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# Evaluation of the Economics of Flare Gas Conversion: A Case Study of Gas-To-Liquids and Compressed Natural Gas Technologies

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***ABSTRACT:*** *Oil and gas are usually produced from remote locations all over the world and the gas, which can come in associated or non-associated forms,are then exported to both local and global consuming centres. The technology deployed for transporting this gas can be liquefied natural gas (LNG), compressed natural gas (CNG), gas-to-liquids (GTL), gas-to-solids (GTS), and gas-to-wire (GTW). In this study, we investigate two options – GTL and CNG in order to comparatively evaluate the economic advantages of the use of one technology over the other in a country like Nigeria where gas monetization project opportunities involving these options are yet to be fully exploited.This work presents the use of robust economic models and gas flaring data from Nigeria to determine the profitability index of the two alternatives guided by computations of initial capital investment (ICI), net present value (NPV), internal rate of return (IRR) and pay-back period (PBP). Results show that both options areeconomically viable. However, the GTL option showed a relativelyhigher value in all the profitability index criteria with the GTL pay-back period lowerthan the alternative (CNG).For example, while the NPV, IRR and PBP for the GTL option are $275,327,653.00, 40.07% and 3.15 years, respectively, the corresponding values for the CNG alternative are $3,876,930.79, 16.75% and 6.42 years, respectively. Furthermore,the break-even feed gas rate for GTL is 2.5 MMSCFDas against the 0.7 MMSCFD recorded for CNG. These options were also evaluated with respect to product prices, including sensitivity to non-economic factors like flare gas rate, available capital, source of capital, gas gathering facilities and risk appetite of investors.Overall, the findings help identify the key advantages and disadvantages of the GTL and CNG alternatives for relatively small scale projects in a gas flaring country such as Nigeria.*

***KEYWORDS -****gas to liquids (GTLs), compressed natural gas (CNG), flare gas conversion technologies, economic analysis, profitabilityindex*

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## I. INTRODUCTION

The Canadian Association of Petroleum Producers has described gas flaring as the controlled burning of natural gas that cannot be processed for sale or used because of technical or economic reasons [1]. Gas flaring may also be used to explain the burning of associated, unwanted or excess gases and liquids released during normal or unplanned over-pressuring operation in many industrial processes, such as oil-gas extraction, refineries, chemical plants, coal industry and landfills [1, 2]. Globally, over 100 billion cubic meters (BCM) of gas is flared annually and, is linked to an annual emission of 400 million tons of carbon dioxide [1]. In Nigeria, the annual gas production is valued at 33.21 BCM, out of which more than 50% is wasted through flaring, resulting to a loss of approximately $2 billion yearly and emitting about 35 million tons of carbon dioxide, which increasingly endangers our environmentthrough the release of greenhouse gases [1, 3, 8, 9].

Figure 1 shows the volume of global gas flares for the top six gas flaring countries in the world with Nigeria flaring about 8 BCM that year (2015)[1, 3, 5].Gas flare reduction efforts, like the World Bank zero routine flare by 2030 initiative, are geared towards reducing routine gas flaring at production facilities [4] by adopting appropriate flare gas conversion technologies. Flare gas conversion technologies may include optionslike pipeline natural gas (PNG), compressed natural gas (CNG), liquefied natural gas (LNG), gas-to-liquids (GTLs), gas-to-methanol (GTM), gas-to-power (GTP), and gas-to-ammonia-and-urea (GTAU) [16]. Among these gas utilization options, GTL and CNG are generating increasing attention because of their ability to provide substitute fuel products for different internal combustion engines used in airplanes and automobiles [1]. In another report and according to British Petroleum [7], Nigeria losses $2.5 billion annually due to gas flare during oil and gas processing [10, 11].Figure 2 shows an aerial view of Nigeria's gas flare sites. This work will evaluate the economics of using these two technologies for gas monetization.

