Evaluation of Performance Metrics: A Comparative Study of Egbin and Afam IV Power Plants in Nigeria's Energy Sector

Ekeriance, D.E., Ukpaka, C. P, * Aferonkhai, J. E.
Department of Electrical Engineering
Faculty of Engineering
Rivers State University, Port Harcourt, Nigeria.
Corresponding Author: ekeriance@yahoo.com
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Abstract
The evaluation of performance metrics for key power plants is crucial to meet the rising energy demands driven by Nigeria's growing population. This study assesses the performance metrics of Egbin and Afam VI power plants over a six-year period (2017–2022), focusing on indicators such as capacity factor, percentage energy loss, and revenue loss due to reduced generation. Results reveal that Egbin Power Plant achieved an average capacity factor of 43.4%, while Afam VI recorded 18.68%, both significantly below the international best practice range of 50%–80%. Energy loss percentages for Egbin and Afam VI were 56.6% and 68.67%, respectively, compared to the international benchmark of 5%–10%. Revenue losses attributed to outages were substantial, with Egbin incurring approximately ₦1.68 trillion and Afam VI about ₦834.52 billion over the study period. These findings underscore that both plants operate below international industrial standards. The study recommends targeted measures to enhance operational efficiency and optimize energy output to bridge the performance gap.

***Keywords**: Percentage loss, Energy Generated, Revenue Loss, Afam VI Power Plant, Egbin Power Plant.*

INTRODUCTION

In modern society, availability of electric power is the bedrock of sustainable development. The demand for adequate and reliable power supply at a very competitive price is continuously increasing with population increase and industrialization growth. The goal of any electric power utilities in the today competitive environment would be to supply consumers with electric energy with certain sufficient level of reliability, efficiency and affordable cost [1]. The performance evaluation of a power plant by way of its efficiency, reliability and other performance factor has a socioeconomic significance both on utilities operating the plant as well as the nation at large. Reliable electric power availability has been observed as effective and indispensable tool for socio-economic development, industrial growth and technological advancement of any nation [2]. Therefore, considering this importance, it is expected that electric power utilities must ensure they meet customer demands at a reasonable level of service. Performance evaluation of electric power plant focuses on how reliable is the generators in the whole electric power system where electric power is produced from the conversion process of primary energy (fuel or gas) to electricity before transmission. In the Nigeria scenario, energy demand has not been addressed with the requisite planning that would guarantee concurrent capacity growth. Indeed, there has been long persisting shortfall especially in electric energy output as compared with the demand by the economy [3]. A significant contribution limiting the meeting of the demand is the inefficient operations of several power plants connected to the national grid, resulting in their inability to generate electricity equivalent to their installed capacity. In Nigeria, Egbin power plant is the largest power generating station with an installed capacity of 1,320 MW and Afam VI power station is a 650MW combined cycle power plant owned by Shell Petroleum Development Company. Both power generating stations supplying over 40% of electrical energy to the national grid system in Nigeria, based on this, there is urgent need for the evaluation of the plants performance considering key indicators such as capacity factor, reduction in generation capacities and loss of revenue, then compare the results with the acceptable international value and proffer recommendations to the utilities if the results falls outside the statutory acceptable limit, in order to enhance electric power generation for improved power supply to the consumers[4].

Review of Related Works

The main reason of performance assessment of power generating plants is to improve the overall power system performance and its reliability. The research is not an exception but addition to the existing knowledge, so relevant literature on performance assessment of power generating plant was reviewed.

According to [7], they proposed a paper on performance evaluation of gas turbine plant in Niger Delta Region of Nigeria, using Afam IV and V gas turbine as their case study. Data of a period of nine years (2005 – 2013) was used for the assessment in order to ascertain its suitability as option for power generation in the region. The results obtained show that only 12.01% of the installed capacity was available under the period of study, the percentage shortfall energy generated ranged from 70.69% – 98.49% as against an acceptable value of 5 – 10%. The plant use factor is 23.5%. It was determine that the plant was expected to generate 57237.84Gwh of energy, it generated 6873.6Gwh amounting to an 87.99% generation loss.

