International Journal of Advanced Academic Research | Sciences, Technology & Engineering | ISSN: 2488-9849
Vol. 4, Issue 5 (May 2018)

# A FEASIBILITY ASSESSMENT OF A GAS-TO-POWER PLANT SCHEME AT THE GULF OF GUINEA, NIGERIA

**By**

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*A dissertation submitted in partial fulfillment of the requirements of the award of*

*Master of Science in Oil & Gas Engineering at the University of Aberdeen*

**(September, 2013)**

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## ABSTRACT

Reliable electricity generation and supply is a major driver of any nation's socio-economic development. The type of generator technologies, feedstock availability in a long-term basis, plant location is of key importance to the electricity generation and its sustainable development.

Nigeria is faced with inadequate electricity generation and supply to meet its growing energy demand from her growing population. This situation has led to social conflicts which affects the nation's effort to realize commercial benefits from her huge natural reserves.

Based on this background, the study combines information from residual knowledge, academic papers, independent sources, newspaper reports, government and international oil company's database for the feasibility analysis.

This study gives an in-depth and clear insight into the requirements for the development of a gas-fired power plant scheme at the Gulf of Guinea, Nigeria in order to contribute meaningfully to Nigeria's energy demand imbalance. It employs the SWOT, PESTLE and LCC Analysis techniques for development concepts and decision making on the project with an Offshore Gas-fired Power Plant scheme emerging as a viable choice. Also for the business case and sensitivity analysis on the alternative uses of the electricity generated from the selected concept (Floating Gas-fired Power Plant), the HOMER Energy software for electricity renewables was employed.

Finally, a comprehensive project risk assessment and execution plan was carried-out for the project.

# LIST OF ABBREVIATIONS AND UNITS

| | |
|---|---|
| CC | Combined Cycle |
| CT | Combustion Turbine |
| CPG | Centralized Power Generation |
| DG | Distributed Generation |
| EIA | Energy Information Administration |
| EOR | Enhanced Oil Recovery |
| ETM | External Turret Mooring |
| EPSR | Electric Power Sector Reform |
| FAT | Factory Acceptance Test |
| FEED | Front End Engineering Design |
| FGN | Federal Government of Nigeria |
| FGFPP | Floating Gas-fired Power Plant |
| GDP | Gross Domestic Product |
| GFPPTL | Gas-fired Power Plant Tension Leg |
| GHG | Greenhouse gas |
| HRSG | Heat Recovery Steam Generator |
| IOCs | International Oil Companies |
| IRR | Internal Rate of Return |
| JV | Joint Venture |
| LCC | Life Cycle Cost |
| LNG | Liquefied Natural Gas |
| NNPC | Nigerian National Petroleum Corporation |

| | |
|---|---|
| NPV | Net Present Value |
| OECD | Organization for Economic Co-operation and Development |
| OPEC | Organisation of Petroleum Exporting Countries |
| PAL | Project Active Life |
| PESTLE | Political, Environmental, Safety, Technical, Legislation Economic |
| PIB | Petroleum Industry Bill |
| PHCN | Power Holding Company of Nigeria |
| PSC | Production Sharing Contract |
| SAT | Site Acceptance Test |
| SWOT | Strengths, Weaknesses, Opportunities and Threats |
| ST | Steam Turbine |
| TSGP | Trans-Saharan Gas Pipeline |
| WAGP | West African Gas Pipeline |

**UNITS**

| | |
|---|---|
| Bbl/d | Barrel per day |
| Bscf | Billion standard cubic feet |
| Tscf | Trillion standard cubic feet |
| Btu | British thermal unit |
| MMscf | Million standard cubic feet |
| Mscf | 1000 standard cubic feet |
| MWe | Megawatts of electricity |

## ACKNOWLEDGEMENT

I specially appreciate my maker, the creator of the Heavens and the earth for a successful completion of this academic study and for being my source of inspiration and help.

I am inexpressibly grateful to my most supportive and amiable wife, Osasere Ebikeme and my precious family for their endless love, understanding, support and most of all, for enduring my absence throughout my post-graduate studies at the University of Aberdeen. To my friend, Olanike Adubiobi, I say a very big thank you for consistent support and help throughout my stay.

I owe a debt of gratitude to my supervisors, Dr. Cornelia Noel (SNEPCO) and Dr. Marina Menshykova (Aberdeen University) for a faultless and helpful supervision. I am deeply excited to have learnt under your erudite scholarship and scholastic efficiency.

To all my colleagues and friends at the city of Aberdeen, I appreciate you all for your invaluable friendship.

Finally, I acknowledge the contribution of all academic and non-academic staffs of this noble institution particularly the School of Engineering, Faculty of Physical Science. I appreciate you all and God bless you tremendously.

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# CHAPTER ONE - POWERING NIGERIA IN THE 21$^{ST}$ CENTURY

The growth, industrialization, national security and economic development of any nation are hinged to its reliable electricity supply industry. Nigeria is no exception in this feat. Nigeria is the most populous country in Africa with estimated population currently standing at 155 million people distributed as 51.7% rural and 48.3% urban and is expected to grow to circa 230 million in 2030 as estimated by the United Nations in 2009. [1] Nigeria is the 12th largest producer of petroleum in the world and also possesses the largest natural gas reserves in the continent. [2] Apart from petroleum and gas, The Federal Republic of Nigeria (FRN) also has a wide array of natural resources which include coal, bauxite, gold, tin, iron ore, limestone, niobium, lead and zinc. The capital-intensive oil sector provides 20 per cent of gross domestic product (GDP), 95 per cent of foreign exchange earnings, and about 65 per cent of budgetary revenues.

With such an enormous wealth and increase pollution, Nigerian governments over times under-estimated the importance of a sustainable development in the Nigeria's electricity sector which has mutilated the growth of the country's production and commercial industries due to its inability to expand its grid capacity combined with the high cost of diesel and petrol generation over the past two decades. [3] At present, Nigeria operates at approximately one-third of its installed capacity (4,000MWe) for its government-owned existing PHCN power station due to aging facilities. This value falls under the rule of thumb of at least 1,000MWe of electricity generation and consumption required for every 1 million head of population of any developed industrial nation, thereby recording Nigeria's per capita electricity consumption amongst the lowest in the world and far lower than other African countries. As shown in **Figure 1.1**, the Nigeria's per capita electricity consumption is just 7% of Brazil's and just 3% of South Africa. This serves as an indicator as to the scale of investments that is needed to be made in the Nigerian Electricity Supply Industry over the coming decades. An adequate, consistent electric power supply will do much to attract foreign investment and entice international firms to establish operations in Nigeria. However, the on-going societal conflicts, mismanagement of revenues, lack of adequate maintenance have left power generation facilities damaged and transmission lines cut.

On a positive note, the Federal Government of Nigeria (FGN) is totally aware of this yucky situation and is conscious of revamping the country's electricity power sector in order for her to join the rest of the world in the race of development. To this end, the full implementation of the National Electric Power Policy 2001/2002 and the promulgation of the Electric Power Sector Reform (EPSR) Act 2005, serves as a fundamental outline in the ownership, control and regulation of the sector thereby incentives and making it favourable for private sectors such as international oil companies (IOCs) to partner with the government in this endeavour.

To meet the Nigeria's vision 2020 target of 40,000MWe (40GWe), large investments is required for the power generating capacity, the fuel-to-power infrastructure and the power transmission and distribution networks. These funds will come from all quotas in a centralized profitable market system which includes the Nigerian government and private sectors (IOCs and others) exploring various ways to contribute to improving the sector.

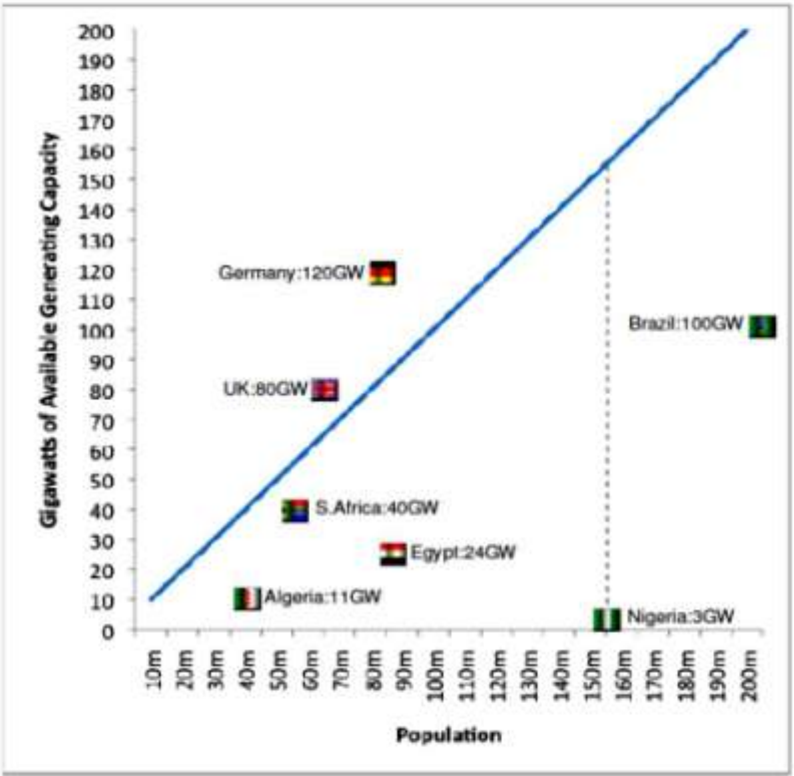


**Figure 1.1:** Gigawatts of available generating capacity versus population for some selected Countries (Source: RMFPSR, 2011)

### 1.1 PROJECT PROBLEM STATEMENT

Onshore electric power generation and supply in Nigeria is done largely through generators driven by a diesel engine. These generators are only operational during regulated hours such as 6am to 10pm. Due to the high cost of transportation of diesel and environmental issues, this form of energy generation and supply is not sustainable.

The offshore oil and gas producers rely on gas turbines to generate power locally for their facilities on a 24-hours basis due to the availability of natural gas which had led to the development of regional pipelines, the expansion of liquefied natural gas (LNG) infrastructure, and also polices banning gas flaring. This scheme of gas-fired electric generation can be done on a commercial large scale in such location and the offshore energy generated be connected to a reliable onshore national grid in an optimal way by Nigerian government utilizing its currently flared natural gas. However, another major obstacle is in launching widespread power in Nigeria involves setting up a power transmission and distribution network. Once you have that network, many activities can be operated at a profit. The problem is how to expand the network, which requires money and an improved regulatory framework. The Nigerian government seeks vast majority of all new power plants be financed and built by the private sector.

## 1.2 Project Location

The Federal Republic of Nigeria (FGN) is located in western Africa on the Gulf of Guinea and has a total area of 924,000 km2. It shares a 4,047 kilometres border with Benin, Niger, Chad, Cameroon, and has a coastline of at least 853 km as shown in **Figure 1.2**. Nigeria has a population density of 167.5 people per square kilometre. [1]


**Figure 1.2:** Nigeria map showing its mainland, surrounding countries and coastline (Source: EIA, 2012)

Nigeria is the largest oil producer in Africa and has been a member of the Organisation of Petroleum Exporting Countries (OPEC) since 1971. Nigeria produced about 2.53 million barrels per day (bbl/d) of total liquids, well below its oil production capacity of over 3 million bbl/d, due to production disruptions in the Niger Delta region (see **Figure 1.3**) that have compromised portions of the country's oil for years. In addition to crude oil, Nigeria holds the largest natural gas reserve in Africa. Nigeria has more than 250 oil and gas fields, with about 2,600 producing oil wells on both onshore and offshore locations.

Off the coast of Nigeria, the Gulf of Guinea is replete with hydrocarbon resources including an abundant supply of gas explored by several multinational oil and gas companies (including OffshoreCo) with over fifty (50) oil blocks and several Oil Mining Leases (OMLs) issued by the Nigerian government. Initially, the gas was flared as a by-product of oil production but it is now being exported as Liquefied Natural Gas (LNG) after the decree issued on the Nigerian Petroleum Industry Bill (PIB) December 2008 and implemented in December 2012 by the Nigerian government to stop the flaring of natural gas in hydrocarbon exploration and production (E&P) activities in Nigeria. [4] Equally, some of this gas could be tapped in an offshore gas-to-power scheme (away from social conflicts) to power onshore Nigeria.

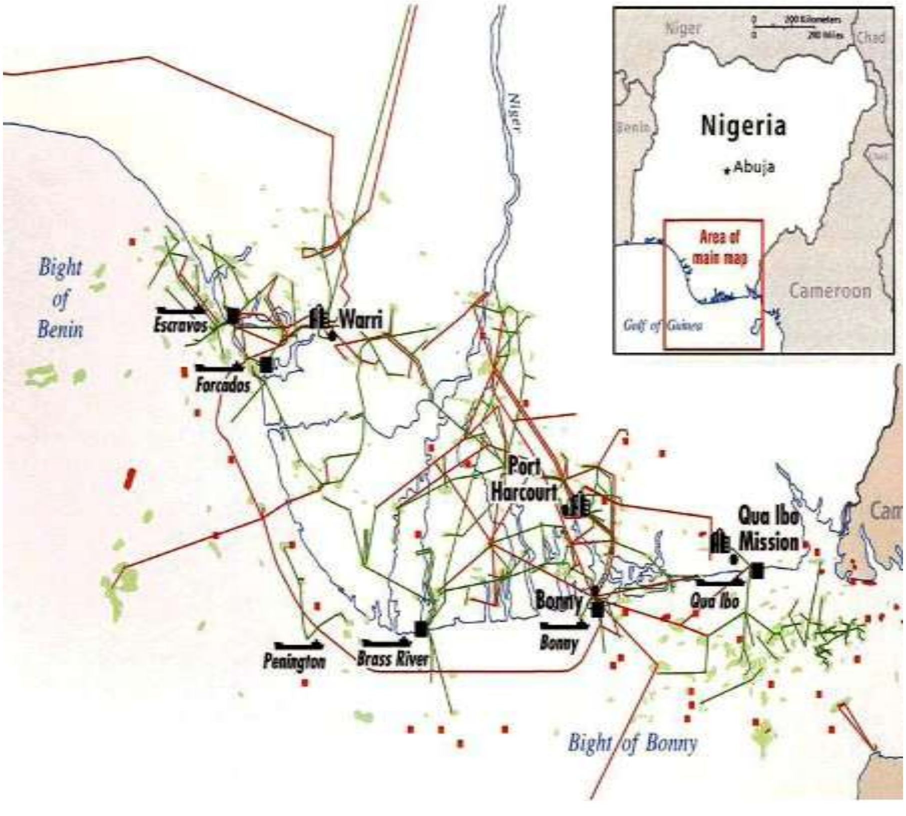


**Figure 1.3:** Niger Delta Region (Source: NNPC, 2013)

## 1.3 SCOPE, AIM AND OBJECTIVE OF THE PROJECT

The **Table 1.1** below shows the scope, aim and objective of the Project.

| | |
|---|---|
| Scope | The pre-feasibility study covers only area of inquiry on an offshore gas-fired power plant scheme and answers these questions surrounding it well enough to form a solid basis for a decision on whether to initiate a detailed feasibility study. |
| Aim | This is to investigate the potential for an offshore gas-to-power scheme to boost the national power grid in Nigeria. |
| Objective | This assesses the technical, economical and operational feasibility of an offshore gas-fired power plant at the Gulf of Guinea, Nigeria. |

## 1.4 STRATEGIC CONTEXT

The Nigeria Government reaffirms its commitment by amendment of its Electric Power Sector Reform (EPSR) Act of 2005 to genuinely realize improvements in the amount and quality of electricity supplied to customers in all regions of the country. This has led to the commercialization of the industry which creates clear and level platform for private sectors to invest. Additionally, the current debate on large capital investment of at least US$ 3.5 billion per annum for the next 10 years in this sector has posed a challenge to the Nigerian government.

OffshoreCo currently operates an offshore gas field in the Gulf of Guinea in a joint venture arrangement with the Nigerian government and other co-investors. OffshoreCo operations include a network of pipelines, gas- and power- plants, export terminals. Accordingly, OffshoreCo has the desire to explore the provision of electrical energy natural gas tapped from its Gulf of Guinea gas lease (Field-X).

## 1.5 PROJECT PERFORMANCE

This dissertation gives general analyses and clear insight into the feasibility of a possible offshore natural gas-to-power plant scheme in an offshore location (Field-X) in the Gulf of Guinea Nigeria.

The process of work will be done by me with general stewardship from OffshoreCo and Academic (Aberdeen University) supervisors providing answers to questions surrounding specific areas such as data, project framing guidance, amongst other things.

# CHAPTER TWO - NATURAL GAS UTILIZATION

Natural gas is a vital component of the earth's energy mix. It was originally obtained in the 19$^{th}$ century as a bi-product of crude oil production. Its most abundant component is the methane accounting for 70-90% quantity, ethane, propane, butane, carbon dioxide, oxygen, nitrogen, hydrogen sulphide and rare gases accounting for the remaining 10%. It is a fuel that is primarily used in power generation, industry, transport and other sector. Natural gas occurs around the world but the most significant deposits are in the Russia and the Middle East which jointly hold an estimated 62% of global reserves. [5, 6] Noticeable growths are seen in natural gas production for other countries such as the United States, Venezuela and Nigeria.

Nigeria had an estimated 182 Trillion cubic feet (Tcf) or 33 Trillion barrels (2.7% of global reserves) of proven natural gas reserves as of the end of 2012, according to the OGJ, making Nigeria the ninth largest natural gas reserve holder in the world and the largest in Africa. [6]

## 2.1 NATURAL GAS – ENERGY OUTLOOK

Natural gas was estimated to accounts for approximately 22 per cent of the world's energy demand in 2012. [2] This figure is skewed because of the 26% gas market share in the United States (US); the biggest consumer where 2.1 million bbl/d (24%) of US oil production was from tight oil and 24 Bcf/d (37%) of natural gas from shale. These resources have boosted gas output by nearly 20% and oil by 30% in the past five years thereby decreasing US natural gas importation from gas producing and exporting countries. [5] OGJ's annual look 2012 at the world's gas reserves shows an increase to 6,793.4 Tcf (6.79 quadrillion cubic feet/Qcf) from 6,746.6 Tcf in previous year's survey with OPEC's gas reserves contributing 49% (3,330.1 Tcf) of the worldwide total which is up to 1 per cent from a year ago. [6] With several gas-producing countries announcing ambitious plans for markedly increasing gas outlet: Qatar, Oman, Venezuela, Nigeria, and Saudi Arabia, Liquefied natural gas (LNG) facilities are currently being built, and serious LNG tanker shortages are forecast for the next 3 to 4 years. Nigeria is clearly targeted as a major oil producer for the next decade, especially from the offshore blocks, but its potential for gas production has been underestimated thus far from the OPEC quota gas production allocation for its member countries.

### 2.1.1 NATURAL GAS – PRODUCTION AND CONSUMPTION TRENDS

The world's primary energy consumption is projected to grow by 1.6% p.a. from 2011 to 2030, adding 36% to global consumption by 2030. [5] The **Figure 2.1** shows that Non-OECD countries accounts for 93% of the energy consumption growth in 2030. This is 61% above the 2011 level, with growth averaging 2.5% p.a. (or 1.5% p.a. per capital) accounting for 65% of world consumption (compared to 53% in 2011). Organization for Economic Co-operation and Development (OECD) energy consumption in 2030 is just 6% higher than in 2011 (0.3% p.a.), and will decline in per capita terms (-0.2% p.a. 2011-30).

Total natural gas production currently at about 305 Bcf/d is projected to grow by 2% p.a., reaching 459 Bcf/d by 2030. Most of the growth is originates from non-OECD countries (2.2% p.a.), accounting for 73% of the world gas production growth. The United States, Western Europe and Japan account for half of the world's gas consumption, but between them, they account for less than one-fifth of the world's natural gas reserves. They rely on imports from gas-producing countries to meet their demand with Nigeria being their major exporter. The discovery of natural gas from shale by the United States increased the US natural gas production to 37% (24Bcf/d) in 2012 which have boosted gas output by nearly 20% and oil by 30% in the past five years. [5, 32]

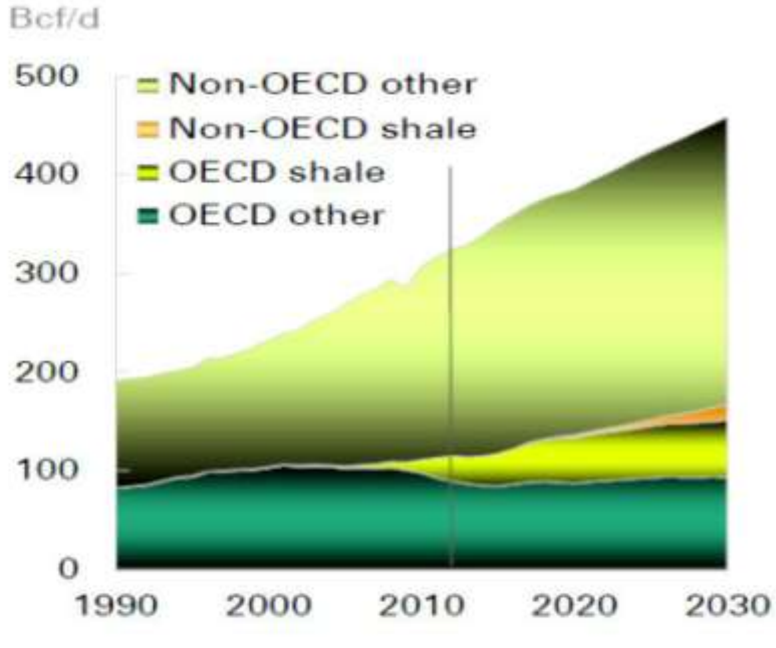


**Figure 2.1**: Gas production by type and region (Source: BP, 2013)

Natural gas produced in Nigeria (amongst the non-OECD) is majorly exported as LNG, with the remainder consumed domestically and other portions exported regionally via the West African Gas Pipeline (WAGP). Dry natural gas production grew for most of the last decade until Shell Nigeria Gas Limited (SNG), a Shell-owned gas sales and distribution company declared a force majeure on gas supplies in order to carry out repairs on pipelines connecting to industries (soku plant) due to damages caused from sabotage by local groups siphoning condensate. This led to a reduction in Nigeria's natural gas production, particularly from Shell's fields in the Niger Delta and a 33 per cent decline in LNG exports in 2009. [2]

### 2.1.2 Natural Gas - Forecasting Energy Demand and Supply

Projections from various energy institutes indicate a rapid increase in the world energy demand. The OPEC World Energy Models forecast that world's energy demand increases by 51% by 2035 with fossil fuels currently accounting for 87% of the primary commercial energy supply; will still make up to 82% of the global total by 2035. Oil dominate the energy type with largest share for most of the projection period but in 2035, it is predicted to be slightly overtaken by coal use which will represent 29% of the total energy similar to today, while oil's share falls from 34% to 28%. Natural gas will rise at faster rates than either coal or oil, in percentage terms and volumes, with its overall share rising from 23% to 25%. [7] The increasing supply to meet expected demand growth is expected to come from non-OPEC unconventional sources (increasing by 8.5million bbl/d) and later from OPEC production expanding by 7.6 million bbl/d as shown in **Figure 2.2** and **Figure 2.3**.

