Monetizing Natural Gas Reserves: Global Trend, Nigeria's Achievements, and Future Possibilities.

A.J. Alawode, M.Sc.[1] and Olusegun A. Omisakin, M.Sc.[2]

[1]Department of Petroleum and Chemical Engineering, Afe Babalola University, Ado-Ekiti, Nigeria.
[2]Department of Economics & Business Studies, Redeemer's University, Redemption City, Nigeria and Centre for Econometrics and Allied Research (CEAR), University of Ibadan, Ibadan, Nigeria.

E-mail: adelawode@yahoo.com[1]
brightolusegun@yahoo.com[2]

ABSTRACT

Natural gas has some positive macroeconomic implications for Nigeria since there is as much gas as there is oil in the country. Also, the overall dependence on oil will soon be reduced and there will be an increasing demand for gas. Oil currently accounts for over 90 percent of Nigeria's foreign exchange earnings; therefore, there is hope for increased revenue from natural gas. It has become important and appropriate for Nigeria to develop her vast natural gas reserves to serve her economy, strengthen regional cooperation, and meet expanding demand in the different world markets.

This paper reviews global natural gas monetization technologies and projects, assesses Nigeria's achievements in monetizing natural gas reserves, and offers future possibilities. The monetization technologies and projects reviewed are liquefied natural gas (LNG), gas-to-liquids (GTL), compressed natural gas (CNG), gas-to-power (gas-fired power generation), and gas-to-solid (gas hydrates). Nigeria's achievement in monetizing natural 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, Bonny Island Gas and Power plant, Nigeria Gas Company, and some thermal power plants. Some of these projects have not reached operational stage; hence, gas utilization in Nigeria is still inadequate when compared to those of other oil and gas producing nations.

Future possibilities of monetizing natural gas 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 markets. These possibilities include geologic storage of natural gas (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, natural gas reserves, global trends, Nigeria's achievements, future possibilities, liquefied natural gas, LNG, gas to liquids, GTL, compressed natural gas, CNG, gas to power, gas to solid, gas hydrates)

INTRODUCTION

Presently, about 20 percent of all of the primary energy requirements of the world are provided by natural gas; though it was once an unwanted by-product of crude oil production. This development has been recorded in only a few years with the increased availability of the gas resources from different countries (Ikoku, 1992). 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).

World gas reserves are more evenly distributed, compared to oil reserves, with one-third in Russia and Central Asia, one-third in the Middle East and one-third in the other parts of the world. This condition favors a more open market and less geo-political tension than crude oil markets and thus is conducive to the long-term development of gas projects.

In Europe, the growing gap between hydrocarbon supply and demand in the future will require large volumes from other producing regions. Also, in spite of the deregulation process and uncertainties in the long-term demand, increased use of gas in industry and for electricity generation in Asia is expected. Apart from the well-established markets like Japan, South Korea, and Taiwan, there are new markets with growing natural gas requirements such as India, China, and Pakistan.

As an oil shortage looms in the future, it becomes a concern for scientists and engineers trying to use natural gas as an alternative source of energy and as a feedstock in chemical industries. In fact, countries that have a large supply of natural gas have started investing in research in this area. Many isolated sources of natural gas, either residual or in stranded puddles remain unexploited because they are distant from an existing pipeline or waterway and/or too small to be utilized for local usage.

The drive to monetize large stranded gas resources, coupled with prudent utilization of gas resource and environmental considerations led to the developments in 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.

Other technologies, such as compressed natural gas (CNG) and gas-to-power 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. Compressed natural gas is also used for the purpose of enhanced oil recovery. Converting gas to solids in the form of hydrates, though is still being researched, has potential to transport and store gas in the future.

It, therefore, becomes important and appropriate for Nigeria to develop her vast 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. This research work, therefore, reviews global natural gas monetization technologies and projects, assesses Nigeria's achievements in monetizing natural gas and offers future possibilities.

METHODOLOGY

Review of Some Natural Gas Monetization Technologies

Gas coming from reservoirs is treated as follows:

(i) Acid gas removal, where acid gases are removed to avoid CO_2 and H_2S freezing in the early stages of the liquefaction process.

