Available online www.jsaer.com

***Journal of Scientific and Engineering Research*, 2021, 8(1):18-26**

Research Article

ISSN: 2394-2630
CODEN(USA): JSERBR

Comparative study of pipeline and marine transportation modes for Gas-to-Liquid (GTL) products from Nigeria to Overseas

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Abstract Transportation modes mainly marine for marketing of Gas-to-liquid (GTL) products from the Niger Delta region of Nigeria to Overseas were evaluated economically using Microsoft visual basic program. Discounted project cash flow analysis was performed to ascertain the discount rate at which the project is economically viable. Marine transportation mode at Capital expenditure (Capex) of $1.7billion, Crude oil price of $70/bbl, Gas price of $4.06/Mscf and assumed discount factor of 10% were evaluated. Results obtained for Net Present Value (NPV), Internal Rate of Return (IRR) and Payout Time (POT) are $139.5million, 11.76% and 7.87years respectively. These suggest that the project is economically viable. Pipeline transportation mode was also evaluated. Consequently, through the profit indicators it was discovered that this mode of transportation is abysmal. Net present value after 20 years is negative of $2.158 billion. Payout out time for pipeline transportation mode is 18.24 years. Return on Investment (ROI) for pipeline transportation mode is 0.01 while marine transportation mode ROI is 0.02 which is better.

Keywords Economics, GTL products, Capex, gas price, crude oil price, Opex, plant capacity, ROI, NPV, IRR, POT, discount, transport, marine, pipeline, analysis

1. Introduction

World reserves in natural gas is more than 5,000 TCF [1]. The Middle East has about 40% of world's natural gas reserve. The former Soviet Union along with Eastern Europe ranked world's second largest natural gas reserves with about 38%. Nigeria with about 187 trillion cubic feet of gas (about 32 billion barrels of oil equivalent) reserves is ranked seventh in the world and the leading country in Africa, based on the country's natural gas reserves. Out of this existing gas reserve in Nigeria, 50 trillion is committed to LNG while over 130 trillion cu ft are stranded. Nigeria contributes about 20% of the total volume of gas flared in the world. With increase in the discovery of gas worldwide, a number of transportation and utilization methods can be used to produce natural gas. Currently, World gas reserves stand at 7121.4 TCF. US has proven gas reserve of 463.3 TCF – with the discovery of shale gas [2]. Nigeria has proven gas reserve of 202 TCF occupying position as the 9th country in the world [3]. US natural gas production has risen to 71.1 BCF/day in 2017 making US the world largest producer of natural gas [4]. Nigeria presently produces 8.5 BCF/day [3].

The shale gas revolution in the US has the potential for natural gas to be exported to Europe and Asia in the form of LNG or even GTL [5-7].

When the plan for construction of GTL plant in Escravos, Nigeria was conceived, mainly Europe and may be US were targets as potential market, for GTL products [8] but with shale gas revolution in US, export of GTL products to US may no longer be feasible. Consequently, market can be sought for the products overseas.

Pipeline is the most suitable means of transporting natural gas from the production centre to distant markets. However, other technologies like liquefied natural gas (LNG) gas-to-liquid (GTL) and compressed natural gas (CNG) can be used as gas transportation and utilization options. CNG and LNG are used for gas transportation to distant markets while GTL technology is used for stranded gas.

GTL products are high quality sulphur free petroleum products obtained from natural gas. They include Diesel, Naphtha and LPG depending on the operating condition. High premium is placed on these products overseas due to the quality and consequently higher revenue. The GTL processes currently in operation convert 10,000 cubic ft. of gas into slightly more than 1 barrel of liquid synthetic fuel [1].

2. GTL Products Transportation Mode

Transportation modes of GTL products include pipeline and maritime transportation.