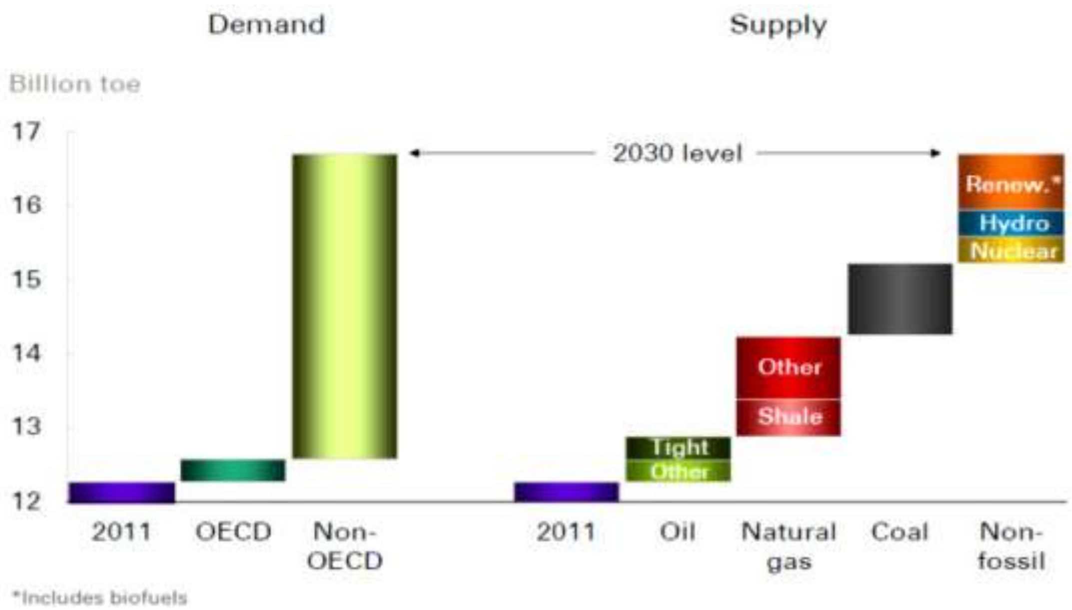


**Figure 2.2**: Energy demand and supply (Source: BP, 2013)

The key drivers behind growing demand for energy are population and income growth. The world population is estimated to reach 8.3 billion by 2030 which implies an additional 1.3 billion people will need energy and world income in 2030 is expected to be roughly double the 2011 level in real terms. [5] The world's demand for natural gas is 225 Bcf/d, giving a production to reserves ratio equivalent to 70 years of production as shown in **Figure 2.4**. There is a universal agreement in all forecasts that gas utilization will increase substantially causing a decrease in the oil share over the next two decades.

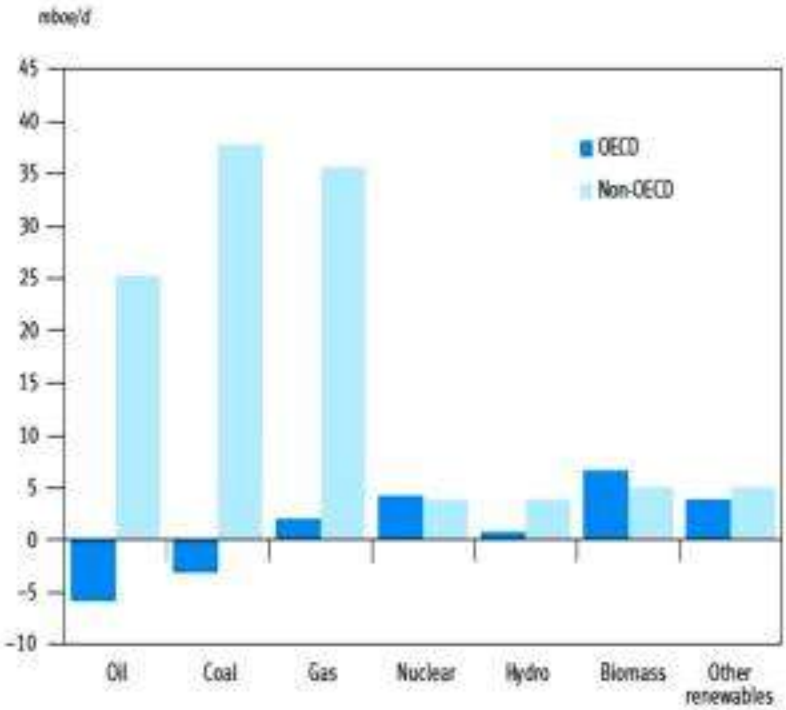


**Figure 2.3**: Increase in Energy demand 2010-2035, by fuel type (Source: OPEC WOO, 2011)

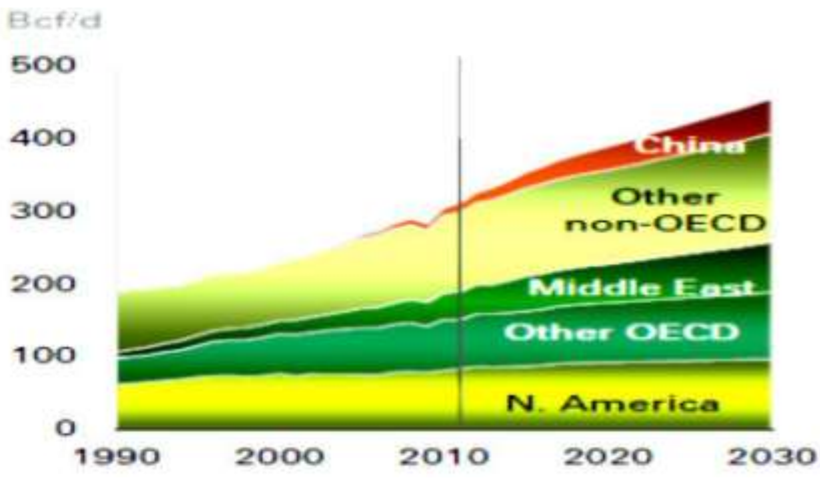


**Figure 2.4**: Gas demand region (Source: BP, 2013)

### 2.1.3 NATURAL GAS – ACCESSIBILITY AND INFRASTRUCTURE

The largest drawbacks to natural gas use had been tied to being political. This is linked with the lack of building and facilitating natural gas infrastructure, less adroit uses of taxes and incentives which play a very constructive, substantive role in a social and economic transformation in the 21st century by various ruling governments. Also in addition, natural gas supply and demand struggle to stay balance as gas consumption increases which is complicated by the inability to predict seasonal weather anomalies and by the masking effect of gas storage as shown in **Figure 2.5** below.

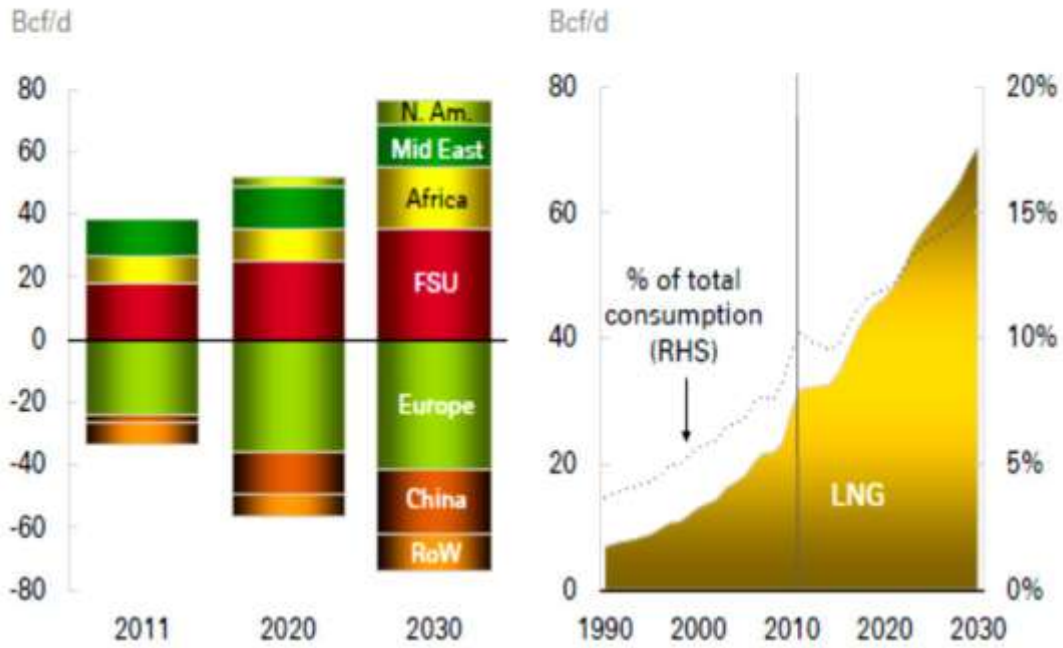


**Figure 2.5**: Regional gas imbalances and LNG exports (Source: BP, 2013)

The current infrastructure for the use of natural gas inside Nigeria includes a transportation network and some gas utilization projects. When the producing oil field is located onshore either on land or swamp, the producing well is tied to a flowstation which serves as a collection centre for many wells and it is used to separate gas from the remaining hydrocarbon field. Previously, higher amount of the separated gas is flared at the flowstation, for fuel for the power turbines with the residual gas sent to the gas-gathering system for treatment for domestic consumption or exported. For gas wells, direct connection is done to processing plant for treatment. Oil wells located at swallow waters are most times tied to a fixed platform where gas is partially separated from the remaining hydrocarbon fluid. Offshore wells (deepwater) are developed with the use of floating production, storage and offloading facilities (FPSOs) capable of full treatment, storage and offloading of the hydrocarbon for immediate export. In some locations, oil wells in shallow waters are routed to the FPSO for full treatment prior to export. [8] With gas flaring banned by the Nigerian legislation [4], the previously flared associated gas from flowstations is now connected to a pipeline network and sent to the nearest LNG facility for treatment and export. Also offshore non-associated gas fields are developed on floating FPSO facilities and piped into an LNG facility located onshore. In the southern part (Niger Delta) of Nigeria, an existing pipeline system supply treated gas to industries. Nigerian Gas Company Limited (NGC), a wholly owned subsidiary of Nigerian National Petroleum Corporation (NNPC), operates a large share of the integrated gas pipeline network to serve the Nigeria's energy and industrial needs and also export natural gas and its derivatives to the West African Sub-region. [9] Several large gas export projects have been initiated and new ones are planned to ensure that revenues are generated from gas resources and gas flaring eliminated. One of such international gas pipelines is the West African Gas Pipeline (WAGP) which exports natural gas since 2011. The 420-mile (672-kilometre) pipeline is operated by the West African Gas Pipeline Company Limited (WAPCo), which is owned by Chevron West African Gas Pipeline Limited (36.7%), Nigerian National Petroleum Corporation (25%), Shell Overseas Holdings Limited (18%), Takoradi Power Company Limited (16.3%), Societe Togolaise de Gaz (2%) and Societe BenGaz S.A (2%). It carries natural gas from Nigeria's Escravos region to Nigeria's neighbors, Togo, Benin and Ghana. WAGP links into the existing Escravos- Lagos pipeline and moves offshore at an average water depth of 35 meters (see **Figure 2.6**). [10]

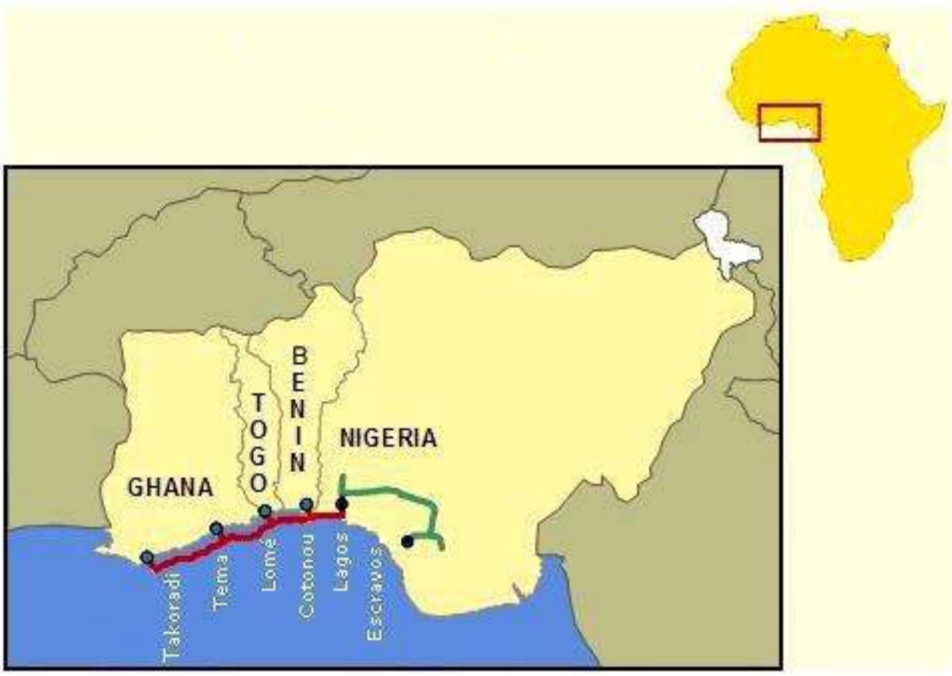


**Figure 2.6**: West African Gas Pipeline, WAGP (Source: EIA-Nigeria)

WAGP had an initial estimated export capacity of 170 million cubic feet/day (170MMcf/d) but plans are underway to expand capacity to as much as 460MMcf/d and possibly extend the pipeline further west to Cote d'Ivoire.

A memorandum of understanding (MOU) was signed in 2002 between Nigeria and Algeria for construction of a 2,500-mile (4,000 km) Trans-Saharan Gas Pipeline (TSGP). This pipeline would carry natural gas from oil fields in Nigeria's Niger Delta region to Algeria's Beni Saf export terminal on the Mediterranean Sea and is designed to supply gas to Europe markets. This project is now under review by the Nigerian government as at May 2013 to determine its viability due to recent developments in the global natural gas industry and the collapse of gas prices. [11] The decline in natural gas prices can be linked to the discovery of oil and gas in more African countries such as Ghana, Mozambique, South Sudan, Kenya and Uganda, and in Europe, while the United states also experiencing an oil and gas boom due to the production from its shale deposits.

Aside from the complete collapse of the gas prices, experts say the Trans Saharan Gas Pipeline, if completed, will be prone to attacks from terrorists and armed gangs operating in the West, Central and North Africa, and it won't be a reliable source of gas supply to its customers. [11]

### 2.1.4 NATURAL GAS AS A FUEL FOR ELECTRIC POWER GENERATION

Total electricity demand grows by 28 per cent in the projection (0.9 per cent per year), from 3,839 billion kilowatt-hours in 2011 to 4,930 billion kilowatt-hours in 2040. [5] Natural gas-fired plants account for 63 per cent of capacity additions from 2012 to 2040 in the BP Reference case, compared with 31 per cent for renewables, 3 per cent for coal, and 3 per cent for Nuclear. Natural gas can provide baseload, intermediate and peaking electric power. It is a reliable source of power that is capable of supplying firm back-up to intermittent wind and solar. Additionally, natural gas power plants can be constructed relatively quickly, in as little as 2 years. [2] Compared to other forms of electric generation natural gas plants have a small footprint from a land use perspective. However, even though natural gas combustion emits fewer GHGs than coal or oil, it still emits a significant amount of CO2. One major factor taken into consideration is that natural gas-fired electric power plants must be sited near existing natural gas pipelines; otherwise the cost of building this infrastructure must be taken into account.

### 2.1.5 GREENHOUSE GAS EMISSIONS

The BP Energy outlook 2030, noted the progress made with the changing fuel mix in particular the rising share of renewables and substitution of coal with gas, results in a gradual decoupling of emissions growth from primary energy growth (see **Table 2.1**).

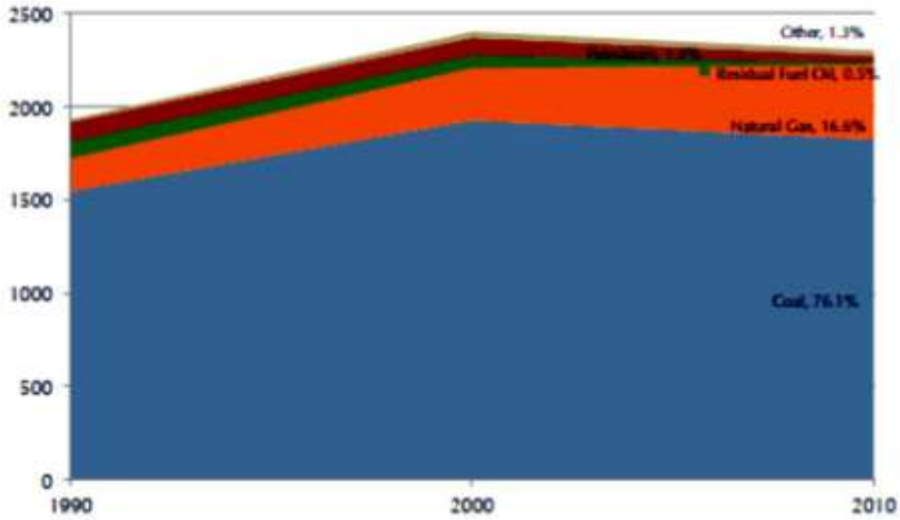


**Figure 2.7**: Emissions: Electric Power Sector (MMT $CO_2$) (Source: EIA, 2011)

The total Greenhouse Gases (GHG) emissions from the electricity sector have decreased since 2000, as shown in **Figure 2.7**, while net electricity generation has increased around 9 per cent over the same period. The PIB also addresses the emission of GHG from GHG related facilities in Nigeria. This was in view of the environmental hazards associated with gas flaring, particularly with regard to damage to the ecosystem including human and aquatic life, where the public is also invited to be involved in the reporting process.

Accordingly, after the December 2012 deadline implementation of the PIB, any person, group of persons or community may lodge a documented report of gas flaring or venting with the nearest office of the Inspectorate. The Inspectorate shall appoint an officer to receive and record reports of gas flaring or venting. An officer appointed who receives a report of gas flaring or venting shall within 48 hours of receipt of such report, inspect the facility where gas is allegedly being flared, verify the authenticity of the report to determine the cause of the gas flaring, the date when the gas flaring commenced and the volumes of gas flared or vented from the facility each day. The officer shall submit a report of the verification exercise to the Inspectorate within seven days of his visit to the facility from which gas is being flared or vented. If the Inspectorate determines that the report of gas flaring is authentic, at his discretion, the officer may impose the fine specified in respect of the volumes of gas flared or vented from that facility or issue a shutdown order mandating the shut-down of the facility in question. On receipt of a shutdown order, the operator of the facility shall comply with the order within 48 hours from the date of receipt of the shutdown order.

In view of the prevailing economic and political environment, it is uncertain how the federal government intends to enforce the December 31 deadline, given that all previous set targets, the last of which was December 31, 2010, were not met by the oil producing companies. Besides, the attempt to increase the penalty for flaring of gas from 10kobo per 1000 British Thermal Units (Btu) to 1.50 Naira per 1000 Btu failed to yield results, as it was more economical for the operating companies to pay the fines than to stop the flares. [9]

**Table 2.1**: Average Fossil Fuel Power Plant Emission rates (Ibs/MWh) (Source: EPA, 2000)

| Generation fuel type | Carbon dioxide | Sulphur dioxide | Nitrogen Oxides |
|---|---|---|---|
| **Coal** | 2,249 | 13 | 6 |
| **Natural Gas** | 1,135 | 0.1 | 1.7 |
| **Crude oil** | 1,672 | 12 | 4 |

## 2.2 NATURAL GAS POTENTIAL MARKET FOR NIGERIA

The two potential markets available to Nigeria's natural gas are domestic to a lesser degree and export to a much larger scale. Domestic uses involve power generation, the cement industry, iron and steel plants, petrochemicals, aluminum smelting and distribution for other industrial uses. The other sectors that utilize gas are the small-scale industry and residential consumption of bottled liquid propane gas (LPG). As shown in **Figure 2.8**, substitute of LPG by compressed natural gas (CNG) is projected to lead domestic consumers relying more on gas but they might not be able to afford the cost of purchasing CNG initially due to the indirect cost of developing the CNG infrastructure acting on it. The anticipated growth in this small-scale energy demand area is dependent on number of factors such as the enabling environment that allows the public and private sector to invest in the industries, regulations that will encourage oil multinationals to invest in gas utilization infrastructure like energy generation, changes in some government monopoly polices and a transparent structure for gas pricing in the country.

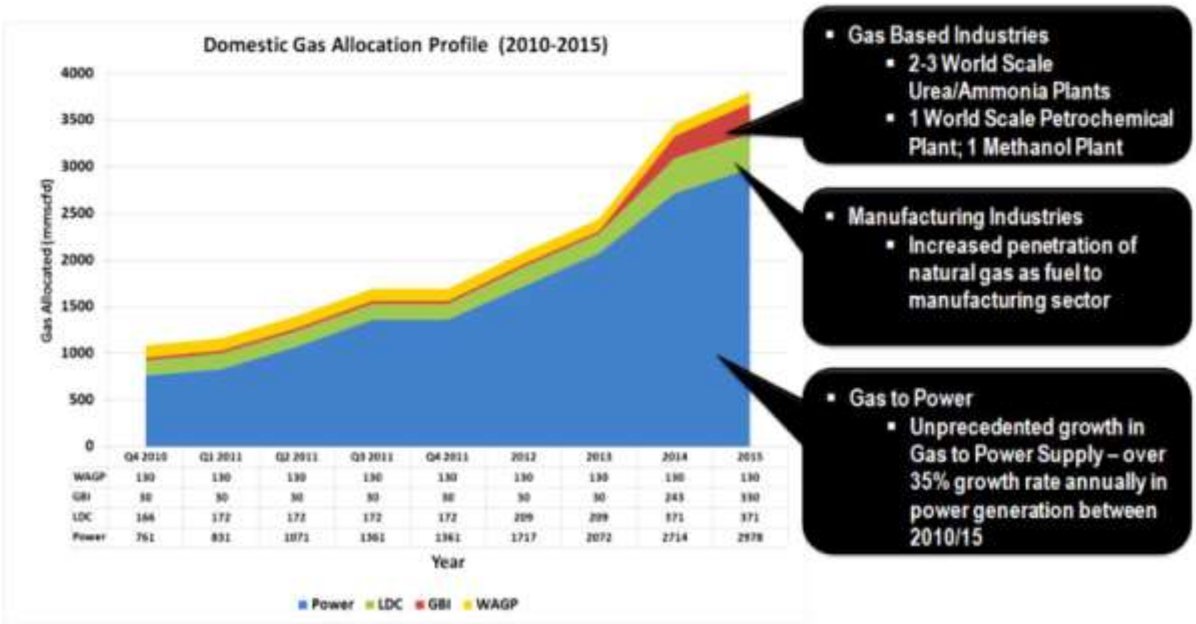


**Figure 2.8**: Nigeria domestic Natural Gas Industry outlook (source: NOGTECH, 2012)

As discussed in **Section 1.2** about the shell's crude oil and gas exploration and production activities, the first export market for Nigeria's natural gas started in 1999 after the construction of the Bonny LNG plant first phase, located in Finima, Bonny Island (refer to **Figure 1.3**). This facility is Nigeria's only LNG complex with the NLNG partners include NNPC (49 per cent), Shell (25.6 per cent), and Eni (10.4 per cent). It currently has six trains and a production capacity of 22 million metric tons of oil equivalent per year (1.1Tcf of LNG). A seventh train is under construction to increase the facility's capacity by 8 million metric tons of oil equivalent per year and it's scheduled for start-up in 2016 keyed on favorable regulation and political input. [12]

Most of Nigeria's LNG is exported to Europe, mainly Spain, France, Portugal with smaller amount to Turkey, United Kingdom and Belgium. Other export destinations include Asia and North America. The US imported 0.86 million metric tons (42 Bcf) of Nigeria LNG in 2010, providing 1 per cent of total US LNG imports. According to EIA data, US imports of Nigerian LNG significantly decreased to 0.05 million metric tons (2.5 Bcf) in 2011, which is the lowest level recorded since Nigeria LNG exports began. However, more of Nigeria's LNG imports were sent to Japan and other Asian countries due to higher demand for LNG imports in these countries. Nigeria exports to Japan more than tripled in 2011 making it notable as a result of Japan's LNG demand increased due to the Fukushima nuclear accident. [10]

### 2.2.1 Natural Gas in Electric Market

The use of natural gas in electric market has grown over time due to low natural gas prices and falling natural gas demand spike in the 1990s which stimulated the rapid construction of gas-fired power plant. Following the trend of natural gas since the 1978 supply shortage which led to the US Congress enacted the Power Plant and Industrial Fuel Acts (FUA), prohibiting the use of oil and natural gas in new industrial boilers and new electric power plants to preserve scarce supplies for the residential customers. This section on the FUA was later repealed in 1987. [13]

Since 1990, natural gas has been gaining market share with electricity generation from this source increasing from around 11 per cent to 23 per cent of the total net generation in 2010, as illustrated in **Figure 2.9** as a result of increased natural gas-fired power generation displacing fuel oil and coal-fired power generation. According to the latest Energy Information Administration (EIA) Annual Energy Outlook (AEO), natural gas-fired generation is expected to be just over 25 per cent of the total generation mix in 2020, rising to 27 per cent in 2035.