According to [8], they carried out a study on performance evaluation of a large – scale thermal power plant considering the best industrial practices. The performance rating was conducted in compliance with the statistical principles. Data for the analysis was obtained for a TPP with an installed capacity of 375MW for a period that spans 8 years (2010 – 2017). They considered four parameters namely: availability, the reliability, the capacity factor and the thermal efficiency to assess the performance of the TPP. The results obtained show that 91% of the expected capacity was available during the study period as against 95% benchmark for the industry best practice. The TPP average reliability average capacity were 95% and 70% respectively as against 99.9% and 40 – 80% which are international values. The thermal efficiency was found to 40% against 49% throughout the studied period. The concluded that the studied TPP is not within the scope of the best industrial practice.

According to [9], they presented a paper on performance evaluation of the Afam VI combined cycle power plant system using energy and energy analysis approach. The capacity of the power plant is 685MW. The data used were extracted from plant's design and operation logs book for a period three years (2013 – 2015). Each sub-components of the plant was analyzed separately with a view of knowing the component with highest source of energy destruction. The results obtained show that the combustion chamber had mean energy efficiency of 14.02% and highest mean energy destruction value of 11,363986kW. While the least mean energy destruction of 56.378kW was found in the pump.

According to [10], they presented a paper on the performance appraisal of the Trans-Amadi Gas Turbine Station. The data used were collected from actual plant operational logbook, Turbine logbook, plant/auxiliaries logbook and generator logbook for the months of February 2011 to November, 2011. Appropriate thermodynamics equations and principle were used to determine parameters which could not be measured directly. The results obtained indicated that an increment of ambient temperature from 25^0C to 34^0C, the power output decreases by 0.08MW, the thermal efficiency decreases by 3.77%, the heat supplied decreases by 421kw, the air fuel ratio increases by 5.22, the specific fuel consumption increases by 0.102kg/kWh and the heat rate increases by 0.23kcal/kwh respectively. They concluded that the plant will consume much fuel for small amount of work. They recommended for routine maintenance.

According to [11], he carried out a study on the performance assessment of a gas turbine power plant which focuses on the energy and energy performance of a 5.67MW rated gas turbine power plant located at Total Exploration and Production, Port Harcourt, Nigeria. Design data were collected from the installation document and temperature readings from the control room. A MATLAB code was written that utilized collected data and various thermodynamic equations to determine various output performance parameters. The simulation of ambient air temperature on the performance of the gas turbine power plant was investigated. The results obtained show that there was increase of 46.1176kW in the work done by the compressor for every time rise in the ambient air temperature, an increase of 33.3888kW in the net power generated 10% rise in the ambient air temperature an increase of 28.71089KJ/kW the heat per every 10% rise in ambient air temperature and a decrease of 0.0062870% in the thermal efficiency of the plant for every 10% rise in ambient air temperature. Solutions in form of recommendation was proffered.

MATERIALS AND METHOD

The materials used in this research are existing data of Egbin and Afam VI power generating station which includes: Annual installed capacity (MWh) data, Annual generated capacity (MWh) data, General information from generating stationsEssential method used in this research is based on analysis. Analytical technique was used to determine the key parameters of both Egbin thermal power plant and Afam Gas power plant VI, the parameters include: Annual capacity factors, Annual power loss

(i) Annual power outage cost (P_A)

(ii) Total power outage cost (P_T)

(iii) Loss of revenue based on generation reduction.

In order to evaluate the performance indicators stated in this research work, equations (3.1) to (3.5) were used as stated:

$$P_T = \sum_{i=1}^{n} P_{\times i} \quad (1)$$

Where,

(P_T) = Total power outages cost

(P_T) = Annual power outage cost for n numbers of turbine.

Also P = Pr x Pi x Cv (2)

$$\text{Pr} = \sum_{i=1}^{n} Pr \quad (3)$$

Pr=Pic-Poc (4)

Where;

Pr : annual power reduction for n number of turbine.

Pic: annual installed capacity in MWh for individual turbine

Poc : annual Generated capacity in Mwh for individual turbine.

Cv: unit cost of power.

The capacity factor, Cf can be determined as using equation (5).

$$\text{Cf} = \frac{Total\ generating\ capcity}{Total\ installed\ capacity} = \frac{Gc}{Ic} \quad (5)$$

Where;

Cf: annual capacity factor for in numbers of turbine.

Gc: generating capacity MW for individual turbine.

Ic: installed capacity in Mw for individual turbine.