(ii) Dehydration to remove the water from the gas to avoid hydrates formation in pipelines and vessels.

(iii) Mercury removal, since the presence of mercury causes corrosion problems in the aluminum heat exchangers used in the liquefaction process.

<u>Liquefied Natural Gas (LNG)</u>: 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. Rosetta (2005) has identified three basic vaporizers: Submerged Combustion Vaporizers (SCV), Open Rack Vaporizers (ORV), and Ambient Air Vaporizers (AVV).

<u>Gas-to-Liquids (GTL)</u>: Syngas production process involves a chemical reaction of dry natural gas (methane) with either oxygen or steam using reformer which then produce a mixture of hydrogen and carbon-monoxide (H_2 + CO). The production of an ideal syngas calls for a H_2/CO ratio of 2:1. There are three principal technologies for syngas production using natural gas as feedstock (Ahmad *et al.,* 2002; Rahman and Al-Masamani, 2004; Apanel, 2005; Rahmin, 2005). They are steam methane reforming (SMR), partial oxidation reforming (POXR), and auto-thermal reforming (ATR).

The conversion of H_2 and CO mixtures to liquid hydrocarbons is based on F-T catalytic synthesis, which ideally calls for a H_2/CO ratio of 2:1. The reaction is strongly exothermic which means significant heat must be removed. In this process, reactors are designed to efficiently remove the heat to required practically uniform temperature conditions for the reaction, depending on the reaction conditions, type of catalyst used, and the reactor configuration. Fischer-Tropsch Synthesis can be used to produce liquid alkanes (paraffins), liquid alkenes (olefins), and oxygenates such as alcohols.

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).

Compressed Natural Gas (CNG): Smaller and isolated hydrocarbon resources stranded by geographic impediments or located in politically hostile environments cannot be transported by pipelines. Also, it is not economical to transport small quantities of gas particularly in offshore locations via LNG or GTL. The most efficient alternative channel of harnessing stranded gas is compressed natural gas technology.

When natural gas is compressed at low or ambient temperature to a density of about 150 to 250 kg/m^3 compared to 600 kg/m^3 for LNG, the fluid obtained is called compressed natural gas. The CNG is filled into large pressure bottles, of about 110 cm diameter and 36 m length, and transported by ship to a receiving terminal.

Compressed natural gas is a safe and environmentally friendly fuel. It produces non-toxic vapor and provides operations with reduced noise pollution; it provides toxic soot pollution reduction by about 75 to 90 percent and smog-forming pollution reduction by about 25 percent compared to conventional automobile fuel.

Gas-to-Power (Gas-fired Power Generation): Natural gas can be used to generate electricity in a variety of ways. The most basic natural gas fired electric generation consists of a steam generation unit, where fossil fuels are burned in a boiler to heat water and produce steam, which then turns a turbine to generate electricity. Natural gas may be used for this process, although these basic steam units are more typical of large coal or nuclear generation facilities. These basic steam generation units have fairly low energy efficiency. Typically, only 33 to 35 percent of the thermal energy used to generate the steam is converted into electrical energy in these types of units.

Gas turbines and combustion engines are also used to generate electricity. In these types of units, instead of heating steam to turn a turbine, hot gases from burning fossil fuels (particularly natural gas) are used to turn the turbine and generate electricity. Gas turbine and combustion engine plants are traditionally used primarily for peak-load demands, as it is possible to quickly and easily turn them on. These plants have increased in popularity due to advances in technology and the availability of natural gas. However, they are still traditionally slightly less efficient than large steam-driven power plants.

Many of the new natural gas fired power plants are what are known as 'combined-cycle' units. In these types of generating facilities, there is both a gas turbine and a steam unit, all in one. The gas turbine operates in much the same way as a normal gas turbine, using the hot gases released from burning natural gas to turn a turbine and generate electricity. In combined-cycle plants, the waste heat from the gas-turbine process is directed towards generating steam, which is then used to generate electricity much like a steam unit. Because of this efficient use of the heat energy released from the natural gas, combined-cycle plants are much more efficient than steam units or gas turbines alone. In fact, combined plants can achieve thermal efficiencies of up to 50 to 60%.