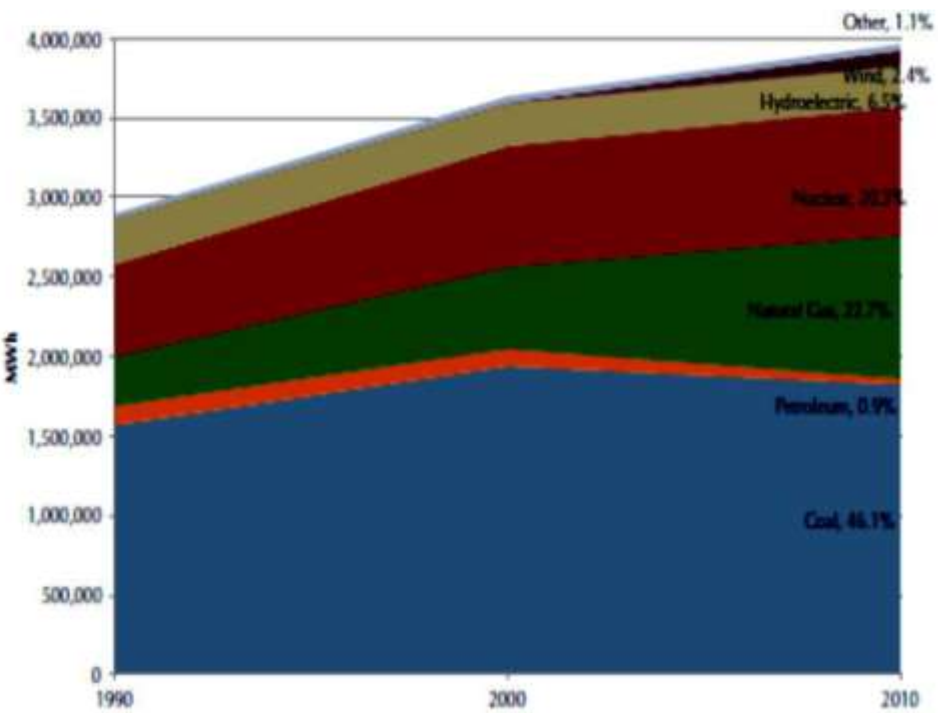


**Figure 2.9**: Electricity Net Generation: Electric Power (GWh) (Source: EIA, 2011)

### 2.2.2 AMOUNT OF NIGERIA'S UNUTILIZED NATURAL GAS AND ITS WORTH

The NNPC 2012 Annual Statistical Bulletin shows an estimation of about 32.35% of Nigeria's gas is flared as it is produced from sixteen (16) IOCs excluding Indigenous and Production Sharing Companies (PSC) over a period of ten years (2003-2012); thus majorly accounting for 12.5% of the world's flared gas second only to Russia. [9] Between 2003 and 2012, Nigeria lost about USD $10.75 Trillion (an average of USD$1.08 Trillion per annum) to gas flaring (See **Appendix B** for calculation).

Gas flaring is defined as the complex un-scientific burning and emitting of excess hydrocarbons consisting of substantial amount of soot, carbon monoxide and greenhouse gases associated with crude oil and gas production processes. It is the final phase of the production process where unwanted and unutilized quantities of oil and gas are flared directly into the atmosphere. [14]

A total of 2,580.17 Bscf (Billion standard cubic feet) of natural gas production was reported for these sixteen (16) Companies in 2012. This shows an increase of 6.96% when compared with 2011 production and of the quantity produced 1,991.50 Bscf (77%) was utilized, while 588.67 Bscf (23%) was flared as shown in the **Figure 2.10.** [9] Also 462.9 Bscf of the gas produced was used for gas re-injection, 72.91 Bscf for gas lift activities while the remaining used for other heat content demanding activities.

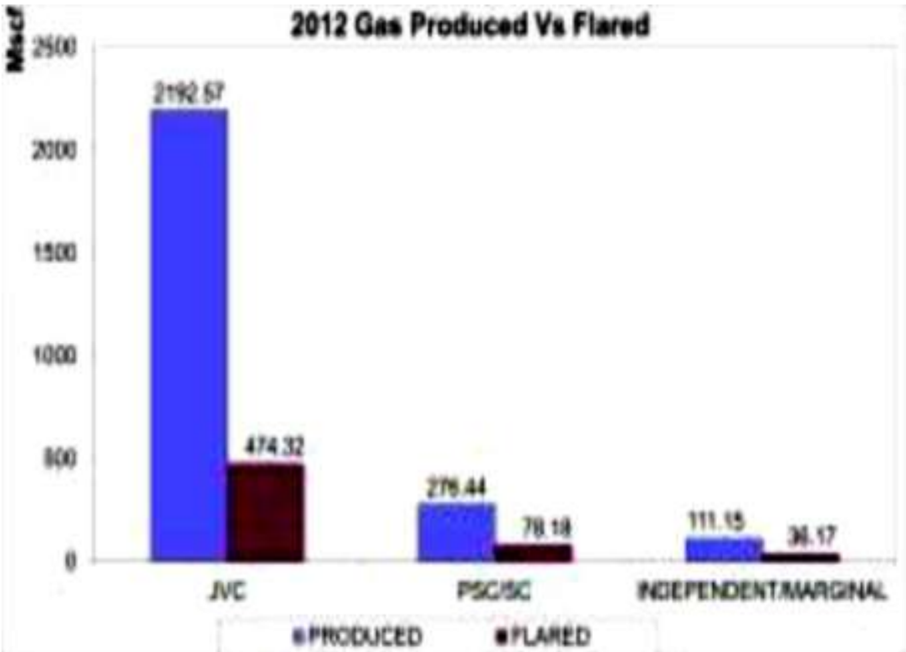


**Figure 2.10**: 2012 Nigeria's natural gas production versus gas flared by sixteen IOCs (Source: NNPC, 2013)

Of the above gas flaring figures, Shell's natural gas production account for about 848.3Bscf and 7.34 per cent (62.3Bscf) was flared. Other IOCs such as Mobil, Chevron, Total E&P, NAOC, Texaco, Pan-Ocean, Addax, SNEPCO, ESSO, NAC and PSC sub-Total are responsible for the rest amount being flared. [9]

Gas flaring has served as an option in Nigeria's crude oil and gas exploration and production due to inadequate or no infrastructures for the excess gas utilization. The far reaching socio-economic, ecological and political impacts of gas flaring can be felt in different ways by Nigerians especially the host communities in the Niger Delta region of Nigeria. The impacts caused are severe environmental damages, loss of plants, animals and human lives, and loss of revenue to both the oil producing companies and the government. Crude oil and gas exploration, exploitation, production, storage, distribution and transportation activities affect the environment in a conspicuously negative manner. Vegetation are removed to make way for seismic lines, sites for rigs are levelled, roads are built and drilling mud and oil sometimes find their way to the streams, surface waters and land thus making them unfit for consumption nor habitable by man or animal. The storage, distribution and transportation of oil and gas using tankers and pipeline network result in some quantities of petroleum products being released into the environment.

The socio-economic problems include, amongst others, poverty, unemployment, ecological deficiencies, health hazards and poor infrastructural development all resulting in low life expectancy rate. The political problems include, amongst others, tussle for resource control between the States and the Federal Government of Nigeria on one hand and the host communities and the government on the other hand leading to youth restiveness, militancy, kidnapping and hostage taking of oil and non-oil workers by the aggrieved communities in the region.

### 2.2.3 POLICY IN PLAY

Generally across the world, policy decisions affecting the electric power generation are driven by the environment effects such as pollution, climate changes with regards to greenhouse gas (GHG) caused by the generation process. Also these policies determine the operation, maintenance, and decommissioning processes to be adopted during the operations to end-of-life for the facilities. These policies are amended at any instant when new studies are made for the respective sectors.

Nigerian natural gas legislations had gone through various changes with major indecisions reach which had slowed down the development of the Natural gas infrastructures over time. Perhaps, the most recent and talked about piece of legislation in Nigeria is the Nigerian Petroleum Industry Bill (the "PIB" or the "Bill"). This bill is a far reaching reform proposes to an industry as a single significant contributor to the national economy.

Originally, introduced in December 2008, the bill has undergone numerous revisions and has been the subject of intense debate. Some important clauses considered for natural gas infrastructures as stated in the bill are as follows; According to the bill, a licensee or lease for the production of oil and gas whether onshore, or offshore shall not be granted to any applicant unless the application for such a license or lease is accompanied by a comprehensive program for the utilization or reinjection of the country's natural gas, and the utilization program shall be in consonance with the recently launched Gas Master Plan, Domestic Gas Supply Obligation, and the national policies as may be made in respect of the gas sector, from time to time by the government.

Section 247 of the bill sets the pace, as it says "The Inspectorate shall take such measures as appropriate to create franchise areas for gas processing facilities in Nigeria to support the National Gas Master Plan." [4]

Section 253 (1) (a) further prohibits gas flaring, stating that, "No person shall direct, permit or otherwise aid, empower or authorize howsoever, any company engaged in oil and gas operations to flare or vent gas." [4]

However, section 253(1) (b) provides an exception to the rule, as it states that "The Minister may grant a permit of not more than 100 days, or such longer period as approved by the Minister, to flare or vent gas in cases of start-up, equipment failure, shut down, safety flaring or due to inability of gas customer to off-take." [4]

As regards the penalty, section 253 (1) (c) says "Any licensee or lessee who flares or vents gas without the permission of the Minister in the circumstances mentioned in subsection (1) (b) of this section shall be liable to pay a fine which shall not be less than the value of gas." [4]

The bill also introduced flaring measurements and reporting programs, such that the volumes of gas flared from any facility that is a part of oil and gas operations shall be measured using the metering equipment specified from time to time by the Inspectorate that is to be established to regulate the sector. According to section 255 (2) "Within three months from the effective date, each licensee or lessee shall install the metering equipment specified in regulation on every facility in its operations from which gas is flared or vented." [4]

Other legislations include the Petroleum (Drilling and Production) Regulation 1969 where the licensee is expected to submit feasibility study, program or proposal for gas utilization not later than five years after the commencement of production. The Petroleum (Amendment) Act 1973 states that Nigerian government may take the gas at the flare at no cost, absence of infrastructure to develop and utilize the produced gas. The Associated Gas Re-injection Act 1979 which require IOCs to submit proposal for the utilizing produced associated gas, IOC were stop flaring at a stipulated date, empowers the minister of Petroleum Resources to grant permission to flare. The Associated Gas Re-injection Amendment 1983 states specific penalty introduced for the first time, penalty was not sufficient to serve as deterrent for gas flaring.

### 2.2.4 Natural gas with Carbon Capture and Storage

Natural gas plant with carbon capture and storage (CCS) capability has been projected to minimize the GHG emission in a carbon-constrained future. [15] This being said, natural gas plays a potentially much greater role in the future of the total generation mix. The success is hinged to CCS projects already in place and several projects planned in the next several years to demonstrate the feasibility of the CCS technology. [16, 17] To date, these projects are undertaken almost exclusively in conjunction with coal-fired power plants or industrial sources with few attempt to natural gas combined heat and power (CHP) plant similar to the combined cycle plant and sequester or storage of the $CO_2$ in an underground saline formation. [17]

Also $CO_2$ is currently being injected into oil wells as part of tertiary, or enhanced, oil production ($CO_2$ -EOR) and gives the operator an added benefit of providing an economic incentive, which is compensation from being a captured $CO_2$ provider.

### 2.3 Focus on Nigeria Electric Power Sector

Power generation and supply in Nigeria is grossly below demand, thereby resulting in under-developments in every facet of life. It ranked amongst the lowest in world and development in this sector is still relatively low. Brazil and Pakistan, two countries with similar population sizes to that of Nigeria, generate 24 times and 5 times more power than Nigeria respectively.

The Nigeria's net generation was estimated to be 26.1 billion kilowatt-hours (KWh) in 2012 for government-owned (PHCN) power plants. Installed electricity capacity has remained relatively low over the last decade at circa 4.6GW, although net generation has slightly increased towards its peak of 33.5 billion KWh in 2012, mainly due to partial involvement from other private independent power producers or projects (IPPs) [18] as shown in **Table 2.2**.

**Table 2.2:** The Nigeria's Annual Average Generation for all grid-connected Power Plants (Source: NEPR, 2013)

| | **As at July 2012** | | | | | |
|---|---|---|---|---|---|---|
| | Actual Generation Capacity of Grid Connected Power Plants | | | | Available Annual Avg | **Note** |
| | PHCN | NIPP | IPP | All | | |
| Hydro | 1,230 | 0 | 0 | 1,230 | 984 | Given available water flow |
| Thermal | 1,862 | 0 | 1,520 | 3,382 | 2,875 | Assuming 85% capacity factor |
| Total | 3,092 | 0 | 1,520 | 4,612 | 3,859 | |

Nigeria's electricity sector is divided into three sub-sectors: with eleven (11) existing Federal Government of Nigeria (FGN) Power Generation facilities now privatized as Power Holding Company of Nigeria (PHCN), seven (7) averagely working National Integrated Power Projects (NIPPs) and six (6) Independent Power Producers or Projects (IPPs). The majority of power stations, both thermal and hydro, are FGN facilities funded by the government, while IPPs are backed by the private sectors (IOCs). The largest power plant in Nigeria is the Afam VI Power Generating Plant (IPP) with installed capacity of 650 Megawatt (MWe) owned by Shell. According to Shell, between 14-24 per cent of overall generation is contributed to the national grid. [12]

The majority of electricity generation comes from thermal power plants (77 per cent), with about two-thirds of thermal power derived from natural gas and the rest from oil. Hydroelectricity contributes 23 per cent of Nigeria's power generation per annum and it decreased gradually from its peak of 8.2 billion KWh in 2002 to 3.5 billion KWh in 2012. As at the end of July 2013, the total monthly actual (on-grid) peak generation capacity stood at 3,515.5MW as compared to the highest peak generation of 4517.6MW in December 2012 as shown in **Figure 2.11**. Nigeria's electricity net consumption was 20.4 billion KWh in 2012, slightly less than generation and exported most of the remainder to Niger through an agreement under the West African Power Pool.

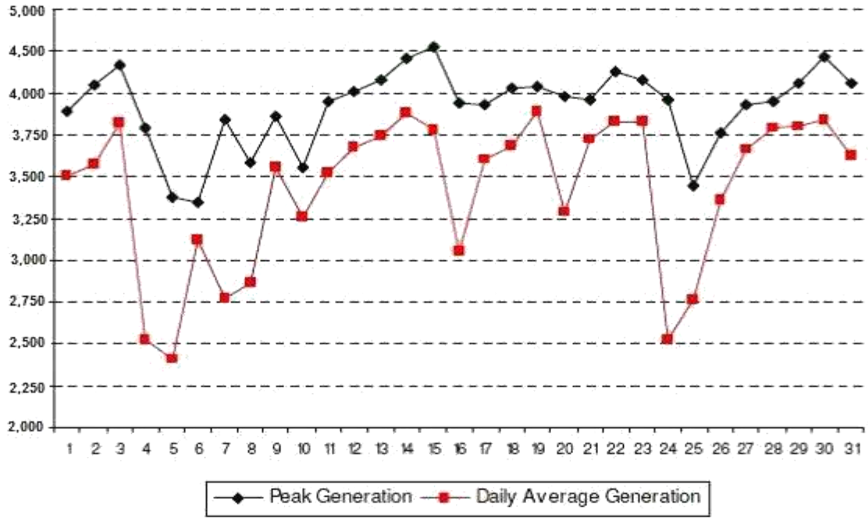


**Figure 2.11**: Daily total Peak and off-peak generation for all grid-connected Power plants as at 2013 (Source: NEPR, 2013)

According to survey carried-out by World Bank, Nigeria experienced power outages on average for 48 days per year from 2007-2008, and outages lasted almost 6 hours on average which is still happening in recent times in parts of Nigeria. Increased population coupled with underinvestment in the electricity sector has led to increased power demand without any substantial increases in capacity, in addition to insufficient feedstock, inadequate maintenance and an ageing transmission network. This has led to businesses purchasing costly generators to use as back-up during outages and the majority of Nigerians use traditional biomass, such as wood, charcoal, and waste, to fulfil household energy needs, such as cooking and heating.

### 2.3.1 Technology Available to Gas-fired Power Plant Scheme

Power generation can be classified into two types namely, Centralized Power Generation (CPG) and Distributed Generation (DG).The former creates large quantities of electricity which are then transported to end-users via electrical transmission and distribution lines. The latter also referred to as self-generation as contrasted to the central power station generates smaller quantities of electricity at or near the location where it will be consumed, obviating the need for long electrical transmission lines. There are three categories of technologies in which natural gas is a fuel that can be used to generate the electricity for both the central power station and self-generation. In the order of their historical development, they are;

1. Steam Turbines

2. Combustion Turbines (CT), and
3. Combined Cycle (CC) Power Plants.

Each plants type has an associated average thermal efficiency. This measures how well a technology converts the fuel input energy (heat) into electrical energy (power). A higher thermal efficiency, other things being equal, implies that less fuel is required to generate the same amount of electricity, resulting in fewer emissions. Steam turbines have the lowest efficiency at around 33-35 per cent, combustion turbines are around 35-40 percent efficient and combined cycle plants have thermal efficiencies in the range of 50-60 per cent. [13] For more information about these three technologies see **Appendix A**.

The potential benefits of DG includes: increased electric system reliability, reduction of peak power requirements, and reduction in vulnerability to terrorism. [19] However, from a greenhouse gas (GHG) perspective, the primary advantage of distributed generation is that there are fewer losses in the transmission of the electric power, both in the bulk transmission system and in the local electrical distribution networks. [19] Lowering line losses means less electricity generation (less fuel and fewer emissions) is required to serve the same electrical demand. In the bulk transmission system which is the backbone of the central power station system, line losses depend primarily on the line voltage, line load, weather, altitude and the distance travelled; the higher the line voltage the fewer losses that a line will experience. [20] Examples of DG that utilize natural gas include micro-turbines (CT or CC) located on-site for commercial and residential application, and combined heat and power (CHP) for industry. The future technology in terms of technological and economical feasible has been projected to improve with respect to supply side efficiency. The thermal efficiencies of steam turbine technology is expected to increase by 3 per cent, combustion turbines to 45 per cent efficient, and combined cycle plants with 70 per cent efficiency by 2030. [18]

## 2.4 SWOT Analysis Comparison for Natural Gas and Diesel Generators

The **Table 2.3** and **Table 2.4** below show a SWOT (Strengths, Weaknesses, Opportunities and Threats) Analysis comparison done for the Natural gas generator and diesel generator respectively;

**Table 2.3**: SWOT Analysis for Natural Gas Generators

| STRENGTHS | WEAKNESSES |
|---|---|
| • Natural gas is a direct product or by-product of petroleum exploration and production activities requiring minimal processing.<br>• Natural gas is cleaner, less expensive than other non-renewable fuels, and is considerably efficient for generating electricity.<br>• Technologies for natural gas generators are well-known and a dual fuel system and multi-feedstock could be used for the power units.<br>• In comparison to oil and coal, the emissions of sulphur, nitrogen, and carbon dioxide (a greenhouse gas) are considerably lower. Hence, natural gas is one of the cleanest fossil fuels when it burns.<br>• It does not produce a pungent odour, which is fairly common in generators powered by oil or diesel.<br>• Natural gas generators are less expensive to run in terms of variable cost, emit less carbon dioxide which is a greenhouse gas. [21]<br>• Natural gas is a hydrocarbon resources used to produce cleaner renewable energy resource (hydrogen economy). | • Natural gas storage requires high safety measures due to its properties where high energy is consumed to stabilize the fuel.<br>• Natural gas generators can be easily affected by impurities such as gas hydrates in fuel stream.<br>• Natural gas generators require a constant and steady fuel supply to increase its reliability. |
| **OPPORTUNITIES** | **THREATS** |
| • Natural gas is also readily available at Field-X, Gulf of Guinea. Hence, when using natural gas powered generators, storage of fuel becomes redundant.<br>• IOCs in Gulf of Guinea, Nigeria seek for infrastructures in location to use their excess gas produced.<br>• It acts as an answer to the PIB's requirements for gas flaring from IOCs operating in Nigeria.<br>• Natural gas fired plant scheme at the Gulf of Guinea serves a solution to Nigerian's Electricity generation saga.<br>• Natural gas generators have low capital expenditure and medium operational cost. Therefore, serve as an additional | • Natural gas is extremely explosive and can be a serious fire hazard source should the pipeline burst.<br>• Change in Nigeria's crude oil and gas exploration and production policies could affect its development.<br>• Political and social unrest from Nigerians especially host communities could after its implementation. |

| | |
|---|---|
| source of income for investors in the location. | |

**Table 2.4**: SWOT Analysis for Diesel Generators

| STRENGTHS | WEAKNESSES |
|---|---|
| • Diesel has a higher energy density which implies that more energy is got out of diesel when used as a fuel compared to same volume of natural gas. Hence, fuel efficiency is by far the single most important advantage of diesel generators.<br>• It has more assurance of a steady power supply in safety critical facilities such as hospitals and emergency shutdown systems (ESD), where power outage could mean the difference between life and death due to its low fuel consumption rate.<br>• In comparison to a generator powered by natural gas, diesel engines are much sturdier, reliable and has low fuel consumption rate.<br>• Another major Technical advantage over gas engines is that diesel engines do not require spark plugs or wires for combustion; this helps in reducing maintenance costs.<br>• The lifespan of a diesel engine is much longer compared to gas engines. | • Diesel generators are known for generating high noise pollution while the newer models are designed to be quieter, the older variants can still be considerably noisy.<br>• Another drawback is that diesel generators are bulky, comprise of large and heavy components. Thus, as opposed to smaller and lighter generators, diesel generators may not be the most preferred portable unit for proposed site (offshore).<br>• Availability of diesel at the proposed location is very slim due to several processes required in diesel production. |
| **OPPORTUNITIES** | **THREATS** |
| • Diesel processing facility at proposed location for fuel production will be an additional infrastructure advantage for IOCs. | • Diesel generators are considerably expensive in terms of cost expenditure in comparison to other generators. However, since the maintenance cost of a diesel generator is quite low, it more than makes up for the initial investment.<br>• Diesel generator has high run cost than natural gas generator as a results of fuel prices which is one of most the important factor when making choices regarding fuel.<br>• Political and social unrest from Nigerians especially host communities could after its implementation.<br>• Given the recent trend of environmental awareness, diesel is considered to be a |

| | |
|---|---|
| | major pollutant because of its high GHG emissions. |

### 2.4.1 Conclusion to SWOT Analysis Comparison

From the SWOT Analysis carried-out for both types of non-renewable fuel generators, diesel generators have quite a number of usefulness in area of strengths for the generating electricity but have short falls in the area of availability of fuel (feedstock) and strategic fit (suitability) at the proposed location which forms part of the major factors considered for any infrastructural development.

In contrast, natural gas generator meets the above requirements and shows good quality in all areas of the SWOT analysis. Natural gas generator works in a manner similar to other generators. Its most basic difference between generators is the fuel that is used to power the units. In this case the source of energy to start the generator is a natural gas where is in abundant in the proposed location.

Therefore, the natural gas-fired power plant scheme is the choice for development at proposed location.

# CHAPTER THREE - THE GAS-TO-POWER PLANT SCHEME

In answer to the Problem Statement stated in **Section 1.1** and Commendation made in **Section 2.4.1** of this report, a feasibility study for the development of a 200MW Gas-Fired Power Plant located at the Gulf of Guinea, Nigeria is carried out here. This study is done in favor of the new and existing International Oil Companies (IOCs) operating in the location and serves not just for income generation but also to meet the fiscal and legal requirements specified by the Nigerian policy in play. This could lead to a network of power generation in the region with potential market value in Nigeria and surrounding oil and gas infrastructures. In addition, this will help justify the business case for the recommended concept while helping the other parties in order to prepare a comprehensive cost estimate.

