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Prospect of Natural Gas Hydrates Technology in Expanding Economic Exploitation of Natural Gas

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Abstract Natural gas reserves growth is relatively similar to that of crude oil. Natural gas can be found in association with crude oil discoveries or as gas filed when drilling for oil. Nigeria has long employed the liquefied natural gas technology and pipelines in the transportation of natural gas. Moreover, the occurrence of pipeline vandalism plus the cost of liquefying the natural gas has been identified to be somewhat expensive especially for short distances. On the other hand, compressed natural gas technology requires the availability of compression stations to compress the natural gas for ease of transportation. This study however, reviews the conversion of natural gas into solid fuels as a method to facilitate the transportation of natural gas for domestic purposes. An economic model was also developed and served as a tool in stating whether natural gas hydrates is more economical than liquefied natural gas. Nonetheless, the economic analysis performed on natural gas hydrates in comparison with other options (LNG, GTL) revealed a positive net present value. This indicated that natural gas hydrate is economically preferable to liquefied natural gas or gas to liquid technology over short distances for domestic transportation.

Keywords NGH, LNG, GTL, crystallization, NPV

1. Introduction

Natural gas predominantly consists of methane with small amounts of heavier hydrocarbons such as ethane, propane, and butane in addition to small amounts of nitrogen. The essence of natural gas to the proper functioning of a modern industrialized economy cannot be completely emphasized. In the year 2006, natural gas accounted for 22.5% of the total energy consumption in the United States, making natural gas of great importance as other liquid fuels [1]. Natural gas remains the cleanest burning fossil fuel – as it generates less greenhouse gases (such as carbon (IV) oxide and carbon monoxide) thus making it to be environmentally friendly. With an associated gas level of about 52%, non-associated gas level of about 48% and at current levels of reserves (184 Tcf) and production levels (5bcf/day), Nigeria's Reserves/Production ratio stands at over 100 years and is ranked 7th largest gas reserves globally. However, current production includes significant volume of flared gas, partly due to the location of the primary core producers of natural gas in the Niger Delta region, some miles away from the primary consumers of natural gas in the North, South East and South West of the country. Compounding this transportation problem is the fact that natural gas is expensive to transport when compared to coal or oil. For a given distance, per BTU shipping costs for coal or oil can be 25% of the shipping costs of LNG due to greater economies of scale and greater competition amongst carriers. Moreover, coal and oil are both produced in a form that can be easily transported in bulk whereas natural gas must be compressed or liquefied for bulk transport. Nigerian gas development can summarily be described in three distinct phases herein referred to as;

i. **Phase 1** Pre 1999 (Demand constrained era):

This phase was characterized by intense flaring of associated gas and consequently focused on developing export (LNG) market. However, there was considerable fiscal incentives but lack of legal framework for gas infrastructure development.

ii. **Phase 2** 1999 – 2005 (NLNG Era):

This phase saw to the establishment of Nigerian Liquefied Natural Gas Company (NLNG) as a strong supplier, leading to the capture of associated flared gas. It also culminated in the diversification into other export projects, e.g. gas to liquid (GTL) and consolidation of fiscal and regulatory regime was commenced.

iii. **Phase 3** 2005 (Demand boom, supply constrained):

In this phase, there was a significant increase in natural gas demand for both domestic and export sectors. This led to a corresponding shift from demand constrained to supply constrained which has led to the development of a Gas Master Plan for long term growth strategy.

Several methods are used to transport natural gas. The most common and most profitable method is using a pipeline to move the natural gas from one location to another. This method is not always practical, especially when it is desired to transport the natural gas between two locations separated by an ocean. Shipping natural gas over water is most commonly done by condensing the natural gas. This is done because the liquefied natural gas (LNG) has 570 times the density of natural gas at standard conditions making it easier to transport large quantities of natural gas. Other possible methods of transporting natural gas include compressed natural gas (CNG), gas to wire (GTW), gas to liquids (GTL), and natural gas hydrates (NGH).