Gas-to-Solid (Gas Hydrates): 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'. However, a comprehensive understanding of hydrate behavior is necessary to design the technology for transoceanic gas transportation.

Gas hydrates could be produced by contacting natural gas with water at 10^0C and 20 bars, after which the temperature is lowered to -10^0C for the gas molecules to be trapped in metastable ice structures that forms solids at ambient temperature. Gas hydrates crystals resemble ice in appearance but do not have the solid structure of ice. They are much less dense and exhibit properties that are generally associated with chemical substance; the main framework of their structure is water and the hydrate molecules occupying the void space in the crystal structure are held together by the chemically weak bonds with the water.

REVIEW OF GLOBAL NATURAL GAS MONETIZATION PROJECTS

LNG: As early as 1877 in the U.S, methane was liquefied in the laboratory. Also, in 1917 the Bureau of Mining demonstrated natural gas liquefaction in association with helium recovery. A decade later, the first commercial liquefaction project was developed at the CAMEL (now GL4Z) plant in Arzew, Algeria. In 1964, British Gas made the first commercial LNG shipment from this plant to the Canvey Island terminal in the United Kingdom. This LNG was then vaporized and delivered into the distribution system (Nexant, 2007).

LNG is generally a more economic form of natural gas transportation than other options for distances over 3,000 km and is employed to move gas from reserves in distant or stranded fields to developed world markets (Nexant, 2007). When no pipelines are available, natural gas can be liquefied cryogenically (-260^oF). The liquefied natural gas (LNG) is transported in specially-designed ships called LNG carriers.

During the 1970s and the early 1980s four import terminals were built in the United States to receive and vaporize LNG. However, due to the drastic price drop of crude oil in the early 1980s, LNG demand fell short of expectations, and several import terminals were essentially moth-balled (i.e., operations suspended indefinitely) until the late 1990s (Ross and Walter, 2008).

The international trade of LNG has expanded at an impressive annual growth rate of about 8 percent since the mid-1990s. During this time, LNG moved away from being a special premium fuel to a mainstream source of supply of natural gas. Part of the reasons for the growth of LNG has been attributed to advancements in liquefaction technology, a critical segment of the LNG value chain (Nexant, 2007).

As crude oil and natural gas supplies have tightened and their prices have risen, LNG has again become attractive both economically and environmentally. LNG has since developed into a global trade where LNG tankers move liquefied natural gas at -160^oC between liquefaction plants and LNG receiving terminals where the gas is vaporized for sale into local markets. Many new world-scale liquefaction facilities have been built or are under construction. These new liquefaction trains will make large quantities of LNG available for the world markets.

Since the year 2000, announcements to construct approximately 125 new LNG receiving terminals or to expand existing LNG receiving terminals worldwide are made. Many of these projects may not be built, but the number of proposed new terminals is an indication of the potential demand in this sector of the energy business (Ross and Walter, 2008).

Since its initial commercialization, the LNG industry has expanded significantly and today it represents over 25 percent of the international traded volume of natural gas. LNG is currently produced in 13 countries namely, Algeria, Libya, Nigeria, United Arab Emirates, Qatar, Oman, Australia, Brunei, Indonesia, Malaysia, United States, Trinidad, and Egypt (Nexant, 2007).

GTL: Until recently, there were only two ways to transport large quantities of natural gas to the ultimate customer, either by pipeline or as liquefied natural gas (LNG). LNG was really the only viable alternative when the reserves were located far from the major customers, as is the case of the Middle East.

However, a constraint on the growth of LNG has always been the 'slow' build up of new LNG markets and the construction of regasification capacity. Given this situation, the increasing commercial viability of gas-to-liquids (GTL) technology, with a "world-scale" plant concept, will undoubtedly have an effect on the demand side of the gas balance equation.

Owners of gas supplies far from existing and potential markets now have an alternative to develop their resource. If they do not want to wait for a suitable LNG or natural gas market to open up, they have an option of turning their gas into valuable liquid fuels. With a middle distillate market at around 20 times the size of the current LNG market, the potential market for GTL is almost unlimited.

There are other driving forces behind the current interest in GTL. Major gas reserves are in many cases not located in the same places as major crude oil reserves. Hence, the increased use of gas to produce liquid fuels provides an opportunity for consumers to diversify their supply sources.

