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Original Article

Natural Gas Utilization: The Opportunities and Limitations militating Developing Economies

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Abstract: Nigeria, a developing nation, has abundant natural gas resources, which are abundant in terms of energy when combined with the known crude oil reserves of the nation. Nigeria is also becoming into a hub for natural gas, with long-term economic growth and development promising long-term environmental benefits. And for good reason—natural gas is the most economical, cleanest, and ecologically benign energy source available to consumers. Therefore, using Nigeria as an example, the current study focuses on the opportunities and constraints associated with the usage of natural gas in developing nations. The study found that, in addition to the opportunities brought about by the use of natural gas, a number of constraints, including funding, funding sources, and, most significantly, the security conditions that currently exist in the Niger Delta region, the primary source of natural gas, have a significant impact on product exploration. Inadequate gas infrastructure, a dearth of domestic and global markets, a lack of interconnecting pipelines, and political and economic concerns all play significant roles. The report offers substitutes, including creating export-focused natural gas projects to open up local, national, and worldwide markets and creating brand-new tangible incentives for natural gas usage.

***Keywords*:** Gas Utilization, Natural Gas, Sustainable Development, Gas Pipelines, Gas Development.

I. INTRODUCTION

The primary energy source is natural gas (NG), which supplies around one-fifth of the world's energy needs compared to one-third from crude oil and one-quarter from coal [1-3]. Table 1 illustrates that natural gas (NG) is not only ecologically beneficial but also burns cleanly. It has a wide range of uses, mostly for power generation in Nigeria, which uses natural gas primarily for domestic economic purposes. As the cleanest fossil fuel available, natural gas is a valuable resource for generating affordable, sustainable power for industrial, commercial, and other uses that promote economic expansion. In addition, Nigeria's earnings from natural gas (NG) have surged dramatically as a result of its ongoing expansion in the LNG project [4-8].

Table 1: Distinguishing Feature between Oil and Gas [9]

S. No	Particular	Crude Oil	Natural Gas
1	Environment	Extra pollution/higher carbon dioxide (Co_2)	Fewer carbon dioxide (Co_2)/cleaner burning
2	Energy density	High	Low
3	Infrastructure	Pressure vessels not necessary	Usually pressurized
4	Storage	Cheap and easily store	Expensive and difficult to store
5	Transportation	Easy transported	Difficult to transport
6	Market	Fungible	Tangled to keen infrastructure

However, natural gas, which was once an unpleasant and unwanted byproduct of the extraction of crude oil, today supplies nearly one-fifth of the world's major energy needs. This remarkable progress has occurred in a matter of years, thanks to the expansion of the nations' gas reserves and the building of large-diameter, long-distance steel pipelines that have transported these plentiful supplies of gaseous fuel to residential, commercial, and industrial consumers located far from one another [10]. In an era where environmental sustainability is of utmost importance, natural gas becomes even more alluring due to its reputation as a cleaner and greener energy source.The transportation infrastructure that moves gas from its source to markets where demand is present is the most important factor in the utilisation of gas deposits. The distant offshore is where large portions of Nigeria's non-associated gas (NAG) reserves are found. Furthermore, evaluations of the world's natural gas resources show that 80% of new discoveries will be smaller than the bare minimum needed to enable the transit of LNG [11].In addition, Nigeria now holds the seventh-largest proven natural gas reserves in the world, with an estimated 182 TCF (trillion