Compressed natural gas is natural gas that is transported at very high pressures. The high pressures increase the amount of natural gas transported per unit volume. Gas to wire is the process of burning the natural gas to generate electricity then transmitting the electricity. Gas to liquids is the process of turning natural gas into longer chain hydrocarbons that are liquid at ambient conditions. Natural gas hydrates is the process of forming a solid phase of natural gas and water that can then be transported.

NGH technology is that of which the three major parts for the purpose of natural gas transportation are hydrate production, transportation and re-gasification. Natural gas hydrates are a solid phase of natural gas i.e. crystalline compounds formed as a result of combination of water and gas molecules under suitable temperature and pressure conditions. The gas molecules become surrounded by a cage of water molecules trapping the gas in a solid phase. With natural gas the most common guest molecules are methane, ethane, and propane. Methane and ethane will form an SI hydrate while propane will form an SII hydrate [2]. For methane, a volume of hydrate will contain about 164 times its volume of natural gas at standard conditions [3]. The compact form of natural gas hydrates makes them a possible method for the transport of natural gas. Methane hydrates are stable at very moderate temperatures and pressures when compared to the conditions required for LNG. NGH provides an opportunity for natural gas or associated gas to be transported efficiently to points of potential utilization. Its application will typically enable the utilization of small and medium size gas fields because most of the known gas fields are too small to justify the costs required to pipe the gas to a plant. There is therefore a necessity to evaluate an economic model which will serve as a tool for adequately selecting the gas type that will be appropriate for transportation over short distances for domestic purpose. Consequently, this study focuses on the application of an economic model which serves as a tool for stating which technology option is most suitable for transportation of natural gas over short distances.

3. Methodology

A comparative economic evaluation of both the natural gas hydrate technologies, the liquefied natural gas technology and gas to liquid was performed, leading to the selection of the appropriate transportation and utilization method for stranded gas that will bring about maximum benefit and good return on investment. This is imperative in order to decide which processing method to accept or reject in a given oil and gas field. The economic model and assumptions made in this study was relative to that of Nweke *et al* [4], with some necessary modifications. A service life of twenty years was proposed with and initial investment cost of a natural gas hydrate plant plus gas truck estimated to be $\$6.81 \times 10^6$ USD per ton/year. Also, an investment cost (Pipeline and gas processing) of a typical LNG plant was estimated at $\$8.71 \times 10^6$ USD per ton/yr of LNG product with operating cost estimated at \$0.51 x 10^6 USD per year while GTL (Gas to Liquid) operating cost was estimated at \$0.35 x 10^6 USD per year.

2.1. Economic Evaluation Model

The model below is a general model propounded to enable management compare the costs of investment in the natural gas hydrate processing, liquefied natural gas processing, and gas-to-liquid processing technologies as well as their transportation costs over an approximate distance of 40 miles.

Cost of investment for NGH,

$$C = INC + OPC \quad (1)$$

$$C_{NGH} = (INC + OPC)_{NGH} \quad (2)$$

And for Liquefied Natural Gas processing and transportation costs (LNG),

$$C_{LNG} = (INC + OPC)_{LNG.} \quad (3)$$

Where,

INC= investment cost;

OPC=Operating cost

The cost, C is then discounted at 15% to obtain the present value,

PV given by:

$$PV = \frac{C}{(1+i)^n} \quad (4)$$

$$PV_{NGH} = \left(\frac{C}{(1+i)^n}\right)_{NGH} \quad (5)$$

$$PV_{LNG} = \left(\frac{C}{(1+i)^n}\right)_{LNG} \quad (6)$$

Where; i = interest rate, n = number of the year

The Net incremental Present Value (NPV) is then calculated.

This is done by using the model;

$$NPV = PV_{LNG} - PV_{NGH}$$

Hence, substituting for PV_{NGH} and PV_{LNG}, the expression becomes;

$$NPV = \left(\frac{C}{(1+i)^n}\right)_{LNG} - \left(\frac{C}{(1+i)^n}\right)_{NGH} \quad (7)$$

The above expression reduces to:

$$NPV = \sum_{n=1}\left(\frac{C_{LNG} - C_{NGH}}{(1+i)^n}\right) \quad (8)$$

Discount factor (d) is expressed as:

$$d = \frac{PV}{FV}$$

Where,

PV= Present Value

FV = Future Value

From equation (8) above, it can be deduced that a positive NPV value will indicate that natural gas hydrate (NGH) technology option is selected while a negative NPV value will imply that liquefied natural gas(LNG) be selected. Subsequently, a zero (0) value of NPV will imply that either of LNG or NGH can be selected as a preferred natural gas infrastructure development option.

