Natural Gas Utilization: A Case Study of GTW AND GTL Technologies

Oluwatobi Ajagbe

University of Oklahoma

This paper is a personal research effort into Natural Gas Utilization Technology.

Abstract

This paper itemizes different utilization technology that could be used to monetize natural gas asset and a comparative techno-economic study of the use of Gas-to-Wire (GTW) technology and Gas-to-Liquid (GTL) to monetize a gas asset was also carried out. A study of this nature is necessary given the increase in the fraction of natural gas in the global energy mix, lower cost of exploration and production of gas reserve and the dip in natural gas price experienced in recent years.

The comparative study includes two scenarios describing the different production condition of the gas asset. Economic metrics such as Net Present Value (NPV), Internal Rate of Return (IRR) and, Payback Period were used to assess the project yield for the two utilization projects.

Sensitivity analysis was carried out on certain market drivers used in the analysis to ascertain the level of influence of each driver on the project yield and to compare how do their level of influence differ with each project. Monte-Carlo simulation was also used to analyze the level of risk involved in the two utilization.

A research of this nature is expected to serve as a guide to a natural gas producer in this era of abundance, but a low price when considering various options on how to monetize their natural gas assets.

Introduction

The natural gas industry has experienced a dramatic change over the past 13 years with the price halving with continued growth in production. The success in the exploration of unconventional resources, mainly in the US contributes to the experienced growth in natural gas supply, by 2040, the US is expected to account for almost one-quarter of global gas production.

At the moment, Natural gas is the fastest-growing energy source according to industry experts, and the consumption of natural gas is projected to rise by almost 70% by 2025 from 92 trillion cubic feet to 156 trillion cubic feet. The electric power sector makes up almost half of the total growth in world natural gas demand over this period. The greatest increase in demand for natural gas is expected to occur among the emerging economies.

Industrial consumption of natural gas is also projected to rise over the next 10 to 15 years from 8 trillion cubic feet in 2003 to 10.3 trillion cubic feet in 2025 according to OECD reports. While natural gas consumption is expected to increase for most industrial sectors, industry reports suggest that decreases are expected to occur in the iron, steel, and aluminum industries. The largest increases in natural gas consumption from 2003 to 2025 are anticipated in petroleum refining, metal durables, bulk chemicals, and food industries. Residential consumption is also projected to grow over this period by nearly 1%.

Russia is the world's largest producer of natural gas. In addition, the largest increases in world natural gas consumption are also projected to occur in Russia, Eastern Europe, and the emerging economies of Asia. By 2025 natural gas consumption is projected to grow by 63%. Emerging economies in Asia are expected to almost triple its current consumption rate in 2025.

The emerging economies are also expected to experience the fastest growth in natural gas production. In comparison, the industrialized or 'mature economies' production in natural gas is projected to decline in 2025, making up only 29 percent while accounting for nearly 45% of world consumption.

The gaseous status of this fuel poses significant challenges in its transport to distant markets. In other words, the disconnection between remote and offshore gas reservoirs and markets has obstructed a fully-developed market and globally traded commodity status for Natural gas. Natural trade for a long time has been through pipelines and limited to supply countries and their neighbors.

Its transport in the liquefied form (LNG) as an alternative to pipeline began in the 1960s mainly as a result of serious energy demand in countries (e.g. Japan) remote from the supply resources. The 600-fold volume reduction on liquefaction made it economical to ship natural gas to such countries using dedicated LNG carriers. In such instances, pipelines were either technologically impossible or economically unattractive. The introduction of LNG as a new natural gas utilization alternative has significantly fostered global natural gas trade. Although pipelines and LNG have been the two most common methods of natural gas transport from large gas reservoirs, a significant portion (between 30 and 80% of proven and potential natural gas reserves) of natural gas is still trapped in the so-called "stranded" category. Recent works studied the possibility of utilizing GTL technology to reduce the dependence of the US on the importation of transport fuel. The study established that the given a continuous supply of gas to the GTL plant for over three years, the technology is a feasible option to help the US produce more transport fuel for local consumption or export purpose. (Ajagbe and Ghanbarnezhad Moghanloo 2018, Da Silva Sequeira and Ghanbarnezhad Moghanloo 2019).

The next section introduces common utilization technologies used to monetize natural gas assets. **Table 7** presents additional technologies with a comparison of their strength and weakness as a natural gas utilization project.

Liquefied Natural Gas

Liquefied natural gas (LNG) is one of the numerous ways of transporting and monetizing natural gas asset, especially when it involves the delivery of natural gas to a location beyond 2500 miles from the source where other means of transporting gas becomes less desirable. LNG involves the physical conversion of natural gas into a liquid using the cryogenic conditions, transporting the LNG to the desired markets is usually by specially designed ocean liners and then regasifying the LNG into a gas phase (Faleh and Abel, 2009).