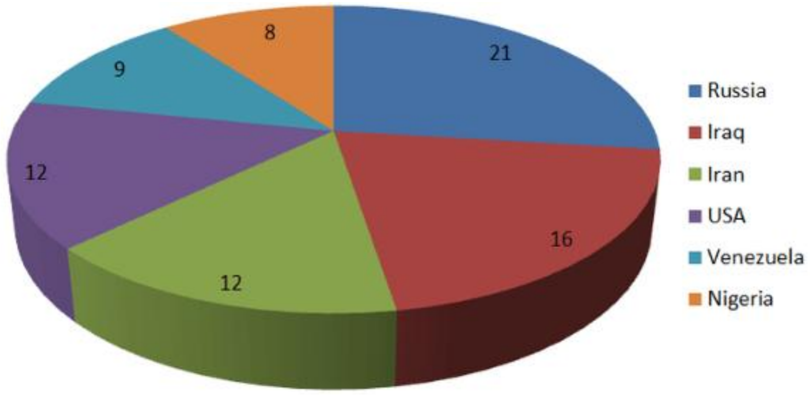


**Figure 1:** Volume of global gas flared by top six gas flaring countries [1, 2, 12]

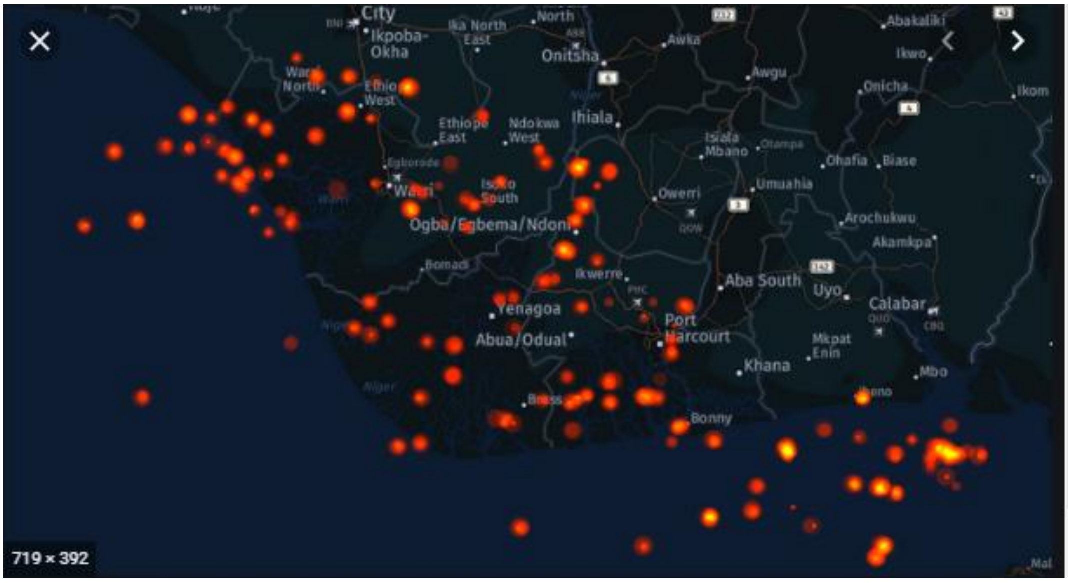


**Figure 2:** Areal view of Nigeria's gas flare sites [1].

## II. METHODOLOGY

### A. Flare Gas Conversion Using GTLsand CNGTechnologies

The process of converting natural gas into synthetic liquid fuels is mostly based on the popular Fischer-TropschSynthesis, which usually starts with the production of synthetic gas (syngas) – which are co-products of carbon monoxide and hydrogen. The syngas production can be achieved through either a catalytic oxidation process or steam reforming process [5]. Further catalytic reaction in the Fischer-Tropsch reactor produces a variety of synthetic liquid fuels (the so-calledsyncrudes). Thereafter, the syncrudes are recovered, upgraded and marketed to end users who find the fuel more attractive due to: the clean and sulfur-free nature of the products, the higher cetane number of diesel produced from this technology, as well as the relatively higher energy density of the liquids, thusmaking it amenable for loading and shipment into clean petroleum product vessels [5]. Other notable advantages of using the GTL option is their easy miscibility with crude oil and petroleum fuels during emergencies [5]. GTLs technology do not need a decompression unit and so can be shipped directly to customers and unloaded at its jetties or port. Figure 3 shows some features of a typical GTL value chain.

