MONETIZING STRANDED GAS RESERVES IN NIGERIA

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ABSTRACT

Stranded natural gas has a huge economic implications for Nigeria since there are 184 TCF stranded gas reserves in the country. Oil currently accounts for over 90 percent of Nigeria's foreign exchange earnings, there is therefore, hope for increased revenue from natural gas, if the gas being flared is monetized. Monetizing stranded gas reserves requires access to distribution infrastructure. It becomes necessary and appropriate for Nigeria to put in place these infrastructure as to develop her vast stranded natural gas reserves to serve her economy, strengthen regional cooperation, and meet expanding demand in the world market. This paper presents current technologies for monetizing stranded gas, and assessment of Nigeria's achievements in monetizing stranded natural gas reserves. The monetization technologies and projects reviewed are liquefied natural gas (LNG), gas-to-liquids (GTL), compressed natural gas (CNG), gas-to-wire (gas-fired power generation), and gas-to-solid. Nigeria's achievements in monetizing stranded gas include the Nigeria LNG plant, Brass LNG plant, Escravos GTL plant, Bonny Non-Associated Gas plant, West Niger Delta LNG plant, Olokola LNG project, Nigeria Gas Company, and thermal power plants. Some of these projects have not reached operational stage, even those that have reached are partially in operation. Some of those that were fully operational, were shut down due to poor maintenance and gas supply. The shutdown of these plants created a drop in power generation in the country. Hence, gas utilization in Nigeria is still inadequate when compared to other oil and gas producing countries of the World. Possibilities of monetizing natural stranded gas in future are suggested for Nigeria to serve her economy, have a steady and enviable electricity generation, contribute to global greenhouse gas (GHG) reduction, and meet expanding energy and petrochemical demands in the world market. These possibilities include natural gas storage (to minimize gas flaring and enhance oil recovery), improved gas-fired power generation, dimethyl ether (DME), and gas-to-ethylene syntheses to mention just a few.

Keywords: Monetize, stranded gas reserves, liquefied natural gas, gas-to-liquids, compressed natural gas, gas-to-wire, gas hydrates, gas flaring

INTRODUCTION

Natural gas as a global energy source has been gaining wider currency in recent years as a result of sustained high oil prices, a need for energy diversification and security, the growing global awareness of environmental issues, and due to the development of new gas-related technologies. Current global natural gas reserves total approximately 6,100 trillion cubic feet (tcf), according to EIA estimates. Of these, roughly half are considered to be stranded, that is, uneconomic to deliver to market. This typically occurs when identified reserves are in remote locations, or when they are located deep under the ocean floor and/or in complex geologic formations. Another form of stranded natural gas is associated gas, or gas found in association with development of large oil fields. While crude oil can be transported to distant markets with relative ease, the practice in the past has been to flare associated gas at the well head (Marcano and Cheung, 2007).

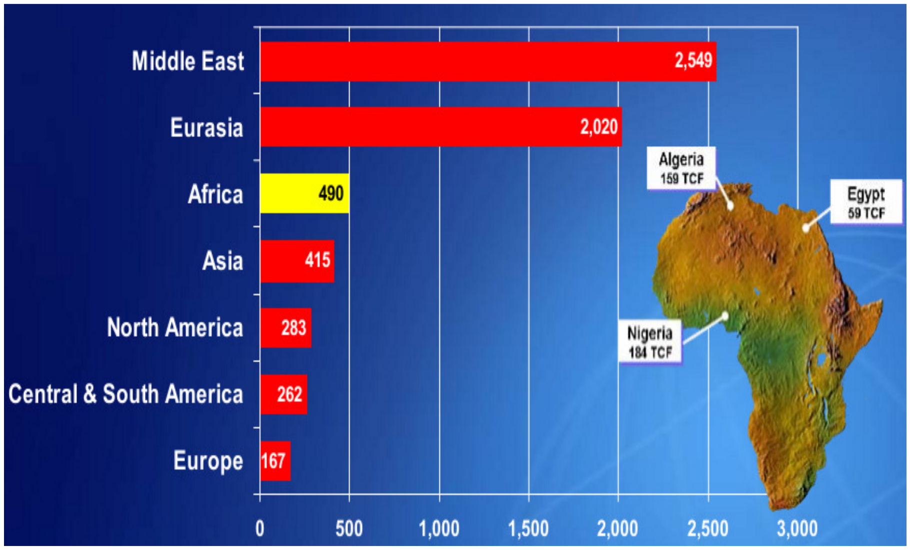
ISSN-L: 2223-9553, ISSN: 2223-9944
Vol. 4 No. 5 September 2013

Flaring natural gas is both wasteful and detrimental to the environment. Approximately 5 trillion cubic feet (TCF) of gas are flared annually (World Bank, 2009). Nigerian oil production has increased significantly. Official data suggest it has hovered around 2 million bbl/d for the last few years, but reached 2.5 million bbl/d in 2004. Oil production levels determine the amount of associated gas (AG) produced, and thus bear on the amount of flaring. On the average, about 1000 standard cubic feet (scf) of gas is produced in Nigeria with every barrel of oil. Therefore, with oil production of some 2.2 million barrels per day, about 2.2 billion scf of associated gas is produced everyday. In the year 2000 it was estimated that gas production of 4.6 bcfd is largely wasted with nearly 55 percent or close to 2.5 bcfd being flared. The gross monetary value of this gas is in the order of US$2.5 billion per year to the economy, amounting to US$50 billion over 20 years. The balance is split between reinjection, NLNG feedstock, internal fuel usage, and a small percentage marketed as LPG. Best estimate of gas-flaring trends in selected countries in the year 2000, table 1 shows Nigeria as flaring the most gas, both absolutely and proportionately, about 46% of Africa's total, and flaring most gas per tonne of oil produced, Nigeria emerges as the world's number one flarer and venter. The Nigerian amount is more than the second and third countries combined and four times higher than the nearest African country, Algeria, which is recorded as having flared and vented 4 bcm (Osuoka, 2005).