"Market-pull" on clean fuels will also be a catalyst in GTL commercialization. Tomorrow's global energy markets will be very different from those in the nineties. The global trend towards cleaner fuels and advances in drive train technology present a major opportunity for GTL. For example, GTL fuel (diesel) is a gas-based fuel that fits well in existing diesel infrastructure and is also compatible with many possible directions of the future transportation fuel markets.

The GTL process, in which a chemical reaction converts natural gas to liquid hydrocarbon products, is not a new invention. After World War I, economic hardship experienced in Germany due to the sanctions imposed on the country motivated German scientists to explore ways of synthesizing liquid petroleum from the country's abundant coal supplies. One of the successful methods, the Fischer-Tropsch process, developed in 1923 by Franz Fischer and Hans Tropsch at the Kaiser-Wilhelm Institute for Coal Research in Műlhem, Germany, converted methane obtained from heated coal into high-quality diesel fuel, lubricating oil and waxes. The diesel fuel combustion is clean, producing emissions with negligible particulates and sulphur content. By 1945, German chemical companies had constructed nine Fischer-Tropsch plants for generating clean, synthetic liquid fuels (Stanges, 2003a).

After World War II, several countries started investigating the generation of synthetic fuels based on the Fischer-Tropsch technique. The German plants were disassembled and moved to Russia where they formed the foundation for industrial efforts to produce waxes and chemicals [Jager, 2003].

In the midst of concerns about future security of hydrocarbon imports, work was started in the USA and South Africa to assess the efficiency of the Fischer-Tropsch reactions at different pressures and temperatures, with different catalysts – iron, cobalt, or nickel, and with different methods for flowing the gases and liquids through the reactor. By 1953, one concept was put into operation in South Africa, and since then, largely driven by restrictions on oil imports, Fischer-Tropsch fuels have met 36% of that country liquid fuel needs (www. safrica.info).

Today, South Africa is the world's leading producer of liquid fuel from natural gas. Sasol, the country's synthetic fuel company, produces about 160,000 bbl/d (25,400 m^3/d) from coal-derived gas at two huge plants near Johannesburg, South Africa. Using conventional natural gas piped in from Mozambique, PetroSA produces an additional 30,000 bbl/d (4800m^3/d) at a third plant (Cottrill, 2002b). It is this aspect of GTL technology, the production of easily transportable liquid fuels from conventional natural gas that intrigues the world's large oil and gas companies.

After the South African companies, Shell was the first, and so far the only other oil and gas company, to operate a GTL plant to produce commercial fuels. After investigating the subject for nearly 20 years, Shell opened a GTL plant in 1993 in Bintulu, Malaysia. With gas from fields offshore Sarawak, the Bintulu plant produces 12,500 bbl/d (1990m^3/d) of clean diesel, kerosene, and naphta using the patented Shell Middle Distillate Synthesis (SMDS) process [Shell Chemical Magazine, 2003]. Shell was committed to test operations at the Bintulu plant knowing that it would not be economic, but hoping to establish an early lead in GTL technology. Today, service stations in Bangkok, Thailand, sell synthetic diesel supplied by the shell GTL plant in Bintulu. In the summer of 2003, Volkswagen launched a five-month test of Shell GTL fuel in Berlin, Germany. Further trials are planned in the state of California, USA, and in London, England and Tokyo, Japan (Watts, 2003).

Shell has learned from its early investments in Malaysia, and is considering several locations – Argentina, Australia, Egypt, Indonesia, Iran, Malaysia Qatar and Trinidad – for its first large-scale plant (Cottrill, 2002a). The current plan is to build a plant capable of producing 75,000bbl/d (11,900m^3/d) from 600,000scf/d (17,200m^3/d) of gas feedstock, and to commit to four such plants within the next few years. Each plant could cost 1.5 billion US dollars.

Other companies have invested years of research into gas-to-liquid technology, and may complete their first large-scale GTL plants before Shell constructs its second-generation plants. ChevronTexaco and Sasol have created a joint venture to build a plant in Escravos, Nigeria [www.chevrontexaco.com, 2001]. Initial production will total 34,000bbl/d (5400m^3/d), but the plant may be expanded to output 120,000bbl/d (19,000 m^3/d). The joint venture expects to spend about 5 billion US dollars on a total of four GTL projects around the world.