For the purpose of this study, a unit cost of energy is assumed to cost ₦100 for 1Kwh, because actual values cannot be gotten. ₦100 is the assumed average unit cost of energy over the six year of investigation.

Table 1: Egbin Power Generating Station Energy Parameter

Year	No of Turbine Unit	Installed Capacity (MW)	Installed Energy Plant Capacity (MWh)	Generated Capacity (MW)	Generated Energy Plant capacity (MWh)
2017	STI-6	1320	11,563,200	610.78	5.350.432.8
2018	STI-6	1320	11563,200	430.76	3,852,297.6
2019	STI-6	1320	11,563,200	537.76	4,710,777.6
2020	STI-6	1320	11563,200	651.87	5,710.381.2
2021	STI-6	1320	11,563,200	660.97	5,790,097.2
2022	STI-6	1320	11563,200	544.63	4770958.8

Source: Adoghe *et al*. (2023) & Research Desk

By using equation (3.5) and data from Table 3.1, the capacities factor of the station from 2017 to 2022 was calculated as this:

$$\frac{Generated\ Capacity}{Installed\ Capacity}$$

$$C_{P\ 2017} = \frac{610.78}{1320} = 0.463$$

$$C_{P2018} = \frac{430.76}{1320} = 0.326$$

$$C_{p2019} = \frac{537.76}{1320} = 0.407$$

$$C_{P2020} = \frac{651.87}{1320} = 0.494$$

$$C_{p2021} = \frac{660.97}{1320} = 0.50$$

$$C_{P2022} = \frac{544.63}{1320} = 0.413$$

Equations (3) and (4) were used to calculate the annual power reduction from 2017 to 2022 as shown in Table 2

Table 2: Annual Power Reduction Calculations from 2017-2022 for Egbin Power Plant

Year	Turbine Unit	Installed Energy Plant Capacity (MWh) PIc	Generated Energy Plant capacity PG	Energy Reduction P_R=PIc-PG
2017	STI-6	11,563,200	5,350432.8	6,212,767.2
2018	STI-6	11,563,200	3,852,297.6	7,710,902.4
2019	STI-6	11,563,200	4,710,777.6	6,852,422.4
2020	STI-6	11,563,200	5710,381.2	5,852,818.8
2021	STI-6	11,563,200	5,790,097.2	5,773,102.8
2022	STI-6	11,563,200	4770958.8	6,792241.2

Source: Research Desk, 2023.

Substituting value of Cf from 2017 to 2022 calculated and values of energy reduction, P_R calculated and taking, CV to be N100 for 1KWh as said earlier. Annual outage power cost can now be calculated from 2017 to 2022 as stated using equation (3.2).

$PC_{P\ 2017} = 6212767.2 \times 0.463 \times 100 \times 1000$

$= N\ 287,651,121400$

$PC_{P2018} = 7710902.4 \times 0.326 \times 100 \times 1000$

$= N256, 773,049,900$

$PC_{P\ 2019} = 6852422.4 \times 0.407 \times 100 \times 1000$

$= N278, 893, 591,700$

$PC_{P\ 2020} = 5,852,818.8 \times 0.494 \times 100 \times 1000$

$= N289, 129, 248,700$

$PC_{p2021} = 5,733,102.8 \times 0.5 \times 100 \times 1000$

$= N288, 655,140,000$

$PC_{P2022} = 6792241.2 \times 0.413 \times 100 \times 1000$

$= N280, 519,561,600$

Revenue loss, for six years under investigation is the total power outage cost, $PC_{P\ =}$

$PC_P\ 1 + PC_P\ 2 + PC_P\ 3 + PC_P\ 4 + PC_P\ 5 + PC_P\ 6$

=N (289,651,121,400+256,733,049,900+278,893,591,700 + 289,129,248,700 + 288,655,140,000 + 280,519,561,600)

PC_P = N 1,683,641,713,000

Similarly as it was done for the Egbin thermal plant, equation (1) to (5) was used together with energy parameter information of the plant for a period of 6 years (2017-2022) under investigation to determine performance indicators for Afam VI