Table 1. Best estimate of gas-flaring trends in selected countries in the year 2000 (After Osuoka, 2005)

COUNTRY	FLARED GAS	SHARE OF WORLD TOTAL(%)[a]	RATIO GAS FLARED TO OIL PRODUCED (m^3/toe)[b]	
			1990	2000
Algeria	6.8	6	79	101
Angola	4.3	4	n/a	118
China	3.2	3	n/a	74
Egypt	0.9	1	37	23
Indonesia	4.5	4	66	66
Iran	10.5	10	70	56
Nigeria	17.2	16	250	166
Mexico	5.6	5	n/a	33
North Sea[c]	2.7	3	18	9
Russia	11.5	11	n/a	77
Venezuela	4.5	4	30	27
United States	2.8	3	10	22
Other countries	33	30	-	-
WORLD[a]	**107.5**	**100**	-	-

Nigeria today currently routinely flares 63% of the associated gas produced per day during the production of crude oil (NAPIMS Bulletin, 2013). This practice however is no longer acceptable due to environmental concerns and, more recently, due to the growing economic value of these reserves in a high energy price environment. Oil producers are now looking to use technology to capture associated gas and take it to consuming markets (Marcano and Cheung, 2007). The World natural gas reserves by region shows that Africa has 490 TCF of stranded gas resources with Nigeria having 184 TCF, figure 1. The addition of flared gas resources to stranded gas reserves will create added-value opportunities and protect the environment (Henry Aldorf, 2008)



Trillion cubic feet

Figure 1. Worldwide stranded gas resources are estimated to add 3,000 TCF—16% in Africa (After Aldorf, 2008)

The total global annual gas consumption is forecasted to rise to 2.9 trillion cubic meters by 2015 accounting for approximately 27% of the total primary energy supply (Patel, 2005)

BACKGROUND

Natural Gas despite being one of the most abundant energy sources on the planet, more than one-third of global natural gas reserves remain stranded so that they cannot be economically delivered to market (Thackeray and Leckie, 2005). About 70% of internationally traded gas is exported by pipeline, and the remaining 30% by Liquefied Natural Gas (LNG). Over the last two decades, several other technologies have been evaluated and proposed for monetizing previously remote gas reserves, Fig. 2. These include Gas-To-Liquid (GTL), gas-to-wire, Compressed Natural Gas (CNG) and gas-to-solid technologies. The latter two technologies are in the research and development stage and, although the potential of these options has been explored in the past decade, no commercial projects exploiting them have been sanctioned (Wood and Mokhatab, 2008).

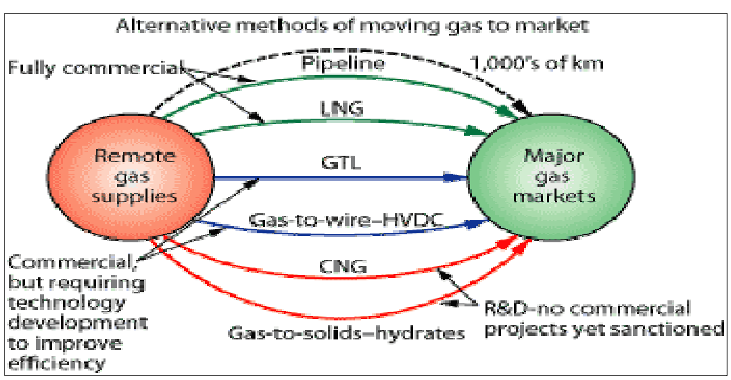


Figure 2. Technologies available to transport natural gas long distances (After Wood and Mokhatab**,** 2008).

Tonkovich, et al (2011), also wrote many technological solutions are currently on the market or in development that address the challenge and opportunity of natural gas without ready access to distribution infrastructure, known as stranded gas. These solutions include compressed natural gas (CNG), liquefied natural gas (LNG), and a family of chemical conversion routes to produce methanol, dimethyl ether (DME), synthetic crude via Fischer-Tropsch (FT) synthesis, or other products.

DEVELOPMENT OF GAS RESOURCES

Large stranded gas resources, remote natural gas, both non-associated and produced in association with crude oil, presents significant handling challenges. Gas cannot easily be transported by tanker, and long-distance undersea gas pipelines are extremely expensive, and are not technically or economically feasible in remote deep water. Growing global energy demand, diminishing oil resources, introduction of no-flaring rules, fiscal penalties and the environmental benefits of low greenhouse gas emissions from the burning of natural gas all lend urgency to the search for commercially viable technologies for handling and transporting gas over long distances. The hydrocarbon liquid content of natural gas (i.e., Natural Gas Liquids, NGLs; Liquid Petroleum Gas or LPG; and pentane plus) continue to provide valuable revenue streams for gas field development. For this reason, International Oil Companies (IOCs) prefer an integrated approach that facilitates NGL and gas revenues from upstream field development, as well as control over gas feedstock supply for downstream gas conversion plants. IOCs emphasize the total value of integrated upstream and downstream gas supply chains.