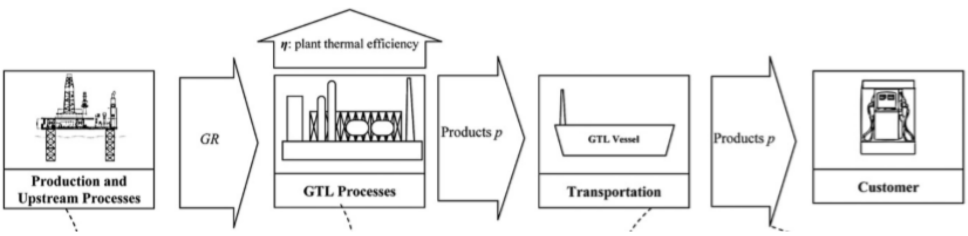


**Fig. 3.** Overview of GTL value chain[5].

Compressed natural gas (CNG)is produced when natural gas is compressed to a higher pressure, typically within the range of between 1500 – 4000 psi [5]. It is then transported mostly using CNG trucks to end users. Figure 4 shows the CNG value chain including the three main stages of compression, transportation and decompression. The compression stage involves the compression of the feed gas to a higher pressure and lower temperature [5]. The cold CNG is then transported to delivery terminals using specially designed CNG vessels, where the product is decompressed to desired pressure before distribution to end users [5].

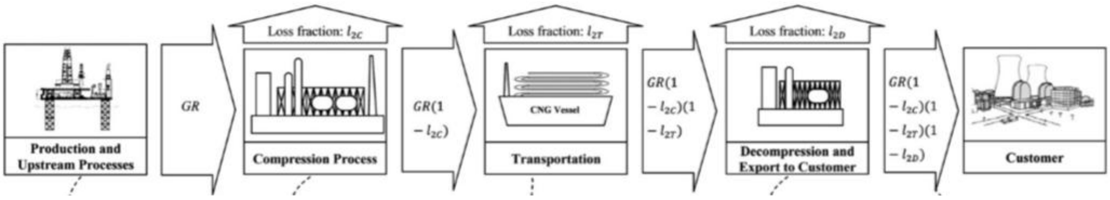

**Fig. 4.** Overview of CNGvalue chain [5].

**B. Small-Scale GTL and CNG Case Study**

The primary objective of this study is to comparatively evaluate the economics of small-scale GTL and CNG technologies and to establish a criterion for selecting an appropriate utilization option for the abundant natural gas resources in Nigeria [13, 14, 15]. Although data collection has been a challenge due to the commercially sensitive nature of these data, where supplying companies express reluctance to release these types of data. However, we have been able to access relevant data from a combination of literature sources, direct communication with stakeholders, and with key consulting companies dealing in these types of projects. For the purpose of this work, we use the feed gas rate as 4.5 MMSCFD of flared gas [1]. From the literature, we found that figures on quantity of gas flared daily and tentative number of flare sites in Nigeria were around 700 – 800 MMSCFD and approximately 178 flare sites, respectively.We choose their maximum values for this analysis and take it as base value for the flare gas utilization options. High and low values of feed gas rate are 0.45 and 45 MMSCFD, respectively.

We assume that both facility would only produce liquid fuels so that the exorbitant storage and handling costs for gaseous products would be curtailed, including product upgrading costs and regulatory bills. We assume that the GTL facility only produce diesel and petrol based on the fact that diesel is dominant in GTL product mix and petrol is, on the hand, consumed daily in Nigeria and the volume has gone up from the 50 million litres in 2017 to the current 56 million liters [6]. We assume a gas-to-liquid conversion ratio of 10Mscf to 1 barrel of produced liquid product [1]. For the natural gas base price used, the Henry Hub natural gas spot price as at the end of October was used, which is $2.33/MMBtu. We assume base prices for both diesel and petrol ($160/bbl and $120/bbl)[7]. In addition, the capital cost for the small scale GTL plant was $45,000/bbl of liquid products. This cost however, covers the following cost components of GTL plants: gas treatment, syngas production, Fischer-Tropsch (F-T) synthesis, product upgrading, utilities, offsets and other process unit costs [7].While capital costs for a compressed natural gas used is $3.85/MMBtu[4]. This also covers gas treatment, compression, loading, transportation and delivery costs. Both the GTL and CNG plants were operated at 60% and 98% plant capacities, respectively [5], while their plant availability were pegged at 95%, corresponding to 347 stream days in a year [1, 5].