## 3.1 OPTIONS CONSIDERED

The following options were considered for the study of a Gas-to-Power Plant Scheme;

### 3.1.1 THE "NO PROJECT" OPTION

This option implies that IOC (OffshoreCo) declines the option to pursue the construction of a gas-to-power plant scheme as the company accepts that a reasonable amount of natural gas as partly estimated in **Section 2.2.2** will be "lost" to flaring, sabotage, and pipeline vandalism as the case may be. The amount of "lost" gas will be tempered by the use of some of the gas produced from the exploration and production process for enhanced oil recovery (EOR), gas lift, and/or gas re-injection. This option eliminates the economic, financial and technological benefits, and knowledge that will be realized if a gas-to-power plant scheme is constructed. Further, IOC (OffshoreCo) will have elected to forgo the opportunity to diversify its revenue base whilst helping to solve Nigeria's electricity demand imbalance. The attendant increase in corporate reputation in an increasingly competitive market is of such value to OffshoreCo that the "No Project" option or sticking to the Status Quo is a non-starter without an initial business/technical assessment of the gas-to-power plant.

### 3.1.2 THE PROJECT OPTION (GAS-FIRED POWER PLANT)

This option considered undertaking the above project as agreed with the IOC (OffshoreCo) to make use of some of its natural gas produced from Field-X and neighboring fields to generate electricity needed to power the facilities and transmit to the Nigerian's national grid. It explored gas-fired power plant technologies and alternative uses of the power generated to help meet the set objectives of OffshoreCo.

## 3.2 DEVELOPMENT CONCEPT PLAN FOR THE GAS-FIRED POWER PLANT

The Gulf of Guinea as described in **Section 1.2** is an offshore location where exploration and production activities are carried out by various IOCs (including OffshoreCo). The region is rich with enormous deposits of hydrocarbon coupled with its moderate climatic condition. The selected field in this location for the development of the gas-fired power plant is Field-X owned by OffshoreCo as shown in **Figure 3.1**.

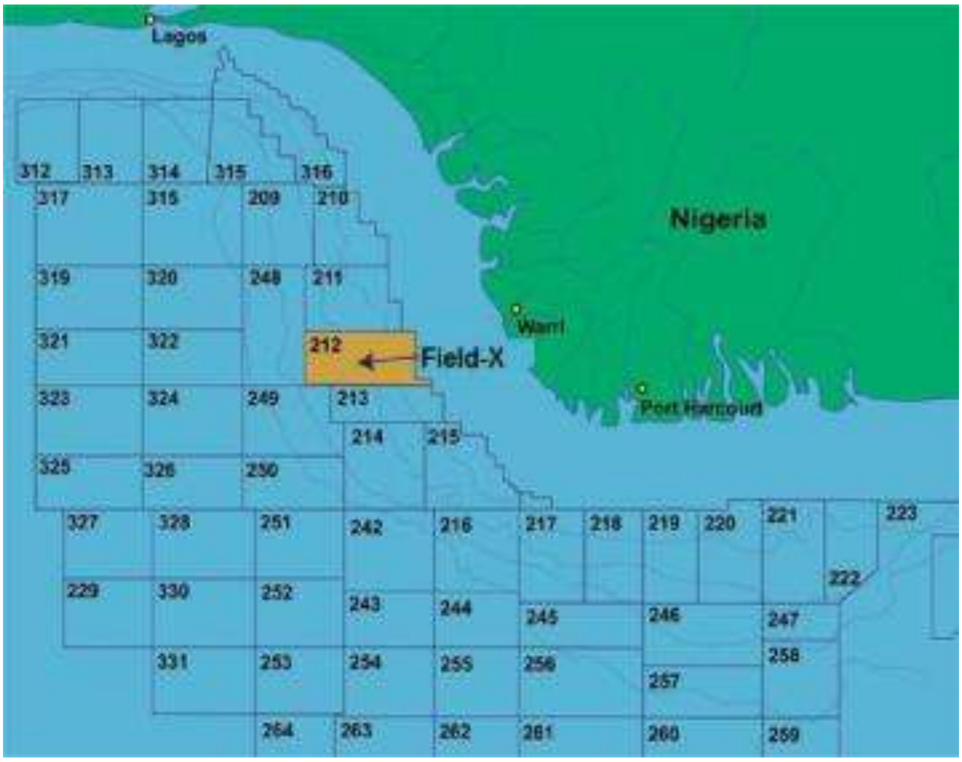


**Figure 3.1**: Locations of Field-X in the Niger Delta Region

Field-X is the first deepwater for OffshoreCo The field is operated by OffshoreCo on under a joint venture (JV) or Production Sharing Contract (PSC) in partnership with co-investors. Field-X is circa 150km southwest of the Niger Delta with real extent of some 60km$^2$, in a water depth of over 1,000m. At the Field-X has the capacity to produce 150 million standard cubic feet (MMcf) of natural gas a day. Some of the gas will be tapped for the purpose of this scheme.

### 3.2.1 PROJECT ASSUMPTIONS

The following were assumed for this development plan and further studies are required for clarity;

- Gulf of Guinea, Nigeria is ideal for the purpose of a network of Gas to Power Generation Scheme and is a gas production zone with existing oil and gas wells and gas pipeline.
- Peak oil and gas production from Field-X is unaltered by this scheme rather the feedstock for the scheme is quota of the gas produced and/or all excess or flared gases are channelled for this purposed.
- The cost of installing, upgrading and decommissioning an additional network of natural gas pipelines connecting existing ones in the location for the scheme is minimal and can be recovered by the mid-life of the project.
- The Gulf of Guinea area is deficient of a centralized clean energy supply network.
- Transmission of the electric power generated is possible through subsea cables run to the nearest National grids located in Nigeria's states such as Lagos, Delta (Warri) and Rivers (Port-Harcourt).

### 3.2.2 Project Constraints

At present, the following observations might serve as a plus or minus to this project in any given scenarios;

- Commercial Scale-Sized Offshore Gas-Fired Power Plant and Transmission has not been demonstrated in the proposed location. However there is a proven project proxy for 100 MW Power Production.
- Cost involved in drilling new gas wells may be a setback.

### 3.2.3 Field-X Existing Data

The **Table 3.1** presents a generic data available for information required for the Field-X and environs located at the Gulf of Guinea, Nigeria.

**Table 3.1**: Field-X, Gulf of Guinea data

| **Parameter** | **Figure** |
|---|---|
| Location | 150km southwest of the Niger Delta landfall with real extent of some 60km2 |
| Depth of Water | Above 1,000m (> 3,280ft) |
| Climate | Moderate |

| | |
|---|---|
| Gas Production | 150 MMcf (150 million standard cubic feet) |
| Nearest National grid location | Delta, Lagos and Rivers states |

### 3.3 Development Concepts

The Gas-to-Power Fired Power Plant concept can be any of the following:

- Floating System Type (MiniFloat III System) in 1000m water depth (deepwater)
- Fixed Platform (Tension Leg) Type in 300 m water depth (near shore)
- Power plant located onshore about 10 km from the coastline

The process of pre-screening to short-list to select the feasible concepts for the development system involves the assessment of the political, economic, social, technical, legal, and environmental (PESTLE) circumstances surrounding both standalone options. [22, 23] The criteria considered to ascertain its viability are summarized in **Table 3.2** below:

**Table 3.2**: PESTLE Analysis criteria for Assessment of a Development Concept

| Criteria | Comments |
|---|---|
| Technical | Feasible, location, feedstock availability, security, durability, integrity, optimally safe and maintenance |
| Environmental | Safety case on impact during construction and operation at location |
| Commercial | Cost (investment), schedule (completion time), economical, job creation and profitable |
| Organizational | Application, viability, logistics, sustainable and reputation |
| Political and Legislation | Operational permit and site accessibility |
| Decommissioning | Ability to disassembly after lifespan, revamp, reuse and disposal of waste. |

The transmission of the electric generation to the onshore national grid will be via subsea cables and will not be covered in this study.

#### 3.3.1 Concept 1 - Floating Gas-Fired Power Plant Vessel (FGFPP)

The Floating Gas-Fired Power Plant Vessel is a commercial scale-sized offshore electricity generation facility that houses the combined cycle power plant equipment, storage for the feedstock needed and the crew members. Its basic design encompasses a ship-shaped vessel, with the topsides aboard the vessel's deck and process gas/water storage below in the double hull. Fuel gas to the facility will be via a 10 km gas line and riser system from Field X. The power delivery to the market is via a 130 km power cable. The **Figure 3.2** shows the proposed location and **Table 3.3** gives the merits and demerits for the Concept 1 respectively.

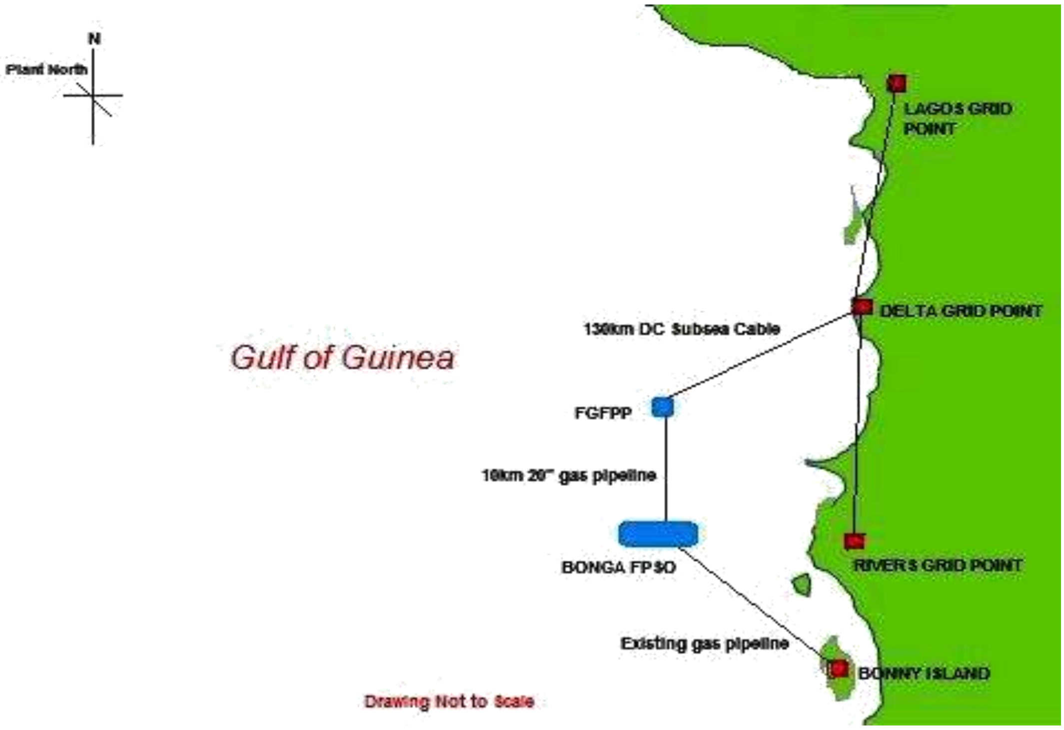


**Figure 3.2**: FGFPP location at Field-X, Gulf of Guinea

**Table 3.3**: Merits and Demerits of Concept 1

| Merits | Demerits |
|---|---|
| 1. No limitation on water depth and ideal for remote areas where pipelines laying and fix construction could not be easily justified.<br>2. Useful for early electricity generation system due to lesser construction time.<br>3. Reduced investment with less overhead over operating durations.<br>4. Easy to change position and location when field (feedstock) is depleted.<br>5. Can evade harsh weather condition by navigating away to safety.<br>6. Abandonment cost is very low due to its being reused /revamped (PIB 2012/OSPAR Decision 98/3).<br>7. Environmentally friendly with less spillage footprints.<br>8. Developed into use of tankers for production and storage of oil and gas.<br>9. Minimal equipment for decommissioning.<br>10. Less prone to attack by sea pirates and others due to construction done | 1. Maintenance and security cost is slightly high due to location.<br>2. Frequency scheduled maintenance could affect reliability.<br>3. Stability during operation is medium. |

| | |
|---|---|
| elsewhere.<br>11. Extensive deck area with large storage capacity (huge benefit in oil and gas development). | |

**Table 3.4**: FGFPP Specification and Justification

| Specification | Description | Justification |
|---|---|---|
| **Power package and Vessel size** | The development is a custom-built 200MW lightweight heavy-duty Power Generation Plant fitted on the vessel (MiniFloat III) to meet the user's particular power requirements. This combined cycle power plant type consist of an output power rating of 140MW gas or combustion turbines package and a 60MW steam turbine package as described in **Section 2.3.1**. The design offers 8 meters between Centre lines, providing for a 4-meters distance between enclosure walls, which is sufficient space for easy sideways rollout of the gas/steam turbine for (or during) service.<br>The vessel's length is 195-meters, breadth of 42-meters and 29-meters deep. It fully ballasted weight is 60,000 tons. | The power package and vessel size was done in accordance to the API RP 11 PGT, which gives general requirements and limitations in applying these standard turbine designs. |
| **Feedstock, storage capacity and electricity transmission means** | A 10-kilometer bundled gas pipeline (20") tied the FGPP vessel to Field-X, which supplies the required feedstock. This flowline uses the exhausted gas from the FGFPP for the Field-X upstream applications such as heat exchange means, gas lift or re-injection, waterflood, enhanced oil recovery (EOR), gas gathering. It also has riser installation provision to tie in ten (10) sub-sea templates and additional gas pipeline from the West Africa Gas Pipeline (WAGP) via tee joint, nearby in the future. The vessel has a regasification system in place, which can handle about 3, 000, 000 cubic meters per day (106,000,000 cu ft/d) of gas and a storage capacity of 175, 000 cubic meter (1.1 million barrels) for both fuel gas and process water. [24]<br>It employs an external turret system for its mooring, transmission of electricity generated through 130km DC subsea (submarine) cables to power fiscal metering point. Also exporting of stored LNG via | Factors considered includes the weather condition (moderate), depth of water (buoyancy for the vessel to float), thermodynamic properties of the gas, production rate of the field (additional storage for future discovered field products i.e. includes redundancy) and frequency of supply and offloading product. |

| | | |
|---|---|---|
| | pipeline or to LNG carriers is incorporated for future plans. | |
| **Accommodation Capacity** | The facility will accommodate 80 persons on board (POB) in its cabins with a peak to 100 POB on a temporary basis. | Consideration made for effective change-over, new employees and others. |

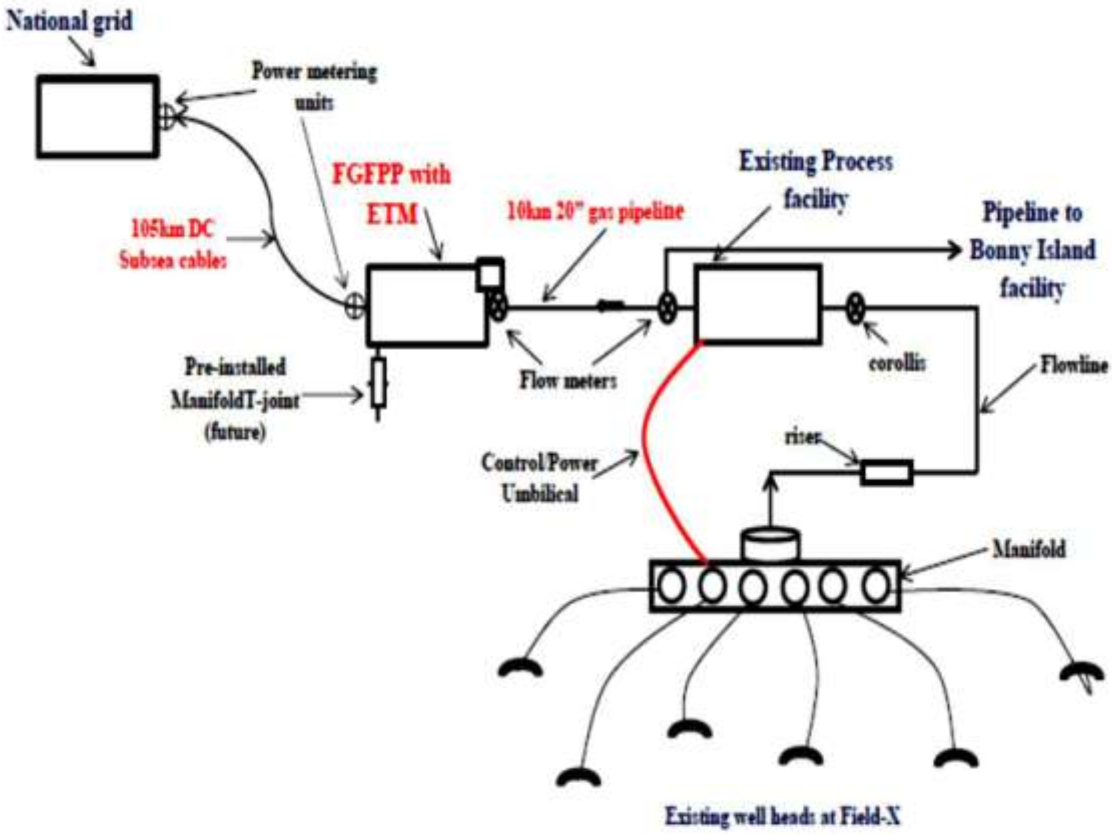


**Figure 3.3**: Flow schematic layout of Concept 1 (FGFPP) at Field-X, Gulf of Guinea

### 3.3.2 Concept 2 – Gas-Fired Power Plant Tension Leg Platform (GFPPTL)

This is an offshore electricity generation facility where the platform carrying the facilities is vertically and permanently moored to the seafloor by means of tethers or tendons grouped at each of the structure's corners. This group of tethers is called a tension leg and its basic design includes four air-filled columns forming a square. These columns are supported and connected by pontoons similar to the design of a semisubmersible production platform. The tension leg mooring system allows for horizontal movement with wave disturbances, but does not permit vertical or bobbing movement which makes it a popular choice for stability such as in hurricane-prone region. The platform deck is located at the top of the hull and the topside consists of the power generation module, regasification system and the living quarters. Fuel gas to the facility will be via a 105 km gas line and riser system from Field X. The power delivery to the market is via a 25 km power cable. The **Figure 3.4** shows the proposed location and **Table 3.5** gives the merits and demerits for the Concept 2 respectively.


**Figure 3.4**: GFPPTL location at Field-X, Gulf of Guinea

**Table 3.5**: Merits and Demerits of Concept 2

| Merits | Demerits |
|---|---|
| 1. It has excellent performance due to stable and rigid foundation to carry heavy topsides.<br>2. High durability because it is constructed with almost maintenance-free materials.<br>3. Possible to float out with some desk facilities in place because it is constructed onshore and floated offshore.<br>4. Can be used to drill the additional oil and gas wells required in future.<br>5. Construction skills largely unskilled and serves as opportunity for Oil and Gas Engineering graduates.<br>6. Decommissioning options available due | 1. Limited to water depth (use for water depth from 1500 to 7000ft).<br>2. No flexibility to site location because it is permanently moored to the seabed.<br>3. High investment cost required due to expensive low corrosive materials required and construction carried out at different locations/stages.<br>4. Deliverable time may take up to five years due to subsea installations required.<br>5. Retrofits difficult due to complex and rigid design.<br>6. Has no storage capacity for future |

| | |
|---|---|
| to it being decoupled, structure could be reused for offshore wind power plant.<br>7. Suitable for harsh and/or arctic environment (like hurricane-prone regions). | increase in production of feedstock.<br>7. Prone to attack by sea pirates and others during installation period. |

**Table 3.6**: GFPPTL Specification and Justification

| Specification | Description | Justification |
|---|---|---|
| **Power package and Platform size** | The development will be a 200MW conventional Combined Cycle Power Generation Plant with Regasification System as its topside facilities. The design service life will be 25 years and its dead weigh total will be between 46,500 and 60,000 tons when moored to the seabed, but up to 70,000 tons when floating freely. The height from the bottom of the base to the top of the column is 60-meters, width of 105-meters and length of 165-meters. The design will have a helideck capable of accommodating an S-92 helicopter. The TLP is anchored to the seabed by eight 28inches diameter tendons with 1.2inches wall thickness. The tendons will be secured to the seabed by piles measuring 120-meters with a 76inches diameter. It will have a thickness of up to 2inches. | The power package and vessel size was done in accordance to the API RP 11 PGT, which gives general requirements and limitations in applying these standard turbine designs. |
| **Feedstock, storage capacity and electricity transmission means** | The platform will be installed 50-meters away from the Field-X and a 105km gas bundled pipeline connected to supply the required feedstock and exhaust gas to and from the power generation plant. The design will have six pre-installed I-tubes for umbilical and provision for 12 (future) flowline risers for new field products hook-up. Electricity generated will be transmitted to onshore national grid via 25km DC subsea (submarine) cables to fiscal metering point. Storage capacity for feedstock is limited to a few days usage and the design operates on instant gas consumption. | The method is adopted due to the water depth and also the weight of the materials used. Also the location of the structure serves as hook up point for other discovered field in the future. |
| **Accommodation Capacity** | The platform will have permanent quarters for 30 people and temporary quarters for a further 25 persons. | The size of facilities and manpower required for effective operations were considered. |

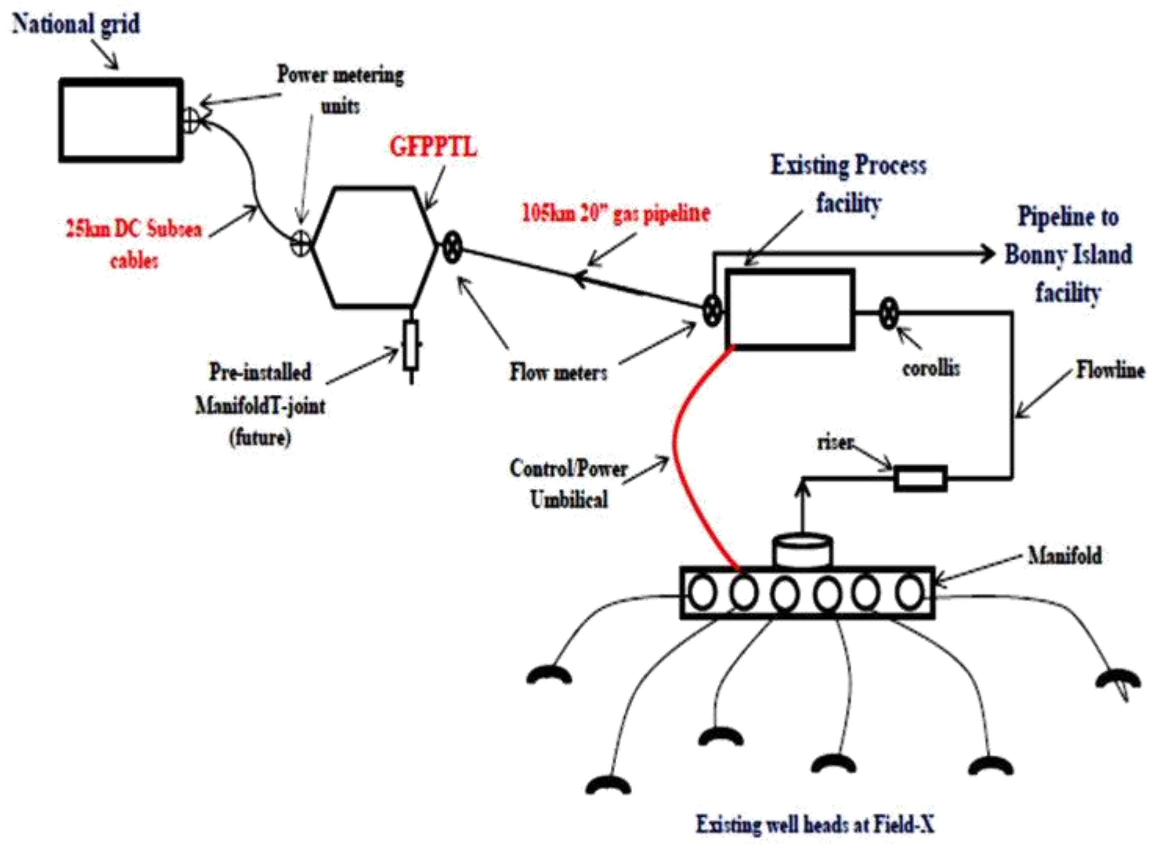


**Figure 3.5**: Flow schematic layout of Concept 2 (GFPPTL) at Field-X, Gulf of Guinea

### 3.3.3 CONCEPT 3 – GAS-FIRED POWER ONSHORE

The location of the power plant onshore is a non-starter for OffshoreCo as the onerous CAPEX and OPEX cost due to security measures to be put in place derails project commerciality. The Shell experience of a disrupted gas supply and the need to declare a force majeure as described in **Section 2.1.1** is enough to cause OffshoreCo deep-seated reservations of an onshore power plant. To this end, this option has been removed from further consideration.