A conventional LNG project involves bringing together four (sometimes five) interdependent activities to connect the gas producer to the end-user in what is called the LNG value/supply chain. These activities consist of exploration and production (E&P), gas gathering (i.e. trunk lines), liquefaction, shipping, and re-gasification. The gas transmission/gas gathering phase by means of trunk lines to deliver the produced gas from the remote fields to the liquefaction plant is sometimes lumped with the E&P phase to reduce the value chain to four (Faleh and Abel, 2009).

Compressed Natural Gas

The basic concept for compressed natural gas (CNG) is to compress the natural gas at pressures ranging between 1,500 and 3,000 psi (about 100-200 atmosphere), and sometimes chill it to lower temperatures (up to - 40°F, -40°C). CNG technology is quite simple and can be easily brought into commercial applications. Nonetheless, no CNG sea transport projects are currently operating, even if the technology is already proven in several applications, including fueling taxis, private vehicles, and buses worldwide. In 1969 the first attempt to build up a CNG carrier vessel brought to commissioning a rudimentary cargo bottles with CNG capacity of 1,300 Mcf, but the overwhelming required investment (compared to the scarce profit achievable in those years with extremely low natural gas prices) made the application and diffusion of the technology impracticable (Marongiu-porcu et al, 2008).

The development in the last decade of several innovative containment concepts is finally promising to make CNG sea transportation attractive. One of these concepts employs high-pressure gas storage and transportation system based on a coil of relatively small-diameter pipe (6 to 8 inches, about 15 to 20 cm) sitting in a steel-girder carousel. Considering natural gas compressed at 3,000 psi and at ambient temperature, a typical CNG carrier assembled with 108 carousels can offer up to 330 MMscf (about 10 MMscm) of capacity. Figure 2 shows such a CNG vessel arrangement (Marongiu-porcu et al, 2008).

Compressed natural gas, CNG. Satisfying small markets and monetizing small reserves are the two main targets that CNG schemes intend to pursue. This would unlock reserves, which otherwise would remain stranded and would supply many small markets that could not be economically justified via pipeline or LNG. The scalability of the CNG sea transport system and the opportunity to reuse its major assets (the carrier vessels) make this concept even more attractive (Wagner et al, 2002).

Gas To Liquid

Gas-to-liquids is a catalytic process which involves the chemical conversion of natural gas (primarily contains methane) into liquid hydrocarbons - naphtha, diesel, and waxes. Conversion of pipeline quality natural gas (essentially methane) to liquids is a polymerization process. Hydrogen is removed, and methane molecules are polymerized to longer chain hydrocarbon or related molecules, similar to molecules found in crude oil fractions. Such fractions include diesel fuel, naphtha, wax, and other liquid petroleum or specialty products (Wood et al 2012).

GTL is one of the appropriate options in the utilization of flared natural gas. The main end-products of GTL include naphtha and transportation fuels such as diesel and jet fuels. Other products include high quality lubes, waxes, and white oils, which are utilized in the food and pharmaceutical industries. A GTL unit comprises of three core technologies: synthesis gas (syngas) manufacture, Fischer-Tropsch (F-T) synthesis and hydrocracking. Mini GTL technologies have been developed with natural gas feedstock capacities ranging from 200 Mscfd to 25 MMscfd.

It can be seen from the brief review of flare gas utilization technologies that, GTW, NGL, and LNG require larger volumes of natural gas feedstock than GTL (especially mini GTL). GTL could be used to monetize low flare gas volume with minimum infrastructure and investment. Again, GTL products are liquid fuels and chemicals (such as alcohols and ammonia), which means that their market potential is wider than other monetization technologies.

Gas To Wire

GTW consists of gas processing and power generation plants at well-site and High Voltage Direct Current (HVDC) transmission. The power plant is better to be Gas Turbine Combined Cycle (GTCC) for high efficiency of totally 50 % thermal efficiency on lower heating value base and at both ends of HVDC, converter stations from Alternating Current (AC) to Direct Current (DC) and again from DC to AC are equipped. Gas properties vary from a well to other well and acid gas like H2S and /or impurities like alkaline metal might be contained (Watanbe et al, 2006).

According to (Watanbe et al, 2006) It is not economical to construct a luxurious gas treatment facility to strip all harmful substances and therefore, practical gas treatment facility shall be designed for each case considering the reliability of the system. GTCC system is applied widely in the world and mainly used for huge power plant due to high thermal efficiency and less environmental impact. And its reliability and availability have already been proven by a long-term operation. However, in order to apply GTCC for marginal gas field or associated gas adjacent to oil fields producing an inconstant volume of gas with uneven properties, it is necessary to design countermeasures for fuel back-up such as oil. HVDC can minimize the transmission loss and be suitable for long-distance and large capacity of power transmission.