In our computations, we used Nigeria's prime lending interests rates of 16.90 %, with capital funded through a capital structure of 65:35 for debt and equity. The plant economics is highly dependent on the discount rate used [1]. Different discount rates give different net present value (NPV) calculations, thereby making economic comparison difficult [1]. Therefore, the decision to use the same discount rate was taken in other to ensure the economic comparison of the two plants is done on the same basis. Hence, the cost of debt for the plants after tax will be: assume a tax rate of 30% which is equivalent to the corporate tax rate in Nigeria, and a depreciation rate of 3.33%. For the CNG plant, the annual sales and operating expenditures were increased annually by 3%, while for GTL plant, the annual sales and operating expenditures were increased by 3% and 5% respectively. This was done to simulate the influence of inflation on the economic analyses. The difference between the percentage increase for both flare gas utilization options can be attributed to the fact that GTL has higher capital outlay compared to a CNG plant. Hence, a GTL plant would naturally have higher operating expenditure than a CNG plant of comparable capacity [1]. However, the operating expenditure for both flare gas utilization options were taken as 5% of capital expenditure. The capital cost for the CNG plant is computed as $6,323,625 using the product of feed gas rate and plant capacity factor, and performing some unit conversion computations. In the case of GTL, the use of a unit conversion computations, say, feed gas rate of 4.5 MMSCFDconversion to barrels of liquid products per day using a conversion ratio of 10MSCF to 1 barrel of produced liquid product gives a capital cost of $12,150,000.

Gross sales values were obtained by multiplying product prices by the respective plant capacities. For the CNG, the plant capacity (4.41 MMSCFD) was multiplied by gas price ($2.33), availability factor (95%) and 365 days to arrive at the actual gross sales value. And similarly, for GTL plant, the gross sales was a combination of both diesel and gasoline sales, where each product was multiplied by their product mix percentage, product price, plant availability and the total number of days in a year [1]. Gross profit was computed by subtracting operating expenditure from gross sales.Multiplying the gross profit by the tax rate of 30% provides the tax value. Net profit was estimated from subtracting the tax payable from the gross profit. In addition, the loan repayment values were taken to be half of the net profit. This decision was taken to be able to pay off debts as soon as possible and still have enough liquidity to sustain the business [1]. The net annual cash flows were generated by subtracting loan repayment values from net profit for each year, while the net cash flows were then discounted to their present values using the weighted average cost of capital as discount rate for each gas flare utilization option. These were later added to get the net present values (NPV) and cumulatively added to get cumulative net cash flows. The calculations were done using Microsoft Excel. Particularly, Solver, a Microsoft Excel add-in was actually used in computing the internal rate of return through variation of the discount rate. Break even prices for both flare gas utilization options were calculated using the solver by varying the product prices to ascertain the particular price which makes the objective function value (NPV) equal to zero. Table 1 and 2 give some of the data and computations obtained for the analysis of these two technology options [1].

**Table 1:** Economics of small scale CNG technology [1]

| Parameter | Value |
|---|---|
| WACC (%) | 14.21 |
| Feed gas rate (MMscfd) | 4.5 |
| Plant capacity (MMscf/d) | 4.41 |
| Capacity factor (%) | 98 |
| Gas price ($/mmbtu) | 2.5 |
| Capital cost ($/mmbtu) | 4 |
| Availability (%) | 95 |
| Tax rate (%) | 30 |
| Gross sales ($) | 3,822,918.75 |
| Gas treatment ($/MMBtu) | 0.420 |
| Gas compression ($/MMBtu) | 0.584 |
| Loading ($/MMBtu) | 0.146 |
| Transportation ($/MMBtu) | 2.200 |
| Delivery ($/MMBtu) | 0.500 |
| CAPEX ($) | 6,323,625 |
| OPEX (Utilities) ($) | 316,181.25 |
| Gross Profit ($) | 3,506,737.5 |
| Tax ($) | 1,052,021.25 |
| Net Profit ($) | 2,454,716.25 |
| Loan repayment ($) | 1,227,358.13 |