Table 3: Afam VI Power Plant Energy Parameters

Year	Turbine Name	Installed Capacity (MW)	Installed Energy Plant Capacity (MWh)	Generated Capacity (MW)	Generated Energy Plant capacity (MWh)
2017	TI-4	650	5,694,000	290.86	2548013
2018	TI-4	650	5,694,000	226.97	1988231
2019	TI-4	650	5,694,000	149.19	1306933.8
2020	TI-4	650	5,694,000	209.03	1831059
2021	TI-4	650	5,694,000	240.42	2106081.2
2022	TI-4	650	5,694,000	92.84	813,295

Equation (5) and data from Table 3 was used to calculate the capacities factor of the station from 2017 to 2022 as shown:

$$C_{P_{2017}} = \frac{290.86}{650} = 0.447$$

$$C_{P_{2018}} = \frac{226.97}{650} = 0.349$$

$$C_{P_{2019}} = \frac{149.19}{650} = 0.230$$

$$C_{P_{2020}} = \frac{209.03}{650} = 0.322$$

$$C_{P_{2021}} = \frac{240.42}{650} = 0.377$$

$$C_{P_{2022}} = \frac{92.84}{650} = 0.143$$

Table 4: Annual Power Reduction Calculations from 2017 to 2022 for Afam VI Power Plant

Year	Turbine Name	Installed Energy Plant Capacity (Mwh) P_{Ic}	Generated Energy Plant Capacity PG(Mwh)	Energy Generation Reduction $P_{Ic} - P_G = P_R$(Mwh)
2017	T1-4	5,694,000	2548013	3,145,987
2018	T1-4	5,694,000	1988231	3,705,769
2019	T1-4	5,694,000	1306933.8	4,387,066.2
2020	T1-4	5,694,000	1831059	3,862,941
2021	T1-4	5,694,000	2106081.2	3,587,918.8
2022	T1-4	5,694,000	813295	4,880,705

By substituting the values of Cp calculated, and values of P_R calculated, the value of C_V is assumed to be ₦100 for 1kwh. Annual outage power cost can now be calculated from 2017 to 2022 as stated using equation (2).

$PC_{P\ 2017} = 3145987 \times 0.474 \times 100 \times 1000$

$= N\ 149,119,783,800$

$PC_{P2018} = 3705769 \times 0.349 \times 100 \times 1000$

$= N\ 129,331,338,100$

$PC_{P\ 2019} = 4{,}387{,}066.2 \times 0.230 \times 100 \times 1000$

=N100, 683,169,300

$PC_{P\ 2020} = 3{,}862{,}941 \times 0.322 \times 100 \times 1000$

=N124, 193,553,200

$PC_{p2021} = 3{,}587{,}918.8 \times 0.37 \times 100 \times 1000$

=N132, 717,116,400

$PC_{P2022} = 4880{,}705 \times 0.413 \times 100 \times 1000$

=N201, 475,502,400

Revenue loss, for six years under investigation is the total power outage cost, $PC_{P\ =}$

$PC_P\ 1 + PC_P\ 2 + PC_P\ 3 + PC_P\ 4 + PC_P\ 5 + PC_P\ 6$

=N (149,119,783,800+129,331,338,100+100,683,169,300 + 124,193,533,200 + 132,717,116,400 + 201,475,502,400)

PC_P = N 837,520,443,200

RESULTS AND DISCUSSIONS

The simulated results in Figures 1 and Figure 2 shows the plot of available energy generated and reduction against the respective year under investigation for Egbin Power Plant and Afam VI power plant respectively