## 3.4 PESTLE ANALYSIS OF CONCEPTS (FGFPP AND GFPPTL)

The following comparisons were carried out for equal output power rating of 200MW for both concepts as shown in **Table 3.7** to ascertain their viability.

**Table 3.7**: Comparisons of Concept 1 and 2

| Criteria | | FGFPP | GFPPTL |
|---|---|---|---|
| Technical, HSSE and economic factors. | Installation | • Technology well understood by firms like Solar, Siemens, SBM, and Hyundai etc.<br>• Construction/installation completion time is between two or three years.<br>• Dynamic in structure and movement.<br>• Installation cost (CAPEX) is medium. | • Complex design structure and TLP construction understood by Rolls Royce, MAN, Samsung Heavy Industries etc.<br>• Requires three to five years construction and installation time.<br>• Rigid in structure and at a fixed location.<br>• Installation cost (CAPEX) is high. |
| | Operation | • Requires trained personnel for maneuvering the unstable vessel using the turret mooring system and dynamic positioning system to keep it in place.<br>• Power generation (CC) process and control operation is similar.<br>• High OPEX due to maintenance of vessel.<br>• High safety standard and quick emergency response system required and in place.<br>• Little or no spillage of process water and exhaust gas. | • It has a fixed structure with more stability.<br>• Similar power generation (CC) process and control operation.<br>• Low OPEX due to structure type and materials.<br>• SOP is being followed as stated on the safety case leading to less risk.<br>• Likely possibility of process water and exhaust gas spillage due to limited capacity. |
| | Decommissioning to meet the Nigerian's PIB and UK's OSPAR in Maritime Area and IMO guideline. | • Easy to disassembly after lifespan, high re-vamp (re-use) for power generation, hydrocarbon, hydrogen economy purpose and complete disposal of waste.<br>• Low decommissioning cost (full removal).<br>• Structure can be completely removed going by the OSPAR. | • Require experienced personnel for disassembling structure after lifespan with low re-use option for same power generation purpose due to complex design and fatigue on tension structural members.<br>• High decommissioning cost (full removal).<br>• Structure will be partial removed/partly leave in place (piling) following |

| | | | |
|---|---|---|---|
| | | | the IMO guideline with its shafts removed below the surface to provide a free navigation depth of 55m. |
| | Environmental impact | • Can be used in both shallow and deep water.<br>• Less impact on marine animals and no cell contents concentrations and drill cuttings exposed to the open water.<br>• Tendency to generate and send vibration waves to seabed disturbing sea creatures. | • Limited to water depth of up to 300m.<br>• More impact on marine mammals and likely large amount of cell contents concentrations exposed to the seawater.<br>• Less vibration generated due to stiffness in the tension leg structures. |
| | Security | • Less prone to attack during operation period due to automated control system.<br>• Requires surveillance system around its vicinity. | • More likely to be attacked due to stationary structure.<br>• Security measures quite expensive. |
| | Gas delivery and electricity transmission | • Feedstock supply can be continuous via gas pipeline.<br>• Not affected by intermittent supply due to large storage capacity.<br>• Pipeline and intermittent LNG delivery to customers via shutter tanker is possible.<br>• Electric Power transmission is via subsea cables. | • Requires continuous supply of feedstock due to limited storage capacity.<br>• It will be affected by intermittent supply to an extent.<br>• Pipeline and intermittent LNG delivery to customers via shutter tanker is possible.<br>• Electric Power transmission is also via subsea cables. |
| | Waste treatment | • Less amount of treated water discharged overboard.<br>• No or minimal gas flaring. | • More amount of treated water discharged overboard due to cells flooded with seawater.<br>• Limited amount of gas flaring. |

### 3.4.1 Concept Selection Criteria

Selection of one concept from the above two concepts will be based on the capital cost and several qualitative factors (suitability to physical and gas fired power generation on site, environmental impact, and strategic fit) weighted to portray OfshoreCo's priorities. The highest weight of 0.8 was given to initial investment cost due to controlled budgetary allocation system for the project, followed by the design technology viability of 0.7 to match the gas-to-power plant scheme, environmental impact given a weight of 0.6 since the company advocates for environmental conservation, health and safety risk a weight of 0.5 and strategic fit a weight of 0.4.

**Concept Capital Expense Estimation**

A life-cycle cost (LCC) analysis of the two possible power plant concepts was completed. The assumptions considered the following factors:

- Water depth
- Offset distance of each offshore power facility from Field X
- Offset distance of each power facility to tie into the National Grid
- Engineering, Procurement, Construction, and Installation contract for the power cable and the pipeline/riser system
- Security charges for the near shore facility
- Project life is 25 years at a discount factor of 10%

The cost comparison of each system is shown in the **Table 3.8** below. From the results obtained the FGFPP (deep water) is only marginally better than the GFPFTL (Shallow water).

**Table 3.8**: Life-Cycle Cost Comparison – GFPPTL vs. FGFPP

| Concepts | GFPPTL (Shallow Water) | FGFPP (Deep Water) |
|---|---|---|
| CAPEX (x 1000 UK Pounds) | | |
| Water Depth, m | £150 | £500 |
| **Front End Engineering Design (FEED)** | | |
| Conceptual Design Studies | £250 | £250 |
| Hull Basic Engineering | £375 | £375 |
| Class Approval in Principle | £200 | £200 |
| Project Management | £200 | £200 |
| ***Feed Subtotal*** | ***£1,025*** | ***£1,025*** |
| **Project Execution** | | |
| Engineering / Drawings | £1,685 | £1,685 |
| Class Approval | £1,000 | £1,000 |
| Project Management | £843 | £843 |
| License Fee | £1,250 | £1,250 |
| ***Project Execution Subtotal*** | ***£4,778*** | ***£4,778*** |

| | | |
|---|---|---|
| **Platform Steel** | | |
| Hull | £10,103 | £10,103 |
| Hull Appurtenance | £4,250 | £4,250 |
| Marine Systems | £2,499 | £2,499 |
| Deck Steel | £29,338 | £29,338 |
| ***Platform Steel Subtotal*** | ***£46,189*** | ***£46,189*** |
| **Mooring Hardware** | | |
| No of Mooring lines | N/A | £5 |
| Anchors | N/A | £1,125 |
| Polyester | N/A | £2,813 |
| Chain | N/A | £900 |
| Fairleads / blocks/ Chain Jacks | N/A | £2,700 |
| ***Mooring Hardware Subtotal*** | | ***£7,538*** |
| **Pipeline Riser** | | |
| Pipeline diameter/length | 20-inch, 105km (Single) | 20-inch, 10km (single pipe) |
| Pipeline/Riser (EPCI) | £209,719 | £26,875 |
| ***Pipeline/Riser Subtotal*** | ***£209,719*** | ***£26,875*** |
| **Power Cable** | | |
| Power cable length, km | 4, 25-km, 50 MW HVDC cable | 4, 130-km, 50 MW HVDC cable |
| Subsea Power Cable (EPCI) | £46,731 | £196,000 |
| ***Power Cable Subtotal*** | ***£46,731*** | ***£196,000*** |
| **Offshore Installation** | | |
| Deck integration with power generation packages(Near quay•-side) | £171,719 | £206,063 |
| Wet tow from GOM yard pre•-lay | £250 | £250 |
| Pre-lay | N/A | £1,500 |
| Mooring line connection | N/A | £500 |
| ***Offshore Installation Subtotal*** | ***£171,969*** | ***£208,313*** |
| **Total CAPEX** | **£480,410** | **£490,717** |
| **Annual OPEX (x 1000 UK Pounds)** | | |
| Security Charges | £1,463 | £0 |
| Maintenance Costs | £1,463 | £1,463 |
| **Total OPEX** | **£1,609** | **£1,463** |
| **Total Net-Present-Cost (25-year life, 10% discount factor)** | **£1,121,067** | **£1,121,064** |

Note that the cost estimates stated above were made after consultation with GE Oil and Gas [25] and Parsons Brinckerhoff [26] on the subject matter as at 2013. Calculations were made using the HOMER Energy software. [27] The software is a hybrid optimization model for electric renewables. See **Appendix C** for results.

**Qualitative Criteria Assessment**

A score card of 0 to 100 as shown in **Table 3.9** was used to rank the design concept relative to the set indicators. High score is interpreted as an acceptable and appropriate design for the gas-to-power plant scheme at the site. Low score implies that the design do not meet the company's expectancy. The order of preferences decrease as the scores reduces. [23]

**Table 3.9**: Criteria for the Concept Selection

| Score (%) | Rank of Importance | Criteria |
|---|---|---|
| 100-80 | High | • Has been successfully implemented with good footprint and economic market values. Optimum performance parameters are available on selected site.<br>• Implementation cost is comparatively low (GBP£100 to 300 million).<br>• Break-even point is reached within a short time (2 to 3 years).<br>• Hazardous events such as fire, blowouts, occupational incidents etc. have a low probability (P20-HSE) of occurrence.<br>• Aligns with company's profile, mission and objectives. |
| 79-50 | Medium | • Has been implemented and successful but few parameters do not meet the standard required for optimum operation at the selected gas zone site.<br>• Medium cost required for implementation (GBP£ 300 to 500 million).<br>• Observable environmental impacts at start-up but returns to normal in a medium term (say 6months to a year) with mitigation applied.<br>• A return on investment is between 5 to 10 years.<br>• Hazardous events such as fire, blowouts, occupational incidents etc. have a medium probability (P50-HSE) of occurrence.<br>• Fairly meets the company's profile, mission and objectives. |
| 49-20 | Low | • Design is in its demonstration stage and yet to be implemented but shows potential signs of suitability for the site.<br>• Has high cost of implementation (GBP£ 500 to 700 million) due to uncertainties.<br>• Impacts on the environment are reversible in a long term.<br>• Returns on investment takes up to 18 years.<br>• Hazardous events such as fire, blowouts, occupational incidents etc. have high probability (P70-HSE) of occurrence.<br>• Partially meets the company's requirements. |
| 19-0 | Unwanted | • No prove of implementation and still under research.<br>• Huge investments required (>700 million).<br>• Possibility of irreversible environmental damage.<br>• Economic viability uncertain.<br>• Hazardous events such as fire, blowouts, occupational incidents etc. have higher probability (P90-HSE) of occurrence. |

| | | |
|---|---|---|
| | | • Do not meet the company's profile, mission and objective. |

### 3.4.2 Score card Output for the PESTLE Analysis

The above two development concepts will be scored according to the concept selection criteria to reflex their feasibility.

**Table 3.10**: Score Card Comparison Output

| Criteria | Weighting (a) | Concepts | | | |
|---|---|---|---|---|---|
| | | FGFPP | | GFPPTL | |
| | | Score (%) ($b_1$) | Output Score (a) × ($b_1$) | Score (%) ($b_2$) | Output Score (a) × ($b_2$) |
| Initial investment cost | 0.8 | 80 | 64.0 | 70 | 56.0 |
| Design viability | 0.7 | 75 | 52.5 | 85 | 59.5 |
| Environmental impact | 0.6 | 85 | 51.0 | 80 | 48.0 |
| Health, safety and security risk | 0.5 | 80 | 40.0 | 80 | 40.0 |
| Strategic fit | 0.4 | 90 | 36.0 | 75 | 30.0 |
| **Overall qualitative score** | | **243.5** | | **233.5** | |
| **Remarks** | | Preferred concept | | Low strategic fit | |

### 3.4.3 Selected Concept and Justification

From above analysis, the Floating Gas-fired Power Plant vessel (FGFPP) is a viable alternative as its operation is not limited by water depth, which matches the parameters of the present site. A commercial scale-sized of such system solely for power generation has not been designed or implemented in such location but development concepts have been validated for 100 - 400 MW offshore power facility which are good proxies for the design and development of the required 200 MW facility. The FGFPP, if implemented has less associated security risks, acceptable installation costs, and rely on known technology. It is for these reasons it was selected as the best development concept for the project.

## 3.5 Major components of selected concept (FGFPP)

As shown in **Figure 3.6** below, the following major components are to be considered during the design and procurement stage of the power generation unit of the FGFPP in other to meet American API design codes requirement and also to align with other regulatory approval that may be required;

1. Air Compressor (AC) compresses the air before combustion and expansion through the turbine.

2. Gas generator (GG) including combustor and gas turbine (GT). This component ignites air and fuel mixture to give a smooth stream of uniformly heated gas into the power turbine.

3. Heat recovery steam generator (HRSG) uses the gas exhausted to produce steam in a heat exchanger which acts as a boiler system.

4. Steam turbine (ST) and condenser system. The steam generated is supplied to the steam turbine where it is expanded to produce more electricity. The exhaust steam is the transfer to the condenser where it is condensed to liquid with a cooling medium at ambient temperature.

5. Power turbine (PT). The power turbine has the task of providing the power to drive the compressor and accessories, by providing shaft power to the driven equipment for power generation, or driving the compressor or pump. It does this by extracting energy from the hot gases released from the combustion system and expanding them to a lower pressure and temperature.

6. Floating Host (MiniFloat III)

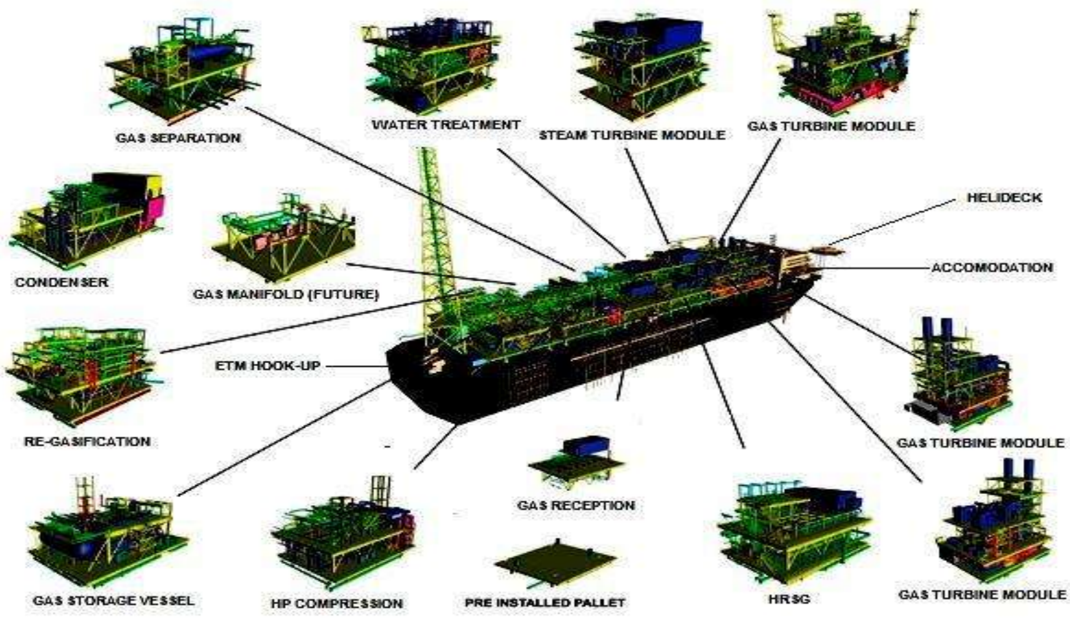


**Figure 3.6**: FGFPP's Modules and skids layout

Further information on how these components inter-relate can be found in **Appendix A**. The other key systems within the package include the fuel system natural gas or liquid, pumps (main, pre/post, back up), the bearing lube oil system including tank and filters, the starter (usually either pneumatic, hydraulic or a variable speed ac motor), driven equipment and seal gas system, cooling systems, and controls (on-skid, off-skid). Other external ancillary equipment to the turbine package includes the enclosure and fire protection, the inlet system including air-filter (self-cleaning, barrier, inertial) and silencer, the acoustic housing, the motor control centre, switchgear, neutral ground resistor and inlet fogger/cooler.

### 3.5.1 ENGINEERING DESIGN FACTORS CONSIDERED

The factors needed to be considered in designing the combined cycle turbines for power generation on the FGFPP include: low weight and dimensions, minimising vibration, resistance to saltwater, resistance to pitch and roll particularly in floating vessel installation. Also, the 3-point mounting will be used to isolate the gas and steam turbines from deck movements.

A more detailed and confidential study is required to be carried out by the Engineering design team to address technical specification requirements of the individual components prior to procurement for customization. The American's API codes and the UK's HSE guidance note PM84 will be adapted for this study. The codes give some flexibility, for example; API 616 Foreword states: "Equipment Manufacturers, in particular, are encouraged to suggest alternatives to those specified when such approaches achieve improved energy effectiveness and reduce total life costs without sacrifice of safety and reliability." [28]

The UK's HSE guidance note PM84 is a document drawn up by a working group which included HSE, offshore operators and turbine suppliers. [28] Manufacturing companies' regular change of specifications will be detrimental if the specific designs that were incorporated in the engineering design of the FGFPP + ETM are not obtainable for this purpose. Specific details of the Engineering design will be made available early enough so that modification jobs can be reduced to the minimum.

## 3.6 RISK ASSESSMENT FOR THE FGFPP

Risk Assessment was carried out to identify and evaluate risks associated with proposed Floating Gas-fired Power Plant (FGFPP) project. The aim is to quantify, minimize and/or eliminate any impacts that could have adverse effect on the project objectives and it was also done to enhance or promote the positive ones according to prevailing/adapted legislations in Nigeria. The key risk prone areas were identified in a risk register based on the project objectives and considered according to PESTLE Analysis risks breakdown as shown in **Figure 3.7** below.

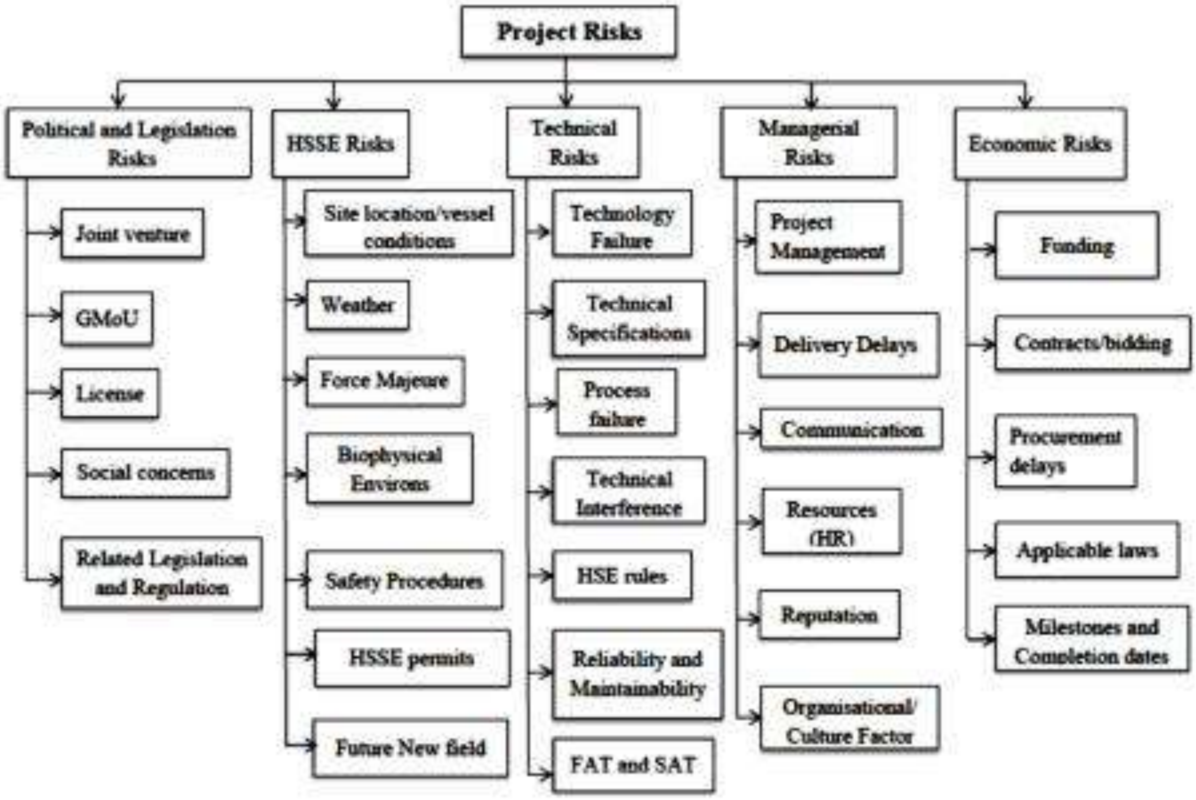


**Figure 3.7**: Project Risk Breakdown Structure

The degree of exposure of the impacts were quantified using the impacts/consequences and probabilities of occurrence. Mitigation measures were been proposed including personnel and collective responsibilities for monitoring the risks within the existing period/areas.

Note that the probabilities of occurrence were estimated due to lack of adequate data because the project is new offshore installation.

### 3.6.1 Methodology for Risk Analysis

The risk analysis uses a sophisticated method to analyse the severity of identified risks against their respective weighted effects on the project cost, benefit, time and environment as shown in the Risk Register in **Table 3.11-8**. These matrices shown in **Table 3.11-1** and **Table 3.11-3** help to prioritize the risks from the analysis in order for ease of decision making. The weights were chosen with respect to the company's priorities and the results show which risks will have major impacts on the chosen types as per criteria. Also, employee cost per unit time, expert judgment and consultation with stakeholders were used in the analysis to obtain the values shown in the Risk Register. The final ranking was categorized, whereby the total value of the impacts were represents in elements as defined in the range of A to D and with colour code for boxes respectively as shown in **Table 3.11-2** and **Table 3.11-4**.

### 3.6.2 Discussion of Findings

As demonstrated in the risk analysis for the FGFPP with ETM, **Table 3.11-6** and **Table 3.11-7** show matrices plot of risks before and after mitigation actions respectively. A total of fifteen (15) of twenty-seven (27) risks analysed were found to be unacceptable and high cutting across the PESTLE parameters, indicating a major impact on the project cost of over GBP 80 million. Eleven (11) medium risks associated mainly with Managerial and Economic and one (1) minor risk as shown in **Table 3.11-6**. However, after implementation of the proposed mitigation actions with effective monitoring, feedback communication and documentation, the unacceptable and high risks were bought to the safe zone with key emphasis key to the Project Management Team in play. OffshoreCo is well known for good HSSE practise will take all possible measures to reduce identified risks including those that may have been omitted in this analysis. The option of share risks to Third Parties with the award of contracts will be adapted by OffshoreCo in accomplishing some of the project phases.

An important area for management consideration is the continuous review, update and management of the project to identify new risks a changing work environment. This will enable the OffshoreCo Senior Management to evaluated the effectiveness of control measures and identify the responsible parties to ensure that a proposed mitigation measures still apply compared to the prevailing conditions. The project cost estimate will include a budget for risks in the project control activities with will be complemented by proper risk mitigation plans and communication activities.

