already stabilized. History of energy use is important to control energy use in the future, determine the base line, whenever energy use continues to increase quite significantly. With the base line data, energy use, can be monitored and controlled continuously. The energy consumption data that was obtained and examined is the consumption of energy in the form of bio diesel (B30) consumption and electricity consumption. Total fuel consumption from Januari 2021 to December 2023 were incorporated for determining energy intensity of the company. Fuel consumption of the powerhouses were considered for identifying electricity production of 4 Diesel power plan and its performance in the form of Specific Energy Consumption and heat rate. Finally, the energy intensity of PT NHM is benchmarked to other energy intensity of gold mining around the world.

Results and Discussion

The main energy source of this mining is bio diesel or B30 that used for generating electricity, transportation, heavy equipment and supporting. Monthly fuel consumption on these categories from 2021 to 2023 is presented on Table 1 and the distribution in the percentage of them is shown on Figure 2.

Table 1, Historical data of Fuel Consumption

Category	Bio Diesel (liter)		
	2021	2022	2023
Transportation	492,975	586,360	4,003,421
Heavy Equipment	4,996,275	6,930,901	4,270,265
Supporting	638,869	1,358,674	817,372
Powerhouse	39,425,037	41,832,129	31,244,933
Total	45,553,156	50,708,064	40,335,990

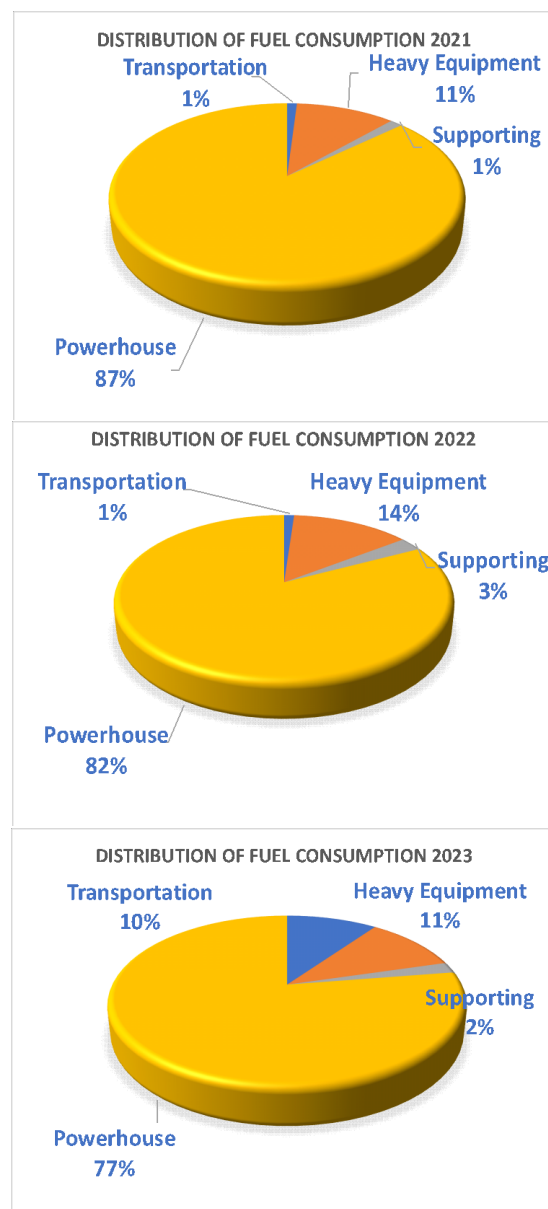


Figure 2. Historical distribution of fuel consumption

Fuel consumption of PT. NHM, especially for power plants, is the largest. Since the source of energy merely from bio diesel and the price of bio diesel is fix then powerhouse can be directly considered as Significant Energy Use (SEU). 2022 is the year with the highest energy consumption as there are many activities for construction to modify the comminution process from fully Merrill Crowe (MCR) process to combination of MCR and Carbon in Leach (CIL) processes. The average biodiesel consumption is 45,532,403 liters or if it is converted into Ton Oil Equivalent (TOE) units is around 32,430 TOE. Based on Government Regulation no. 70 of 2009 which was updated with Government Regulation no. 33/2023, PT. NHM is mandatory to implement energy management system [18].