Anti-flaring legislation is encouraging development of stranded gas in many countries. Once a common industry practice, flaring is now widely discouraged, and many countries, including Nigeria and Norway, are instituting anti-flaring or emission policies and taxes to discourage wasting gas. In addition, a growing number of International Oil Companies (IOCs) are introducing policies to reduce or halt flaring, and are pushing the development of gas conversion technologies. Countries in West Africa are selling gas as a feedstock at very low prices-less than $0.25/MMBtu-to encourage employment and investment in gas conversion facilities. Gas-rich nations such as Qatar, Trinidad, Malaysia and Norway are integrating their marketing strategies to more efficiently produce numerous gas-derived products, and are building specialized gas-conversion hubs where numerous plants are located in close proximity. By creating such hubs, planners can allow multiple facilities to share processing and pretreatment infrastructure, utilities, ports, administrative offices, fire-fighting equipment, skilled labor and other specialized resources to mitigate capital costs. As a result, gas-rich nations diversify revenue while allowing developers to reduce capital costs (Wood, 2005).

BRINGING STRANDED GAS TO MARKET

The drive to monetize large stranded gas resources, coupled with prudent utilization of gas resources and environmental considerations led to the developments of liquefied natural gas (LNG) and gas-to-liquids (GTL) Fischer-Tropsch technologies. Chemical conversion of natural gas also yields, apart from GTL, dimethyl ether (DME), methanol, and other petroleum products that are used as motor fuels, polymers, and industrial chemicals.

A number of alternative technologies exist that have the potential to make the development of small fields - of under five tcf in size - economically viable. The most advanced among these alternative technologies include (i) floating LNG, (ii) GTL floating production storage and offloading (GTL-FPSO), (iii) Gas-to-solids, though is still being researched, has potential to transport and store gas in the future and (iv) compressed natural gas (CNG). This is also used for the purpose of enhanced oil recovery. These technologies have been developed to a point where commercial scale deployment is not too far away, in the case of GTL and NGH, and demonstration plants have been in operation for several years. Others include gas-to-wire using high voltage direct current (HVDC) to move gas or electricity derived from it over short and medium distances, are attracting interest of specialized markets.

It, therefore, becomes important and appropriate for Nigeria to develop her vast stranded natural gas reserves to serve her economy, strengthen regional cooperation, and meet expanding demand in the different world markets. Certainly, gas has some positive macroeconomic implications for Nigeria, as the dependence on oil will soon be reduced. Since oil currently accounts for over 90 percent of the Nigeria‟s foreign exchange earnings and there is as much gas as there is oil, then the increasing demand for gas brings hope for increased revenue.

PROCEDURE

Review of Some Natural Gas Monetization Technologies

Gas coming from the reservoirs is treated to get read of the following:

1. Acid gas removal, where acid gases are removed to avoid CO2 and H2S freezing in the early stages of the liquefaction process.
2. Dehydration to remove the water from the gas to avoid hydrates formation in pipelines and vessels.
3. Mercury removal, since the presence of mercury causes corrosion problems in the aluminum heat exchangers used in the liquefaction process.

Liquefied Natural Gas (LNG)

The LNG technologies involve liquefaction, shipping, and regasification and delivery into the pipeline grid. When natural gas, mainly methane, is cooled and liquefied through cryogenic processes at a temperature of approximately -260°F (-162°C), liquefied natural gas (LNG) is formed. As a result of this, natural gas volume is reduced to one six-hundredth (1/600), allowing its transportation by specialized LNG tanker ships over long distances. A typical LNG receiving terminal includes storage tanks and infrastructure for the regasification processes (Alawode, and Omisakin, 2011).

Gas-to-Liquids Process

Gas-to-liquids (GTL) is sometimes used as a general term for all technologies that convert natural gas into a liquid product, including methanol, dimethyl ether (DME) and others. Here, it is confined to FT-based processes that convert natural gas into synthetic fuel products. This process, diagrammed in Figure 3, has two primary processing steps (1) methane reforming, and (2) Fischer-Tropsch synthesis.

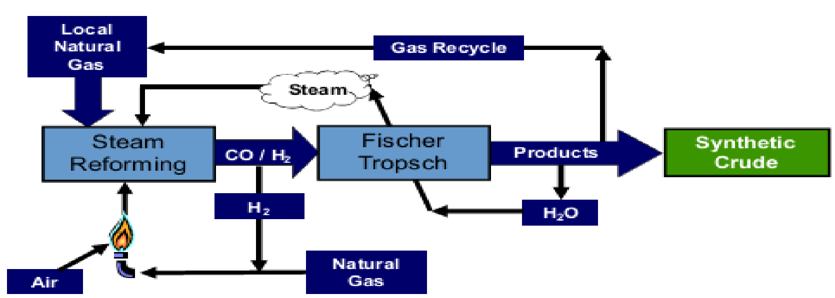


Figure 3. Both primary GTL processes, SMR and FT, can be intensified using microchannel process technology (After Tonkovich et al, 2011)

Methane Reforming

Front end of the GTL process is the conversion of natural gas to a high energy mixture of carbon monoxide (CO) and hydrogen (H_2) known as synthesis gas, or simply syngas. Reforming technologies fall into two basic categories: partial oxidation (POX) and steam methane reforming (SMR). POX reforming encompasses a range of technology, but is essentially incomplete combustion (oxidation) of methane to yield carbon monoxide (CO) and hydrogen (H_2). Complete combustion results in carbon dioxide (CO_2) and water (H_2O). Although more complex, SMR is also a more efficient path to syngas; for this reason it is used most commonly to produce hydrogen, accounting for over 90% of this market. SMR is a high temperature (700–1100°C) catalytic process that yields syngas from methane (CH_4) and steam (H_2O). The reaction, shown in standard equation nomenclature below, is reversible in nature.