cubic feet). Given the mainly unexplored position of the resources, there are undiscovered gas reserves in Nigeria in addition to the recoverable reserve estimate. There is almost no sulphur, low CO2 and a significant quantity of liquids (condensate) in the gas. Nonetheless, Nigeria is one of the top gas flaring nations in the world, contributing over 16% of gas flares worldwide [12]. According to official data from 2004, Nigeria lost more than 8.5 TCF of natural gas due to flaring in only that one year (Petroleum Economist, November 2007). This amount of petrol is equal to roughly 5% of all proven reserves in the nation.It has been determined that stranded gas caps, or reserves of gas that are not currently accessible, account for over 40% of Nigeria's proven gas reserves. Furthermore, the great majority of the reserves that are accessible in the short- to medium-term are made up of non-associated gas [13].However, there are sizable—and frequently sparse—amounts of these unrelated gas reserves in the far offshore. The near-term availability of the NAG reserves is therefore limited by the economic and technical difficulties involved in accessing and extracting such far-off sources.The goal of the Gas Master Plan is to ensure Nigeria's long-term gas security through regulated resource exploitation, per the country's gas national agenda. Maintaining a portfolio of strategic gas utilisation options with a readily available and reasonably priced supply is hence the difficulty. That is, to match the entire demand for petrol with the supply in a way that promotes sustainable growth. For the hydrocarbon gas field to be developed effectively, a suitable development concept must be chosen. There are numerous technical concepts and technological methods available for handling and processing gas. Nevertheless, commercial and regulatory policy parameters, in addition to technical principles, determine the viability of natural gas production initiatives. Consequently, appropriate strategic measures that address the difficulties of effectively utilising vast natural and remote stranded gas reserves are needed to assure the feasibility of the potential for gas development and, consequently, to accomplish the objectives of the national Gas Master Plan. [14-16].

II. LIMITATIONS FACING NATURAL GAS UTILIZATION IN NIGERIA

Some of the selected limitations currently facing natural gas utilization are discussed as listed below.

A. Niger Delta Region Security Challenges:

Delta State, Bayelsa State, River State, Akwa Ibom State, and Cross River State make up the majority of the Niger area. One significant barrier to the development of gas is the persistent security situation in the Niger Delta region. In addition, the Niger Delta's terrain is made up of rivers, creeks, marshlands, swamps, and deep seas. The Movement for the Emancipation of Niger Delta (MEND), which protests the district's underdevelopment, is one of the armed militias and rebel groups that impede access to deep and surface waters as well as certain inaccessible settlements [17]. In addition, violent protests are terrifying, as are violent crimes and threats to public order. It's a wandering habit, kidnapping and holding hostages for ransom. The development of gas, investment in the gas business, and the security of the oil and gas sector are all under jeopardy. Due to this, it is now mandatory for military personnel and armed police officers (MOPOL) to be present in the region in order to maintain both peace and continuous oil and gas production. However, it is extremely difficult to use the gas that is generated together with oil when it is produced under severe security conditions, which typically results in flaring [18].

In addition, there's the problem of criminal gangs occupying oil facilities for financial gain, piracy, and oil theft. As a result, a few oil corporations decided to stop producing in Nigeria or to declare a force majeure on oil shipments. For example, Nigeria's oil and gas production was cut from 2.9 million barrels per day to approximately 1.7 million during the height of the crisis in 1999–2003 [19].However, with the December 2009 start of the Amnesty Programme for the Youth of the Niger Delta Revolution, there has been a decrease in the frequency and scope of attacks against oil and gas infrastructure.

B. Lack of Funding Infrastructural Development:

For natural gas to be sent to end users, it needs an opulent network of connected pipes and flow/compressor postings to gather and collect scattered gas from marginal oil producing fields in the Niger Delta region. Infrastructure for natural gas needs to be significantly invested in if economic growth is to continue. For example, the ground in some places is too soft to anchor gas pipelines, and the creeks' waterways are too shallow to utilise barges for shipping. This demonstrates that the geography of the Niger Delta region makes significant capital expenditures necessary for the development of Nigeria's gas business. When it comes to providing money for oil and gas industry projects, the majority of local banks lack the financial capacity to dedicate funds for long-term oil and gas infrastructure projects. The interest rate on loans may be too expensive to warrant the investment, even in cases where banks decide to give them. Additionally, investors are scared off by Nigeria's opaque business procedures, which fuels underdevelopment. The risk of a business disaster also poses a threat to investments in gas development, as seen by the failures of Ajaokuta Steel, Aladja Steel, ALSCON, and NAFCON in the 1990s, which put multibillion-dollar pipeline infrastructure investments at risk. A few years after the NGC connected these establishments to the national gas organisation network at great government expense, they vanished due to mismanagement [20–22]. These are obvious obstacles that work against Nigeria's gas

industry's development. Moreover, [23] argued that the Niger Delta region's revolt and the ensuing unpredictability have continued to impact potential investors' confidence and awareness of the MNOCs whose multibillion-dollar investments are seriously at danger. Undoubtedly, one of the biggest challenges is finding the money to build such a massive infrastructure given the dire security situation in the Niger Delta region. The security issue is a massive endeavour to make natural gas the residential sector's fuel of choice because of institutional inefficiency and harmonisation to outgrowth investment to promote the development of natural gas infrastructure.