Table 2: Economics of small scale GTL technology [1]

| Parameter | Value |
|---|---|
| WACC (%) | 14.21 |
| Feed gas rate (MMscfd) | 4.5 |
| Plant capacity (bbl/day) | 270 |
| Capacity Factor (%) | 60 |
| Gas price ($/mmbtu) | 2.5 |
| Capital cost ($/bbl) | 45,000 |

| | |
|---|---|
| Availability (%) | 95 |
| Diesel product fraction (%) | 70 |
| Gasoline product fraction (%) | 30 |
| Diesel price ($/bbl) | 160 |
| Gasoline price ($/bbl) | 120 |
| Production ratio (-) | 0.428571429 |
| Diesel sales ($) | 10,485,720 |
| Gasoline sales ($) | 3,370,410 |
| Gross sales ($) | 13,856,130 |
| CAPEX ($) | 12,150,000 |
| OPEX (Utilities) ($) | 607,500 |
| Gross Profit ($) | 13,248,630 |
| Tax ($) | 3,974,589 |
| Net Profit ($) | 9,274,041 |
| Loan repayment ($) | 4,374,877.50 |

## III. RESULTS AND DISCUSSIONS

Tables 3 shows variation of feed gas rate with NPV for small scale GTL and CNG flare gas conversion plants, respectively. It can be observed that the GTL plant generates negative net present value below 4.5 MMSCFD feed gas rate, while the CNG plant generates negative net present value of 1 MMSCFD feed gas rate. And in other to clearly determine the tipping feed gas rates, at which the net present values turn negative, a break-even analysis was carried out as depicted in Figures 4 and 5 for GTL and CNG flare gas utilization plants, respectively.

**Table 3:** Variation of feed gas rate with NPV for small scale GTL and CNG plants [1].

| Gas feed rate (MMscfd) | Net Present Value ($) | |
|---|---|---|
| | GTL | CNG |
| 0.5 | -289,424,416.0 | -317,536.33 |
| 1 | -218,830,407.0 | 206,772.06 |
| 2 | -77,642,390.20 | 1,255,388.84 |
| 4.5 | 275,327,653.0 | 3,876,930.79 |
| 6 | 487,109,678.9 | 5,449,855.97 |