**Table 3.11-1**: Criteria for ranking Risk on Benefit, Cost, Time and Environment

| Impact type in GBP (£) / Rank | Unacceptable | High | Medium | Low | Negligible |
|---|---|---|---|---|---|
| | 10 | 8 | 5 | 3 | 1 |
| Benefit (negative effect on the company's profit) | >30M | 30-20M | 20-10M | 10-5M | <5M |
| Cost (Deficit on the Expenditure) | >20M | 20-10M | 10-5M | 5-2M | <2M |
| Time (Effects on the schedule) | >9months | 9-7months | 7-5months | 5-3months | <3months |
| Environment, safety and security (Lost Time Incident (LTI) and clean-up cost) | >50M | 50-30M | 30-10M | 10-5M | <5M |

**Table 3.11-2**: Overall Weight of Impact code representation

| Impact Category (Overall Weight Range = B+C+T+E) | | Definition |
|---|---|---|
| Unacceptable (above 100) | A | Overall weight of impact of the risk on benefit, cost, time and environment will cause either noticeable increase in expenditures, disruption of schedule, reduce the benefits and /or lead to environment degradation. |
| High (80-100) | B | Overall weight of impact of benefit, cost, time and environment may likely cause some significant increase in either expenditures, disruption of schedule, and/or environment degradation. |
| Medium (40-80) | C | Overall weight of impact of benefit, cost, time and environment may have a mild effect on either expenditures, disruption of schedule, and/or environment degradation. |
| Minor/Negligible (<40) | D | Overall weight of impact of benefit, cost, time and environment have little or no effect on either expenditures, disruption of schedule, and/or environment degradation. |

**Table 3.11-3**: Probability of Occurrence

| Ranks | Probability (%) |
|---|---|
| Very likely to occur | 0.7 |
| Could occur | 0.5 |
| Unlikely to occur | 0.3 |
| Very unlikely to occur | 0.1 |

**Table 3.11-4**: Indicator Definition

| Indicator | Definition and Mitigation |
|---|---|
| Unacceptable/High | Could lead to severe injury/death, project loss/major system damage or irreversible/reversible environmental damage. High priority risk management team attention and concentrated action is required to control acceptable risk. |
| Medium | Injury requires medical attention, illness, system damage, or mitigatible environmental damage. The project risk management team will do some response planning for these risks. |
| Low | Possible minor injury, minor system damage or minimal environment damage. No response plans is required for these risks because it will be cover in the project's work frame. The project will monitor and action on these risks as they occurs. |

**Table 3.11-5**: Prob. of Occurrence ($P_i$) versus Total Impact ($I_i$) boxes

| Probability of occurrence ($P_i$) | | | 0.1 | 0.3 | 0.5 | 0.7 |
|---|---|---|---|---|---|---|
| Impact severity on Time, cost and benefits ($I_i$) | Probable | A | (0.1A) | (0.3A) | (0.5A) | (0.7A) |
| | Occasional | B | (0.1B) | (0.3B) | (0.5B) | (0.7B) |
| | Remote | C | (0.1C) | (0.3C) | (0.5C) | (0.7C) |
| | Improbable | D | (0.1D) | (0.3D) | (0.5D) | (0.7D) |

**Table 3.11-6**: Risks before Mitigation

| | | | |
|---|---|---|---|
| 12 | 15 | 10, 18 | 2 |
| | 8 | 5,14,16, 17 | 1, 11, 20, 21, 22 |
| | 9, 23, 27 | 3, 4, 6, 7, 13, 19, 24, 26 | |
| | | | 25 |

→

**Table 3.11-7**: Risks after Mitigation

| | | | |
|---|---|---|---|
| | | | |
| | | | |
| 12, 13, 24, 26, 27 | 1, 5, 11, 14, 18, 21 | 15 | |
| 3,4, 6, 8, 9, 17, 19, 20, 22, 23, 25 | 7, 10 | 2, 16 | |

**Table 3.11-8**: Risk Analysis Register

| PESTLE Analysis | | Risk Description | Risks Analysis before Mitigation | | | | | | | | Risks Analysis after Mitigation | | | | Responsible Parties |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Magnitude of Risk/Impact | | Ti me (T) x3 | | | Equiv.Impact Rankcode(I i) | i) | Exposure(X i) = P i x I i) | Mitigation Actions | i) | Equiv.Impact Rankcode(I i) | Exposure(X ) | |
| Political and | 1 | Disagreement of joint venture allocation among stakeholders. | 20 | 40 | 24 | 4 | **88** | **B** | **0.7** | **0.7B** | Use of existing sharing formula amongst stakeholders. | **0.3** | **C** | **0.3C** | OffshoreCo Senior Management. |
| | 2 | Establishment of a good and working Global memorandum of Understanding (GMoU) with | 20 | 50 | 30 | 40 | **140** | **A** | **0.7** | **0.7A** | Liaison officers to work closely with company's representatives in development | **0.5** | **D** | **0.5D** | Liaison Rep/Community |
| | 3 | Licence for new field development and certifications required for operation. | 2 | 25 | 15 | 4 | **46** | **C** | **0.5** | **0.5C** | Work closely with Nigerian regulatory bodies such DPR, NAPIMS, NCD,SON, COREN etc. | **0.1** | **D** | **0.1D** | Project Management Team. |
| | 4 | Social and political acceptance concerns. | 10 | 25 | 24 | 20 | **79** | **C** | **0.5** | **0.5C** | Liaise with relevant social and political leaders in Nigeria. | **0.1** | **D** | **0.1D** | Liaison Rep/Community Leader. |
| HSSE | 5 | Lost Time Incident (LTI) due to failure to follow safety procedures. | 10 | 40 | 10 | 32 | **92** | **B** | **0.5** | **0.5B** | Ensure all workforces are provided with trainings, PPE, Certified Equipment and tools. | **0.3** | **C** | **0.3C** | Project HSSE Team, QA/QC dept. and ICP. |
| | 6 | Delays in HSSE approval and permits for MLCS, NAPIMS etc. | 20 | 25 | 15 | 4 | **64** | **C** | **0.5** | **0.5C** | Work with Nigerian authorities and HSSE executives on negotiation. | **0.1** | **D** | **0.1D** | Project HSSE Team. |
| | 7 | Greenhouse gases emissions ($CO_2$, $H_2S$ etc.) from operations. | 20 | 15 | 9 | 32 | **76** | **C** | **0.5** | **0.5C** | Continuous environmental monitoring and emergency response equipment and measures in place. | **0.3** | **D** | **0.3D** | Project Engineering, QA/QC, HSSE Team. |
| | 8 | Distortion on operation due to seismic activities for additional new field development. | 10 | 40 | 24 | 20 | **94** | **B** | **0.3** | **0.3B** | Ensure all operation procedures are followed with caution and pre-geological surveys done with barriers. | **0.1** | **D** | **0.1D** | Project Management team/Exploration Team. |
| | 9 | Effects on marine habitants and bio-physical environment. | 16 | 25 | 9 | 20 | **70** | **C** | **0.3** | **0.3C** | Continuous environmental monitoring and adequate mitigation measures in place. | **0.1** | **D** | **0.1D** | Project HSSE Team. |
| | 10 | Accidents during the implementation phase of the project. | 20 | 50 | 30 | 20 | **120** | **A** | **0.5** | **0.5A** | All workforces to be provided with adequate awareness trainings and quick emergency response system available. | **0.3** | **D** | **0.3D** | HSSE Team/Human Resource Team. |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 11 | Changing weather condition effects. | 6 | 40 | 30 | 4 | **80** | **B** | **0.7** | **0.7B** | Proper planning & scheduling within the summer period of project location. | **0.3** | **C** | **0.3C** | Project Management Team. |
| | 12 | Force Majeure natural disaster. | 20 | 40 | 24 | 40 | **124** | **A** | **0.1** | **0.1A** | Have quick emergency and evacuation system in place. | **0.1** | **C** | **0.1C** | Survey/HSSE Team. |
| Technical | 13 | Floating vessel construction delivery delays and External Turret Mooring system installation failure. | 6 | 40 | 24 | 4 | **74** | **C** | **0.5C** | **0.5C** | ➢ Early contract award and reasonable construction time.<br>➢ Monitor, communicate and synchronise planned schedule with contractor firms. | **0.1** | **C** | **0.1C** | Contractors/ Engineering dept., Project Management Team. |
| | 14 | Inaccurate design specifications and procedures. | 10 | 40 | 15 | 32 | **97** | **B** | **0.5** | **0.5B** | ➢ Ensure proper design information is given to suppliers.<br>➢ FAT/SAT to be carried out before shipping and installation respectively. | **0.3** | **C** | **0.3C** | Supplier, supply chain management team, Engineering dept., Project Management Team. |
| | 15 | Combined cycle mechanical failure as a result of continuous and cyclic duty application of FGFPP with ETM (creep, thermo-mechanical fatigue, high cycle fatigue, metallurgical embrittlement, corrosion, environment attack, erosion, oxidation and foreign object damage). | 20 | 50 | 30 | 32 | **132** | **A** | **0.3** | **0.3A** | ➢ Research and feasibility study on various materials and existing technology usage.<br>➢ Follow specifications and material selection for fabrication of machine parts.<br>➢ Ensure proper certification for ICP and proper implemented inspection scheme (FAT and SAT). | **0.5** | **C** | **0.5C** | Project Research Team, Supplier, ICP, Engineering, Construction and Project Management Team. |
| | 16 | Design variations in modules and skids. | 16 | 40 | 15 | 12 | **83** | **B** | **0.5** | **0.5B** | ➢ Follow modified design in accordance to Engineering dept.<br>➢ Communicate modified design and updated to every stage of Project. | **0.5** | **D** | **0.5D** | Engineering design dept. and Project Management Team. |
| | 17 | Lack of adequate experienced and technical work force. | 6 | 40 | 24 | 20 | **90** | **B** | **0.5** | **0.5B** | ➢ Recruitment exercise and hiring of consultants.<br>➢ Adequate training and certification programs for work personnel. | **0.1** | **D** | **0.1D** | OffshoreCo Senior Management, HR Management and Project Management Team |
| | 18 | Installation of subsea lines and demand risks associated with national grid connections. | 20 | 40 | 30 | 32 | **122** | **A** | **0.5** | **0.5A** | Work with Nigerian Electricity Authorities to incorporate grid frame. | **0.3** | **C** | **0.3C** | Engineering, Project Management and Commissioning Management Team. |
| | 19 | Equipment reliability, security, safety and operation/performance failures in location. | 10 | 25 | 9 | 12 | **56** | **C** | **0.5** | **0.5C** | ➢ Automation 24-hrs surveillance security system in place.<br>➢ Use of certified critical safety systems and proper documentation for operations.<br>➢ Ensure proper certification and condition of equipment in place. | **0.1** | **D** | **0.1D** | Engineering design team, O&M team and Security Team. |
| Ma nag erial | 20 | Lack of communication. | 16 | 25 | 15 | 32 | **88** | **B** | **0.7** | **0.7B** | ➢ Trainings and team work activities.<br>➢ Daily reporting and tracking system in place for updated activities. | **0.1** | **D** | **0.1D** | Project Management Team. |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 21 | Inability to meet project schedule activities. | 10 | 40 | 32 | 4 | **86** | **B** | **0.7** | **0.7B** | ➢ Adequate relationship and daily communicate with all parties involved.<br>➢ Coordinate and synchronise schedule and plan. | **0.3** | **C** | **0.3C** | Project management Team. |
| | 22 | Inexperienced management of offshore floating gas-fired power plant vessel. | 20 | 40 | 24 | 12 | **96** | **B** | **0.7** | **0.7B** | ➢ Proper on-board rotation-scheme of top management.<br>➢ Adequate training and relaxation scheme for workforce. | **0.1** | **D** | **0.1D** | OffshoreCoSenior Management, HR Management and Project management Team. |
| **Economic** | 23 | Failure to avail funds when required. | 6 | 0 | 30 | 32 | **68** | **C** | **0.3** | **0.3C** | ➢ Constant update of work progress with investors, stakeholders, Senior Management.<br>➢ Utilise available money judiciously. | **0.1** | **D** | **0.1D** | OffshoreCoSenior Management, Project Management Team. |
| | 24 | Equipment, skids and modules procurement delays. | 6 | 40 | 24 | 4 | **74** | **C** | **0.5** | **0.5C** | ➢ Work with responsible parties per schedule.<br>➢ Early purchase of the equipment and early bidding procedures to suppliers. | **0.1** | **C** | **0.1C** | Engineering Design, Supply chain management Team, Project Management |
| | 25 | Losses incurred due to inflation or price fluctuations on construction materials and activities. | 3 | 15 | 9 | 0 | **27** | **D** | **0.7** | **0.7D** | Contingency/ forecast estimates cover for these increments. | **0.1** | **D** | **0.1D** | Project Finance Team. |
| | 26 | Over-runs expenditure due to late completion of project. | 20 | 40 | 9 | 0 | **69** | **C** | **0.5** | **0.5C** | Coordinate, synchronise plans and schedule with all departments. | **0.1** | **C** | **0.1C** | Construction Management and Project Management Team. |
| | 27 | Effects due to prevailing commercial laws and regulations. | 10 | 25 | 15 | 4 | **54** | **C** | **0.3** | **0.3C** | Work with regulatory authorities and financial Controllers | **0.1** | **C** | **0.1C** | Commercial Management Team. |

# CHAPTER FOUR - BUSINESS CASE ANALYSIS AND EXECUTION PLAN

## 4.1 BUSINESS CASE ANALYSIS

The use of the electricity generated from the selected concept (FGFPP) in **Section 3.3.1** is being analyzed and an execution plan for its implementation is drawn out. Three alternative uses of the electricity are considered as shown in **Table 4.1**. Case 1 analyzes the Project as a Centralized Power Station where the total electricity generated is transmitted to the Nigeria's National grid while Case 2 and Case 3 considers the electricity generated for Self-Generation (Distribution Generation) where it is use to power other neighboring facilities and Self-Utilization for OffshoreCo facilities alone in the Gulf of Guinea, Nigeria respectively. The economic viability was analyzed using the probability decision matrix, which compared the Net Present Value (NPV), Capital Expenditure, Revenue and IRR of each alternative. [29] These alternatives were also compared against their respective suitability to technical, environmental and strategic criteria as shown in the **Table 4.2** using the score card criteria from **Table 3.9** to give a final overall end-user comparison. Here, a probability of 90% (0.9) represents a high likelihood of occurrence while 20% (0.2) represents the uncertainty of achieving the assumed stated estimate.

**Table 4.1**: Commercial Evaluation of Alternative uses of Electricity generated

| **Case 1**: FGFPP as a Centralized Power Station (CPS) Power Transmitted to Nigeria's National grid | | | | | | |
|---|---|---|---|---|---|---|
| | Installed Capacity = 200MWe | | Probability of occurrence | | | Remarks |
| | | | 0.2 | 0.7 | 0.9 | |
| Financial | CAPEX in GBP (£ million) | 491 | | | √ | Reasonable investment. |
| | Natural gas Price in GBP (£/cubic meter) | 0.09 | | √ | | Potential for gas price increase post start-up. |
| | Revenue (income) £million/yr. | 11.4 | | | √ | Affected by low power sales price to National grid. |
| | **NPV** @ 10% GBP (£million) | 103 | | | √ | Average returns on investment as at today. |
| | IRR % | 19.2 | | | √ | Slightly risk indicator lower than bank fixed deposit interest rate. |

| | | | | | | |
|---|---|---|---|---|---|---|
| | Payback period (years) | 12 | | √ | | Average time period compare to PAL cycle. |

**Case 2**: FGFPP as a Distribution Generation (DG) to other IOCs facilities in the vicinity

| | Installed Capacity = 200MWe | | Probability of occurrence | | | Remarks |
|---|---|---|---|---|---|---|
| | | | 0.2 | 0.7 | 0.9 | |
| Financial | CAPEX in GBP (£ million) | 541 | | √ | | Depends on OffshoreCo budget. |
| | Natural gas Price in GBP (£/cubic meter) | 0.09 | | √ | | Potential for gas price increase post start-up. |
| | Revenue (income) £million/yr. | 268.1 | | | √ | Good returns due to high power sales price. |
| | **NPV** @ 10% GBP (£million) | 2,432.7 | | | √ | High profit as at today's monetary value. |
| | IRR % | 24.6 | | | √ | Monetary risk is very low. |
| | Payback period (years) | 8.6 | | | √ | Early break-even time frame. |

**Case 3**: FGFPP as a Self-Utilization (SU) (Offshore facilities)

| | Installed Capacity = 200MWe | | Probability of occurrence | | | Remarks |
|---|---|---|---|---|---|---|
| | | | 0.2 | 0.7 | 0.9 | |
| Financial | CAPEX in GBP (£ million) | 516 | | √ | | Depends on OffshoreCo budget. |
| | Natural gas Price in GBP (£/cubic meter) | 0.09 | | √ | | Potential for gas price increase post start-up. |
| | Revenue (income) £/yr. | 56.7 | | | √ | Good returns due to high power sales price. |
| | NPV @ 10% GBP (£) | 514.0 | | | √ | Satisfactory profit as at today's monetary value. |
| | IRR % | 22.8 | | | √ | Monetary risk is very low. |
| | Payback period (years) | 10.8 | | | √ | Early break-even time frame. |

Simulation results can be seen in Appendix C.

The following assumptions were made for the three cases respectively; **CASE 1 (CPS)**

- £0.15/kWh is the sales price to the National grid (fixed).
- 10 MW of power generated is consumed by the FGFPP.
- Natural gas price increases may be forced on OffshoreCo in an attempt to make up revenue shortfalls due to possible decrease LNG prices (competition from US shale gas).

**CASE 2 (DG)**

- An equivalent sales price of £0.34/kWh sales price to the vicinity grid, Power to IOCs - 3 x 30 MW @ 0.45/kWh (power connection is £50 million); £0.15/kWh is the sales price to the National grid.
- 10 MW of power generated is consumed by the FGFPP.
- Natural gas price increases may be forced on OffshoreCo in an attempt to make up revenue shortfalls due to possible decrease LNG prices (competition from US shale gas).

**CASE 3 (SU)**

- An equivalent sales price of £0.21/kWh sales price to the OffshoreCo grid, Power to OffshoreCo - 1 x 30 MW @ 0.45/kWh (power connection is £25 million); £0.15/kWh is the sales price to the National grid.
- 10 MW of power generated is consumed by the FGFPP.
- Natural gas price increases may be forced on OffshoreCo in an attempt to make up revenue shortfalls due to possible decrease LNG prices (competition from US shale gas).

Note that for the three cases analyzed above, the values do not incorporate any incentives. Incentives such as Nigerian Government tax-relief and emission (carbon) credits impact the calculation of levelized cost of energy.

**Table 4.2**: Matrix for Alternative uses of electricity from FGFPP

| Alternatives | Case 1 (CPS) | Case 2 (DG) | Case 3 (SU) |
|---|---|---|---|
| Technical Feasibility | Medium | High | High |
| Strategic fit | Medium | High | High |

| | | | |
|---|---|---|---|
| Environmental and Risk Implications | Low | Low | Low |
| Economic viability | Medium | High | Medium |
| Final score | | | |
| **Remark** | Contributes to Nigeria Power demand although the payback period maybe long. | Better investment but keyed on market availability. | Contributes only to OffshoreCo. |

### 4.1.1 DISCUSSION OF RESULTS AND SELECTION

From the above analysis, the three cases on the alternative uses of the power generated are generally satisfactory on the basis of levelized cost of energy (See **Appendix B** for definition) with major influence from the sales prices of the fuel (natural gas) used and sellback rate (Power tariff) to the consumers. Case 1 is more sensitive to change in Natural gas price and this serves as a set-back to it (See **Appendix C**, **Figure C-1**). Case 2 and 3 as shown in **Figure C-2** and **Figure C-3** respectively, seem to be the most economically profitable investment with natural gas and sellback price changes still give good returns within the project life time. A short-fall to both cases is that they do not contributing to solving the Nigeria Power imbalance which is a keyed aspect the OffshoreCo had set out to address.

## 4.2 COST ESTIMATE (FGFPP + ETM)

The Float Gas-fired Power Plant (FGFPP) has an estimated capital expenditure (ball-park cost) for total construction and implementation of GBP£491 million (USD$736.5 million). The amount was reached after research and consultation with various credible suppliers and services firms.

Quotations from suppliers were taken into consideration to estimations of the project cost and updates of the quotes if any, will be covered for in future.

The project construction will be done as an integrated facility of four (4) sub-projects of major facilities. This is to enable contracts (Lump sum/fixed cost, Turn-key and cost reimbursable) to be awarded in other to meet up with the budgeted cost and start-up time set in by the OffshoreCo Senior Management and Project Management Team. The four sub-projects are as follows;

- Construction of Floating Vessel Hull (MiniFloat III).
- Construction of Gas and Steam turbine modules (Topsides).
- Construction of External Turret Mooring (ETM) system.
- Construction of Subsea Pipelines and Electricity Transmission Lines.

The contracts for the construction of Subsea Pipelines and Installation of the Subsea electricity transmission lines channel from the floating vessel to the Nigeria's National grid is awarded as lump sum/fixed price contract while the floating vessel and gas/steam turbine systems are awarded as a turn-key contract. Other activities such as hiring of consultants, semi-skilled workforce etc. will be by cost-reimbursable contracts. These options are good for the business because the contractors and suppliers will deliver on the specifications, and within the specified project period and budgeted cost. Additionally, the risks associated with these sub-projects are transferred to/shared with the third-party handlers.

- Sub-project 1: Construction of Floating Vessel Hull
  Worth: GBP£46.2 million
  Contractor: Marine Innovation & Technology
  Time frame: 18 months
- Sub-project 2: Construction of External Turret Mooring (ETM) system
  Worth: GBP£7.6 million
  Contractor: SBM.
  Time frame: 15 months
- Sub-project 3: Construction of Gas and Steam turbine modules (Topsides)
  Worth: GBP£15 million
  Contractor: GE Oil and Gas (notional)
  Time frame: 24 months
- Sub-project 4: Construction of Subsea Pipelines and Electricity Transmission Lines.

  Worth: GBP£26.9 million
  Contractor: GE Oil and Gas (notional)
  Time frame: 24 months

The Project management and Installation of sub-projects by various contractors to build the integrated facility to commissioning stage will be closely monitored by;

- Client: OffshoreCo/Contractor (Project Management Department)
  Contract type: cost reimbursable
  Worth: GBP£208.4 million
  Completion Time frame: 48 months
  Project Contingency (±40%) for the Integrated Project is already incorporated in the price.

The integrated project will be fast-tracked for the procurement of major machines (Floating Vessel's hull, gas and steam turbines, heat recovery steam generator (HRSG), heat exchangers, cool tower and pump) to meet the design quality and specification despite the schedule opted for detailed planning. The project will employ the Earn Value Management (EVM) Technique for effective Project control and decision making for program adjustment within the window period (2014 - 2017) available. In the event that restructuring and crashing the scheduling is envisaged, caution will be taken to ensure that these changes do not lead to excessive use of fund with increased effectiveness and efficiency as the option.

This project will involves working a 24-hours shift divided into 2-shifts of 12- hours per day. This is considered in order to minimize risks and operational costs in the offshore environment.

### 4.3 PROJECT EXECUTION PLAN

The project involves the set-up a commercial scale sized gas-to-power scheme which utilizes natural gas from an offshore location (Bonga field, Gulf of Guinea, Nigeria). The feasibility study carried out shows that floating gas-fired power plant with external turret system is viable and more details can be seen in **Section 3.3.1** of this study.

#### 4.3.1 SPECIFIC PROCESS WORK DESCRIPTIONS

The **Figure 4.1** below summarises the Float Gas-fired Power Plant with External Turret Mooring system (FGFPP) project work cycle. The cycle includes three (3) major phases (strategic, medium and long) and nine (9) stages involved in the project development.