2.1. Maritime Transportation

Ships operate mostly in international trades. They carry mostly liquids and dry bulk cargo and often non mixable products in separate compartments. Ships are made in different sizes. Ship sizes are rated by its weight carrying capacity and the volume capacity of the products being transported. Dead weight (DWT) is the weight carrying capacity of a ship, in metric tons. Tankers are designed to carrying liquids in bulk. Gross Tons (GT) is the volume of the enclosed spaces of the ship in hundreds of cubic feet. Hauling capacity of a ship is the product of ship size and its speed, while handling capacity of a ship is the cargo loaded or unloaded per unit time [9].

However, there are some challenges in marine transportation which include the following:

(a) Higher uncertainty in their operation due to their higher dependence on weather conditions and on technology,

(b) Floods or periods of low water may limit when or where they can operate,

(c) Slow speed about 28km/hr,

(d) Delays encountered in Ports during loading and offloading especially where rapid deliveries are required [10].

Table 1: Tanker Categories and Carrying Capacities [11]

Tanker	Length (ft)	Capacity (bbl)
Panamax	760	500,000
Aframax	800	800,000
Suezmax	900	1,000,000
VLCC	1000	2,000,000
ULCC	1300	3,000,000

2.2. Pipeline Transportation of Liquid Petroleum Products

Pipeline transportation of liquid products is better for shorter hauls and thus should dominate local and regional trade. Within local and regional trade, pipeline transportation is cheap, less hazardous and more environmentally friendly. Pipelines accrue the costliest fixed cost and smallest variable cost among other transportation modes. High fixed costs emanates from the right of way of pipeline construction and the necessity to have control stations, and pumping capacity. Subsea pipeline construction is both economically and technically challenging. Most liquid products at sea is transported by tank ships. All international trade of Crude oil and petroleum product that involve long distance and trans-oceanic carriage is done by ship despite the fact that tank ships may run empty during return trips [12].

2.2.1. Constraints on the Pipeline System Subsea Transportation

Potency of soil and stability of the sea floor with other environmental conditions such as water depth, temperatures, marine life and other activities in the area such as shipping and industrial operations affect laying of pipelines. Safety and reliability of the pipeline system must be guaranteed. Laying of pipeline in arctic conditions require thorough survey. This means looking for ice gouges and strudel scours. Ice gouging can occur when ice keels contact the sea floor. The gouges indicate where pipeline must be buried to protect them from the Ice keels. Strudel scours are formed during the spring melt, when fresh water from local stream and river break ups flow over the sea ice. This water finds seal breathing holes or cracks in the ice pipeline [11].

3. Materials and Methods

i. In this research work, two transportation modes namely marine transport and pipeline were considered for marketing of GTL products from production terminal at Escravos in the Niger Delta region of Nigeria to US.
ii. Economic evaluation of the two transportation modes was performed to ascertain the impact of the transportation modes on the overall project economics of the GTL plant at Escravos. The economic model used three economic indicators namely, Net present value (NPV), Internal rate of return (IRR), and Pay out time (POT).
iii. Microsoft visual basic program was designed to show the impact of the two transportation modes on the entire project economics.

3.1. Methods of Calculation for different Transportation modes of GTL products

The total cost is obtained with equation 3.1

Total Costs = Operating cost + ROI * MMI 3.1

(Smyk2010)[13].

Where MMI – the capital invested in processes related to transport mode measured in dollars.

ROI – return on Investment.

Operating costs is calculated by using equation 3.2

Operating costs = TC * D * AVT where 3.2

(Smyk, 2010)[13]. where

AVT - volume of products being transported (Barrels)

TC - Cost of transportation per barrel per Km

D - Distance of transportation, Km and ROI is obtained using equation 3.3a or 3.3b

$$ROI = \frac{\text{Annual average cash flow}}{Net\ investment\ outlay\ .} \quad 3.3a$$

or

$$\frac{\text{Gross Revenue} - \text{Taxes} - \text{Opex}}{Economic\ Life\ of\ the\ project} / CAPEX \quad 3.3b$$

3.1.1. Calculations on Marine Transportation of GTL Products

Using the data below, operating cost and ROI can be calculated using equation 3.2 and 3.3a or 3.3b respectively.