Gas To Hydrate

Studies have been carried out to investigate the transportation and storage of natural of gas in a solid-state (Gudmundsson et al. 1990, 1992, 1994 & 1995; JPT Staff 1999; Pallipurath 2008; and Wilson et al 2008). Natural gas hydrate (NGH) forms when water molecules encage molecules of natural gas at low temperature and high pressure to form a solid-state compound which forms the basis of gas to hydrae (GTH) technology. Natural gas hydrate is made up of one molecule of water to eight molecules from natural gas mainly methane, ethane, propane, normal butane, iso-butane, nitrogen gas (N_2O) Carbon dioxide (CO_2), and Hydrogen sulfide (Carson and Katz 1942; Sloan 1991; Wilson et al. 2018).

Natural gas hydrates naturally occur in the deepwater plays and it is believed to potentially exceed all other hydrocarbon resources all around the world (Hancock et al. 2019). This report will focus only on artificially forming hydrate to transport or store natural gas.

Until recently, as long as transportation and storage of natural gas is concerned, natural gas hydrate was considered a nuisance because it causes problems for production and surface facilities such as the plugging of blowout preventer (BOP), blockage of transmission lines, collapse of tubings and casings, poor working condition of heat exchangers, expanders, valves, etc. (Sloan 1991). Lowering pressure and increasing temperature via methanol injection is a common practice to remove or prevent hydrate formation of these facilities.

Gudmundsson et al. 1990, 1992 and 1994 carried out experimental works to lay a foundation of how to exploit the thermodynamic properties of natural gas in order to use hydrate for large scale storage and transportation of natural gas. The volume of gas that can be stored in hydrate form is one-fourth that that could be transported via LNG. This is because NGH has void spaces trapped within the hydrate structure while a significant portion of the structure is water molecules. GTH hedged LNG in terms of economic constraints of ships of equivalent size. Gudmundsson et al. (1994) established that a ship transporting hydrates do not need a refrigerating unit, just an insulated bulk part keeping the hydrate at favorable temperature and pressure. The stability of NGH at atmospheric pressure when the temperature is below 32^0 F makes GTH a potentially viable transportation and storage technology (Wilson et al. 2008).

GTH technology is well suited for offshore transportation of natural gas as the storage condition of this technology is moderate relative to LNG and CNG. Wilson et al. (2008) reported that a pilot GTH plant is currently in operation but some technical issues remain unresolved before the technology becomes commercially viable.

Case Study

In this section, a comparison of the economic benefits of using GTL and GTW as a utilization project of the same asset is carried out. An assumption that GTL and GTW plants are located near the gas asset/wellbore and as such cost of gas as feedstock to the plants will be neglected. Also, the cost of treating the gas will be assumed to be the same for the 2 utilization efforts. Other assumptions are summarized in **table 1** and **2**.

Table 1. Economic consideration for the case study

	GTW	GTL
Gas Rate	10 MMScfD	10 MMScfD
Interest	10%	10%
Efficiency	60%	60%
Depreciation	MACRS 20 yrs.	MACRS 15 yrs.
Tax rate	20%	20%
Period	25 years	25 years
Product	Power	Jet-a-fuel
Product value	$0.103/KWh	$65/Barrel
CAPEX	$978/KW	$25000/BPD
OPEX	$0.03/KWh	$2.5/Barrel

Table 2. Additional GTW consideration

Plant Capacity	63.13 MW
Overnight Cost	$978/KW
Heat Rate	6600 Btu/KWh

The Efficiency for the GTW only includes the combined gas turbine conversion efficiency while the distributed power (DP) conversion efficiency is not factored in the analysis. It should be noted that some GTL plant only produces an intermediate product and may require further treatment to generate the final product. In this study, we are assuming the GTL plant produces the final product and we are considering jet-a fuel as the final product. Also, the cost of transporting product generated to the final consumer of intermediate sellers such as the Utility companies in case of GTW and Gas station in case of GTL is not included in the analysis.

Two scenarios were analyzed, the first was an optimistic case were the decline or change in gas supply was not considered while the second case considered a scenario where there's a natural decline in gas supply from the source. The yearly decline used in this analysis is summarized in **table 3**.

Table 3. Yearly decline rate consideration for the realistic case

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Rate	41%	27%	24%	19%	15%	12%	10%	9%	8%	7%	7%	7%	7%	6%	6%	6%	6%	6%	6%	6%	6%	6%	6%	6%	6%

Analysis of Result

The required capital needed to implement a gas to power project to monetize a gas asset with a flow rate of 10 MMScfD and other assumptions stated in **table 1**. Amounts to about $61.7 million while the needed capital to implement same gas asset for a GTL project amounts to about $25.8 million.

Table 4. Economic results

	GTW		GTL	
	Realistic	Optimistic	Realistic	Optimistic
NPV	$ 74,300,000	$ 312,600,000.00	$ 30,400,000.00	$ 155,000,000.00
IRR	39.89%	67.32%	44%	77%
Payback	1.38 years	1.48 years	4.79 years	2.60 years

The outcome for both utilization using various economic metric is summarized in **table 4**. GTW project appeared to be more favorable when the economic yardstick is NPV and payback period, but the GTL project is more favorable if IRR is to be used as the economic metric for comparison of these utilization projects.