C. Economic Structure and Growth:

The economic structure and development challenges that impede progress are deeply ingrained. Examples include inadequate local content, inadequate energy integration, and insufficiency in the gas supply chain as measured by the quantity of goods and services produced locally. A significant obstacle to the growth of gas is the lack of cottage industries, energy-intensive businesses, and plants throughout Nigeria that are also close enough to gas sources to economically capture a large portion of the associated gas produced. This hinders not just the use of petrol but also overall economic expansion. Like in most industrialised nations, the gas sector's potential for rapid development has been constantly thwarted by the industrialization process's early stages and the small-scale use of natural gas by the sector's current industries. Numerous production facilities and workshops that rely on gas for efficient operations have closed. For example, the Ajaokuta steel plant never saw the light of day, while the iron and steel industry in Aladja is operating dejectedly. Aladja Steel was shut down for a number of years, and in 2007 the Nigerian government sold an Indian corporation its stake in the steel company [18]. Due to the lack of demand caused by these steel manufacturers' inactivity, enormous sums of money were wasted building gas pipes and other natural gas infrastructure to reach these plants. Furthermore, the Ikot-Abasi ALSCON only operated for a few years before collapsing, a circumstance that also applied to NAFCON and the petrochemical plants in Warri and Kaduna. They were all extremely well-planned initiatives with the specific goal of using flared associated gas as an industry feedstock and for power generation. Less than 40% of the installed capacity of the thermal power plants at Egbin, Afam, Ughelli, Sapele, and other locations that are supposed to use a significant amount of flared associated gas is being used at nominal capacity. The strategically planned use of gas to stimulate domestic economic development through the gas to power electricity project is in disarray. There are numerous examples of underperforming projects that were supposed to employ flared associated natural gas for operations, and they can be found throughout Nigeria.

D. Natural Gas Evaluation:

The way natural gas is valued, mostly in the domestic market, discourages investment in gas growth and discourages considering gas as a potential fuel source and alternative energy source. In response, [24] contended that the low price of petrol in Nigeria, particularly in the domestic market, has deterred investment in the expansion of the sector. As per [19], local pricing management makes it economically impractical to assemble petrol for local use. In order to encourage investment in gas infrastructure, natural gas prices must be competitive with the rate of the global market and set at commercial levels for local companies and users. It is also imperative that great care be taken to prevent price discrimination that could negatively impact Nigeria's domestic gas market. Petrol prices are incredibly cheap by global standards and unfairly low on the domestic market, often falling below the cost of supply [24]. Nigeria's industrial and energy supply depend heavily on natural gas, yet the price of gas at home is discouraging investment in the downstream sector. This is consistent with the assertion made by [25] that the price system does not accurately represent economic sincerity to promote significant investment in the gas industry. Furthermore, the interests of gas producers, end users, regulators, and the government conflict to the point where gas producers are unwilling to invest what is necessary to build the infrastructure that is needed to distribute gas to domestic end users. The National Domestic Gas Supply and Pricing Policy and Regulation, however, now addresses pricing trials in the industry. The pricing strategy aims to establish a framework for addressing transparency regarding the domestic petrol price on the domestic network's supply and distribution chain.