Distance of transportation, Km (D) = 10,400 Km

Capacity of the ship (AVT) = $2x10^6$ barrels

Cost of transporting 2×10^6 barrels per Km = $1293.27

Cost of transportation per barrel per Km (TC) $ 647×10^{-6}

Speed of transportation 28Km/hr [10]

Hence Operating cost = $\$647 \times 10^{-6}$/bblkm x 10,4000 Km x 2×10^6= $\$13.5 \times 10^6$

$$ROI = \frac{(\$828.6 \times 10^6 - \$93.2 \times 10^6 - 35.9 \times 10^6)/20}{1.7125 \times 10^3 \times 10^6}$$

$$ROI = \frac{34.975 \times 10^6}{1.7125 \times 10^3 \times 10^6}$$

ROI = **0.02**

MMI = $ zero because no capital was invested in marine transport.

Total costs = (Operating cost) +(ROI * MMI)

= ($\$13.5 \times 10^6$) + (0 * 0.02)

= ($\$13.5 \times 10^6$) +(0)

Total cost. = $\$13.5 \times 10^6$million

3.1.2. Calculations on Pipeline Transportation of GTL Products

Pipeline construction costs depends on diameter, operating pressures, distance and terrain. Other factors include climate, labour costs, safety regulations, population density and rights of way which may cause construction costs to vary significantly from one region to another. Universally, the investment required to lay a long distance large diameter line (46 to 60 inches), enabling a throughput of about 15 to 30 m^3/year, currently amounts to $1billion to $1.5billion/1000km [14]. Investment on offshore pipelines are much higher depending on water depths. Distance to be covered from west Africa to US=10,400 Km [15].

Speed of oil through pipelines is 3 to 8miles per hour. Pipeline transport speed depends on the diameter of the pipe, the pressure under which the oil is being transported and other factors such as the topography of the terrain and the viscosity of the oil being transported. To transport oil through pipeline from Houston Texas to New York it takes about 14 to 22 days or Saudi Arabia to UN in just 23 to 61 days [16].

Distance of transportation (D) = 10,400km

Quantity of GTL product being transported (AVT) = 2 x 10^6 barrels

Speed of transportation = 6mph or 9.66km/hr.

Time required for delivery of GTL product over a distance of 10,400km

= 10400/9.66 = 1076.6hrs or = 45 days

Operating cost of transporting 1 barrel of GTL product is $0.10 per 1000miles or $0.10 per 1609km [17].

From eqn 3.2 above

Operating cost =$0.00006215/barrel km + 10, 4000km 2 x 10^6 barrels

= $1292720 or $1.3MM.

3.2. GTL Products and Marine Transportation Cash Flow Model Parameters

Nigeria Escravos GTL plant capacity of 34,000 bbls/day, and 328.78MMCF/day of natural gas feed stock are considered for the economic evaluation in this study. The plant is expected to produce Diesel Oil, Naphtha, and LPG. The recoverable values assumed in this study are: Diesel Oil-75%, Naphtha-20%, and LPG-5%. This is based on previous study conducted by industry experts [18].

To evaluate economically GTL products and transportation, some assumptions are made as part of the major input parameters in the economic model and are needed to show the effect of transportation on the entire project economics.

The following assumptions and parameters are used in the analysis.