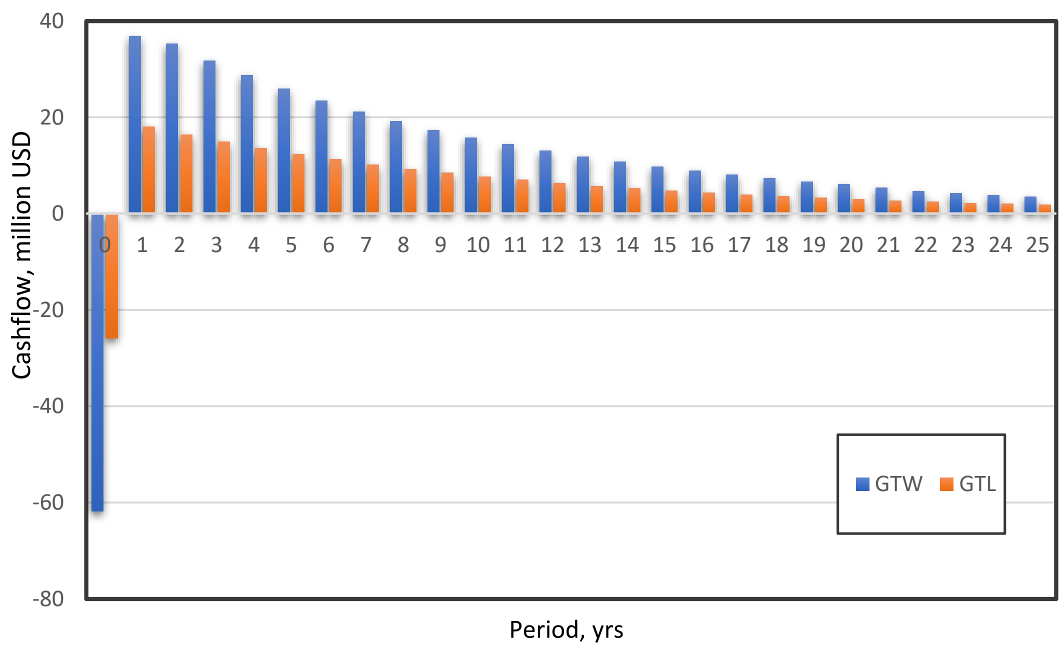

Figure 1. Discounted cashflow of the optimistic Case for GTW and GLT projects

From **figure 1** and **2**, it can be established that the capital requirement for the GTW utilization is greater that of the GTL for this gas asset, and, also the expected yearly discounted cashflow also favors a GTW project in both the optimistic and realistic cases. While the expected cash flow in the later years in the realistic case will become very minimal for a GTL project the GTW project will still experience a considerable cash flow in the year 20 – 25.