E. Dearth Gas Gathering and Inadequate Distribution Infrastructure:

The capacities needed to sustain gas distribution have decreased as a result of the absence of structures for the domestic economy to collect and distribute gas. Some recently commissioned power plants in the Western portions of Nigeria are experiencing gas shortages due to the lack of a suitable pipeline connecting the Niger Delta Area's gas supply reserves to the expanding markets of the North and West. However, [26] contended that low capacity consumption is the result of the infrastructural deficiencies in gas pipelines today. The primary responsibility of the state-owned NNPC subordinate, the NGC, is to protect gas supplies to prospective clientele for projects involving power generation, the cement and fertiliser industries, the

iron and steel industry, petrochemical plants, glass manufacturing, and the food and beverage industries within the national context. However, the domestic network's gas pipeline length has also substantially risen, rising from just 2000 km in the 1990s to over 9,265 km in 2005 [26, 27]. Precisely to the contrary, the Africa Development Bank Group [28] observed that there remains a significant mismatch between robust infrastructure investments to grow natural gas needed for electric power generation and gas as feedstock for the local economy's industrial sector and feeble infrastructure investments for export-oriented gas projects like LNG, GTL, or the West African Gas Pipelines (WAGP). There is currently not enough gas infrastructure in place for local demand for the recently installed gas turbines, including gathering, transmission, and distribution.

III. NATURAL GAS UTILIZATION OPTIONS

There are numerous uses for natural gas with various application techniques. However, yearly flare-offs of massive amounts of natural gas in Nigeria's Niger Delta Area create environmental hazards. In areas with little natural gas infrastructure, gas flaring is a serious issue [29]. Natural gas was not a feasible fuel during the early stages of petroleum discovery since it was difficult to handle or transport. To prevent fires brought on by malfunctioning machinery or human mistake, gas was either vented into the atmosphere or allowed to burn in the well. The amounts of fossil fuel that are produced, kept, processed, and used are directly correlated with the emissions from petrol flaring [30].

Data from the US National Oceanic and Atmospheric Administration (NOAA) and the World Bank's Global Gas Flaring Reduction collaboration show that the US accounted for 70% of the global decline, with gas flaring falling by 32% between 2019 and 2020 due to an 8% decline in oil production and creative infrastructure to use gas that would otherwise be flared [31]. For nine years in a row, Russia, Iraq, Iran, the United States, Venezuela, Algeria, and Nigeria have been the top seven gas-flaring nations, making up half of global crude oil output and around 75% of all gas flared. Global oil output and gas flaring from 1996 to 2021 are depicted in Figure 1. It is evident that since 1996, there has been a roughly 20% rise in oil output and a 13% drop in the amount of associated gas released.