Leveraging catalysts and reactor research conducted by Conoco parent company DuPoint, ConocoPhillips has made rapid advances in GTL technology. Since1997, ConocoPhillips has designed, manufactured and tested more than 5000 catalysts for gas-synthesis Fischer-Tropsch processes. The company completed a GTL demonstration plant in 2003 in Ponca City, Oklahoma, USA. The plant will convert 4 MMcf (114,600m^3) per day of natural gas into 400bbl/d (64m^3/d) of sulphur-free diesel and naphtha (www.conoco.com, 2002).

BP has produced its first synthetic oil from a US$86 million GTL test plant in Nikiski, near Kenai, Alaska, USA (Bradner, 2003; Font *et al.*, 2003). The BP plant, designed to produce 250 bbl/d (40 m^3/d), is testing a more compact gas-reformer design than the designs Sasol and Shell are currently operating in South Africa and Malaysia. The new reformer is about one-fortieth the size of reformers in use at other GTL plants. If the compact GTL technologies being tested in Alaska are successful, BP will consider using them to develop stranded natural gas reserves worldwide.

ExxonMobil Corp. has invested US$400 million in GTL research since 1981 and has a commercial test plant at the ExxonMobil refinery in Baton Rouge, Louisiana, USA (www.exxonmobil, 2001). The company is carrying out a technical feasibility study for a large-scale plant in Qatar that could convert the reserves of the North field at a rate of 75,000bbl/d. The North field is the largest natural-gas field in the world, and ExxonMobil is one of the several companies interested in developing GTL plants to help exploit it. Qatar could soon become home to several plants capable of generating more than 200,000bbl/d (31,800m^3/d) of synthetic fuels.

Japan, lacking domestic petroleum resources, has long had an interest in synthetic fuels. Japanese research on synthetic fuels began in the 1920s, only a few years after Fischer and Tropsch invented their successful technique. The Japanese conducted laboratory research on the Fischer-Tropsch conversion processes, but in their haste to construct large synthetic-fuel plants, they bypassed the pilot-plant stage, and were unable to advance to large-scale production in those early years (Stanges, 2003b).

Early failure has been replaced by recent successes. The Japan National Oil Corporation (JNOC) announced late in 2002 that its venture with five private Japanese companies successfully produced the country's first manufactured GTL products at their pilot plant in Yufutsu, Tomakomai City, Hokkaido, Japan (www.jnoc.go.ip, 2002). The construction of the pilot plant began in July 2001 and finished in March 2002; the first GTL products were produced in November 2002. Pilot plant operation, with a maximum liquid-fuel production capacity of 1.1m^3/d (6.9bbl/d), continued through 2003 thereby allowing engineers to evaluate the basic design for commercialization.

JNOC and Pertamina, an Indonesia state oil and gas enterprise, have been conducting a joint feasibility study on the applicability of the Japanese GTL technology to development of gas fields in Indonesia.

The Russian Federation has discovered natural gas reserves of around 48.5 trillion m^3 (1690 Tcf) (www.eia.doe.gov, 2003). However, production from their major gas field is declining, and the remaining 90% of reserves lie in East and West Siberia, the Arctic shelf and the Russian Far East. These regions are too remote to access existing Russian gas-transmission networks.

After searching over the last decade for gas-transportation alternatives to pipelines, Russia's Gazprom, the world's largest gas company, announced in March 2003 that it would begin preliminary analysis into building a GTL industry in Russia [www syntroleum, 2003]. An agreement between the Gazprom research and development affiliate, VNIIGAZ, and Syntroleum Corporation, based in Tulsa, Oklahoma, outlines a study of 12 locations throughout the Russian Federation as potential GTL sites. The GTL plants would use Syntroleum technology to produce low-viscosity arctic grade diesel, petrochemical feedstock and specialty lubricants. Plant capacities designed by Syntroleum could handle gas input rates from 1 billion m^3 (34.9 Bcf) per year to 10 billion m^3 (349 Bcf) per year.