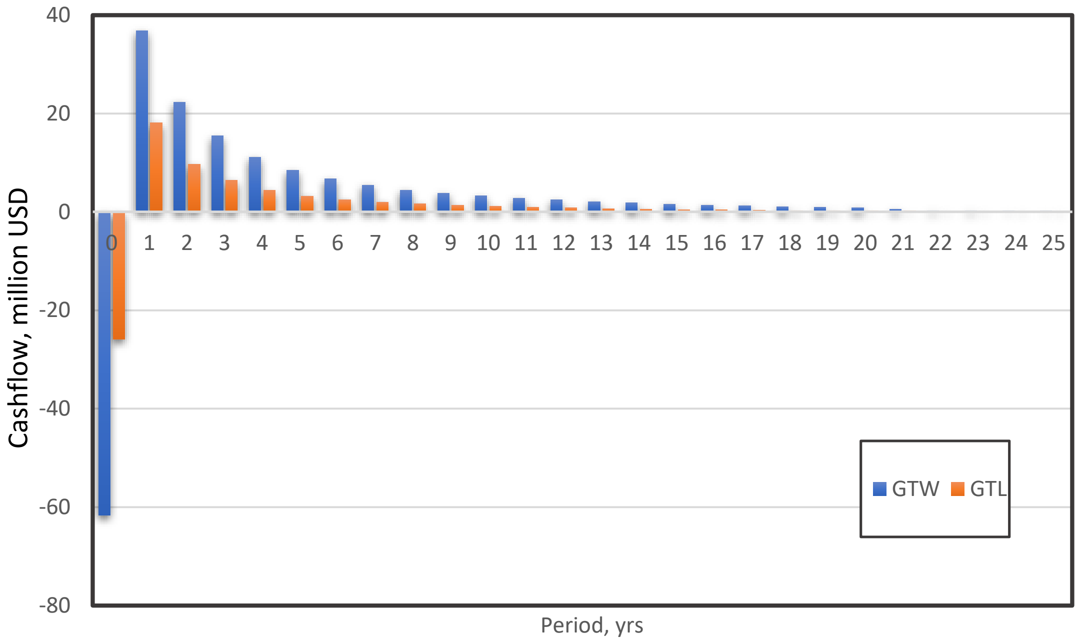

Figure 2. Discounted cashflow of the realistic Case for GTW and GLT projects

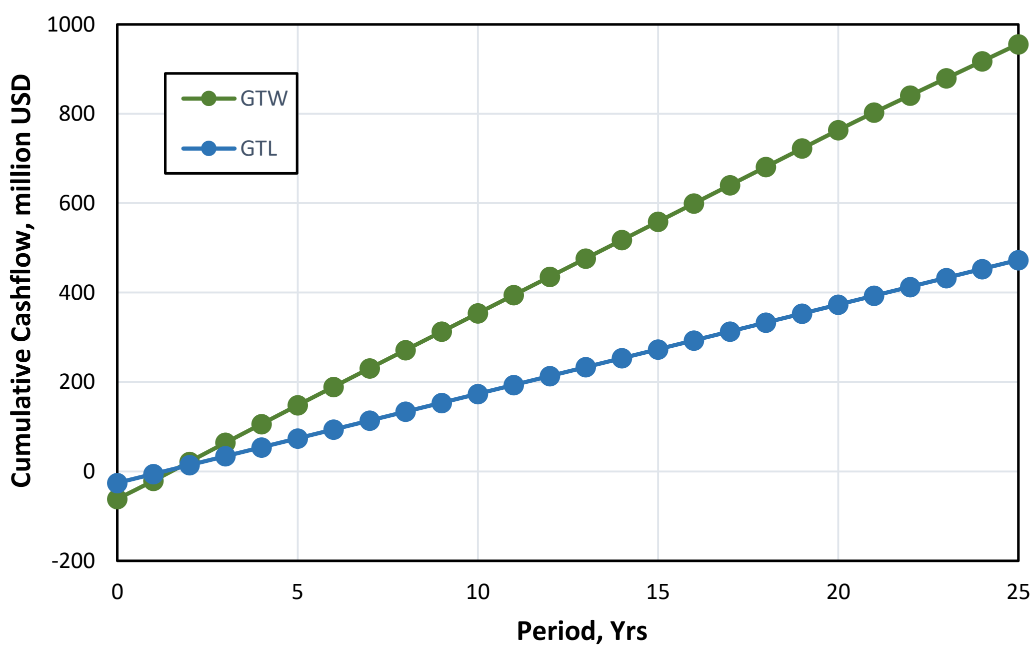

Figure 3. Optimistic cumulative cashflow for the GTW and GTL projects

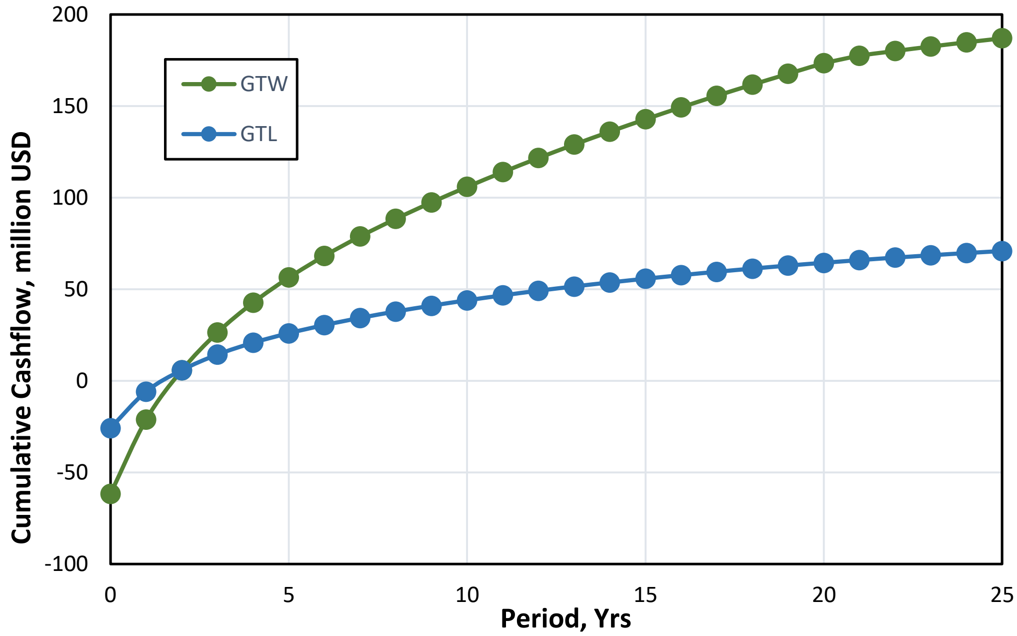

Figure 4. Expected realistic cumulative cashflow for the GTW and GTL projects

The realistic case exaggerates the cumulative cash flow when compared to the realistic case in both utilization projects as established in **figure 3** and 4. The **figure 3** and **4** also show that the project yield at the end of the project life of the GTW utilization effort will be about twice that of the GTL project for both the realistic and optimistic cases.