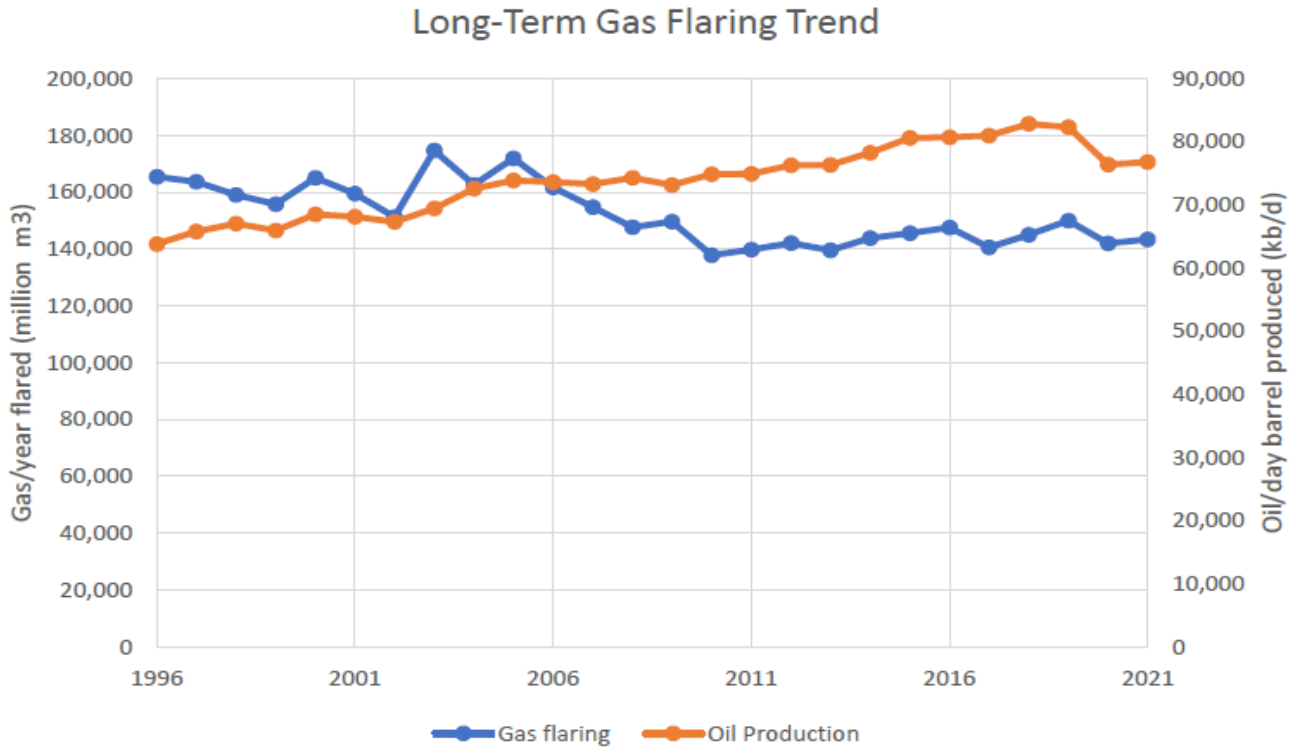

Figure 1: Global Gas Flaring and Oil Production: 1996 to 2021 [32]

This indicates that as the long-standing relationship between gas flaring and oil output is increasingly broken, the oil sector is progressing [32]. Furthermore, a limited handful of sizable flare locations are responsible for the majority of the world's flaring. For example, in 2020, 75% of the total flaring volume worldwide came from 12% of flare sites [33]. The most recent ranking of the top ten gas-producing countries between 2012 and 2021 is displayed in Figure 2. Russia leads the globe in gas

flaring, as shown in Figure 2, with an estimated 25.4 billion cubic metres of natural gas burnt in 2021. Iraq (17.8 billion cubic metres), Iran (17.3 billion cubic metres), the USA (8.7 billion cubic metres), Venezuela (8.2 billion cubic metres), and Algeria (8.1 billion cubic metres) follow [32]. Furthermore, with a volume of 6.6 bcm, Nigeria ranks seventh among the top 30 flaring countries and accounts for more than 40% of Africa's overall yearly flaring volume.