Energy intensity of the enterprise is calculated based on the ratio of energy consumption to ore milled and Dore bullion production. Table 2 presents the three years historical data of both ore milled and Dore bullion production.

Table 2, Ore Milled and Dore Bullion Production						
Month	Minerals (Ton)			Dore Bullion (Ounces)		
	2021	2022	2023	2021	2022	2023
January	66,445	78,103	83,723	25,021	34,495	27,122
February	59,215	77,356	77,490	21,746	27,972	23,120
March	68,026	83,332	85,092	32,448	32,573	20,916
April	65,255	78,052	66,836	20,412	32,185	16,794
May	72,846	80,193	39,799	23,831	27,239	9,480
June	68,783	76,943	47,467	19,395	26,112	9,300
July	69,497	78,571	27,532	21,343	27,840	6,260
August	68,309	81,989	63,998	19,515	33,612	21,305
September	64,394	82,221	45,350	25,715	36,550	9,050
October	72,302	86,287	61,620	19,379	26,163	21,219
November	67,872	79,401	61,885	22,738	33,963	19,814
December	72,283	82,600	75,798	34,837	32,666	14,618
TOTAL	815,227	965,048	736,590	286,380	371,370	184,184

The average energy intensity by ore milled is 54 liter/ton and the average energy intensity by Dore Bullion production is 162 liter/ounces. Using the assumption that 31.5 MJ/liter is the heating value of Bio diesel and the unit conversion 1 MJ= 0.278 kWh, the energy intensity by ore milled is 475 kWh/ton or minerals or 1,710 MJ/ton and energy intensity by Dore bullion production is 1,420 kWh/oz or 5,108 MJ/oz.

Energy consumption and electricity production from 4 powerhouses will be discussed in detail since powerhouse units considered as SEU. Fuel consumption for powerhouses is presented in Table 3, and Electricity production is presented in Table 4.

Table 3, Historical data of Bio diesel consumption on the powerhouse

Month	Bio diesel (liter)		
	2021	2022	2023
January	3,235,182	3,528,585	3,481,235
February	2,865,220	3,235,121	3,205,304
March	3,255,281	3,542,451	3,613,440
April	3,164,707	3,434,446	2,766,698
May	3,316,917	3,491,557	2,339,272
June	3,217,373	3,482,327	1,821,004
July	3,249,593	3,430,417	1,839,058
August	3,425,211	3,521,151	2,448,584
September	3,296,419	3,568,710	2,059,687
October	3,476,101	3,629,983	2,456,024
November	3,435,852	3,460,268	2,540,471
December	3,487,180	3,507,112	2,674,155
Total	39,425,037	41,832,129	31,244,933

Table 4, Historical data of Electricity Production of the powerhouses

Month	Electricity (kWh)		
	2021	2022	2023
January	12,686,989	13,837,590	13,648,930
February	11,236,157	12,686,750	12,463,717
March	12,765,809	13,891,964	14,012,272
April	12,410,615	13,468,415	10,690,284
May	13,007,518	13,692,380	9,009,415
June	12,617,149	13,656,184	6,966,022
July	12,743,503	13,452,617	7,065,562
August	13,432,201	13,808,434	9,407,313
September	12,927,132	13,994,943	7,879,453
October	13,631,768	14,235,226	9,425,184
November	13,473,930	13,569,680	9,780,953
December	13,675,217	13,753,382	10,332,942
Total	154,607,989	164,047,565	120,682,047

Performance of the powerhouse can be identified from the Specific Fuel consumption (SFC) and the heat rate. SFC defines as the ratio of fuel consumption to electricity production. The average of SFC from all the data point from January 2021 to December 2023 is 0.256 l/kWh. Typical diesel power generator burn fuel at an average 0.263-0.345 liter for 1 kWh electricity production depending on the size, loading condition, fuel grade and other factors [26]. It means all the powerhouses had operated perfectly. Moreover, they have large size and operated on almost full load.

Heat rate of a power plant expresses as the amount of energy used to generate 1 kWh. The US Energy Information Administration (EIA) state heat rates in British Thermal Unit (BTU) per net kWh generated [27]. Table 5 shows the benchmark heat rate of prime mover or powerhouse, and

Figure 3 shows the historical average data of heat rate of the PT NHM power houses.