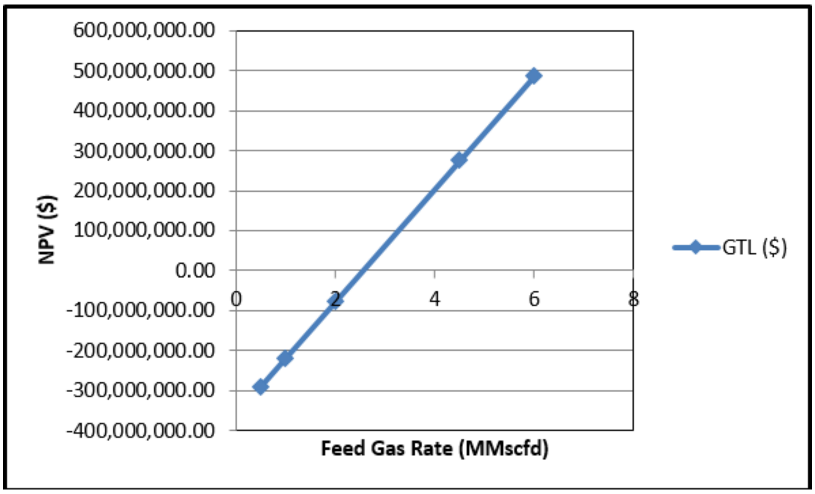


**Figure 4:** Variation of feed gas rate with NPV for small scale GTL plant [1]

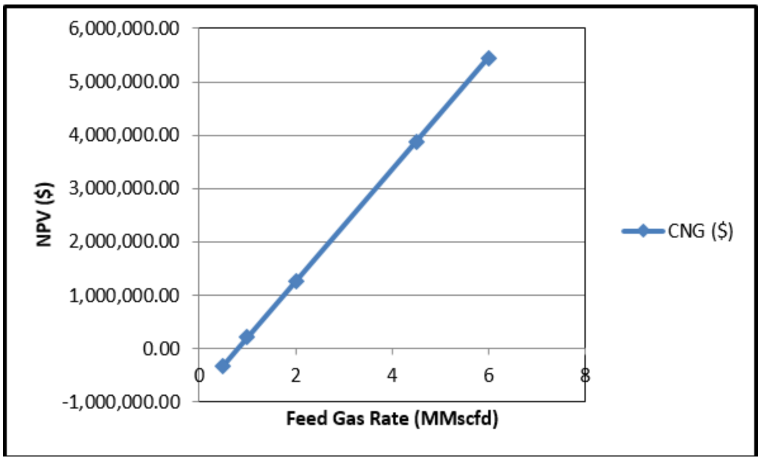


**Figure 5:** Variation of feed gas rate with NPV for small scale CNG plant [1].

Gauging where the trend line on each graph crossed the horizontal in figures 4 and 5, helped in revealing the feed gas rates at which net present value (NPV) became negative for each plant. From the results, the break-even prices for GTL and CNG gas utilization plants were 2.5 MMSCFD and 0.84 MMSCFD, respectively. This shows that a GTL plant becomes valuable when fed at flare gas rates higher than 2.5 MMSCFD. And for the CNG case to become valuable, it must receive flare gas at rates higher than 0.84 MMSCFD. The results are attributable to the fact that capital or installation costs for a small scale GTL plant is significantly higher than capital costs for a small scale CNG plant. The main reason for the disparity in installation costs is because miniaturized GTL technology is a new technology compared to small scale CNG technology [1].

Also, Table 4 and Figure 6shows variation of product mix with internal rate of return (IRR) for the GTL plant for various feed gas rates. It can be deduced from table 4 that there exists a direct, proportional relationship between internal rate of return (IRR) of a small scale GTL plant and the percentage of diesel in the product mix. While the percentage of petrol in the product mix was found to exhibit indirect, proportional to internal rate of return. This is expected since the price of diesel is relatively higher than the price of petrol. Therefore, more diesel and less petrol in the product mix generates more sales and ultimately more returns [1].

**Table 4:** Variation of product mix with IRR for small scale GTL plant for feed gas rate of 4.5 MMSCFD

| Diesel product mix percentage (%) | Petrol product mix percentage (%) | Internal rate of return (%) |
|---|---|---|
| 90 | 10 | 47.10 |
| 80 | 20 | 45.33 |
| 70 | 30 | 43.57 |
| 50 | 50 | 40.07 |
| 30 | 70 | 36.60 |
| 20 | 80 | 34.88 |
| 10 | 90 | 33.16 |

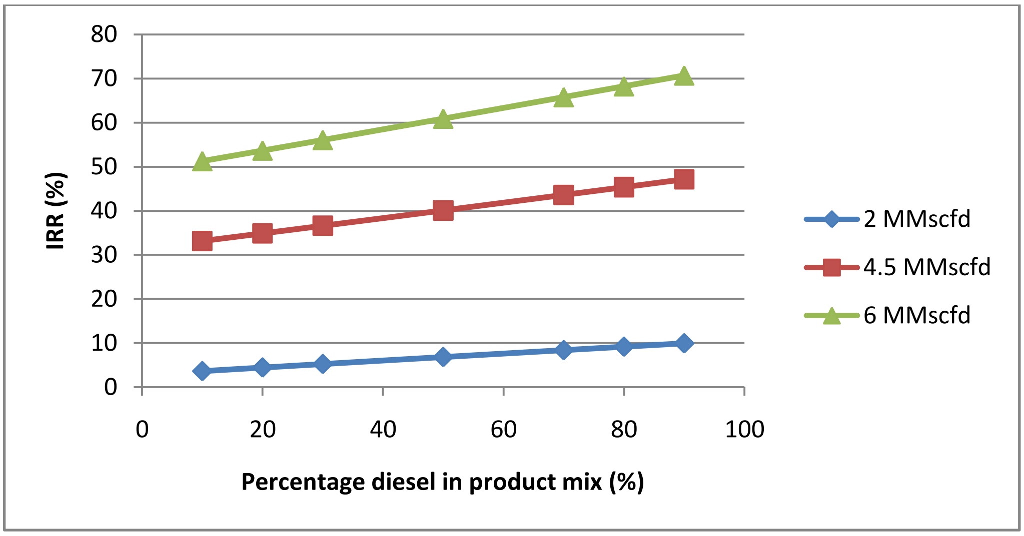


**Figure 6:** Variation of product mix with IRR for small scale GTL plant [1].

Table 5 and Figure 7 show break-even prices for the small scale GTL option as a function of various feed gas rates. From the Table 5, it can be deduced that break-even prices for the products were indirectly proportional to feed gas rate. Hence, as feed gas rates were increasing, the break-even prices were decreasing. This can be explained by the fact that at higher feed gas rates, effects of economies of scale become prominent. This is because higher feed gas rates means larger flare gas conversion plant capacity, which drives down unit costs thereby giving room for lower product price scenarios. This results are depicted in Figure 6, which equally shows that economy of scale effects are felt more at lower feed gas rates than at higher feed gas rates [1]. Generally, the economics of a GTL plant was very sensitive to product price, which can be attributed to very high capital costs.