The economic analysis provides a useful tool to investigate which natural gas type is most suitable for the transportation over short distances of about 40 miles.

Hence substituting the relevant parameters into equation (8), it is expressed as;

$$NPV = \frac{11{,}902{,}259 - 9{,}000{,}766}{(1 + 0.15)^{20}}$$

$NPV=11.35\times10^6$

Therefore, since NPV is positive, select NGH processing.

Similarly, utilizing eq. (8) but for GTL,

$$NPV = \frac{10{,}066{,}326 - 9{,}000{,}766}{(1 + 0.15)^{20}}$$

NPV= 65106.01323

Hence, since NPV is positive, NGH processing should be selected over GTL.

Internal Rate of Returns (IRR) was used as an indicator to obtain the discount rates at which the NPVs of GTL, LNG and NGH becomes zero. The internal rate of returns may also be termed as discounted cash flow rate of return.

The economic model imbibed in this study acted as a poise for determining the cheaper method of gas transportation.

3. Results and Discussion

Table 1: Undiscounted cost for NGH processing

		NGH PROCESSING	
YEARS	INC ($) ×10^6	OPC ($) ×10^6	COST ($) ×10^6
0	6.81	0	6.81
1	0	0.35	0.35
2	0	0.35	0.35
3	0	0.35	0.35
4	0	0.35	0.35
5	0	0.35	0.35
6	0	0.35	0.35
7	0	0.35	0.35
8	0	0.35	0.35
9	0	0.35	0.35
10	0	0.35	0.35
11	0	0.35	0.35
12	0	0.35	0.35
13	0	0.35	0.35
14	0	0.35	0.35
15	0	0.35	0.35
16	0	0.35	0.35
17	0	0.35	0.35
18	0	0.35	0.35
19	0	0.35	0.35
20	0	0.35	0.35
			$13810000

Table 2: Undiscounted cost for LNG processing

		LNG PROCESSING	
YEARS	INC ($) ×10^6	OPC ($) ×10^6	COST ($) ×10^6
0	8.71	0	8.71
1	0	0.51	0.51
2	0	0.51	0.51
3	0	0.51	0.51
4	0	0.51	0.51
5	0	0.51	0.51
6	0	0.51	0.51
7	0	0.51	0.51
8	0	0.51	0.51
9	0	0.51	0.51
10	0	0.51	0.51
11	0	0.51	0.51
12	0	0.51	0.51
13	0	0.51	0.51
14	0	0.51	0.51
15	0	0.51	0.51
16	0	0.51	0.51

17	0	0.51	0.51
18	0	0.51	0.51
19	0	0.51	0.51
20	0	0.51	0.51
			$18,910,000

Table 3: Discounted cost at 15% PV for NGH

		NGH PROCESSING	
YEARS	INC ($) ×10^6	Discount factor	15% PV ($) ×10^6
0	6.81	1	6.81
1	0.35	0.869565217	0.304347826
2	0.35	0.756143667	0.264650284
3	0.35	0.657516232	0.230130681
4	0.35	0.571753246	0.200113636
5	0.35	0.497176735	0.174011857
6	0.35	0.432327596	0.151314659
7	0.35	0.37593704	0.131577964
8	0.35	0.326901774	0.114415621
9	0.35	0.284262412	0.099491844
10	0.35	0.247184706	0.086514647
11	0.35	0.214943223	0.075230128
12	0.35	0.18690715	0.065417503
13	0.35	0.162527957	0.056884785
14	0.35	0.141328658	0.04946503
15	0.35	0.122894485	0.04301307
16	0.35	0.10686477	0.037402669
17	0.35	0.092925887	0.03252406
18	0.35	0.080805119	0.028281792
19	0.35	0.070265321	0.024592862
20	0.35	0.061100279	0.021385098
			$9,000,766