- Plant capacity = 34,000 bbl/day
- Natural gas price = $4.06/MSCF ($4.06/MMBTU)
- Plant cost = $1.6 billion
- Plant installation cost = $1 million
- Cost of pipelines and meters = $10.4 million
- Tank cost = $700000
- Operating cost per bbl of product = $1.0
- Maintenance cost per bbl of product = $1.0
- Feed gas volume per day = 328.78 MMscfd
- Ship cost per journey = $2.33 million
- Ship capacity = 2 MM bbl
- Tank capacity = 2 MM bbl
- Crude oil price = $70/bbl
- Royalty = 5% of Gross Revenue
- Tax = 30% of Gross Income
- Project life span = 20 years
- Operational days = 330 days
- Discount rate = 10%
- Efficiency = 60%

3.3. Economic Indicators used in the Analysis of GTL Project

3.3.1. NPV for the GTL Project

Net Present Value, (NPV) is an economic indicator for project acceptability or unacceptable. The NPV of an investment proposal is the present value of the proposal's net cash flows less the proposal's initial cash outflow. The expected cash flows on an investment set out year by year and brought to a present value by the use of present value factors at the appropriate rate [19]. NPV compares the value of 1 dollar today to its value in future taking inflation into consideration. If the NPV of a prospective project is positive, it is accepted. However, if NPV is negative, the project should be discouraged because cash flows will also be negative [20]. An investment with the best NPV is ranked first when considering two or more investment that are mutually exclusive

$$NPV = -ICO_0 + \sum_{n=O}^{N} \frac{CFn}{(1+k)^n} \qquad 3.4$$

Where,

ICO_o = Initial Cash outflow at zero year, which is the CAPEX

CFn = Operating Cash Flow for the nth year

N = Project Life, in year

K = discount factor or rate.

3.3.2. Internal Rate of Return (IRR)

The internal rate of return for an investment proposal is the discount rate that equates the present value of the expected net cash flows with the initial cash out flows. The IRR is closely related to the NPV since it is the discount rate used when the NPV is equal to zero. An investment is acceptable if the IRR exceeds the required return, otherwise it should be rejected [21]. The acceptance criterion generally employed with the internal rate of return method is to compare the internal rate of return to a required rate of return, known as the cutoff, or hurdle rate. The discount rate assumed for the purpose of this research work is 10% [22]. The IRR is calculated using equation

$$ICO_0 = \sum_{n=O}^{N} \frac{CFn}{(1+IRR)^n} \qquad (3.5)$$

Where,

ICO_O = CAPEX

CF_n = Operating Cash Flow for the n^{th} year.

N = Projects useful Life Cycle.

3.3.3. Pay Out Time

The payout time is defined as the expected number of years required for recovering the original investment. At this point, the cash receipts exactly equal the cash disbursements. Payout time does not give information on the profitability of the project but gives information on the period the initial cash investment is expected to be recovered during the plants working life. Payout time is calculated from the net cash flow by two different methods. The first method requires accumulating the negative net cash flow each year until it turns positive. Using interpolation between the two values (negative and positive) the time is calculated. The second method involves plotting the cumulative net cash flow versus time [23]. A Microsoft visual basic program was written to perform the cost and revenue analyses of GTL products transportation modes.

3.4. Pipeline Transportation Mode of GTL Products

3.4.1 Economic Assumptions and Parameters for Pipeline Transportation Mode of GTL Products

1. Plant capacity - $34, 000 bb.day
2. Natural gas price - $4.06 / MSCF (4.06/mmbtu)
3. Plant cost - $1.6 billion
4. Plant installation cost - $1 million
5. Cost of pipeline and meters - $10.4 million

6. Tank cost for each product - \$700, 000
7. Operating cost per bbl of product - \$1.0
8. Maintenance cost per bbl of product - \$1.0
9. Feed gas volume per day - 328.78 mmscfd
10. Pipeline capacity - 2 million bbl
11. Tank capacity - 2 million bbl
12. Crude oil price - \$70/bbl
13. Royalty - 5% of gross revenue
14. Tax - 30% of gross income
15. Project life span - 20 years
16. Operational days - 330 days
17. Discount Rate - 10%
18. Efficiency - 60%
19. Pipeline capex - \$2335. 1 million
20. Pipeline opex - \$29.7 million
21. Cost of pipeline transportation per bbl - \$0.6464
22. Pipeline transport distance (km) - 10,400km or 6464miles
23. Flow rate of GTL product - 34, 000 bbl day
24. Diameter of pipeline - 7.8inches

3.5. Pipeline Design and Economic Analysis of Pipeline Transportation Mode

Pipeline cost components are based on pipeline diameter, pipeline length, location of pipeline, pipeline capacity and year of completion.

