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Economical Utilization of Associated Gas in Nigeria

Oil production is often accompanied by associated natural gas as valuable by-product of oil processing. Large amount of this vital energy component is flared during these processes, mostly in developing countries. For a longer period of time more gas is flares in Nigeria than anywhere else in Africa and second to Russian in the world, with daily estimates of roughly 2.5 billion cubic feet. This is equivalent to around 40% of all Africa´s natural gas consumption, and annual financial loss to Nigeria is about 1.8 billion Euros. Gas flaring contributes to major environmental pollution problems, which affects oil producing areas of the Niger Delta in Nigeria. This research attempts to look into the environmental issues in the region and proposes possible solutions, with recommendations that will contribute to improve associated gas utilization. This study describes gas to liquid (GTL) conversion technology as a sustainable option to utilize associated gas in Nigeria, and also evaluates the economic attractiveness of the process. This conversion technology could contribute to total elimination of gas flaring and reduces the overdependence on importation of refined products (petrol, diesel and kerosene) from foreign countries into Nigeria.

Keywords: *associated natural gas, gas utilization, gas to liquid technology, Fischer Tropsch Synthesis, market analysis*

1. Introduction

Gas flaring is the burning of associated natural gas during oil production. More often than not, natural gas is associated with crude oil and this presents operational risks during exploration and processing. To prevent these risks, additional infrastructure needs to be set up to collect the associated gases and safely dispose them or put to use. These processes present financial challenges to so many oil exploration exercises, chemical plants and refineries, and as such have found a way to dispose these gases by burning them off. This flaring process of gas disposal occurs in almost all the nine southern oil exploration states of Nigeria and as a result, it poses a huge environmental, health and resource management problems.

The gas released during this exploration processes is known as associated gas (AG). This gas is found in association with oils is either in dissolved form or as a cap of free gas above the oil. Drilling companies routinely flare or vent this gas for safety reasons or as an unwanted by-product of oil production. There is a substantial reduction of gas flaring in developed countries, partly due to the ever increasing demand and prices of natural gas and the discovery of AG's in many uses.

According to the World Bank estimates (2009), it shows that more than 100 billion m^3 of AG are flared or vented worldwide annually, and Africa´s contribute to about 37 billion m^3. More gas is flared in Nigeria and Russian than anywhere in the world (EIA, 2009). According to Bassey (2008) Nigeria currently flares over 23 billion m^3 of gas annually and this can be used to produce 100 terawatts of electricity which is equivalent to 25 % of the current power demands of Africa.

In 2009 World Bank estimated Nigerian flaring to be 75 percent of total gas production, which amounts to 70 metric tonnes (Mt) of carbon dioxide emission. In line with this, Nigeria contributes a measurable percentage of the world´s total emissions of greenhouse gases (GHGs). Due to low efficiency or poor effectiveness much of this gas is released as methane which has a high warming potential.

All the major oil companies in Nigeria, principally the Shell petroleum development company (SPDC), and American oil companies (Chevron and Exxon Mobil) contribute to gas flaring.

The global share of flared gas in total gas output varies among the main oil and gas producing countries. A study conducted by the National Geophysical Data Centre (NOAA, 2008) suggests that, Russia is number one in terms of gas flaring with an estimated flared gas of 40.6 billion m^3. Nigeria ranks as second with 15.1 billion m^3 followed by Iran. In fact, these three countries accounts for more than one third of global gas flaring.

However, this product that was traditionally disposed could potentially bring economic benefits to the society, and improve poor standard of living, most especially in Nigeria which among the poorest countries in the world today. The gross monetary value of wasted gas in Nigeria is estimated to be around 2.5billion US$ per year to the economy, amounting to 50billion US$ over 20 years (Unicef, 2010). Apart from economical advantage, maximum utilization of AG could reduce the environmental effect of GHGs emissions.