Table 4: Discounted cost at 15% PV for LNG

		LNG PROCESSING	
YEARS	INC ($) ×10^6	Discount factor	15% PV ($) ×10^6
0	8.71	1	8.71
1	0.51	0.869565217	0.443478261
2	0.51	0.756143667	0.38563327
3	0.51	0.657516232	0.335333279
4	0.51	0.571753246	0.291594155
5	0.51	0.497176735	0.253560135
6	0.51	0.432327596	0.220487074
7	0.51	0.37593704	0.19172789
8	0.51	0.326901774	0.166719905
9	0.51	0.284262412	0.14497383
10	0.51	0.247184706	0.1260642
11	0.51	0.214943223	0.109621044
12	0.51	0.18690715	0.095322647
13	0.51	0.162527957	0.082889258
14	0.51	0.141328658	0.072077616
15	0.51	0.122894485	0.062676187
16	0.51	0.10686477	0.054501033
17	0.51	0.092925887	0.047392202
18	0.51	0.080805119	0.041210611
19	0.51	0.070265321	0.035835314
20	0.51	0.061100279	0.031161142
			$11,902,259

Table 5: Undiscounted cost for GTL processing

		GTL PROCESSING	
YEARS	INC ($) ×10^6	OPC ($) ×10^6	COST ($) ×10^6
0	7.5	0	7.5
1	0	0.41	0.41
2	0	0.41	0.41
3	0	0.41	0.41
4	0	0.41	0.41
5	0	0.41	0.41
6	0	0.41	0.41
7	0	0.41	0.41
8	0	0.41	0.41
9	0	0.41	0.41
10	0	0.41	0.41
11	0	0.41	0.41
12	0	0.41	0.41
13	0	0.41	0.41
14	0	0.41	0.41
15	0	0.41	0.41
16	0	0.41	0.41
17	0	0.41	0.41
18	0	0.41	0.41
19	0	0.41	0.41
20	0	0.41	0.41
			$15,700,000

Table 6: Discounted cost at 15% PV for GTL

		GTL PROCESSING	
YEARS	INC ($) ×10^6	Discount factor	15% PV ($) ×10^6
0	7.5	1	7.5
1	0.41	0.869565217	0.356521739
2	0.41	0.756143667	0.310018904
3	0.41	0.657516232	0.269581655
4	0.41	0.571753246	0.234418831
5	0.41	0.497176735	0.203842461
6	0.41	0.432327596	0.177254314
7	0.41	0.37593704	0.154134186
8	0.41	0.326901774	0.134029727
9	0.41	0.284262412	0.116547589
10	0.41	0.247184706	0.10134573
11	0.41	0.214943223	0.088126721
12	0.41	0.18690715	0.076631932
13	0.41	0.162527957	0.066636462
14	0.41	0.141328658	0.05794475
15	0.41	0.122894485	0.050386739
16	0.41	0.10686477	0.043814556
17	0.41	0.092925887	0.038099614
18	0.41	0.080805119	0.033130099
19	0.41	0.070265321	0.028808782
20	0.41	0.061100279	0.025051114
			$10,066,326

Table 7: Discounted Cash Flow for NGH

		NGH PROCESSING		
YEARS	operating cost ($) ×10^6	Discount factor	Income($MM)	15% DCF ($) ×10^6
0	0	1	0	0
1	0.35	0.869565217	0	-0.304347826
2	0.35	0.756143667	3.73584	2.560181474
3	0.35	0.657516232	3.73584	2.22624476
4	0.35	0.571753246	3.73584	1.935865009
5	0.35	0.497176735	5.23224	2.427336144
6	0.35	0.432327596	5.23224	2.110727082
7	0.35	0.37593704	5.23224	1.835414854
8	0.35	0.326901774	7.47426	2.328933231
9	0.35	0.284262412	7.47426	2.025159332
10	0.35	0.247184706	7.47426	1.761008114
11	0.35	0.214943223	7.47426	1.531311404
12	0.35	0.18690715	7.47426	1.331575134
13	0.35	0.162527957	7.47426	1.157891421
14	0.35	0.141328658	7.47426	1.006862105
15	0.35	0.122894485	7.47426	0.875532265
16	0.35	0.10686477	7.47426	0.761332404
17	0.35	0.092925887	7.47426	0.662028178
18	0.35	0.080805119	7.47426	0.575676676
19	0.35	0.070265321	7.47426	0.500588414
20	0.35	0.061100279	7.47426	0.435294273
				$27,744,614