Sensitivity Analysis

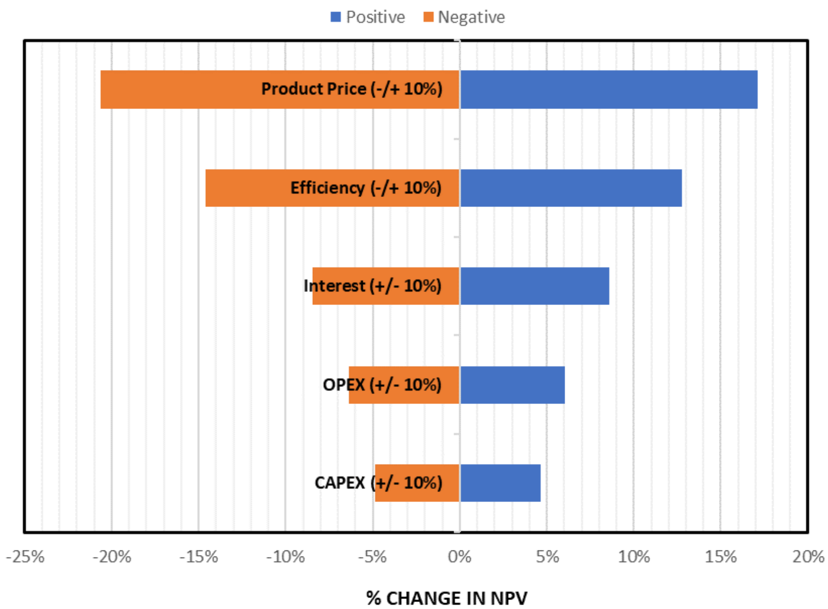

Figure 5. Sensitivity analysis of 10% change in market drivers on NPV for a GTW

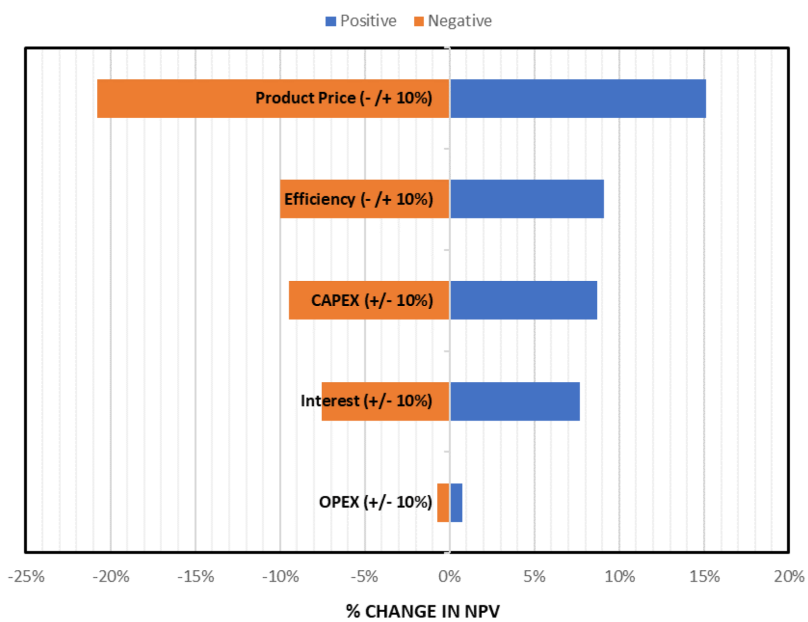

Figure 6. Sensitivity analysis of 10% change in market drivers on NPV for a GTL

As established in **figure 5**, for every 10% reduction in CAPEX, the NPV for the GTW project increases by about 5%, while from **figure 6**, 10% reduction in CAPEX of a GTL project will increase the NPV by almost 8%. Product price and Efficiency are the most influential market drivers in both projects, but the least influential market driver is different in both projects. While OPEX is the least influential market driver in the GTL project, CAPEX is the least influential in the GTW

Monte-Carlo Risk Analysis

Figures 7 and **8** present the risk analysis of the two projects and 1,500 of Monte-Carlo simulation of the realistic case was used in this analysis. The range of possible project yield of the GTW project can be seen in **figure 7** with the average possible NPV standing at about $74 million, it can also be established that there is 95% assurance that the GTW project will yield an NPV of about $61.7 million. The highest possible NPV from this project is about $90 million.