3.5.1. Calculation of Pipeline Diameter

Pipeline diameter can be calculated using this formula:

$$V = S \times L \qquad 3.6$$

where V – capacity of the pipeline ft^3, S – cross sectional areas ft^2,L - length of the pipeline ft [24].

Pipeline capacity = 2×10^6bbl

Converting bbl to $ft^3 = 2 \times 10^6 \times 5.615 = 11.23 \times 10^6\ ft^3$

Length of pipeline = 10,400 km or 6464 miles converting miles to ft

L = 6464 x 5280 ft = 34129920 ft

From 3.17

$$S = V/L = \frac{11230000}{34129920} = 0.329\ ft^2$$

$$S = \frac{\pi D^2}{4},\quad D = \frac{4S}{3.14} = \frac{4x.329}{3.14} = \frac{1.3161447}{3.14}$$

$D^2 = 0.4189$

$D = \sqrt{0.4189} =$ **0.6472 ft**

Therefore, Diameter of pipeline required = 0.6472ft or 7.8 in.

3.5.2. Pipeline Capital Expenditure (CAPEX)

Cost per mile increases with the pipe size. Total offshore construction cost of pipeline with 4-10 in diameter over a distance of 10,400 km (6464miles) = \$1589 million [25]. This amount includes pipe material cost, pipe coating, wrapping cost, and labour cost of installing the pipeline. Interval between pump stations is 150km (93.23miles) apart [26].

Consequently, number of booster stations = 6464/93.23= 69

Using the following data [27]

Throughput = 34,000 bbl/day

Outside diameter = 7.8 in

Wall thickness of the diameter = 1/4 inch
Suction pressure of booster station = 20 psi
Discharge pressure = 1933 psi
Station horsepower = 813 *HP*
Pump efficiency = 81%
Total hydraulic horsepower over a distance of 10400km can be calculated as 813 HP x 69 = 56097 HP
Total capital cost of all booster station along the 10,400 km pipeline = $1000 / HP x 813HP x no of booster stations, where $ 1000/HP and no of boosters station are obtained from Chang-Won Park [26].
$ 1000/HP x 813HP x 69 = $56.1 million
Monomooring cost can also be calculated using the value as $10 million per unit of booster station [26].
For 69 units of booster station = $10 million x 69 = $690 million
Monomooring sea platform comprises of metal structure anchored to the ground and a head projecting from the sea surface and carried by a metal structure by a bearing to the vertical axis of which the head is freely rotatable.
Pipeline capex is composed of cost of pipeline material, pipe coating, wrapping cost, labour cost of installing the pipeline, pump station cost and cost of monomooring sea platform. The cost of right of way (Row) is not considered in this analysis as it is difficult to estimate and varies widely from project to project.
Pipeline capex = offshore construction cost + total pump station cost + total monomooring sea platform cost.
Pipeline capex = $1589 million + $56.1 milllion + $ 690 million = $2335.1 million.
Total Capex = Pipeline capex + GTL plant capex = $2335.1million + $1712.4 =$4047.5 million.

3.5.3. Operating Cost of Pipeline (OPEX)

Operating cost of transporting 1 barrel of GTL product is $0.1 per 1000 mile [17]
Opex for 10,400 km (6464) miles length pipeline = $\frac{\$0.1}{1000} \times \frac{6464}{1}$ = $0.6464 per bbl
Therefore, for 2 million bbl = $0.6464 x 2 million = $1.3 million.
It should be noted that the pipeline was assumed to be built on a level terrain because unit construction cost will be higher if pipelines are constructed in areas with steep terrain as the pipeline will be longer, more hours of construction labour will be required and additional booster stations will be needed.