$$CH_4 + H_2O \leftrightarrow CO + 3H_2 \quad \ldots\ldots (1)$$

Fischer-Tropsch (FT) Process

The FT process was first developed by Franz Fischer and Hanz Tropsch in Germany in the 1920s and 1930s. The chemistry is based on making longer chain hydrocarbons from a mixture of CO and H2 at an elevated pressure and temperature and in the presence of a catalyst. The reaction is exothermic and excess heat is typically removed by boiling water. The majority of the products from FT synthesis are paraffinic waxes based on the following chemical equation.

$$nCO + (2n+1)H_2 \rightarrow C_nH_{2n+2} + H_2O \quad \ldots\ldots (2)$$

Byproducts from the FT process are lighter hydrocarbons, including methane and naphtha. After the FT process, synthetic crude can be blended with petroleum crude oil for transportation to the world market, or be upgraded to produce distillate products, notably diesel and jet fuel (Strange, 2003).

F-T products are further treated to maximize their sales value or to meet particular market needs. Consequently, the upgrading of paraffins and olefins can be done by using standard hydro-cracking, hydrogenation, oligomerization, and isomerization processes. The breakdown of the fractions of GTL is naphtha 15-25%, middle distillates 65-85%, and associated LPG condensates about 0-30% (Fleisch et al., 2002).

Floating LNG (FLNG)

This concept combines LNG processing and storage technologies with deepwater offshore production experience. Floating oil production vessels have been around for nearly forty years, during which time more than 125 such vessels have been put into service. FLNG vessels are conceptually attractive because of the potential they provide to develop small and remote natural gas fields. Ships with liquefaction facilities onboard can be deployed over several fields in sequence as each field is depleted, eliminating the need to build new facilities. These vessels will work in association with relatively small and isolated installations. Few people would be affected in the event of an accident, enhancing safety and security by virtue of their remoteness. This factor is of particular importance in today's security-conscious world. Several companies, most notably Royal Dutch Shell, have been actively promoting this concept.

GTL FPSO

This technology combines the infrastructure of an FPSO vessel with proven GTL technologies, and is broadly similar in concept to a floating LNG vessel. GTL is based on the

Fischer-Tropsch (FT) process, which was originally developed in the 1920s, but did not attract commercial interest until the recently emerged emphasis on energy diversity, energy efficiency, and environmental responsibility. Syntroleum Corp., a developer of GTL technology, together with Bluewater Energy Services BV, recently finished the feasibility study of the world's first FPSO with GTL capabilities. The vessel will have daily production capacity of 17,000 barrels of FT products, 40,000 barrels of oil, and 10,000 barrels of distillates, and will have a storage capacity of 2.3 million barrels (Marcano and Cheung, 2007).

Gas-to-Solids

The concept of storing and transporting stranded gas to market as dry hydrates, hydrate pastes and hydrate in crude oil slurries has been extensively researched and laboratory tested for more than a decade. Gas hydrates are clathrates in which the guest gas molecules are occluded in a lattice of host water molecules, and are commonly encountered in the industry as a production problem in pipelines. BG Group, Marathon, NTNU and others have worked on a range of gas-to-solids transportation technologies, and tested them at small-scale pilot plants, where concepts include storage and transport of gas (Fischer,2001). Gas hydrates are ice-like solid crystalline compounds formed by the chemical combination of natural gas and water (where individual gas molecules exist within cages of water molecules, $CH_4.nH_2O$ where n greater than or equal 5.75), under pressure and temperature considerably higher than the freezing point of water. In the presence of free water, hydrate will form when temperature is below a typical temperature called hydrate temperature. NGH can contain up to $160m^3$ of methane per 1 m^3 of hydrate. Hydrate technology development has focused on using gas hydrates to convert gas to a solid (GTS) to transport natural gas to market as a low cost solution to managing associated gas in regions lacking in gas infrastructure and/or market. Gas hydrates form naturally in certain subsea sediments and it may offer another solution for the gas supply chain. Major quantities could be stored because volumes are reduced by a factor of about 180 which is less than the 200 and 600 volume reductions for CNG and LNG, respectively. Compared to alternative technologies such as LNG and gas to liquids, GTS hydrates conversion is relatively simple, low cost, and does not require complex processes or extremes of pressure or temperature. It can be small-scale, modular and particularly appropriate for offshore associated gas applications.

Put simply, the hydrate production concept amounts to adding water to natural gas and 'stirring' (Alawode,and Omisakin, 2011).

Compressed Natural Gas (CNG)

CNG offers proven technology that can provide an economic solution for remote offshore gas developments with small to medium reserves, or for associated gas reserves in large oilfield developments. CNG would be applicable where subsea pipelines are not viable because of distance, ocean topography, limited reserves, modest demand or environmental factors, and where LNG is also not economical due to its high cost of liquefaction and regasification facilities, and due to community or safety issues. Safety and security are issues for CNG, but the community-related safety and environmental issues that have prevented permitting of LNG receiving terminals onshore are eliminated by locating CNG offloading facilities tens of kilometers offshore. Energy consumed in operating a CNG project is about 40% that of an LNG project, and about 15% that of a methanol or GTL project. Greater than 85% of CNG project costs are likely to be associated with ships, which are based upon conventional bulk carriers with at least four competing certified containment designs (Hatt, 2003)

Gas-to-Wire

High Voltage DC transmission lines offer the most technically viable solution to moving large quantities of electric power over large distances (up to about 1,500 km), and keeping line losses less than 10%. Alternating current technology is only viable over short distances before suffering unacceptable line losses. However, HVDC is capital intensive and requires costly converter stations at either end of the transmission line. Indicative costs for a 1,200-km, 500-kV bipolar HVDC line to transmit 3 GW of power would cost close to US$2 billion. Additional costs for installing, operating and maintaining gas turbines at the remote site would be incurred. (Hill et al, 2002).