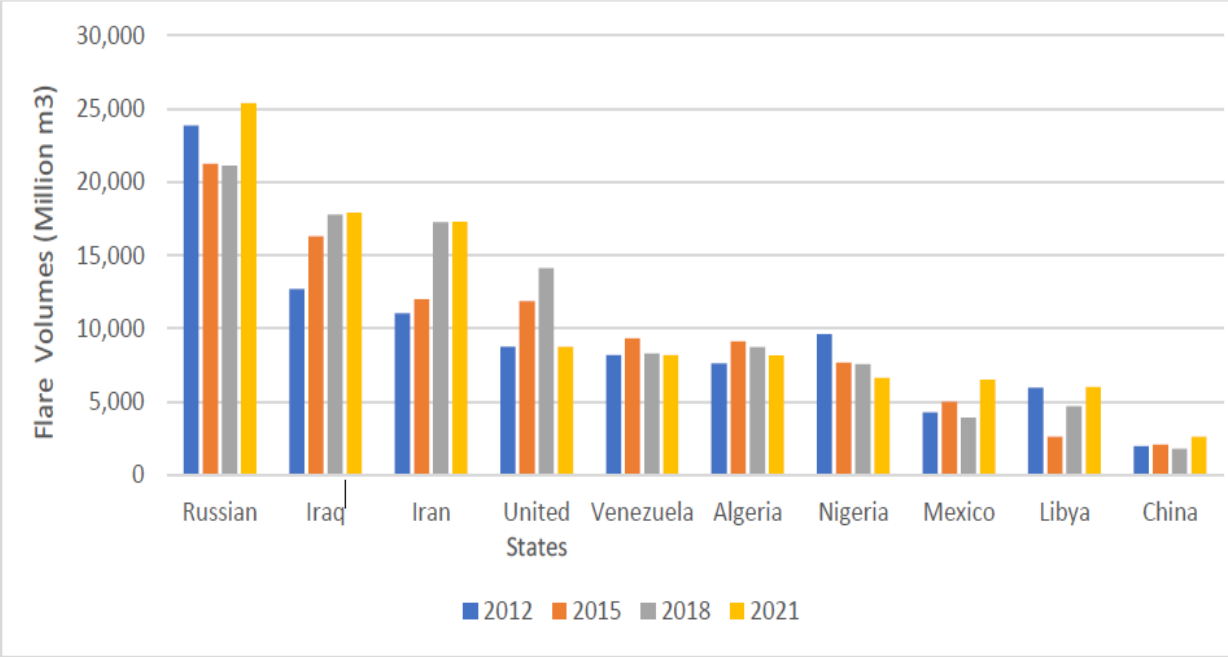

Figure 2: Flare Volumes for the Top 10 Flaring Countries for 2012, 2015, 2018, And 2021 [32]

However, natural gas can be effectively used in place of flaring through the following techniques: compressed natural gas (CNG), gas to fertiliser (GTF), liquefied petroleum gas (LPG), gas to liquid (GTL), natural gas to methanol (GTM), natural gas to hydrogen (GTH), liquefied natural gas (LNG), etc.

A. Compressed Natural Gas (CNG):

Natural gas is compressed at normal atmospheric pressure to less than 1% of its original volume to produce compressed natural gas [34, 35]. The main ingredients of CNG, which is treated and delivered in large steel cylinders at 220 bar (3200 psi) [35], are methane, ethane, propane, and butane. In addition, it is the greatest substitute for gas pipelines and LNG plants [34] and contains gases such as carbon dioxide, hydrogen sulphide, nitrogen, helium, and water vapor[36, 37]. It is an easy-to-use, precise technology that reduces the need for expensive offshore oil and gas processing facilities and gas infrastructure for gas treatment or processing.

B. Natural Gas to Fertilizer (GTF):

At a 5.0% CAGR, the worldwide fertiliser market is projected to reach USD 323,375.0 million by 2028, up from USD 221,428.6 million in 2020 [38]. Fertilisers like urea and ammonia, which are widely used in Nigerian agriculture, are mostly made from natural gas [38]. Nitrogen and hydrogen (from natural gas reforming) are reacted at high temperatures and pressures to produce ammonia [38]. Heat and pressure are used to liquid ammonia and liquid carbon dioxide to produce urea. Commercial grades have 45–46 percent nitrogen, which lowers the expense of handling, storing, and shipping. With 16% of all nitrogen consumed, urea is the most widely used dry nitrogen fertiliser in countries like Nigeria and the United States of America [39, 40]. The most popular and quickly expanding dry nitrogen fertiliser is urea. It meets 62% of the world's requirement for this vital nutrient and is the primary fertiliser traded internationally [41]. Nigeria is one of the top producers of fertilisers high in nitrogen in the world. The value of its exports to nations including Ghana, Senegal, Uganda, and Kenya exceeds $1 billion USD. Nigeria made significant progress in 2018 by producing 1.8 million metric tonnes of nitrogenous fertilisers. The 1.5 Mtpa Dangote fertiliser factory in Lagos state and the 1.4 Mtpa Indorama fertiliser and chemical plant are two examples of commercialised GTF plants in Nigeria.

C. Liquefied Petroleum Gas (LPG):

Estimated to be worth USD 134,887 million in 2021, the global LPG market is projected to grow at a compound annual growth rate (CAGR) of 5.02% from 2022 to 2032 [42]. Because of their environment, temperate countries have a sizable gas market for air conditioning, refrigeration, cooking and heating [42]. LPG is a hydrocarbon gas that is derived from oil or natural gas and can be utilised for this purpose. It is made up of 45% crude oil and 55% refined natural gas [42]. Propane, butane, or a combination of the two make up LPG.These chemical feedstocks are utilised in place of fuels: ethane, ethylene, propylene, butylene, isobutene, and isobutylene. In addition, an estimated 60% of Nigerians still cook with wood and coal, which exacerbates climate change and deforestation [44–45]. Although LPG is more efficient and environmentally benign than kerosene [46], the vast majority of Nigerians still use coal and kerosene. The adoption of LPG as a cooking fuel is hindered by the initial cost of LPG appliances (gas cylinders), the absence of LPG delivery, a lack of information, and social and cultural problems. Because of this, the Nigeria LNG company increased the amount of LPG it supplied to the domestic market in 2019/2020, going from 350,000 mt/year to 450,000 mt/year, and in 2022, increasing that amount to 100% of output [47].