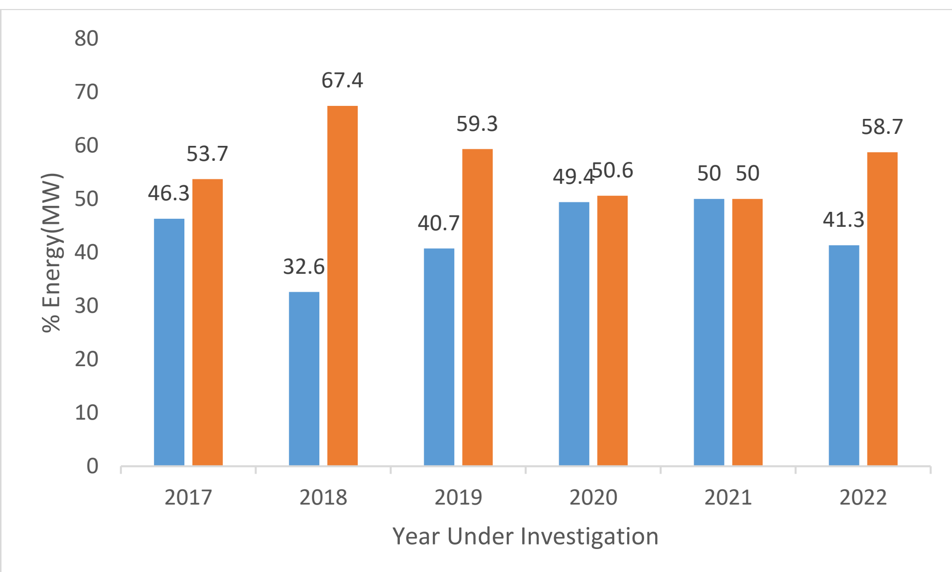

Figure 1: Plot of Available Energy Generation and Reduction Versus Year

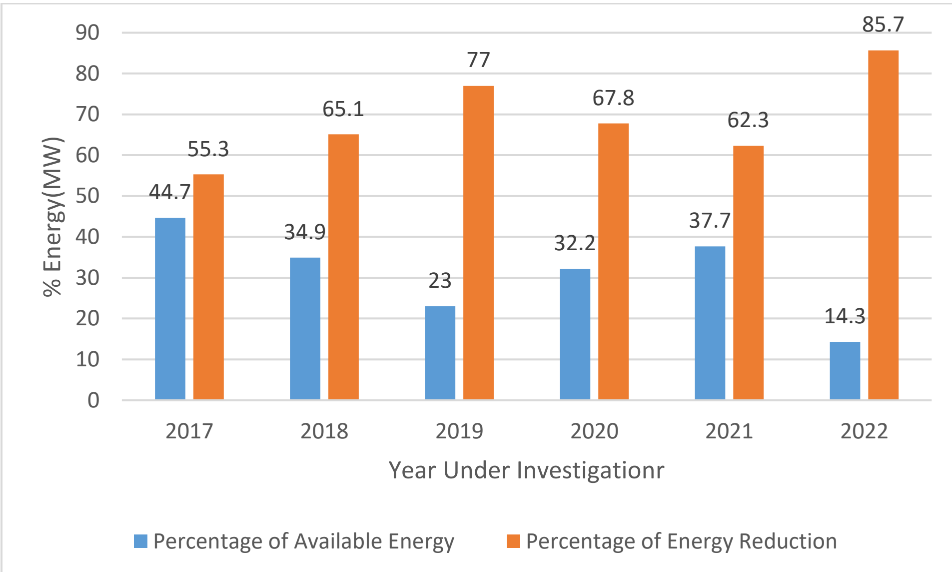

Figure 2: Plot of Percentage Available Energy Generation and Energy Reduction Versus Year

The plot of Figure 1 indicated that only 43.4% of Egbin Power Plant installed energy capacity was available within the six year period of study, while percentage of energy loss is 56.6%. This is a huge departure from 5% - 10% which is in

Similarly, Figure 2 shows the percentage of available energy generation capacity and percentage reduction of the installed capacity of Afam VI Power Plant within six year period under investigation are 31.13% and 68.87% respectively. The percentage of energy loss violates the acceptable international best practices.

Discussions of Loss of Revenue Based on Generation Reduction in the Study Cases Power Plants.

Figure 3 shows the plot of loss of revenue due to reduction in power generation against the respective year under review for Egbin and Afam VI power plants.