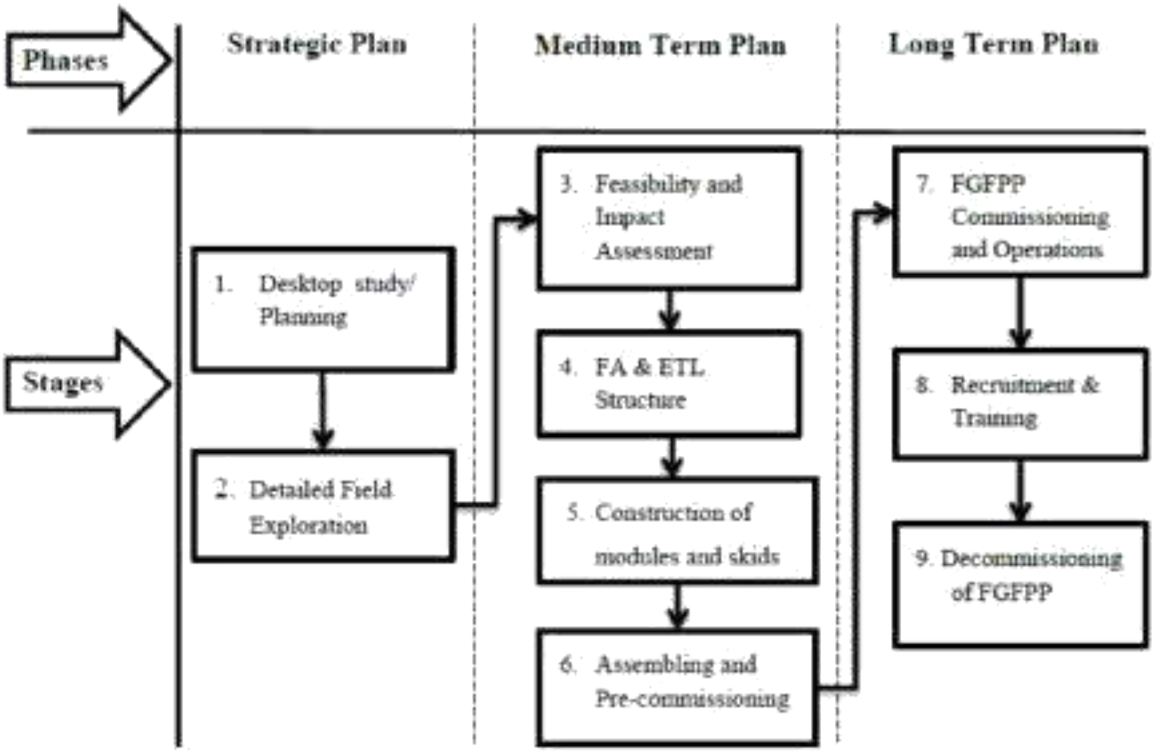


**Figure 4.1**: FGFPP Development Cycle

**PHASE 1: STRATEGIC PLAN**

**Stage 1**: Desktop Study Plan

**Scope:** This involves a desktop review and analysis of available data from the Bonga field, Gulf of Guinea, which includes the geological data, pipeline installation network, preview feasibility study and Front End Engineering Design (FEED) of the existing Bonga's FPSO, available gas to power plant technologies, current legislations on offshore operations, decommissioning and licencing activities among others.

**Output**: Produce working document, inception reports and detailed program for layout of FGFPP and ETM, subsea pipelines and transmission line network.

**Workforce:** OffshoreCo Project Research Team.

**Duration**: 4 months

**Stage 2**: Detailed Field Exploration.

**Scope:** Involve field measurements to determine the well performance of existing Bonga field for availability of natural gas, collection of samples such as soil and laboratory tests analysis. In addition, environmental studies of the proposed site will be carried out.

**Output**: A conceptual model of the FGFPP system will be created from data acquired. Pipeline and Transmission line channels to other IOCs facilities will be considered.

**Workforce:** OffshoreCo/GE Oil and Gas Project Team.

**Duration**: 6 months.

**Phase 2: Medium Term Plan**

**Stage 3**: Feasibility Study and Environmental Impact Assessment

**Scope:** Front End Engineering Design (FEED), detailed drawing and prototype design of the FGFPP with ETM components, their specifications, and material selection to suit the prevailing conditions. Identify and mitigate potential political, social and management issues; carry out environmental impact study and establish project viability through a thorough financial and economic analysis such as the thermo-economics (Exergoeconomics) of the proposed system.

**Output**: Economically viable, environmentally friendly feasibility study that is acceptable to stakeholders' investment and regulatory bodies.

**Workforce**: OffshoreCo/Contractors shall handle the feasibility study.

**Duration**: 6 months.

**Stage 4**: Fuel Availability and Electricity Transmission line Structure

**Scope:** Discussion with other IOCs in the location on the available centralized pipeline network for their unutilized natural gas.

**Output:** Obtain permission and agreement for the connection of pipeline network outlets to their facilities for their unutilized natural gas to minimise their gas flaring and exhaust gas channel for their exploration activities such as EOR, gas lifting, carbon capture and storage (CCS) etc.

**Workforce**: Contracted to Subsea7 but under the supervision of OffshoreCo/GE Oil and Gas Project Management Team

**Duration**: 24 months.

**Stage 5**: Construction of Floating vessel's hull, External Turret Mooring system, gas and steam modules

**Scope**: This shall be done by the various contractors in their respective own site location and afterwards transported through the waterway of the coast of Gulf of Guinea, Nigeria to the proposed site. Frequent Site Acceptance Test (SAT) and Factory Acceptance Test (FAT) shall be done as the construction progress at various locations to meet the specified standards.

**Output**: The contracts (Lump-sum and Turnkey) employed implies that associated construction risks of the above components is absorbed by the contractors and the estimate Sub-project cost and completion time for these facilities are not affected making the project change constant.

**Workforce**: Hyundai, SBM, OffshoreCo/GE Oil and Gas.

**Duration**: 24 months.

**Stage 6**: Assembling and Pre-commissioning of Integrated facility

**Scope**: Monitoring to ensure that modules, skids and trains of the sub-projects are delivered to site in due time and installed done in accordance to the design procedures at the proposed location. Proper documentation of each components will done for future reference to ease maintenance or/and replacement as the case maybe.

**Outcome**: modification on constructions during transition for ideal to actual state will be minimized. The percentage completion of the facility will be tracked with these proactive documentation and reporting system.

**Workforce**: All parties involved.

**Duration**: 42 months.

**Phase 3: Long Term Plan**

**Stage 7**: FGFPP Commissioning and Operations

**Scope**: This involves the start-up of the integrated facility in a systematic way to avoid any distortion such as accident which may lead to delay in operation activities. This will be done by the availability of fuel through the pipeline to its processing unit (re-gasification system) to the gas turbine, next steam turbine and afterwards to the exploration activities channels for proper disposal of exhaust fuel. The day to day running of the power plant will be run on the 24 hours and 7 days weekly basis with a well-planned schedule for regular staff members, maintenance and overhauls activities.

**Workforce**: Contractors, OffshoreCo/GE Oil and Gas.

**Duration**: Start-up to Plant active life.

**Stage 8**: Recruitment and Training of OffshoreCo staffs

**Scope**: This is a key aspect for sustainable development in the crude oil and gas sector leading to further research and developments of the sector to meet the rising energy demand of humanity. A recruitment scheme will be incorporated for training of graduate and experienced members by existing OffshoreCo and Industrial qualified and experienced staff in the various department of the OffshoreCo business.

**Workforce**: OffshoreCo Human Resources Department.

**Duration**: Yearly basis.

**Stage 9**: Decommissioning of the FGFPP facility.

**Scope**: The project is expected to be decommissioned at the end of its active life of fifteen (15) years. It is essential aspect of this investment that will not be overlooked. Further operation will be determined by the OffshoreCo Project Asset Integrity Department. Decommissioning will be done in accordance to the existing regulatory bodies such as the Nigerian's PIB, UK's OSPAR in Maritime Area and IMO guideline. Decommissioning cost will be incorporated and saved from the revenue received from inception of the Project. Other options for the re-use, re-cycle etc. of the decommissioned facility will be decided by the Decommissioning Department in future.

**Workforce**: OffshoreCo Project Asset Management and Integrity Department.

**Duration**: Plant Active Life.

### 4.3.2 FGFPP with ETM's Location

The Floating Gas-fired Power Plant (FGFPP) is an electricity generation facility position 80-kilometers from the existing offshore Bonga's FPSO in the Bonga field location at 120km southwest of the Niger Delta landfall, Gulf of Guinea, Nigeria. Refer to Table 3.4 for the FGFPP Specification and Justification.

### 4.3.3 Current Status of Project

The Project is at Phase 1 Strategic Plan, Step 1 desktop study and planning stage. Procedure for submission of proposal to the OffshoreCo Senior Management is on-going.

### 4.3.4 FGFPP's Scope

The Floating Gas-fired Power Plant (FGFPP) with External Turret Mooring System (ETM) shall be limited to electricity generation from the offshore location using natural gas made available from the Bonga's FPSO in the Bonga field and other IOC's facilities connected to the gas pipeline network. It will serve as a distribution and storage facility of liquefied natural and exhaust gas as the case maybe.

### 4.3.5 Project Programme

The Floating Gas-fired Power Plant (FGFPP) with External Turret Mooring System (ETM) project milestones are as follows;

- Front end Engineering Design (FEED) by December 2013
- Manufacturing and Construction of Modules and skids by October 2015
- Arrival and Assembling of Integrated FGFPP with ETM Facility by December 2016
- Pre-commissioning of Integrated FGFPP with ETM facility by June 2017
- Commissioning and Start-up Operation of FGFPP with ETM facility by December 2017.

### 4.3.6 Confidentiality

The Project developers (OffshoreCo) will keep confidential all disclosures made to them by patent technologies owners. Documents relating to these activities will be kept with great caution and will not be disclosed.

## 4.4 Critical Success Factors of the Project

The critical success factor of the FGFPP development is when it is demonstrating in an Incident and Injury Free (IIF) approach during the Construction and Commissioning phase of the project with the implementation of risk mitigation actions to deliver on its promise of electricity generation within the project time frame.

Also, beneficial operation of the facility with electricity supplied to the Nigeria's National grid within one month of start-up and henceforth.

# CHAPTER FIVE – CONCLUSION AND RECOMMENDATION

## 5.1 CONCLUSION

The HOMER Energy financial simulation of the floating power system concept (see HOMER results in Appendix C) paints a rosy picture of business feasibility for Case 2 and Case 3. However, this analysis is not weighed down by OffshoreCo corporate economic assumptions. For example:

- Working Capital and General Office Overhead = 5% of Sales
- Corporate Income Tax = 32%
- Nigeria Inflation Rate = 13 %

Despite this drawback, the HOMER financial simulation result is helpful in pinpointing the business case sensitivity of the project to input with high uncertainty like the natural gas price. As a consequence of this analysis, it is clear to OffshoreCo the business strategy going forward – “Win-Win”. In the “Win-Win” strategy, the floating gas-fired power plant (FGFPP) will be used as vehicle to provide offshore gas to the IOCs with the residual power channelled to the National Grid. The pricing mechanism selected is one whereby the IOCs underwrite the cost of providing power energy to the local population.

Specifically, the IOCs nominal power price of £0.23/kWh is in line with the equivalent price of offshore electricity they pay at this time. The upside potential is that the IOCs are being provided with a service at no incremental cost to themselves but at a reduced level of GHG emissions; the floating gas-fired power plant efficiency is 60% versus 30% for an IOC distributed generation system. An additional upside is that the IOCs can make use of the extra space on the FPSO (made available by decommissioning the existing power generators) to harvest more oil and gas at a faster clip using subsea boosting and gas compression technology. At the same time the local community benefit from having a power resource at a cost that is keeping with the current prevailing prices of £0.04/kWh.

There is need for further work to be done to optimize the engineering solutions mentioned in: MiniFloat III, subsea power cable. All other technologies required for this project are available off the shelf. The business case for action is clear but there are yet economic benefits that can be allocated to this project to attract the attention of potential investors.

## 5.2 RECOMMENDATIONS

The following recommendations are required to facilitate or/and sustain the Offshore Gas-fired Power Plant scheme to become a diversified power network at the Gulf of Guinea;

1. The scheme should be based on a production sharing formula with the investors and ruling government in order for economic benefits and risks involved to be adequately shared.

2. Nigeria government should implement realistic tax-relief and emissions credit incentives regulations that will encourage Investors to invest in electricity generation infrastructures in Nigeria.

3. Natural gas owned by the Nigerian government could be traded for power generation in an agreement contract between electricity generation plant owners and the Nigeria government to cushioning the effect of natural gas price fluctuation.

4. Favorable legislations regarding the Nigerian electricity generation sector should be passed especially the Multi-Year Tariff Order (MYTO) regime and implemented within considerable notices by the Nigerian government to help tackle its Power demand imbalance.

5. Issues surrounding security of water-way and security fees allocation at the Gulf of Guinea should be treated in a dialogue with the various investors at the location.

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**APPENDIX**

**APPENDIX A: POWER PLANT TECHNOLOGIES**

**1. STEAM TURBINES**

The **Figure A-1** below shows the principle for generating electricity with steam turbines. This generation station uses pulverized coal or (oil, natural gas, wood waste, nuclear fission, etc.) as a fuel to heat water in a boiler to generate steam. The high temperature, high pressure steam is piped toward turbine blades that rotate a turbine shaft, which spins a generator, where magnets within wire coils produce electricity. The steam units have a relatively low efficiency with approximately 33 – 35 per cent of the thermal energy used to generate the steam is converted into electrical energy. Large coal and nuclear steam units on the order of 500 – 1000 MW or greater are typically used to provide baseload generation, implying that they supply low-cost electricity nearly continuously. [30]

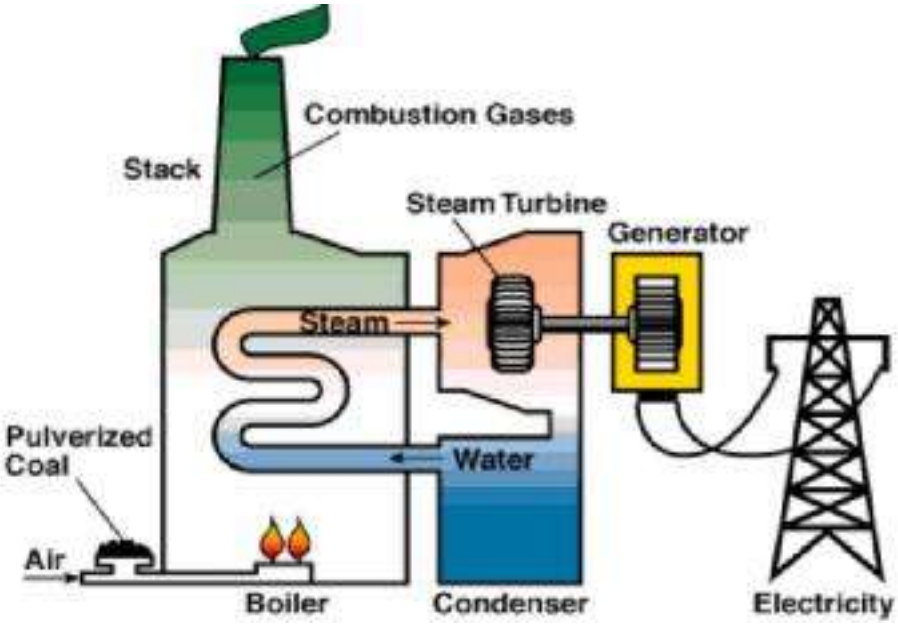



**Figure A-1:** Steam Turbine (Source: C2ES, 2013)

**2. COMBUSTION TURBINES**

This is another widespread centralized power generation technology. In a combustion turbine as shown in **Figure A-2** below, compressed air is ignited by burning fuel (diesel, natural gas, propane, kerosene, biogas, etc.) in a combustion chamber. The resulting high temperature, high velocity gas flow is directed at turbine blades that spin a turbine, which drives the air compressor and the electric power generator. Combustion turbine plants are typically operated to meet peak load demand, as they are able to be switched on relatively quickly. An additional advantage of this generator set is that, they can provide a firm backup to intermittent wind and solar on the power grid if needed. The typical size is 100 – 400 MW and their thermal efficiency is slightly higher than steam turbines at around 35 – 40 per cent. [13]

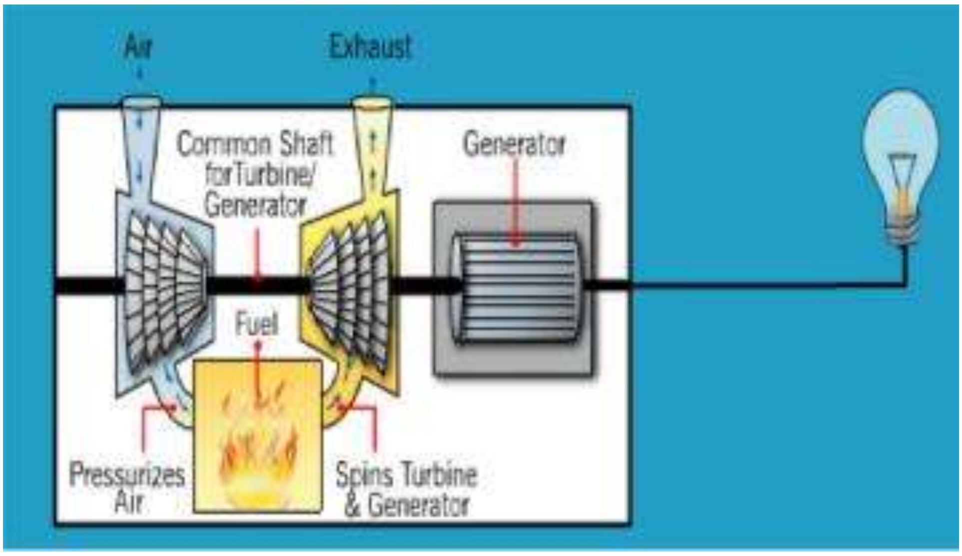



**Figure A-2**: Combustion Turbine (Source: Duke Energy, 2013)

### 3. COMBINED CYCLE

A basic combined cycle power plant combines a gas turbine and a steam unit all in one, although there are other possible configurations. As combustion turbines became more advanced in the 1950s, they began to operate at ever high temperatures, which created a significant amount of exhaust heat. The gas/steam cycle is a combination of two thermodynamic cycles, such as the Brayton cycle and Rankine cycle. A combined cycle power plant is essentially an electrical power plant in which a gas turbine and a steam turbine are used in combination to achieve greater efficiency than would be possible independently.

In **Figure A-3** below shows a conventional Combined Cycle (CC) which comprises of a compressor, external heat exchanger (combustion chamber) and gas turbine. The gas turbine drives an electrical generator while the gas exhausted is used to produce steam in a heat exchanger (called a Heat Recovery Steam Generator, HRSG) to supply a steam turbine whose output provides the means to generate more electricity. [13] The gas exhausted is sent to the HRSG to produce steam, which is expanded in a turbine. The turbine is a condensing turbine which transfers steam to a condenser where the cooling medium is the ambient. Combined cycle plants have thermal efficiencies in the range of 50 – 60 per cent. They are generally used as intermediate power plants to support higher daytime loads. However, newer plants are providing baseload support. The newest GE natural gas combined cycle power plant is advertised as a 510 MW unit with a baseload efficiency of more than 61 per cent. [25] It has reduced fuel-burn of 6.4million cubic metres of natural gas per year, and a smaller carbon footprint (12,700 metric tons of $CO_2$ per year and reduced $NO_X$ emission on the order of 10 metric tons per year). [31]

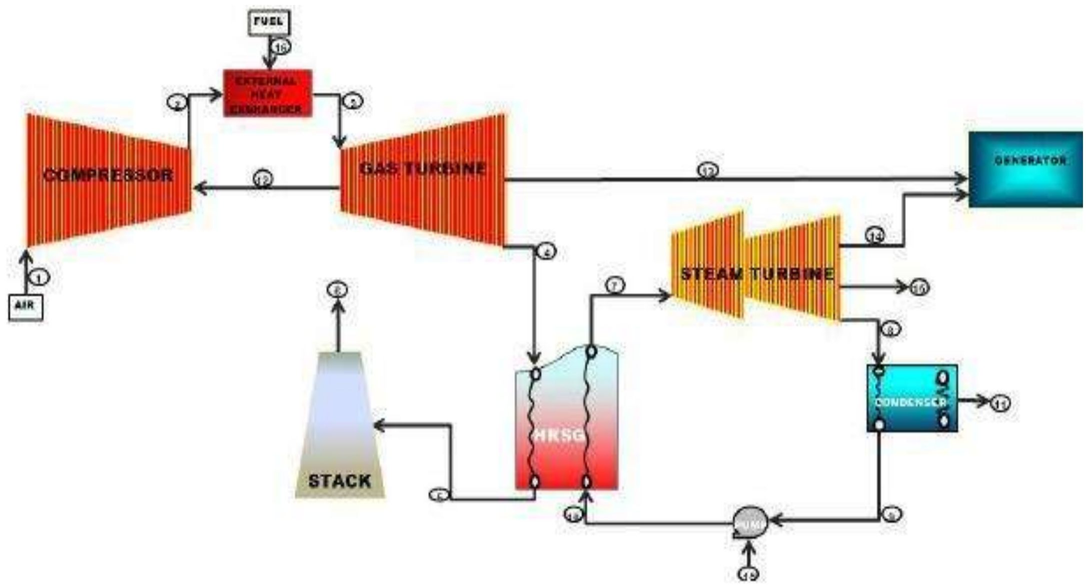



**Figure A-3**: Combined Cycle Power Plant (Source: C2ES, 2013)

**APPENDIX B: PLANT TERMINOLOGIES AND CALCULATIONS**

Some of the technical terms associated with combined cycle power plant technologies are as follows;

**Design Conditions:** The power plant is designed for a specific range of operating conditions. Natural modifications of the combined cycle power plant in terms of pressure, temperature and gas content, can alter the net output from the plant. Power factor, cooling water or ambient air temperatures (seasonal effects) are also specified design conditions, and very often the plant operates out with these parameters. The electric output will be corrected to account for the above-mentioned deviations.

**Installed Capacity** (MWe) is the reference value for the power plant set by the manufacturer as its target output when the plant is operating at its optimum design conditions. Possible reserve units should not be considered as part of the installed capacity, but may be accounted separately.

**Maximum Load (**MWe) is the highest average value over one hour during the time of investigation of the MWe output from the power plant as measured at the generator transformer supply voltage terminals, when operating at its stated design conditions or corrected to the design point conditions. It can also be called “Running Capacity” or “Maximum Net Deliverable Capacity”.

**Annual Produced Electricity:** The Annual Produced Electricity is the electricity annually generated by the power plant during the observation time (in MWh). This electric output is measured at the generator transformer supply voltage terminals.

**Gas/Steam Supply:** Gas/Steam supply is the average steam plus non-condensable gas mass flow (in t/h) delivered to the turbine and gas extraction system to enable the turbine to achieve its Maximum Load.

**Plant Efficiency or Heat rate**: is the ratio of Power generated to the Heat supplied to the Plant.

**Levelized Cost** represents the present the value of the total cost of building and operating a generating plant over an assumed financial life and duty cycle converted to equal annual payments and expressed in terms of real dollars to remove the impact of inflation it reflects overnight capital cost, fuel cost, fixed and viable O&M cost, financing costs and assumed utilization rate for each plant type. [2]

- **Planned outage** – An outage scheduled well in advance (at least two weeks) of the actual outage.
- **Forced outage -** Unplanned outage that requires the plant to be taken out of service immediately or before the next planned outage.

Due to the importance of highlighting the effects of Planned/Forced Outages, two separate availability factors must be determined, including or excluding the time lost during the planned outage with respect to the actual operating hours.

**CALCULATION**

The amount of fuel used to generate electricity depends on the efficiency or heat rate of the generator (or power plant) and the heat content of the fuel. Power plant efficiencies (heat rates) vary by types of generators, power plant emission controls, and other factors. Also, fuel content varies.

The Amount of fuel used to generate a unit of electricity can be calculated from the formula below;

( )

( )

( )

Or

( )

( )

Assumptions made for Natural gas are as follows;

- Amount of fuel used to generate one kilowatt-hour (kWh) = 0.00798Mscf (1000 standard cubic feet).
- kWh generated per Mscf (1000 standard cubic feet) of Natural gas used = 125kWh

Therefore;

Power plant heat rate for natural gas turbines is 8,152Btu/kWh

Also the Heat content is 1,021,000 Btu per Mscf.