Another project involving Syntroleum Corporation's GTL Technology was recently announced by the United States Department of Energy (DOE) to tap stranded gas reserves on the North Slope of Alaska, USA (www.icrc-hq.com). Converted gas from Alaska's North Slope could be transported through the under-utilized Trans-Alaska Pipeline System. The pipeline currently carries crude oil from the giant Prudhoe Bay field on the North Slope to Valdez, Alaska, for tanker shipment. Production from Prudhoe Bay field is declining at a rate of about 10 to 20% per year. Even with additional oil from new fields, pipeline flows will eventually fall below the minimum volume needed for economic operation.

The focus of the DOE project is to demonstrate the feasibility of using a compact GTL plant to convert natural gas into ultra-clean diesel fuel for use in vehicles. The project team will include experts from Syntroleum Corporation, Marathon, the University of Alaska, Daimer-Chrysler Corporation, West Virginia University, Massachusetts Institute of Technology, Sloan Automotive Laboratory, and A.D. Little. After building and operating a GTL plant of sufficient size to prove the technology on a commercial scale, the team will then evaluate the produced fuel in existing and next-generation diesel engines, and in laboratory research engines focused on future engines and emission control technologies (Thackerery, 2003).

A report made by the International Energy Agency (IEA Report, 2000) accomplished that, GTL-FT technology offers a number of advantages as a gas market option. They also stressed that marketing F-T products would avoid cost associated investment by relying on the marketers and the existing crude oil infrastructure which includes storage facilities, terminals, pipelines, and tankers. More so, its environmental advantages will also enhance the economic attractiveness of the project. Fischer-Tropsch Synthesis (FTS) technology is expected to allow for potential development of small and remote gas deposits. GTL technology is widely accepted to be a gas development alternative that will succeed the LNG project.

CNG: The Honda 2004 Civic GX runs on CNG and as of January 2006 is the cleanest federally certified passenger vehicle available in California, with the exception of zero-emission electrified vehicles (Meets EPA's Tier 11 bin 2 Emission Standard). There is no evaporative emission during refueling and the occurrence of knock and explosions in the cylinders are not in CNG vehicles. Pollution cost by disposal and recycling is reduced due to a reduction in the amount of lubricating oil consumed. The operation and maintenance cost of CNG vehicles are much reduced compared to conventional diesel and gasoline vehicles; also, the cost of consumption of CNG per kilometer road is less than that of conventional fuels.

CNG technology is gaining momentum worldwide due to its environmental advantages over traditional gasoline. Already, over 130,000 CNG vehicles are on the United States roads including passenger cars and trucks, heavy-duty transit buses, school buses and refuse haulers use

CNG. According to US Department of Energy (DOE), over 10 percent of the nation's fleet of transit buses and 20 percent of new buses on order operate on CNG. There is growing number of natural gas refueling stations, currently numbering over 1,300 across the country (Fuel Maker Corporation, www.fuelmaker.com).

The transport of CNG by ship is currently being evaluated by Total Group Research and development teams, and it appears promising for distances of about 1,000 km and flows ranging from 1.4 to 14 million m^3/day.

Gas-fired Power Generation: Global electricity consumption is rising at a faster rate after thirty years of growth, averaging 3.3% annually. The environmental qualities inherent in natural gas are optimized in gas-fired power generation. The Total Group has, therefore, developed several gas-fired power generation projects downstream from its operation. Total is a partner in Thailand Bang Bo power plant, which is one of the world's most outstanding combined-cycle power plants with an efficiency of about 56%. Also, in the Middle East, the Group is a stakeholder in Abu-Dhabi'sTaweelah A1 cogeneration power plant. In 2006, a forthcoming extension to this plant was approved to boost capacity by 241 MW and further improve the overall energy efficiency of the facility when it is commissioned in 2009.

In Nigeria, Total in conjunction with the NNPC, has launched the construction of a 440 MW combined cycle power plant. The Group also has co-generation facilities at several refineries located in Port Arthur in the United States, Lindsey in the United Kingdom, Gonfreville in France, and Antwerp in Belgium.