THE ACHIEVEMENTS OF NIGERIA IN MONETIZING STRANDED GAS RESERVES

The discovery of gas in Nigeria is as old as that of oil, but not much attention has been directed at this source of energy. From November 1938, almost the entire country was covered by a concession granted to the then Shell D‟‟Arcy to explore for petroleum resources. The company made the first discovery of gas in 1956 at Afam in the Niger Delta. Also, in the same year, another major discovery was made at Saku also in the Niger Delta with a reserve of 3.5 trillion cubic feet. This dominant role of Shell in the Nigerian oil industry continued for many years, until Nigeria‟‟s membership of the Organization of Petroleum Exporting Countries (OPEC) in 1971, after which the country began to take a firmer control of its oil and gas resources, in line with the practice of the other members of OPEC. This period witnessed the emergence of National Oil Companies (NOCs) across OPEC member countries, with the sole objective of monitoring the stake of the oil-producing countries in the exploitation of the resource. Whereas in some OPEC member countries the NOCs took direct control of production operations, in Nigeria the Multinational Oil Companies (MNOCs) were allowed to continue with such operations under Joint Operating Agreements (JOAs), popularly known as Joint Ventures, which clearly specified the respective stakes of the companies and the Government of Nigeria in the ventures. The period also witnessed the arrival on the scene of other MNOCs such as Gulf Oil and Texaco (now ChevronTexaco), Elf Petroleum (now Total), Mobil (now ExxonMobil), and Agip, in addition to Shell which was already playing a dominant role in the industry. These other companies were also operating under JOAs with the national oil and gas operator in Nigeria - Nigeria National Petroleum Corporation (NNPC), with varying percentages of stakes in their respective acreages. To date, the above companies constitute the major players in Nigeria oil industry, with Shell accounting for just a little less than 50% of Nigeria's total daily production, which currently stands at about 2.4 million barrels of oil per day (Madaki, 2005).

Nigeria's endowed abundant natural gas resources, which in energy terms, is in excess of the nations proven crude oil reserve needs to be appropriately utilized. The 63% being flared ought not to be so. Only 7% - 17% is being utilized (NAPIMS Bulletin, 2013). The proper utilization of the abundant natural gas would offer a lot of benefits for the nation. The benefits include, just to mention a few, production of dry gas for local consumption, production of liquefied petroleum gas for exports, production of liquid hydrocarbons from natural gas, availability of gas as a cheaper alternative source of energy to boost commercial activities and eventually employment level and national income, advancement of knowledge through research, gas technology transfer and the development of indigenous expertise in the Nigeria gas industry, the use of natural gas in electricity generation, and promotion of environmental protection and safety through the elimination of gas flaring (OPEC Bulletin, 1997).

ISSN-L: 2223-9553, ISSN: 2223-9944
Vol. 4 No. 5 September 2013

Nigerian Liquified Natural Gas (NLNG) Projects

The Nigeria Liquefied Natural Gas Company (NLNG) was incorporated as a limited liability company in 1989 to harness Nigeria's vast natural gas resources and to produce LNG and natural gas liquids for export. Shell holds a 25.6% interest in NLNG together with NNPC (49%), Total LNG Nigeria Ltd (15%) and Eni (10.4%).With the completion of a sixth production train in December 2007, the Nigeria LNG Plant at Bonny Island has an overall capacity of some 22 million tonnes a year of LNG and 4 million tonnes per annum of LPG. It accounts for approximately 11% of the world's total LNG capacity and is well positioned to serve the European and North American markets. SPDC is the major supplier of gas to the NLNG Bonny Island plant from its onshore and offshore fields (Obayemi, 2013). NLNG has a wholly owned subsidiary, Bonny Gas Transport Limited (BGT), which provides shipping services for the NLNG. Currently Nigeria is embarking on the construction of an LNG plant through NLNG (Nigeria Liquefied Natural Gas) Ltd, in collaboration with three partners, namely, ELF, AGIP, and SHELL. The LNG plant site is located at Finima in the Eastern region of Nigeria and, these three companies in joint venture with NNPC, will also supply up to 1 billion standard cubic feet of natural gas for feed stock/fuel to the plant from their Obite, Obiafu and Soku fields respectively. It is expected that flaring will be substantially reduced by the time these projects come on stream, in addition to the expected huge revenue (Alawode and Omisakin, 2011).

Brass LNG (BLNG) Project

In 2006, the four shareholders of Brass LNG Limited signed the Shareholders' Agreement for the Brass LNG Project. The shareholders are Nigerian National Petroleum Corporation (NNPC) 49% Equity, ENI International 17% Equity, Phillips (Brass) Limited (an affiliate of ConocoPhillips) 17% Equity, and Brass Holdings Company Limited (an affiliate of Total) 17% Equity. The Shareholders' Agreement regulates the manner in which Brass LNG Limited will undertake the project for the construction and operation of two liquefied natural gas (LNG) trains in Brass in Bayelsa state and the delivery of LNG to the Atlantic Basin gas market. The contract for the Front End Engineering Design (FEED) for the project was awarded to Bechtel Corporation; a San-Francisco, USA based engineering company, in November 2004. The work has focused on optimizing FEED designs, preparing the scopes of work for the award of Engineering Procurement and Construction (EPC) contracts, and pre-qualifying contractors for the EPC activities.