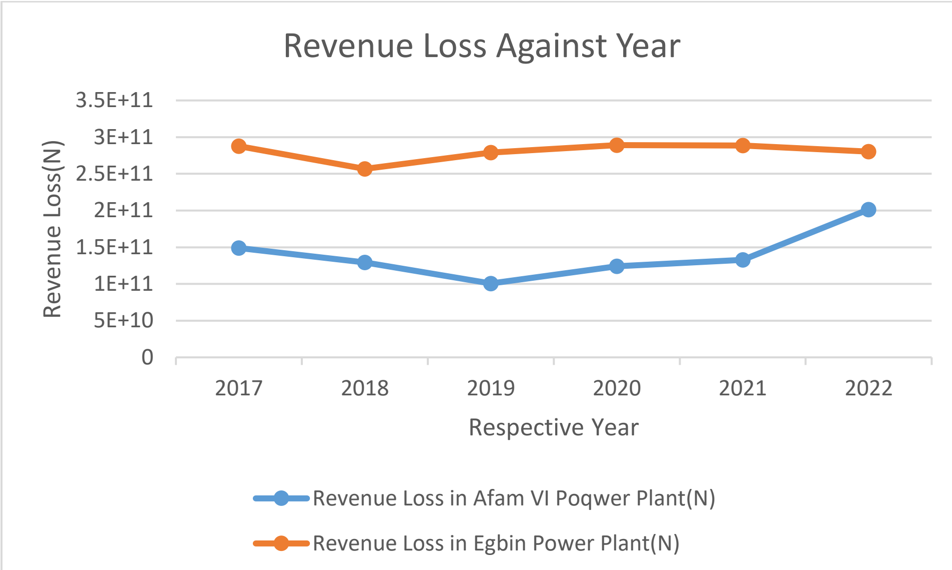

Figure 3: Plot of Revenue Lost Versus Respective Year

The plot of Figure 4.3, revealed a total revenue loss of ₦1, 683,641,713,000 for Egbin Power Plant under the six years of investigation based on generation reduction. The minimum revenue loss of ₦256, 773,049,900 for the year (2018) and maximum revenue loss of ₦289, 126,248,700 for the year (2020).

Similarly, the plot indicated a total loss of revenue of ₦837, 520,443,200 for Afam VI Power Plant within (6) six years period of review based on generation reduction. The minimum revenue loss occurred in 2019 with a value of ₦124, 193,553,200 and a maximum revenue loss of ₦201, 475,502,400 for the year (2020).

Table 1 Annual Capacities Factor

Egbin Power Plant		**Afam VI Power Plant**	
Year	**Capacity Factor**	**Year**	**Capacity Factor**
2017	0.463	2017	0.447
2018	0.326	2018	0.349
2019	0.407	2019	0.230
2020	0.494	2020	0.322
2021	0.500	2021	0.377
2022	0.413	2022	0.143
TOTAL	**2.603**		**1.868**

Source: Research Desk

Table1 revealed an average capacity factor of 43.4% with a minimum value of 33.3% for thr year 2018 and a maximum value of 50% the year 2021 for Egbin Power Plant under the (6) six year.

Table 1 also revealed an average capacity factor of 31.13% with a minimum value of 14.3% for the year 2022 and a maximum value of 44.7% in 2017 for Afam VI Power Plant under (6) six year. These values are far from the international best practice which ranges from 50% to 80 % [12], which indicates that both Egbin Power plant and Afam VI Power Plant were running at a huge loss.

CONCLUSION

The performance metrics of a power plant is majorly hinged on the plant's generated power output and the running hours. Since stable operation of power plants is desired in accordance with international best practice standard, power plant performance evaluation is very paramount, which prove the need to carry out this research. The performance metrics evaluation of Egbin power plant and Afam VI Power Plant has been carried out with emphasis on three (3) key performance indices: overall capacities factor, percentage reduction in generation capacities and revenue loss due to reduction in generation. For the six (6) years under investigation (2017 - 2022), the study shows that the average overall capacity factor for Egbin Power Plant was 43.4% (32.6% minimum (2018), 50% maximum (2021). While that of Afam VI Power Plant revealed an average overall capacity factor of 18.68% (14.3% minimum (2019), 44.7% maximum (2021). It is observed that both were not operated within the international best practice capacity factor standard that lies within 50% to 80% [12].

Furthermore, under the (6) six years period of investigation, overall percentage loss in energy for Egbin Power Plant is 56.6% while that of Afam VI Power Plant is 68.87%.The values fall short of the international industrial best practice that ranges from 5%-10%. This has resulted to huge revenue loss by the generation companies that owned the plants. Number of reasons such as low plant availability due to breakdowns/failures, aging of plant component, disruption in gas supply etc., were adduced to be responsible for the shortfall in performance indices as against the set standard. In order to minimize the problems, total overhaul of the plants and periodic maintenance schedule should be in place by the operators, availability of spare parts for maintenance should be ensured, and training and retraining of the O & M staffs should be put in place, so as to equip them in carrying out major maintenance duties. Moreover, adequate supply of gas should be taken as a priority.

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