Table 8: Discounted Cash Flow for LNG

		LNG PROCESSING		
YEARS	OP cost ($) ×10^6	Discount factor	Income($MM)	15% DCF ($) ×10^6
0	0	1	0	0
1	0.51	0.869565217	0	-0.443478261
2	0.51	0.756143667	3.24352	2.066933837
3	0.51	0.657516232	3.24352	1.797333772
4	0.51	0.571753246	3.24352	1.562898932
5	0.51	0.497176735	4.54272	2.004974564
6	0.51	0.432327596	4.54272	1.743456143
7	0.51	0.37593704	4.54272	1.51604882
8	0.51	0.326901774	6.48928	1.954637238
9	0.51	0.284262412	6.48928	1.699684555
10	0.51	0.247184706	6.48928	1.47798657
11	0.51	0.214943223	6.48928	1.285205713
12	0.51	0.18690715	6.48928	1.117570185
13	0.51	0.162527957	6.48928	0.971800161
14	0.51	0.141328658	6.48928	0.845043618
15	0.51	0.122894485	6.48928	0.734820537
16	0.51	0.10686477	6.48928	0.63897438
17	0.51	0.092925887	6.48928	0.555629896
18	0.51	0.080805119	6.48928	0.483156431
19	0.51	0.070265321	6.48928	0.420136027
20	0.51	0.061100279	6.48928	0.365335676
				$22798149

Table 9: Discounted Cash Flow for GTL

		GTL PROCESSING		
YEARS	OPC ($) ×10^6	Discount Factor	Income($MM)	15% Discounted CashFlow ($) ×10^6
0	0	1	0	0
1	0.41	0.869565217	0	-0.356521739
2	0.41	0.756143667	3.423712	2.278799244
3	0.41	0.657516232	3.423712	1.98156456
4	0.41	0.571753246	3.423712	1.723099617
5	0.41	0.497176735	4.791432	2.178346058
6	0.41	0.432327596	4.791432	1.894213963
7	0.41	0.37593704	4.791432	1.647142577
8	0.41	0.326901774	6.845218	2.103684179
9	0.41	0.284262412	6.845218	1.829290591
10	0.41	0.247184706	6.845218	1.59068747
11	0.41	0.214943223	6.845218	1.383206496
12	0.41	0.18690715	6.845218	1.202788257
13	0.41	0.162527957	6.845218	1.045902832
14	0.41	0.141328658	6.845218	0.909480724
15	0.41	0.122894485	6.845218	0.790852803
16	0.41	0.10686477	6.845218	0.68769809
17	0.41	0.092925887	6.845218	0.597998339
18	0.41	0.080805119	6.845218	0.519998556
19	0.41	0.070265321	6.845218	0.452172657
20	0.41	0.061100279	6.845218	0.393193615
				$24853599

Table 10: NPV at different discount rates for GTL, LNG and NGH

NPV	DISCOUNNT RATES(%)	GTL	LNG	NGH
NPV@0	0	97933266	88809360	110259620
NPV@15	15	17353599	14088149	20934614
NPV@30	30	2486483	352186	4414902
NPV@45	45	-2146290	-3906195	-749779