The Brass LNG facility, being built on Brass Island in Nigeria's Bayelsa state, will initially consist of two trains with a combined capacity of 10m t/y to be on stream in 2011. The plant will also produce 2.5m t/y of LPG and some condensates with facilities for liquefied butane and propane extraction, segregation, and treatment; two 185,000 m^3 LNG storage tanks; two 110,000 m^3 LPG storage tanks; one 500,000-barrel capacity NGL tank; marine facilities for the products export; and accommodation for plant operators. Brass LNG products will be loaded onto vessels by cryogenic pipelines and then transported to terminal facilities in the Atlantic Basin. The natural gas will then be transported to the United States and Mexico.

The project is expected to produce 10 million tons of liquefied natural gas per year during its 20-year lifetime. Bechtel Corp. of the United States is the project manager of the plant site. Their responsibilities include site preparation, construction camp and construction dock, permanent operator housing and amenities, marine facilities and support services, tankage, utilities and offsite. The project costs an estimated US$8.5 billion. (Alawode,and Omisakin, 2011).

Olokola LNG Project

Olokola LNG (OK-LNG) was part of Nigerian government commitment to ensuring sustainable economic growth in the country. In April, 2005, the NNPC, Chevron, BG International, Ltd. and Shell Gas and Power development signed an MOU on the Olokola LNG project to be sited in Olokola Free trade Zone. NNPC has 40% equity in OK-LNG, Chevron holds 19.50%, Shell has another 19.50%, and BG Group holds 14.25%, while the remaining 6.75% is for strategic investors. This project was the outcome of two separate studies conducted by Chevron and BG, and Shell, which proposed to NNPC the development of their respective Greenfield LNG project in the Olokola area, due to its natural deepwater berth and other factors. OK-LNG will have four trains with a capacity of 22m t/y by 2012/13, with the first two trains (11m t/y) to be on stream in 2011. In the second phase the complex will also produce about 300,000 b/d of LPG and condensate. Ultimately, the complex will have the capacity of 33m t/y of LNG.

It is hoped that Nigeria will supply natural gas to Equatorial Guinea, which is having its own LNG export venture. OK-LNG and related pipeline projects will cost about $10 billion. Gas supply to OK-LNG would initially come from Shell and Chevron operated JVs. About 1,000 MCF/d of gas would be required for each train. Another 500 MCF/d will be needed for internal energy consumption. The BG group, one of the shareholders, has option to participate in the supply of gas to the third and fourth trains (Alawode, and Omisakin, 2011).

West Niger Delta LNG Plant

The plant is the second LNG facility jointly floated by NNPC, Chevron Texaco, Conoco and ExxonMobil and operated by ExxonMobil. The MOU to conduct feasibility studies for this project was signed in February, 2001 and the plant came on stream by 2005 (Garba, 2007).

Escravos GTL (EGTL) Project

Chevron Nigeria Limited (CNL) (75% share) along with the Nigerian National Petroleum Company (NNPC) (25% share) is constructing the 33,000 barrel per day (bpd) Escravos Gas-to-Liquids (EGTL) plant in Escravos, Nigeria (this is expected to be expanded to a 120,000bpd capacity within ten years of its completion). The project was 76% complete by June 2011. The Escravos site is located about 100km south-east of the Nigerian capital Lagos. The plant will receive gas from Chevron-operated Escravos Gas Plant (EGP).A pre-feasibility study of EGTL was carried out in April 1998 while the FEED started in July 2001 and completed in 2002. The environmental impact and socio-economic assessments were completed and project critical path site preparation activities commenced in early 2002. The plant EPC was announced in April 2005, the EPC contract was awarded to Team JKS, a consortium composed of JGC Corporation of Japan, Kellogg-Brown-Root (KBR) of the United States and Snamprogatti of Italy. Lately, tangible progress has been made. Site geotechnical work is going on and the construction of the pioneer camp and concrete batching plant has been completed. The EGTL project was ready for commissioning towards the end of 2009.

The EGTL project is expected to be provided with about 300 million standard cubic feet (MMscf) of dry natural gas as feedstock from the Escravos Gas Project Phase-3 (EGP3). The EGTL plant will use the Sasol Slurry Distillate (SSPD) process which optimally integrates three state-of-the-art GTL technologies of converting natural gas into liquid hydrocarbon products such as diesel, naphta, and LPG that contain virtually no sulphur or aromatics. Europe and the United States are expected to be the primary market for the Escravos GTL (Net Resources Bulletin, 2012).

Bonny Non-Associated Gas Plant (BNAG)

The feed gas for the Nigeria LNG has been non-associated gas mostly from natural gas reserves operated by the shell Nigeria Gas Ltd. Therefore, Shell Petroleum Development Company (SPDC) in 2004 began a $48 million expansion of the BNAG plant from 300 million cf/d to 450 million cf/d with a view to increasing supply to the NLNG Plant's fourth train. Non-associated gas reserves will include the Shell-operated Shoku field of 4.4 trillion cubic feet capacity and Bomu field of 1.1 trillion cubic feet, and the Agip-operated Oshi and Idu fields of 2.5 trillion cubic feet. However, according to plan, the associated gas supply was to be about 65% by the year 2010 (Garba, 2007).

NIGERIAN GAS COMPANY LIMITED

The Nigerian Gas Company Limited (NGC) was established in 1988 as one of the 11 subsidiaries of the Nigerian National Petroleum Corporation (NNPC). It is charged with the development of an efficient gas industry to fully serve Nigeria's energy and industrial feedstock needs through an integrated gas pipeline network and also to export natural gas and its derivatives to the West African Sub-region.