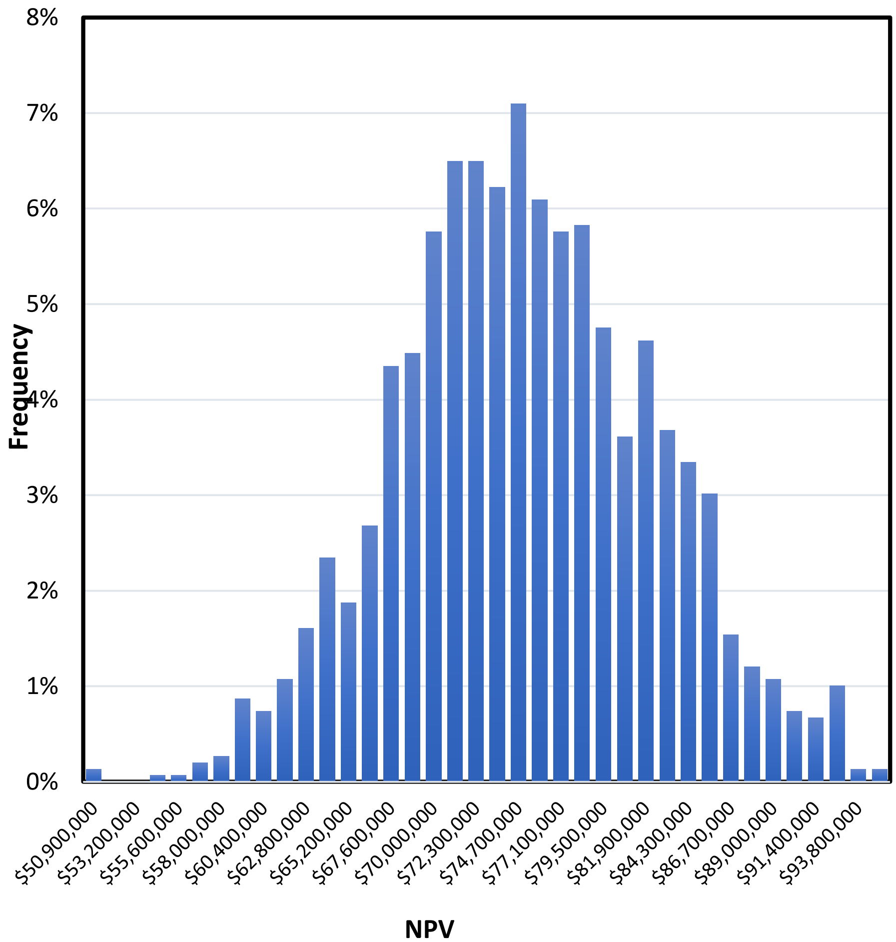

Figure 7. GTW Risk Analysis showing an array of possible project yield

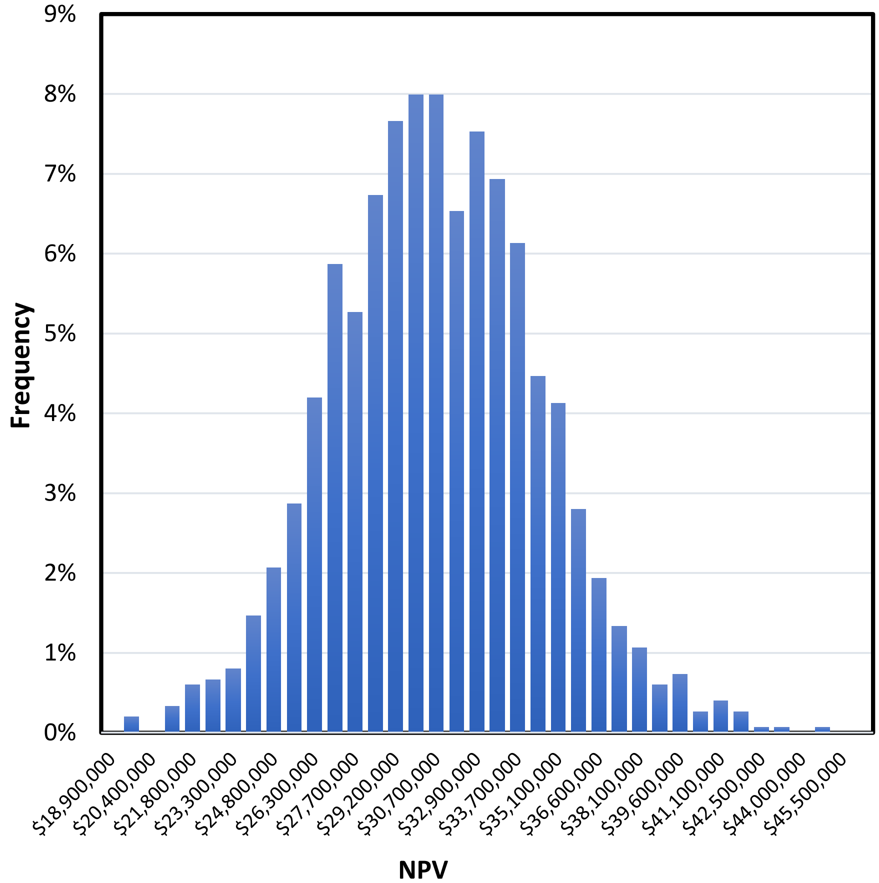

Figure 8. GTL Risk Analysis showing an array of possible project yield

The range of possible project yield of the GTL project can be seen in **figure 8** with the average possible NPV standing at about $30 million, it can also be established that there is 95% assurance that the GTL project will yield an NPV of about $24.6 million. The highest possible NPV from this project is about $45 million. **Tables 5** and **6** provides additional information about the yield from the two utilization projects. There is about 5% probability (P5) that GTW project would yield at most about $63 million as against $25 million that could be gotten from GTL in 25 years. The P10 and P25 of the two utilization projects in 25 years can also be seen in **Tables 5** and **6.**