Prime Mover BTU/kWh	Coal	Petroleum	Natural gas	Nuclear
2007				
Steam Generator	10,158	10,398	10,440	10,489
Gas Turbine		13,217	11,632	
Internal Combustion		10,447	10,175	
Combine Cycle		10,970	7,577	
2008				
Steam Generator		10,356	10,377	10,452
Gas Turbine		13,311	11,576	
Internal Combustion		10,427	9,975	
Combine Cycle		10,985	7,642	

Source: Reproduce from EIA

From January 2021 to December 2022 the heat rate almost constant representing that powerhouse run on full load. Starting January 2023 heat rate increases slightly in the range of maximum 7200 BTU/kWh. The average heat rate is 7,049 BTU/kWh, it is still lower than the EIA benchmark heat rate

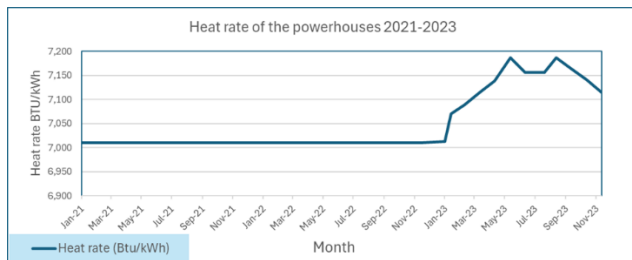


Figure 3. Historical heat rate of PT NHM power houses

(10,427 Btu/kWh). This shows the powerhouse have excellent performance. This can also be seen from the value of specific fuel consumption which is on average lower than others typical diesel generator.

Distribution of electricity production from 4 powerhouses which are, Primary powerhouse, Secondary powerhouse Toguraci powerhouse and rental Agrekko are shown on Figure 4.

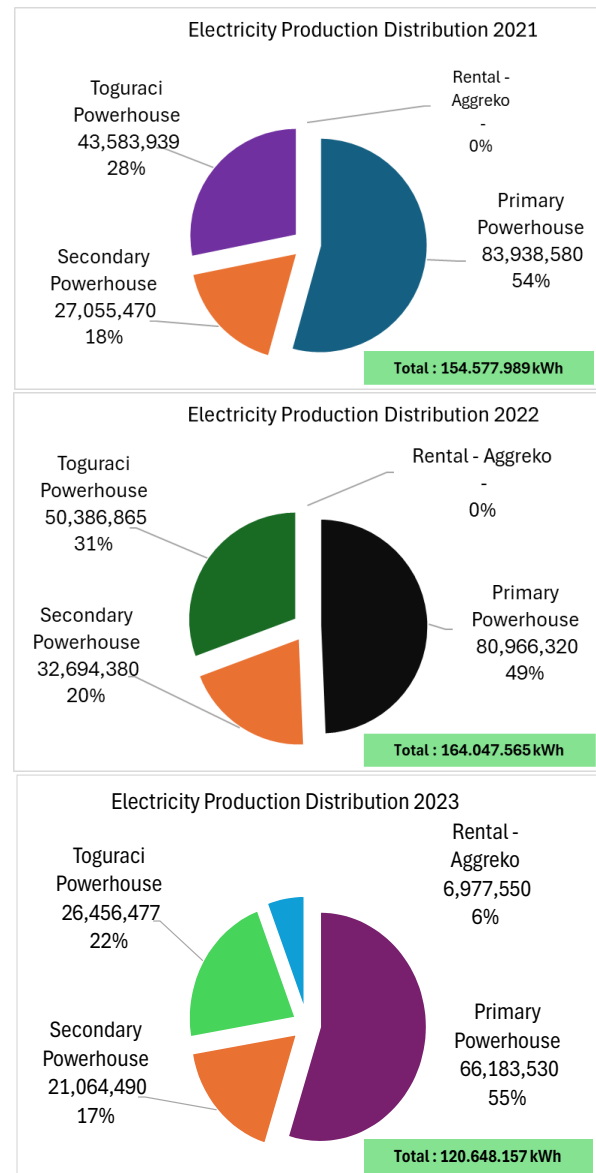


Figure 4. Historical data of electricity production of PT NHM power houses

Primary powerhouse contributes electricity the most then it is considered as SEU. Further investigation for primary powerhouse can be done in the future.