The NGC currently operates eight (12) supply systems namely: The Aladja Gas Pipeline System which supplies the Delta Steel Company, Aladja; the Oben-Ajaokuta-Geregu Gas Pipeline System, which will form the back-bone of the proposed Northern Pipeline System, supplies Gas to Ajaokuta Steel Company, Dangote's Obajana Cement Company and PHCN Geregu Power Plant; the Sapele Gas Supply Systems which supplies gas to PHCN Power Station at Ogorode, Sapele; the Imo River-Aba System for gas supply to the International Glass Industry Limited PZ, Aba Textile Mills and Aba Equitable Industry; the Obigbo

North -Afam system caters for PHCN Power Station at Afam; the Alakiri to Onne Gas pipeline system supplies gas to the National Fertiliser Company (NAFCON) now Notore Chemicals for fertilizer production; the Alakiri -Obigbo North -lkot Abasi system for gas supply to the former Aluminum Smelting Company of Nigeria (ALSCON) Plant now Rusal Industries in Ikot Abasi; the Escravos-Lagos Pipeline (ELP), which supplies gas to NEPA's Egbin Power Plant near Lagos. Subsequent spur lines from the ELP supply the West African Portland Cement (WAPCO) Plants at Shagamu and Ewekoro, PZ Industries at Ikorodu, City Gate in lkeja Lagos, PHCN Delta IV at Ughelli, and Warri Refining and Petrochemical Company at Warri; Ibafo – Ikeja Gas Supply Pipeline System supplies gas to Ikeja City Gate from where Gaslink distributes to the Lagos Industrial Area (LIA). Ikeja – Ilupeju – Apapa Gas Pipeline System currently operated by Gaslink for Gas Supplies to Greater Lagos Industrial Area; Ajaokuta – Geregu Gas Pipeline System which supplies gas to the Geregu PHCN Power Plant; Ajaokuta – Obajana Gas Pipeline System which supplies gas to Dangote's Obajana Cement Plant (OCP).

All these facilities comprise of over 1,250 kilometres of pipelines ranging from 4 to 36 in diameter with an over all design capacity of more than 2.5 billion standard cubic feet of gas per day (bscf/d), 16 compressor stations and 18 metering stations. The facilities represent a current asset base of more than N21 Billion (NNPC Bulletin, 2012).

Thermal Power Plants in Nigeria

The thermal power plants in Nigeria are shown in the table 2 below with their various operational capacity, year of completion and the turbine type.

Table 2. List of power stations in Nigeria (After Nigeria Mbendi Information Services, 2013)

Power Station	Community	Type	Capacity	Status	Year completed
AES Barge	Egbin	Simple cycle gas turbine	270 MW	Operational	2001
Aba Power Station	Aba , Abia State	Simple cycle gas turbine	140 MW	Taking off (I quarter 2013)	2012
Afam IV-V Power Station	Afam , Rivers State	Simple cycle gas turbine	726 MW	Partially Operational	1982 (Afam IV)- 2002 (Afam V)
Afam VI Power Station	, Rivers State	Combined cycle gas turbine	624 MW	Operational	2009
Alaoji Power Station	Abia state	Combined cycle gas turbine	1074 MW	Partially operationa	2012-2015
Egbema Power Station	Imo State	Simple cycle gas turbine	338 MW	Under Construction	2012-2013
Egbin Thermal Power Station	Egbin	Gas-fired steam turbine	1320 MW	Partially Operational	1985-1986
Geregu I Power Station	Kogi State	Simple cycle gas turbine	414 MW	Unknown	2007
Geregu II Power Station	Kogi State	Simple cycle gas turbine	434 MW	Taking off (I quarter 2013)	2012
Ibom Power Station	Ikot Abasi	Simple cycle gas turbine	190 MW	Partially Operational	2009
Ihovbor Power Station	Benin City	Simple cycle gas turbine	450 MW	Under Construction	2012-2013
Okpai Power Station	Okpai	Combined cycle gas turbine	480 MW	Operational	2005
Olorunsogo Power Station	Olorunsogo	Simple cycle gas turbine	336 MW	Partially Operational	2007
Olorunsogo II Power Station	Olorunsogo	Combined cycle gas turbine	675 MW	Partially Operational	2012
Omoku Power Station	Omoku	Simple cycle gas turbine	150 MW	Operational	2005
Omoku II Power Station	Omoku	Simple cycle gas turbine	225 MW	Under Construction	2013
Omotosho I Power Station	Omotosho	Simple cycle gas turbine	336 MW	Operational	2005
Omotosho II Power Station	Omotosho	Simple cycle gas turbine	450 MW	Operational	2012
Sapele Power Station	Sapele	Gas-fired steam turbine and Simple cycle gas turbine	1020 MW	Partially Operational(135MW)	1978 - 1981
Sapele Power Station	Sapele	Simple cycle gas turbine	450 MW	Operational	2012
Delta - Ughelli Power Station	Ughelli	Simple cycle gas turbine	900 MW	Partially Operational (360M	1966-1990

DISCUSSION

Storage of Natural Gas

Long- term demand variations require large storages of natural gas. These seasonal demand variations can be satisfied in two ways: peak load plants which can be brought quickly into operation and as swiftly shut down, and underground natural gas storage. This is important in order to maintain stable production; thus optimizing upstream investment at the production, processing, and transport levels. Natural gas storage also helps to minimize gas flaring that contributes to emission of greenhouse gas causing climate change.