Figure 7 and **8** clearly established that the least and highest possible NPV from a GTW project is respectively greater than that of a GTL project. Hence its least risky of an investment

Conclusion:

NPV, IRR and Payback period were calculated and base on the values of all inputs in each case and sensitivity analysis was carried out to rank the level of influence of base parameters on economic performance benchmarks. Monte Carlo simulation with 1500 cases was used to carry out a risk analysis on each business case. Our observation from this study agrees with earlier works to investigate the use of GTL to meet the growing transport fuel demand in the US (Ajagbe and Moghanloo. 2018)

The following conclusions can be drawn from the results presented in this study:

- The most influential market driver in both utilization project is the product value and the efficiency of the process
- The least influential market driver in a GTW utilization project is the CAPEX while the OPEX is the least influential market driver.
- The capital requirement to monetize a gas asset using GTW technology is about twice using GTL technology on the same gas asset
- We are 90% confident that the GTW project will yield about $65.3million and that GTL will yield $25.8million at the end of the 25-year period
- NPV and Payback period favors GTW as the most desirable investment while IRR favors the GTL as the better utilization effort for the gas asset.

Nomenclature

CNG – Compressed Natural Gas

GTCC – Gas Turbine Combined Cycle

GTH – Gas to Hydrate

GTL – Gas to Liquid

GTW – Gas to Wire

HVDC – High Voltage Direct Current

BLP – Barrel of liquid-product per day

BTU – British Thermal Unit

NPV – Net Present Value

NGH – Natural Gas Hydrate

IRR – Internal Rate of Return

PBPeriod – Payback Period

P5 – 5% probability

P10 – 10% probability

P25 – 25% probability

MACRS – Modified Accelerated Cost Recovery System

MMScf- Million standard cubic feet

MW – Mega Watts

NGL – Natural Gas Liquid

OECD – Organization of Economic Cooperation and Development

SD – Standard Deviation

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Appendix

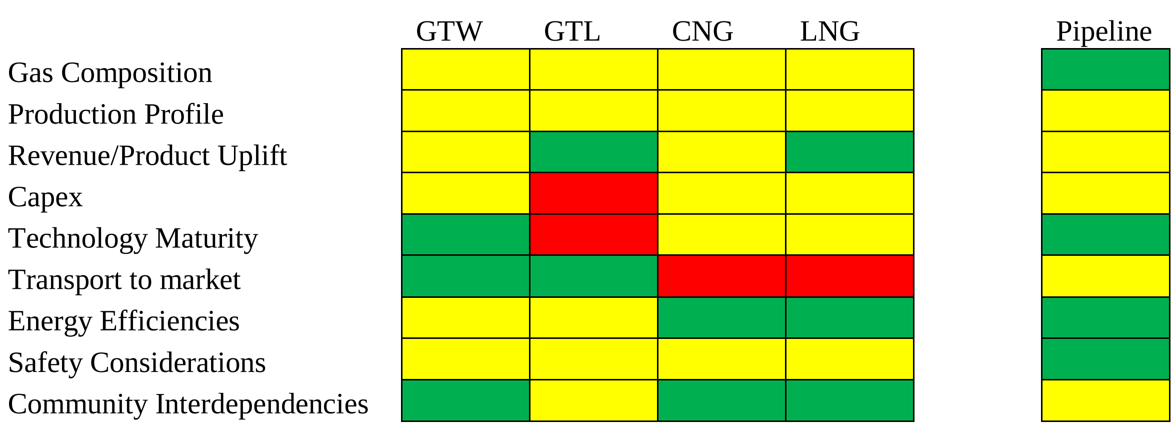
Table 5. Additional results from GTW Monte Carlo Simulation

mean	$ 74,400,000.00
Median	$ 74,200,000.00
SD	$ 7,200,000.00
Percentiles	
5%	$ 62,700,000.00
10%	$ 65,300,000.00
25%	$ 69,300,000.00

Table 6. Additional results from GTL Monte-Carlo Simulation

Mean	$ 30,400,000.00
Median	$ 30,300,000.00
SD	$ 3,700,000.00
Percentiles	
5%	$ 24,600,000.00
10%	$ 25,900,000.00
25%	$ 27,800,000.00

Table 7. Color-code ranking of sensitivity analysis of various Natural Gas utilization projects



Adapted from Shell's Gas Utilization Brochure 2015.