**Table 5:** Break-even prices for small scale GTL plant products at various feed gas rates [1].

| Gas feed rate (MMSCFD) | Break-even price ($/bbl) | |
|---|---|---|
| | Diesel | Petrol |
| 0.5 | 894.69 | 533.26 |
| 1 | 367.87 | 346.11 |
| 2 | 194.98 | 162.01 |
| 4.5 | 86.99 | 71.67 |
| 6 | 62.80 | 56.19 |

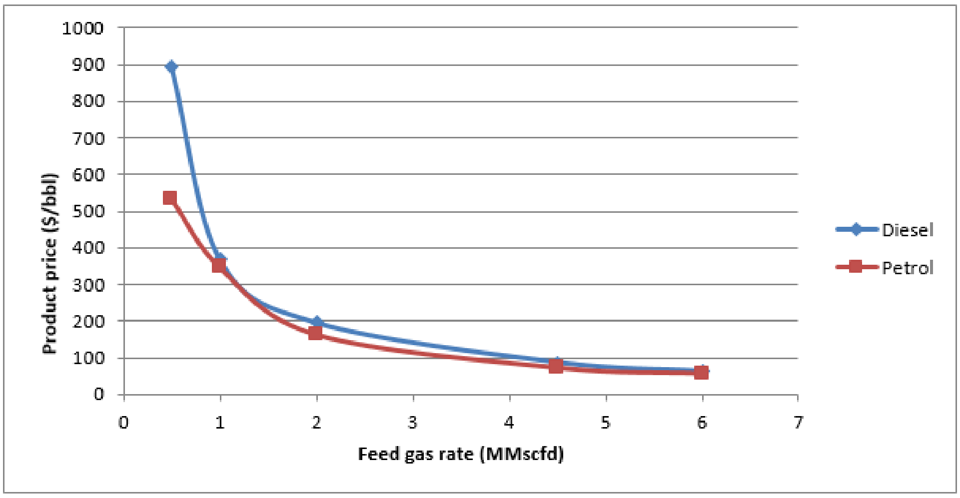


**Figure 7:** Break-even prices for small scale GTL plant products at various feed gas rates [1].

Table 6 and Figure 8 shows break-even gas prices for the small scale CNG option at various feed gas rates, where the break-even gas prices were seen to be indirectly proportional to feed gas rates. As feed gas rates increase, break-even gas prices decrease, attributable to the economy of scale effects, implying that higher feed gas rates means larger plant capacity, thus driving down unit costs and lowering product price scenarios. Figure 8 also depicts this trend. It can be said that CNG plant economics are not very sensitive product price due to their relatively less required capital [1].

**Table 6:** Break-even gas prices for small scale CNG plant versus feed gas rates [1].

| Gas feed rate (MMscfd) | Break-even gas price ($/MMBtu) |
|---|---|
| 0.5 | 2.39 |
| 1 | 2.31 |
| 2 | 2.27 |
| 4.5 | 2.252 |
| 6 | 2.248 |