Underground storage of natural gas involves injecting the gas into natural rock or sand reservoirs which have suitable interconnected pores spaces and it is retained for future use. Such storage sites are usually depleted reservoirs. Natural gas can also be stored in aquifer and salt cavities. The storage sites must be close to users to obtain the most cost-effective response to peaks in gas demand. Sites having characteristics required for guarantee safe long-term storage are not common. However, storage in depleted reservoirs is relatively advantageous because the infrastructure is already in place and the reservoir geological and engineering data are available. These provide a better bargain in marketing, and more importantly, could be used for enhanced oil recovery in cases of marginal production.

In Nigeria, since the discovery of oil, natural gas has been consistently flared as mentioned above and the immediate consequences of flaring include huge revenue loss, acid rain, and subsequent increases in atmospheric temperature. On this ground, it becomes necessary that Nigerian government should, partner with multinational oil and gas companies to monetize natural gas through storage especially in depleted reservoirs.

Improved Gas-fired Power Generation

The electricity supply in Nigeria is grossly inadequate and is highly epileptic". The welfare of Nigerians has enormously being affected as a result of this. Small and medium scale enterprises find it difficult to thrive well amidst this situation, thus affecting the economy of Nigeria. The bigger industries are not doing perfectly well, because electric power could not operate optimally leaving them with the option of considering relocating to some African countries with remarkable power supply.

Nigerian Government as a matter of urgency should partner with multinational Oil and Gas Companies and indigenous companies, to construct more power plants in each State of the Federation to complement the existing ones and seriously strengthen power generation via natural gas utilization. The transmission and distribution of the power so generated should, of course, be effective for the people to benefit from.

Dimethyl Ether (DME) Synthesis

Di-methyl ether (DME, CH_3-O-CH_3) is a simple oxygenate that has physical properties similar to LPG, enabling it to be handled in a similar way. DME's boiling point is -25°C at atmospheric pressure, rising to ambient temperatures under 5-6 bars (atmospheres) of pressure. Existing LPG tankers and receiving terminals could be easily converted to handle DME distribution. DME has been produced on a small scale by dehydration of methanol as a premium-price specialist chemical from natural gasl, and has potential as a clean, versatile and easily handled fuel that can be manufactured at a lower cost than FT-GTL diesel. It is presently being used on a small scale as an aerosol propellant in the cosmetics industry (about 150, 000 metric tons per year). However, it has future opportunities in a broad range of applications. It can be used as a fuel for power generation; General Electric, Hitachi and Mitsubishi have already approved it for use in their gas turbines. DME serves as a viable option to natural gas in isolated regions where there are difficulties in transporting natural gas and construction of LNG regasification terminals are not economical. DME could be produced on a reduced cost since it is transported at a temperature of -25^{0}C as compared to -163^{0}C for LNG. There is an opportunity of using DME as an automobile fuel because of its high octane number and non-pollutant nature, and slight engine modification for its usage. Researchers are presently conducted on the commercial viability of using DME to manufacture olefins for making polymers.

To promote the industrial use of DME as a fuel in the Nigerian market, the Nigerian government should emulate the present partnership between Japan and the Total Group that constructed an industrial pilot using innovative natural gas conversion technology with thermal efficiency (of about 65 to 70%) which is higher than that of the Fischer-Tropsch synthesis used in GTL process (Alawode, and Omisakin, 2011).

Gas-to-Ethylene (GTE) Synthesis

Ethylene is one of the most important largest-volume petrochemicals in the world today. It is used extensively as a chemical building block for the petrochemical industry. Global demand for ethylene has grown steadily in the past and is expected to reach 140 million tons by the year 2010 (Hall, 2005). The importance of ethylene is attributable to the double bond in its molecular structure that makes it reactive.

Gas-to-ethylene is a new technology of ethylene production which was recently developed at Texas A&M University because of the technical and economic deficiencies exhibited by most common processes of converting hydrocarbon to ethylene; the most common in the United States is the thermal cracking of ethane and propane using a fired tubular heater. Others are thermal cracking of naphtha using a fired heater as widely practiced in Europe and Japan, autothermic and fluidized bed technique of production from crude oil, and production from carbon monoxide/hydrogen synthesis from coals and heavy oils. GTE is a direct conversion method and does not require syngas production that makes GTL process rather expensive. The flow diagram of GTE process is divided into five sections: cracking, compression, hydrogenation, amine treatment, and ethylene purification (Abedi, 2007). The Nigerian government should embrace and harness the technical and economic opportunities that GTE technology would offer in the petrochemical industry.

CONCLUSIONS

The monetization of stranded gas reserves in Nigeria include Nigeria LNG plant, Brass LNG plant, Escravos GTL plant, Bonny Non-Associated Gas Plant, West Niger Delta LNG Plant, Olokola LNG Project, Nigeria Gas Company, and some thermal power plants. The assessments of these achievements showed that some of the projects have not reached operational stage; hence, gas utilization in Nigeria is still inadequate when compared to other oil and gas producing countries of the World. Future possibilities of monetizing stranded gas suggested for Nigeria include storage of natural gas (to minimize gas flaring and reduce GHG emission), improved gas-fired power generation (to improve the wellbeing of the people and enhancement of the economy), dimethyl ether synthesis (for industrial use as fuel) and gas-to-ethylene synthesis (serving as chemical building block for petrochemical industry).

RECOMMENDATIONS

It is necessary for Nigerian government to embrace and harness the huge economic opportunities that natural gas monetization would offer to the nation. If this is pursued with all sincerity of heart and patriotism, without undue politics and corruption, then the Vision 20-2020 of the Federal Government of Nigeria will be realized that is Nigeria being among the first twenty economies in the world.

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