D. Natural Gas to Methanol (GTM):

When compared to petrol, methanol naturally emits less CO, NOX, and hydrocarbons when used as fuel [46]. Furthermore, in cars that are equipped, methanol can be used in place of diesel or blended with petrol. Since methanol is primarily produced by hydrogenating carbon monoxide, the process of producing hydrogen from natural gas via natural gas reforming (also known as synthetic gas production) comes first when producing methanol from natural gas [48].The process of making methanol has two stages: the first stage uses steam reforming to turn natural gas feedstock into synthesis gas [49], and the second stage turns synthesis gas into methanol. For each of these procedures, there are several technologies available. While the techniques to onshore and offshore GTM are similar, the design variables (space, safety, weight, and height) are not.The process of producing methanol uses the second-most hydrogen after ammonia and is the energy carrier of choice for the partial oxidation, auto-thermal reforming, and other processes that synthesise hydrogen.It provides electricity in direct methanol fuel cells. It can be conveniently kept and utilised as a solvent in intricate chemical mixtures. Methanol can be mixed with regular petrol for use in transportation without requiring significant changes to the vehicle. One example is M85 fuel, which is 85% methanol and 15% unleaded petrol.

E. Liquefied Natural Gas (LNG):

By melting and condensing natural gas into a liquid and lowering its volume by 600 times, liquefied natural gas facilitates long-distance transportation and makes the resource easier to carry and store [50–53]. The liquefaction and transportation of LNG, receiving ports for LNG, development of gas resources, and connecting customers through power plants or municipal gas companies are just a few of the many chains that make up the LNG sector. Within the framework of the global energy transition being spearheaded by the European Commission, this provides a means of cutting greenhouse gas emissions and combating global warming. It reduces diesel noise in transportation by 50%, particularly in trucks. It's also an interesting petrol option because of its cheaper cost when compared to typical transportfuels like diesel. It lowers emissions of carbon dioxide by 25%, nitrogen oxide by 90%, sulphur and fine particle emissions by 90%–100% when used as a marine fuel. It can be used in industrial areas or locations without natural gas grids because it has the lowest environmental impact, the highest thermodynamic yields, and the highest energy efficiency of all fuels.The use of cheap methods to use unconventional gas deposits, the increasing production of LNG by several providers, and the controlled use of natural gas as a feedstock have given natural gas and LNG a significant advantage over products tied to crude oil. In the EU, LNG is more attractive due to a carbon tax. Its energy savings (3–5% more efficient than items fueled by oil) show that using petrol is a sustainable option. LNG's broad resource base and simplicity of delivery make it a viable energy option.By increasing liquefaction efficiency and creating larger LNG trains—up to 7.8 million tonnes per year (Mtpa)—developers have improved the economics of LNG expansion (located in Qatar).

IV. CONCLUSION

Oil and gas are essential to Nigeria's economic development. The petrol market has grown quickly over the past ten years due to factors like sustainable development, environmental protection, and increased global demand. However, Nigeria has entered the gas age as evidenced by the numerous gas projects that have been spawned by project-specific fiscal incentives and the gas policy framework. However, barriers to domestic pricing, infrastructure, funding, regulations, and security in the Niger Delta region—the primary source of natural gas—have significantly impeded the much-needed gains expected from natural gas. In addition, it is horrifying how frequently violent protests, violent crimes, and threats to peace occur. Kidnapping for financial

gain is becoming more common. The development of gas, investment in the gas business, and the security of the oil and gas sector are all at risk. This has made it necessary for military personnel and armed police officers (MOPOL) to be present in the region in order to ensure ongoing oil and gas production as well as to keep the peace.

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