Gas Hydrates: Particularly in Norway and Japan, gas hydrates technology is under study and the results are potentially hopeful; however, there is still the need to resolve diverse problems related to gas hydrates treatment. Furthermore, gas hydrate transport may not be an economically attractive choice at present because the technology involves carrying four times more water than gas.

ASSESSMENT OF NIGERIA'S ACHIEVEMENTS IN MONETIZING NATURAL 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).

As of 2001, Nigeria's gas reserves were estimated at 182 trillion cubic feet (or 25 billion barrels of oil equivalent) which is almost as high as the country's estimated oil reserves of 27 billion barrels. Appropriate utilization of the abundant natural gas in Nigeria 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).

Nigerian LNG (NLNG) Project: Nigeria LNG is jointly owned by the Nigerian National Petroleum Corporation (49%), Shell (25.6%), Total LNG Nigeria Limited (15%), and ENI (10.4%). It was incorporated as a limited liability company on May 17, 1989, to harness Nigeria's vast natural gas resources and produce liquefied natural gas (LNG) for export. Nigeria LNG is headquartered in Lagos, Nigeria. NLNG has a wholly owned subsidiary, Bonny Gas Transport Limited (BGT), which provides shipping services for the NLNG.

After the incorporation of Nigeria LNG Limited, BGT was established on December 10, 1989 to take care of the shipping arm of the project. The company was set up in Bermuda with an ordinary equity holding from Nigeria LNG Limited and preferential equity holding from the sponsors i.e., shareholders of NLNG.

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 at 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. (www.gulfoilandgas.com). 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.

Escravos GTL (EGTL) Project: Chevron Nigeria Limited (CNL), a subsidiary of ChevronTexaco, and the Nigeria National Petroleum Corporation (NNPC) (having respective equities of 75% and 25%) are constructing a Gas-to-Liquids plant of 34,000 barrels per day (bbl/d) capacity. The plant is located approximately 60 miles (about 100 kilometers) south of Lagos, Escravos Nigeria.

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.

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).

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).

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 (www.ondostategovernment.com/articles.html).

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.

Bonny Island Gas and Power Plant: In March 2005, ExxonMobil signed a memorandum of understanding with the NNPC to build a power plant in Nigeria. The first phase of this project will include a plant producing 4.8 Mton per year of LNG at Bonny Island, Southern Rivers State. Nigeria will invest $70 billion in the next ten years on this phase; it is one of the highest LNG investments in the world.

Nigeria Gas Company (NGC): The Company was established under the NNPC to effect and regulate domestic gas markets with overflow to neighboring West African countries. The Company is situated at Ekpan, Delta State and its mission was to be fulfilled by establishing adequate reservoirs, conducive for gas reinjection or storage, processing plants and a network of supply and distribution pipeline across its projected market space with the Nigeria LNG in Bonny. The NGC has in place more than 1,000 km of pipeline with gas systems and fourteen compressor stations. About 75% of NGC'sales is to four thermal power stations run by the Power Holding Company of Nigeria (PHCN) Plc. (www.mbendi.co.za/indy/oil/gas_/af/ng/p005.html)

Thermal Power Plants in Nigeria: Among the thermal power plants in Nigeria are the Okitipupa Power Plant**,** Papalanto Gas Turbine Power Plant, Egbin Power Station, and Utorogun Gas Plant.

The Okitipupa Power Plant has a production capacity of 335 MW with eight GE 6B Gas Turbines and a 132 kV Substation.

The Papalanto Gas Turbine Power Plant has a production capacity of 335 MW and the client is PHCN. PHCN is developing an eight unit 335 MW OCGT, based on GE technology. The plant is planned for conversion for future conversation to a CCGT station. Scott Wilson is acting as Owner's engineer and provides the following services: project management of the EPC/BOOT contract for the entire project, multi-disciplinary technical audit of turnkey contractor's design, site supervision, commissioning co-ordination, and procurement support. Scott Wilson is acting to assist PHCN meets its challenging targets for power supply in Nigeria (www.scottwilson.com).

The Egbin Power Station has a production capacity of 1,320 MW.