Currently there are three main categories of projects to minimize continuous flaring or venting of associated gas in Nigeria and each of these have different characteristics. There is a project to re-inject associated gas, particularly in remote fields without marketing it. Secondly, there is a project for the conversion or use of AG for energy purposes, at the production site or after the gas is transported to the domestic or international markets. Lastly, where flaring cannot be avoided, there is a project to increase the efficiency of flares, resulting in a greater percentage of the AG being burned rather than simply ventilated that causes substantial environmental damage.

There are many technologies available for the successful implementation of each of the above stated AG projects. The type of AG minimization project dictates the type of technology to be adopted. Each one of them has advantages and disadvantages. For the purposes of eradicating gas flaring in Nigeria, this study has adopted gas to liquid technology.

2. Gas to liquid technology (GTL)

The term gas to liquid refers to a promising way of converting stranded AG to synthetic oil, which can be processed further into fuels and hydrocarbons based products. Conversion of AG to synthetic fuel has attracted more attention in some countries because of the economic and environmental benefits derive from it. The main distinguishing advantage of this technology is that it can use existing infrastructure. The products can be stored, handled, transported and sold through conventional methods that are already well established and can also use established equipments for conversion, such as internal combustion engines. In the most basic configuration, without the last upgrade step of the process, the final product can even be transported along with the oil produced by the same field (Branco et al, 2009).

GTL technology was first invented by two German scientists, Franz Fischer and Hans Tropsch in 1923. The technology is based on catalytic conversion of carbon monoxide (CO) and hydrogen (H) into synthesis gas; it was further developed in 1925 by converting this synthesis gas in laboratory to oxygenated products and liquid hydrocarbon (Stanley, 2009). The process tears natural gas molecules apart and reassembles them into longer chains hydrocarbon. This conversion is carried out on a surface of catalysts such as cobalt, nickel, or iron through a technology known as Fischer–Tropsch (FT) synthesis (Bao et al, 2010). Almost all GTL processes today are still based on this technology (see Figure 1).

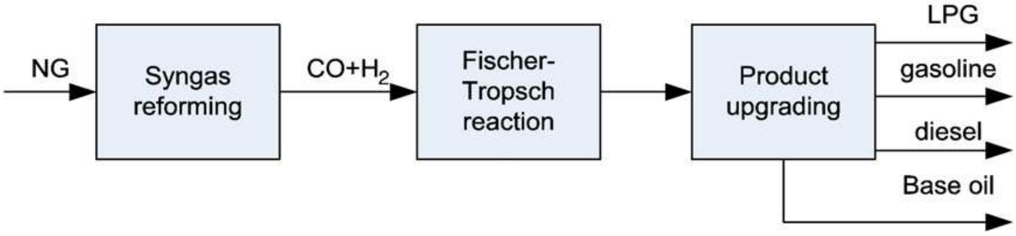

Figure 1. Fischer-Tropsch GTL process (Source: Bao, et al., 2010)

3. GTL Chemistry

The complete process for conversion of natural gas to liquid fuels can be divided into three stages, and each consists of different processes (as illustrated in 1). The first step is production of synthetic gas, a mixture of predominantly CO, and H_2. This process can be carried out without the use of any catalyst, but it was found that the use of a catalyst like Nickel, iron, or Cobalt can improve the quality of production (Al-Shalchi, 2006). Synthesis gas is generally produced from natural gas by one of these three established processes.

a). Partial oxidation (POX): In this process, natural gas reacts with pure oxygen in an open flame at a temperature of 1200-1500^oC. The process is called catalytic partial oxidation because catalysts increased the productivity of the technology per unit volume. The gas phase of H_2 to CO ration in this process is 2:1 (H_2/CO). The chemical equation that represents the process is shown in equation 1.

$$CH_4 + 1/2\ O_2 \longrightarrow CO + 2H_2 \quad (1)$$

b). Steam reforming (SR): The process converts natural gas (methane) with steam on a nickel catalyst at temperature between 800-1000^oC and atmospheric pressure of 30 to a hydrogen rich synthesis gas. It does not require oxygen and high temperature to produce H_2 and CO_2 (see equation 2).