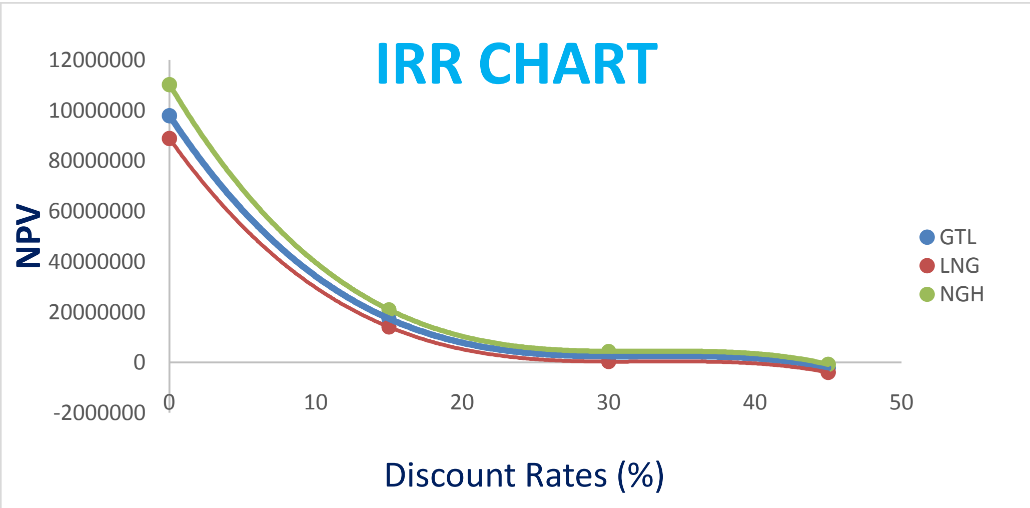

Figure 1: Comparative Internal Rate of Returns chart for NGH, GTL and LNG

3.2 Discussion

Table 3 and Table 4 shown below illustrates the discounted cost at 15% PV for NGH and LNG respectively. This shall be used by substituting into equation 8 to make the decision on which is more economical gas utilization between Natural Gas Hydrate (NGH) processing and LNG processing. There is a need to make an economic comparison between natural gas hydrate processing with gas to liquid processing, which will act as a node to ascertain which gas type is suitable or rather, economical on the part of costs and perhaps returns. Table 5 and 6 illustrates the undiscounted and discounted costs of GTL processing respectively.

Since the incremental Net Present Value gave a positive value, it implies that natural gas hydrate should be selected over liquefied natural gas for the estimated assumed distance of 40 miles. When comparisons were also made between NGH and GTL, the economic indicator (NPV) selected NGH over GTL. However, for distances greater than approximately 40 miles, the capital costs for NGH transport could be higher, which will relatively affect to NPV comparison with the other alternative transportation modes. Thus, preliminary assumptions in this study was in reference to the claim that capital costs of a NGH production plant are about 35% less than a LNG plant and capital costs of NGH carrier vessels are approximately 6% less of capital costs of LNG carriers [5]. Moreover, the internal rate of returns curves shown in fig.1, reveal discount rates of 40%, 43% and 44% for LNG, GTL and NGH respectively. This implies that, a discount rate greater than 40% for LNGwill result in a negative NPV, thereby rendering the investment on LNG less feasible. The same principle applies to GTL and NGH for their respective internal rate of returns.

The discounted cash flows for NGH, LNG and GTL are represented in Table 7, Table 8 and Table 9 respectively. However, Table 10 shows the net present values at different discount rates for the three gas states. The IRR curves for LNG, GTL and NGH are illustrated in fig.1.

4. Conclusion

Inquest to investigate the gas type which is best for the transportation of natural gas over short distances, an economic model was employed. Three major technology type were primarily considered Natural Gas Hydrate (NGH), Liquefied Natural Gas (LNG) and Gas to Liquid (GTL). The cost of using the NGH facility and the truck for its transportation was roughly estimated to be $6.81 million while that of LNG facility costs $8.71 million. However, the economic analysis performed suggested that NGH be selected over LNG as a means for the transportation of natural gas over a maximum distance of 40miles for domestic purposes. The discounted costs for GTL (which is $10,066,326) is cheaper compared to that of LNG (which is $11,902,259). Thus, in the absence of NGH processing, GTL is preferable to LNG for distances of about 40miles. However, comparison between NGH and GTL indicated through a positive NPV that NGH be selected over GTL. To sum up, when the discounted cash flow rate of returns' indicator was employed, Natural Gas Hydrate gave the highest value of Net Present Value (NPV) at a zero discount rate when compared to that of LNG and GTL. It can therefore be deduced that, natural gas hydrates are much more economically viable when compared to LNG and GTL for short distances.

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