Other useful formulas are;

( ) ( ) ( )

( ) ( ) ( )

( ) ( )

All performance indicators are dimensionless and can be expressed as per cent and annual period is **8760** hrs. The unavailability (%) of the plant (100 – availability factor). For the Software simulation, Capacity and load factor assumed was 90% and 85% respectively.

Calculation of the worth of gas flared is as follows;

Given,

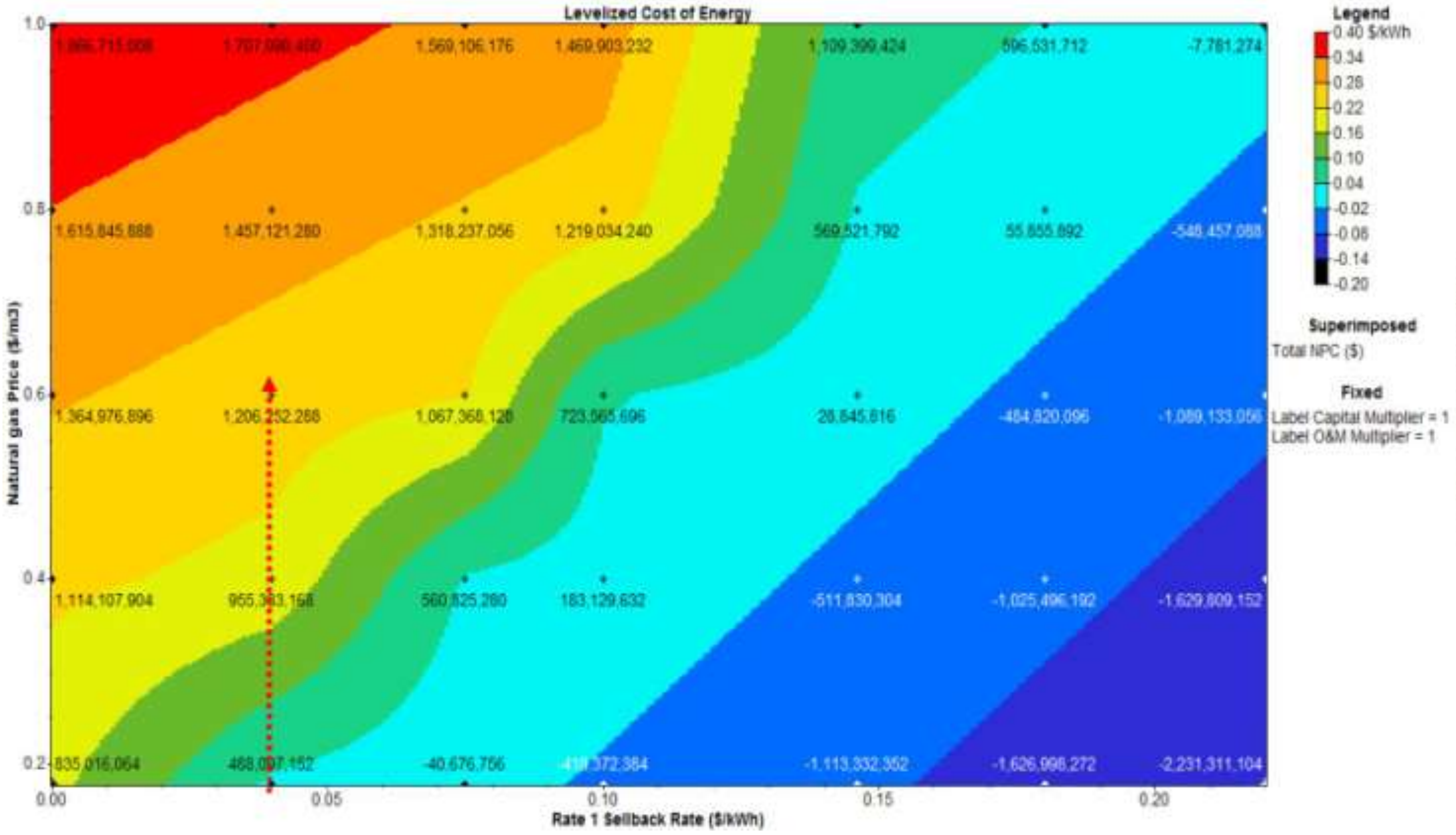
28.34 cubic meters ($m^3$) ≈ 1Mscf (1000 standard cubic feet) ≈125kWh ≈ 1.021MMBtu ≈ \$1.5 (£1) assuming inflation rate is on an average.

Volume of gas produced by the sixteen IOCs for a period of 10 years (2003 -2012) = 22.101 Tscf (Trillion standard cubic feet) [9]

Volume of gas flared by the sixteen IOCs for a period of 10 years (2003 -2012) = 7.024 Tscf (Trillion standard cubic feet) [9]

Therefore,

**APPENDIX C:** SIMULATION RESULTS FROM THE HOMER ENERGY SOFTWARE [27]



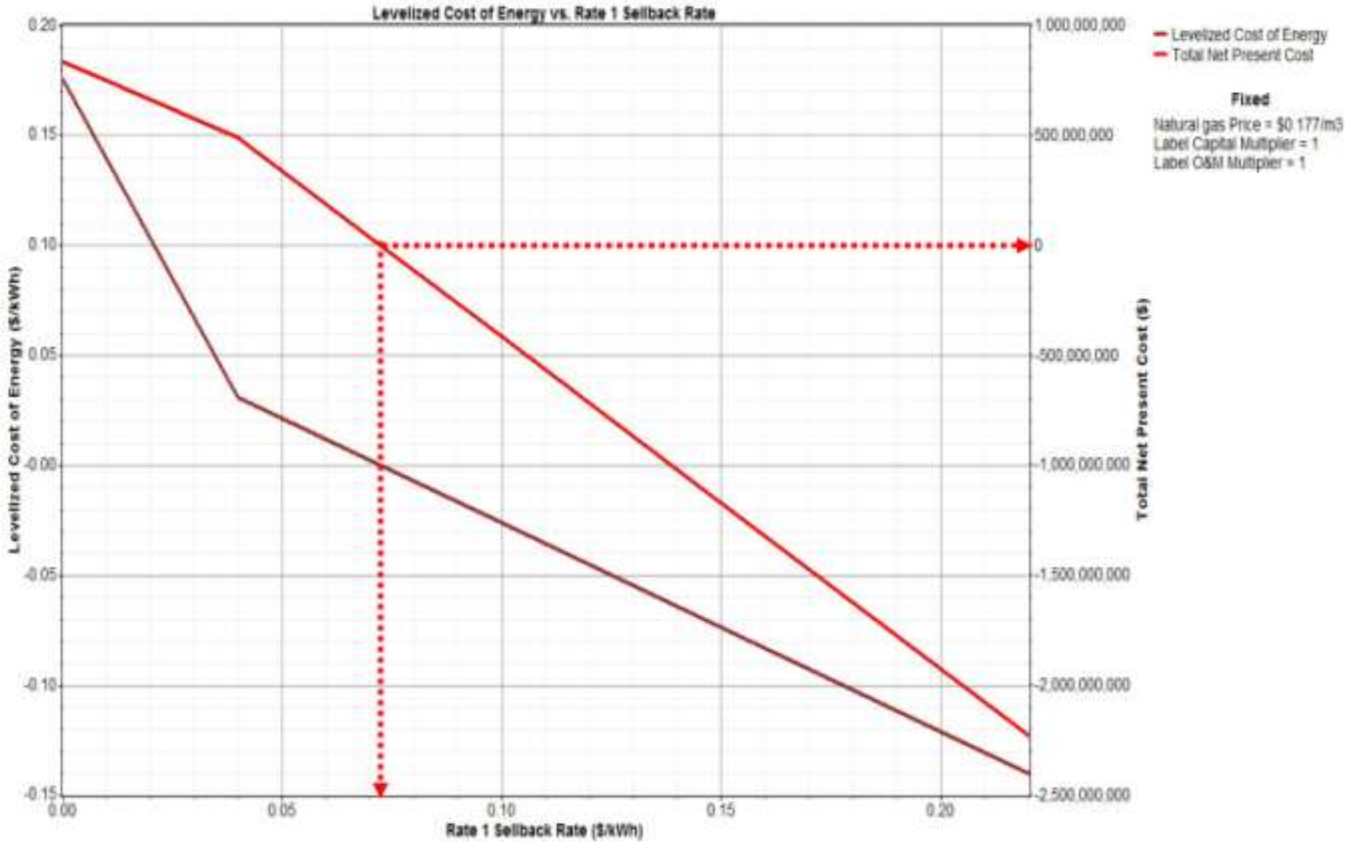
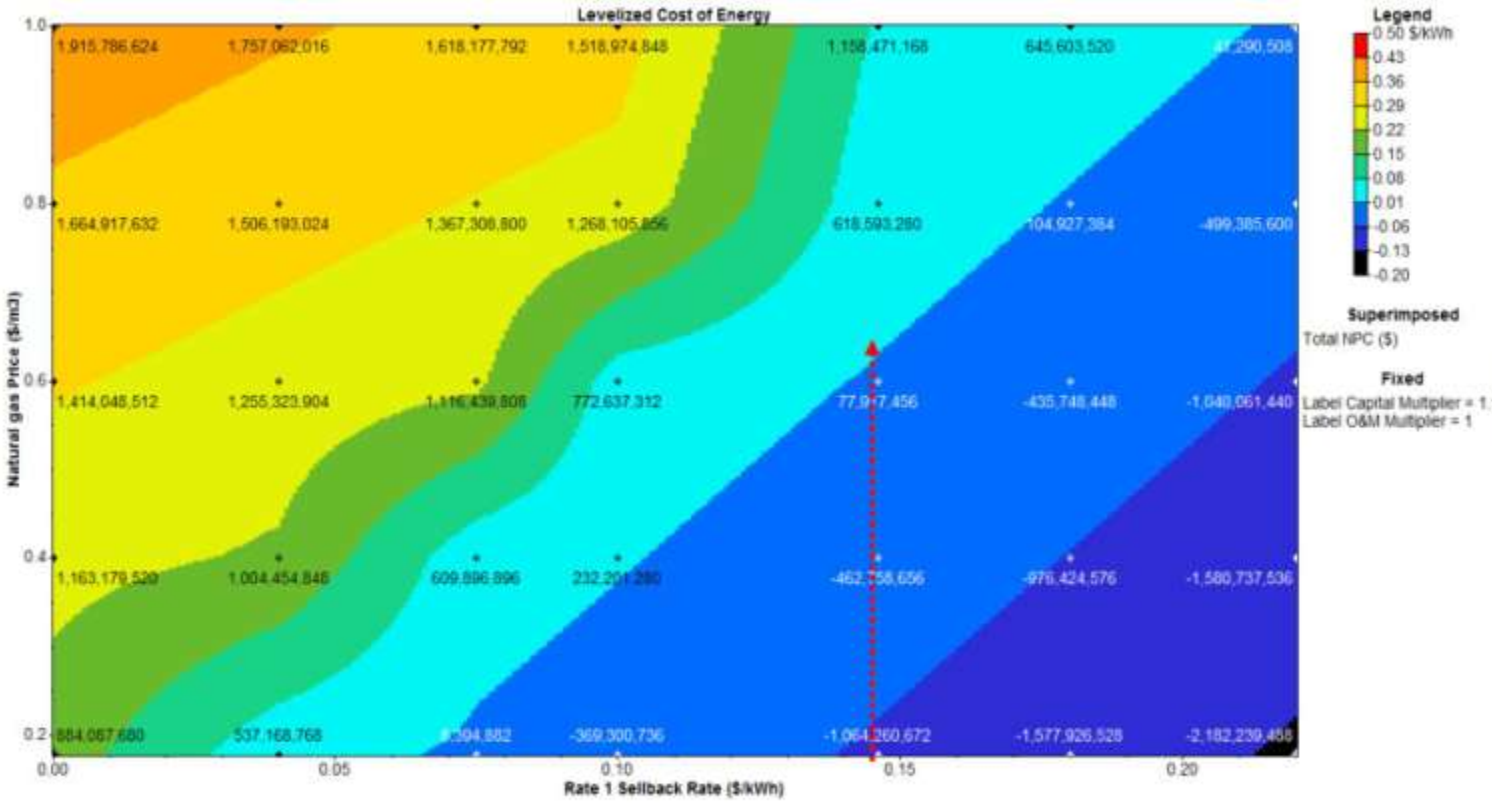




**Figure C-1:** FGFPP - Centralized Power Station for Power Transmission to Nigeria's National Grid (Case 1) NB: For the 90% probability of success case, the equivalent power sell back rate to the grid for break-even is **£0.072/kWh**



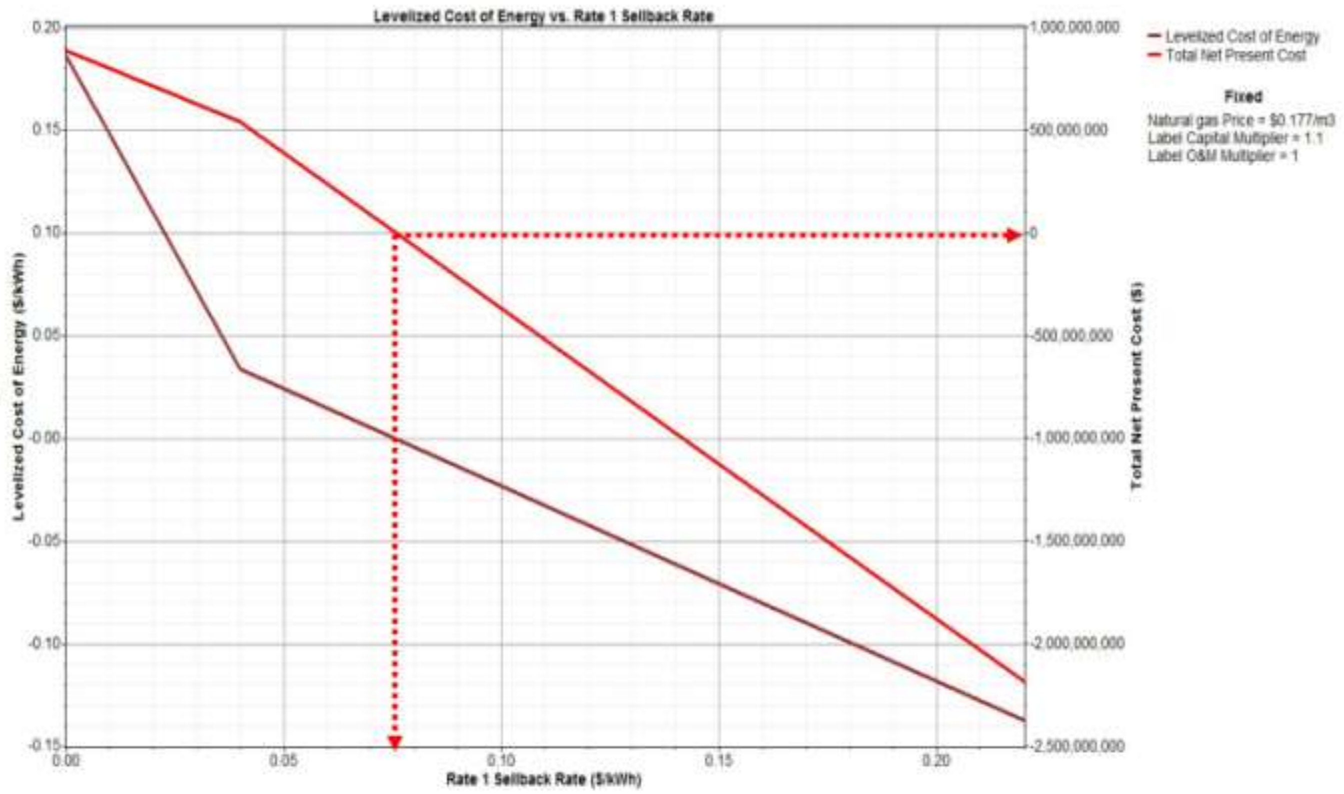
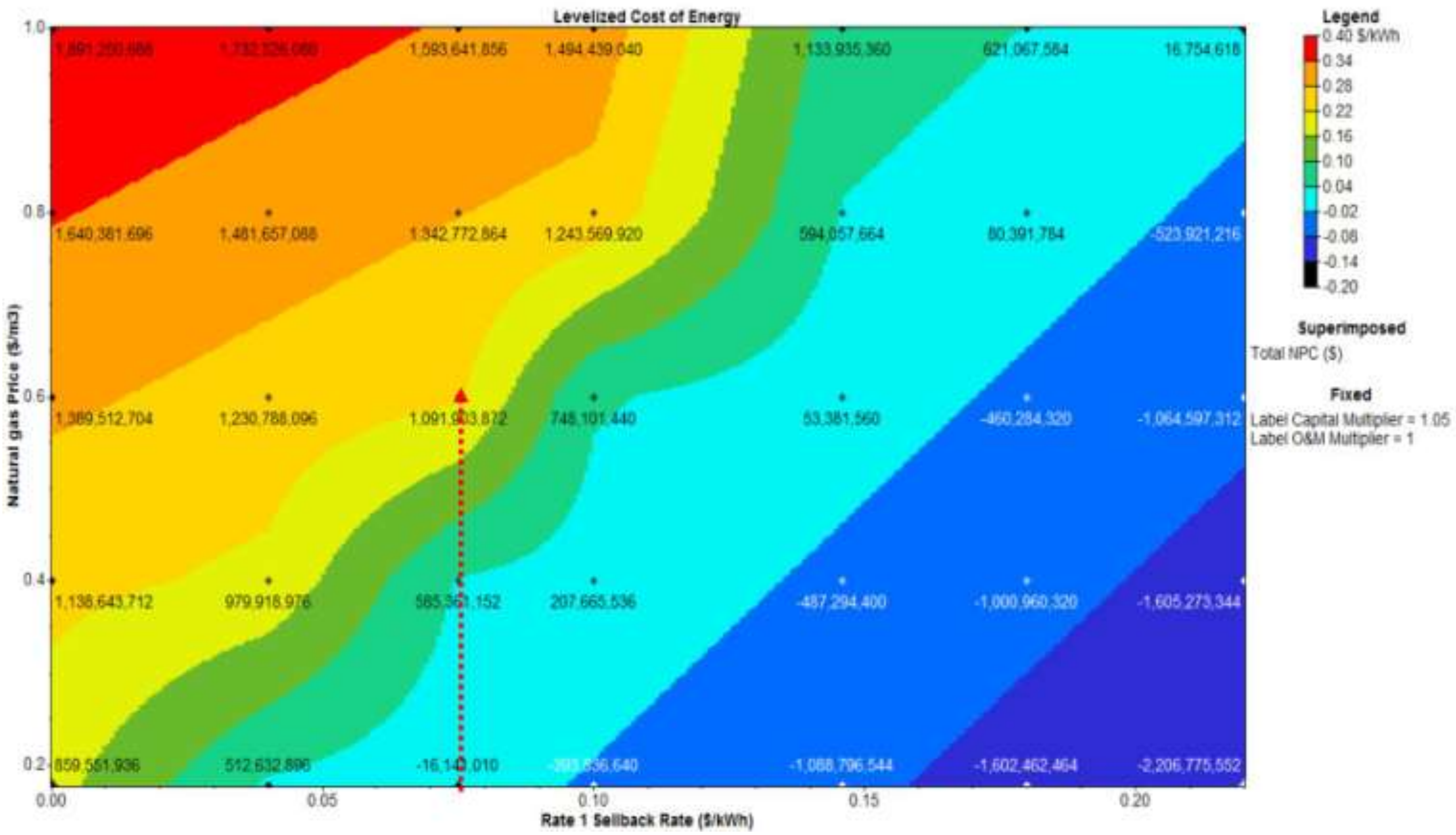



**Figure C-2**: FGFPP as a Distribution Generation to other IOCs facilities in the vicinity (Case 2) NB: For the 90% probability of success case, the equivalent power sell back rate to the grid for break-even is **£0.076/kWh**



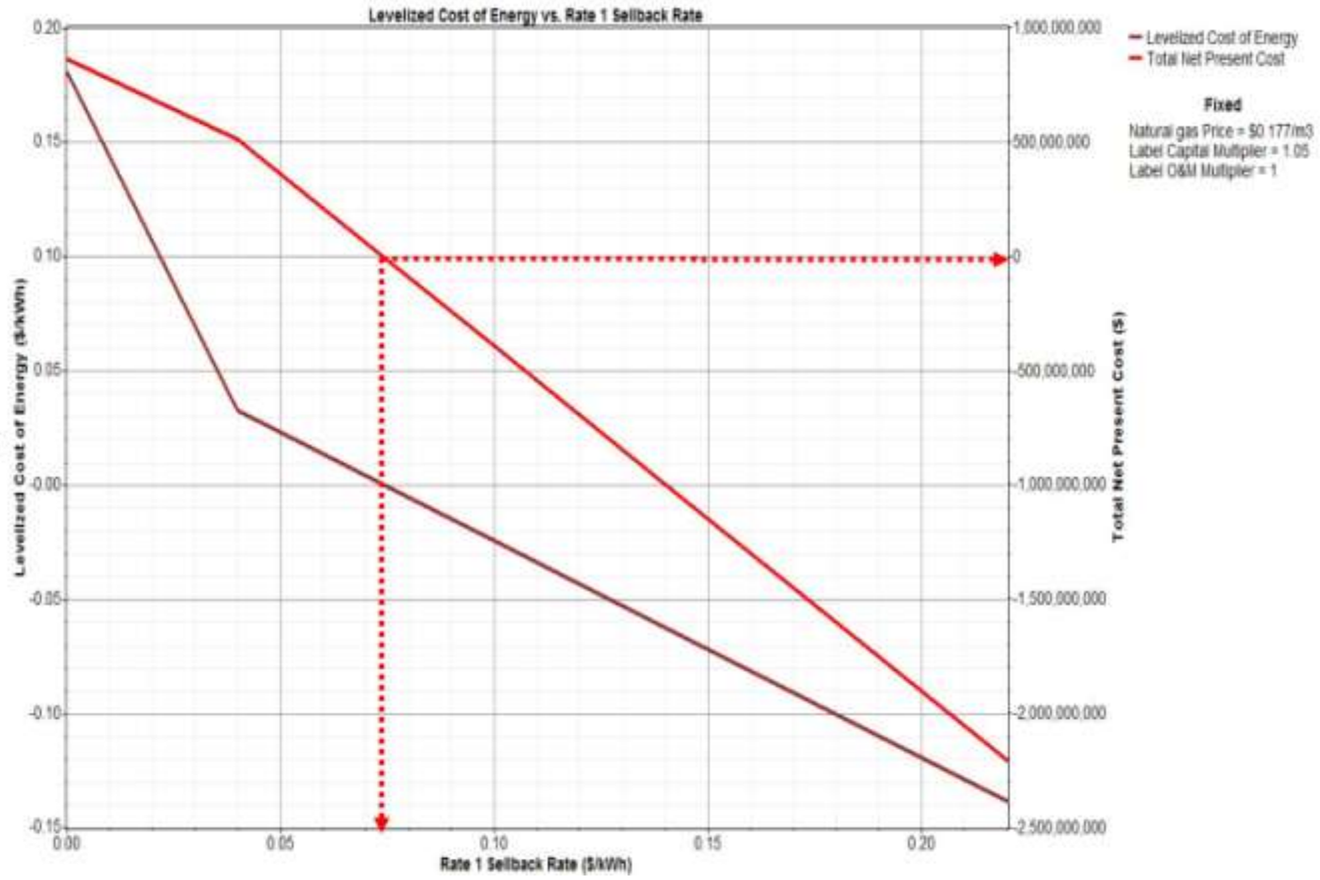




**Figure C-3**: FGFPP as a Self-Utilization - OffshoreCo Facilities (Case 3) NB: For the 90% probability of success case, the equivalent power sell back rate to the grid for break-even is **£0.073/kWh**

**NB**: **Positive (+)** values on plots implies **-NPV** and **Negative** (-) values implies **+NPV**