Electricity was distributed to 4 main division include: Kencana underground mine, Toguraci underground mine, MCR Process and Flight and Camp. Historical data of electricity consumption distribution presents in Figure 5. Among the four locations, Toguraci underground mine as expected is the largest electricity consumer. The uniqueness of this mine is incomparable therefore benchmarking to others site seem imbalanced. The best way to justify is comparing the common unit or equipment for example the comminution process, etc.

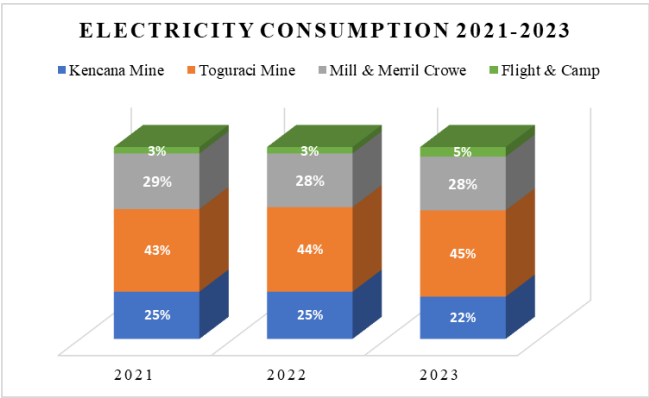


Figure 5. Historical data of Electricity Consumption Distribution

The total fuel consumption and the actual consumption electricity can be used to calculate the energy intensity for the company and for production processes, respectively. However, the available data for this comparison is limited. Mostly energy intensity is expressed in the unit of total energy consumed to ore milled or product. Figure 6 presents the total energy intensity by ore milled of PT NHM and energy intensity some other gold mining in other part of the world that were collected from their Environment, Social and Government (ESG) report [28], [29], [30], [31], [32]. It shows that PT NHM in the position of very high energy consumption even though the powerhouses have very outstanding performance. The main reason is the distinctiveness of Toguraci underground mine that consume bigger energy due to the availability of hot water.

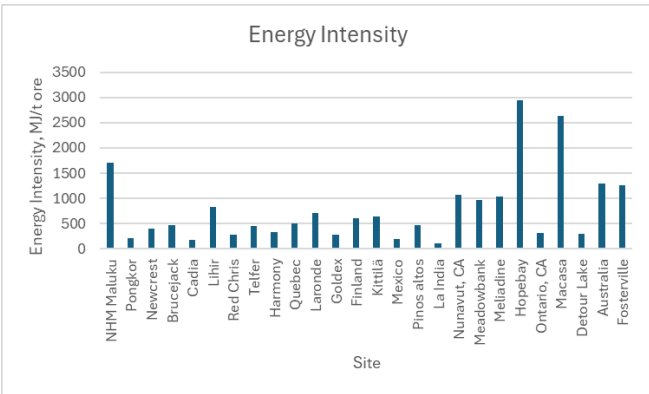


Figure 6. Benchmark of Energy Intensity

Conclusion

Energy performance indicator on the production of Dore bullion had been presented incorporating fuel consumption, electricity production and consumption, specific energy consumption, and energy intensity. Powerhouses consume bio diesel the most among transportation, heavy equipment and supporting unit in the range of 80 %. Primary powerhouse is the main electricity producer and Toguraci underground mining is the main electricity consumer about 45 %. Powerhouses operated extraordinary as the heat rate and the specific fuel consumption is lower than any typical power generator. However total energy intensity by ore milled is

very high. Toguraci underground mining exclusivity contribute to this condition. As part of the energy audit report the result of this paper is beneficial for preparing document of energy management system, environmental management system, quality management system and LCA.

Many significant opportunities identified on the energy audit report for reducing mining’s energy consumption include optimization, big data and artificial intelligence. In addition, if zero emissions energy sources are deployed for mining equipment e.g., renewable energy, energy storage and alternative fuels particularly empowering the hot spring inside Toguraci underground mining then the industry may well be able to achieve zero emissions, leaving a relatively small role for offsets and carbon credits to play.

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