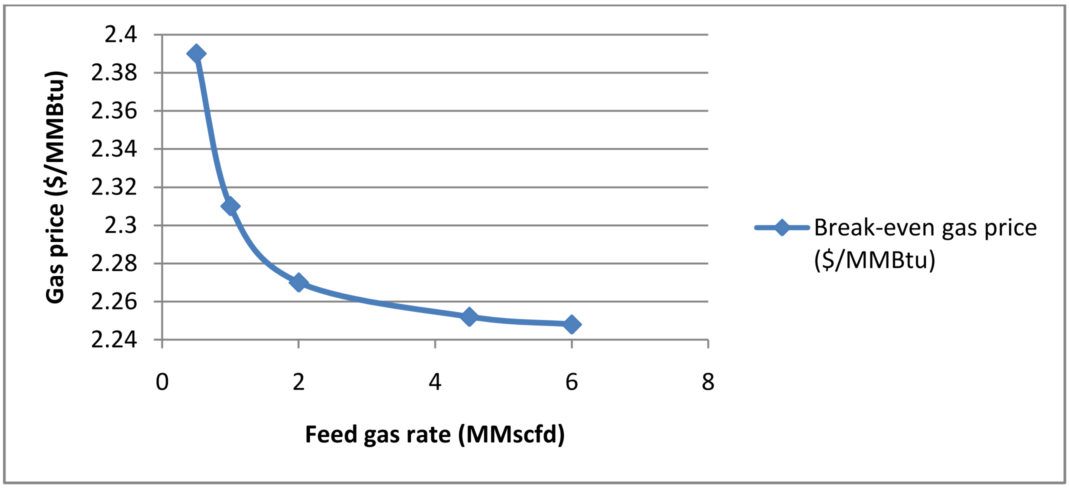


**Figure 8:** Break-even gas prices for small scale CNG plant product at various feed gas rates [1].

Table 7 summarizes the profitability indices for the flare gas conversion options at prevailing economic realities and GTL product ratio of 1 (50% diesel and 50% petrol). The GTL plant gave higher values for all the profitability indices considered except for pay-back period. Therefore, GTL flare gas utilization plants have higher initial capital, net present value and internal rate of return. Judging by net present value (NPV) decision criteria, which is to accept an investment option with positive net present value, both gas flare utilization options can be embarked on because they both have positive net present values. However, in situations of limited capitalan other factors, a GTL plant should be chosen over CNG plant since the former has higher net present value ($275,327,653.00)when compared with the CNG option with a net present value of $3,876,930.79.

**Table 7:** Summary of current profitability indices for GTL and CNG plants.

| Profitability index | Small scale GTL plant | Small scale CNG plant |
|---|---|---|
| Initial capital ($) | 12,150,000 | 6,323,625 |
| NPV ($) | 275,327,653 | 3,876,930.79 |
| IRR (%) | 40.07 | 16.75 |
| Payback period (years) | 3.15 | 6.42 |

Based on internal rate of return decision criteria, which is to accept investment options with internal rate of returns higher than the hurdle rate, both investment options are, again, viable because of their respective internal rates of return of 40.07% and 16.75% vis-a-visthe hurdle rate of 14.21%. In the case of limited capital, the investment option with higher internal rate of return is usually accepted. Again, a GTL plant will be accepted over a CNG plant since it has a higher internal rate of return.But judging by initial capital, the decision criteria usually favours lower initial capital investments, especially in a specific case of limited capital. This is because investors will most likely prefer investments with lower capital in order to free up capital for other investments. Hence, a CNG flare gas utilization plant with an initial capital of $6,323,625 can be more attractive over the GTL case since it has lower initial capital of $12,150,000 [1].

Similarly, capital investment decisions using pay-back periods will favour capital investments with shorter payback periods for the same reason, especially for risk-averse investors. Therefore, a GTL flare gas utilization plant will be accepted over a CNG plant since it has shorter pay-back period of 3.15 years, compared to a CNG with a pay-back period of 6.42 years.From the foregoing, both flare gas monetization options are viable but the final choice of technology will depend on other factors like flare gas rate, available capital, source of capital, gas gathering facilities and risk appetite of the investors [1]. An Investor with huge amounts of cheap capital can decide to embark on both gas monetization options, while those with small capital might be constrained to pay the gas flaring penalty fee rather than invest in either or both options.

## IV. CONCLUSION

We presented an economic evaluation of two gas monetization technologies – GTL and CNG using a comparative approach and our findings suggest that both the GTL and CNG options are economically viable, with GTL requiring relatively higher values of profitability index in terms of capital costs, net present value, internal rate of returnand with higher incentive with respect to pay back time. Also, break-even feed gas rate for gas to liquid (GTL) plant was higher than break-even feed gas rate for compressed natural gas (CNG) plant. In addition, the gas to liquid (GTL) plant economics is more sensitive to product prices compared to compressed natural gas (CNG) plant. Overall, the GTL options is apparently the more attractive investment option.

However, the choice of one option over the other is equally influenced by non-economic factors like flare gas rate, available capital, source of capital, gas gathering facilities and risk appetite of investors.

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