The Utorogun Gas Plant is operated by the Anglo-Dutch oil firm, Shell Petroleum Development Company in Ughelli, Delta State. The company supplies 244 million standard cubic feet of gas per day to the Nigerian Gas Company, a subsidiary of the NNPC for onward transmission to the PHCN and other industrial consumers.

DISCUSSION

Future Possibilities of Monetizing Natural Gas Reserves in Nigeria

Geologic Storage of Natural Gas: Natural gas storage is of paramount importance to secure gas supply to consuming areas by adjusting supply to meet strong seasonal fluctuations in demand and maintaining stable production; thus optimizing upstream investment at the production, processing, and transport levels. Natural gas geologic storage also helps to minimize gas flaring that contributes to emission of greenhouse gas causing climate change.

Natural gas can be stored in aquifer, salt caverns, or depleted reservoirs and 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 are 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 and the immediate consequences of flaring include revenue loss, acid rain, and subsequent increases in Nigerian atmospheric temperature. The Nigerian government should, therefore, partner with multinational oil and gas companies to find an effective means of monetizing natural gas through geologic storage especially in depleted reservoirs.

Improved Gas-fired Power Generation: It is a known fact that the electricity supply in Nigeria is grossly inadequate and is being referred to as 'epileptic'. This has, of course, affected the welfare of the people and the economy of the nation as small and medium scale enterprises that depend on electric power could not operate optimally and big industries are considering the options of relocating to some African nations having remarkable electric power supply.

In view of this, it has become a matter of urgency for the Federal Government of Nigeria in partnership with multinational and indigenous companies, to construct more power plants in each geopolitical zone of the nation to complement the existing ones and seriously strengthen power generation via natural gas utilization. The transmission and distribution should, of course, be effective for the people to benefit from the power so generated.

Dimethyl Ether (DME) Synthesis: At present, DME (a clean, colorless gas that is easy to liquefied and transport) is produced by dehydration of methanol from natural gas. 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 and its synthesis can be done on existing liquefied petroleum gas (LPG) facilities. 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.

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

Nigeria's achievements in monetizing natural gas reserves include Nigeria LNG plant, Brass LNG plant, Escravos GTL plant, Bonny Non-Associated Gas Plant, West Niger Delta LNG Plant, Olokola LNG Project, Bonny Island Gas and Power Plant, Nigeria Gas Company, and some thermal power plants. After assessing these achievements, it was found that projects have not reached operational stage; hence, gas utilization in Nigeria is still inadequate when compared to those of other oil and gas producing nations.

Future possibilities of monetizing natural gas suggested for Nigeria include geologic storage of natural gas (to minimize gas flaring and reduce GHG emission), improved gas-fired power generation (to improve the welfare of the people and enhance the economy), dimethyl ether synthesis (for industrial use as fuel) and gas-to-ethylene synthesis (serving as chemical building block for petrochemical industry).

RECOMMENDATIONS

The Nigerian government should embrace and harness the economic opportunities that natural gas monetization would offer the nation. If this is pursued with genuine sincerity and patriotism, without corruption and undue politics, then Nigeria will be heading towards being among the first twenty economies in the world as expected in the 'Vision 20-2020" of the Federal Government of Nigeria.

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ABOUT THE AUTHORS

Adeolu Julius Alawode, is a Lecturer at the Department of Petroleum and Chemical Engineering, Afe Babalola University, Ado-Ekiti, Nigeria. He obtained his Masters of Science degree in Petroleum Engineering from the University of Ibadan, Ibadan, Nigeria. Prior to this, he had obtained Bachelors and Masters of Engineering degrees in Mechanical Engineering from the University of Ilorin, Ilorin, Nigeria. His areas of interest are reservoir engineering and enhanced oil recovery. He is a COREN-registered Engineer.

Olusegun Akin Omisakin, graduated from the University of Ado-Ekiti, Ado-Ekiti, Nigeria where he obtained a Bachelor of Science degree in Economics. He also obtained a Masters of Science degree in Economics from the University of Ibadan, Ibadan, Nigeria where he is presently a Ph.D. student. His areas of interest are oil and gas economics, applied econometrics, energy economics, and general equilibrium modeling. He is presently a Lecturer at the Department of Economics and Business Studies, Redeemer’s University, Redemption City, Nigeria.

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