3.5.3.1. Total Pipeline Operating Cost for the 3 Products in One Year

Total pipeline operating cost = (for the 3 products in one year)

$$\left[\frac{330}{\left(Tank^{cap}/_{ddp}\right)} * Poc\right] + \left[\frac{330}{\left(Tank^{cap}/_{ndp}\right)} * Poc\right] + \left[\frac{330}{\left(Tank^{cap}/_{ldp}\right)} * Poc\right] \quad 3.7$$

Where $Tank^{cap}$ =Tank capacity, Poc =Pipeline operating cost.
From 3.7
Pipeline cost for diesel transportation=[(330/2000000/25500)x1300000]
=$5.47MM.
For Naphtha transportation=[(330/2000000/6800)x1300000]=$1.46MM
For LPG transportation = [(330/2000000/1700)x1300000]=$0.36MM
Total pipeline operating cost for the 3 products per annum (P_T)= $5.47MM+$1.46+$0.36MM= **$7.29MM**.
Operating Expenditure for pipeline [(operating cost per bbl of product+ maintenance cost per bbl of product)*(ddp+ndp+ldp)]*330+P_T
= [($1/bbl+$1/bbl)*(25500+6800+1700)]*330+$7.29MM
=$29.74MM.
Tax= 30% of Gross Income= .3 x .3170 **= 0.0951 billion.**
Gross Revenue **= $828.6 million**
Royalty = 5% of Gross Revenue = .05 x $828.6 million **= $41.43 million.**
Gross Income = NR – Operating expenditure – Cost of natural gas
=$787.2 million - $29.7 million - $440.5 million **=$317 million**

Net Revenue (NR)= Gross Revenue (GR) – Royalty = $828.6 - $41.43**= $787.2million**
Net Cash Flow= Gross Income – Tax =$317million - $95.1million **= $221.9 million.**

Return on Investment (ROI) = $\frac{\text{Gross Revenue} - \text{Taxes} - \text{Opex}}{\text{Economic Life of the project}} / CAPEX$

Return on Investment (ROI) = $\frac{828.6-95.1-29.7}{20}/4047.5$ **= 0.01.**

4. Results and Discussion

Net present value (NPV), Internal rate of return (IRR), Pay Out Time (POT) and Return on Investment (ROI) for marine transportation mode are $139.5 million, 11.76%, 7.87 years and 0.02 respectively while for pipeline transportation mode NPV is -$2.158, IRR is below 0%, POT is 18.24 years and ROI is 0.01.

5. Conclusion

Pipeline transportation mode increases cost of investment since CAPEX is $4.0475billion , IRR < 10% (Hurdle rate), POT is 18.24 years and return on investment is 0.01 while Marine transportation mode CAPEX is $1.7billion, IRR is 11.76%, POT is 7.87 years and ROI is 0.02. Therefore marine transportation mode is better where pipeline construction is required which increases investment cost.

Nomenclature

Bbl/day - Barrels per day
IRR - Internal rate of Return.
POT - Pay Out Time
NPV - Net Present Value.
ROI - Return on Investment
CAPEX - Capital Expenditure
OPEX - Operating Expenditure
MMI - Capital invested in processes related to transport mode
AVT - Volume of product being transported (barrels).
TC - Cost of transportation per barrel per km
D - Distance of transportation
% - Percentage
$/Mscf - Dollar per thousand standard cubic feet
$MM - Millions of dollars
$B - Billions of dollars
Yrs - Years
SCF/d - Standard cubic feet per day
Mscf - Thousand standard cubic feet
MMscf - Million standard cubic feet.
GTL - Gas-to-liquid
LNG - Liquified Natural Gas

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