$$CH_4 + H_2O \longrightarrow CO + 3H_2 \quad (2)$$

c). Autothermal reforming (ATR): This process is a combination of steam reforming and partial oxidation process in a single step. ATR is also known as endothermic syngas reforming reactions. The benefits are; lower reaction temperature, lower oxygen assumption, and has most favourable ratio of H_2/CO for cobalt base catalyst, which is suited for the FT synthesis. The main reactions occurring in the ATR process express in equations 3, 4 and 5.

$$CH_4 + 1/2\ O_2 \longrightarrow CO + 2H_2 \quad (3)$$

$$CH_4 + H_2O \longrightarrow CO + 3H_2 \quad (4)$$

$$CO + H_2O \longrightarrow H_2 + CO_2 \quad (5)$$

3.1. Fischer Tropsch reaction

The second step is FT reaction, where syngas (CO and H_2) gases pass through the reactor. There are two types of reactor used, moving bed and fixed bed reactor. Moving bed reactors recycle part of the products from reaction through outside tubes to assist the internal cooling system (Bao et al, 2010), while fixed bed reactors place catalyst inside the tubes for surface reaction to take place. The temperature applied can either be low or high. The high temperature range between 300 and 330^oC and low temperature is between 200 and 230^oC (Al-Shalchi, 2006). The FT reaction is very high exothermic, and thus influencing the efficiency of the whole process. The equation 6 expresses the kinetic behaviour of the process.

$$2nH_2 + nCO \longrightarrow C_nH_{2n} + nH_2O \quad (6)$$

3.2. Product upgrading

Lastly, the product obtained is upgrading to make suitable fuels like gasoline, kerosene, and diesel. The percentage of these products depends on the technology employed, nature of catalyst, conditions of reaction used and other chemical factors. Figure 2 shows the representation of the base case of GTL flow sheet.

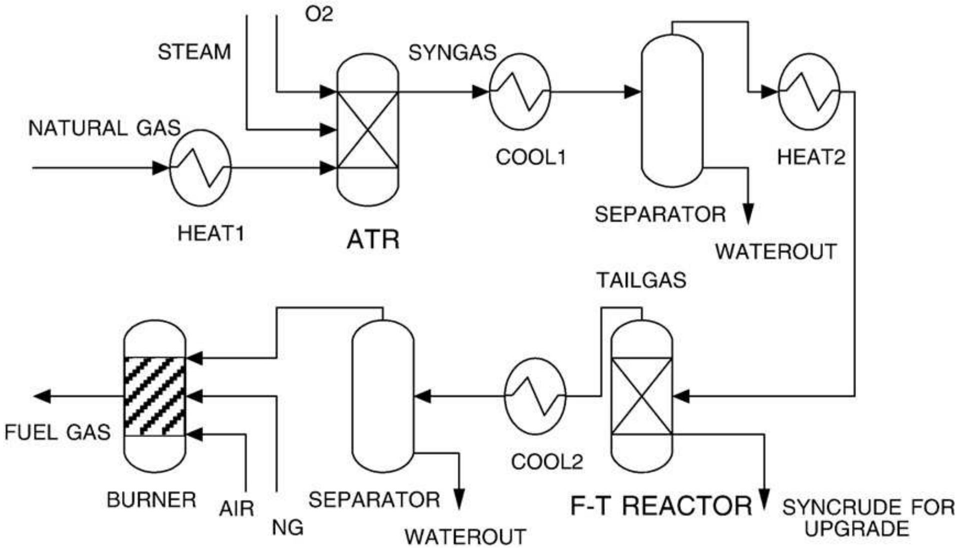

Figure 2. Overall representation of Fischer-Tropsch flowsheet (Source: Bao et al, 2009)

4. GTL and the environment

One of the best solutions to the problem of environmental pollution caused by gas flaring is to adopt the GTL technology (Al-Shalchi, 2006). This can put an end to flaring of the associated natural gas completely in Nigeria, by simply industrialize this gas and change it into valuable liquid fuels, or products used as feedstock by other industries. Products of the GTL technology can also be used in blending the refineries products to improve the output specifications. As described in Figure 3, mixing of GTL diesel product with refinery diesel can reduce the emission of sulphur into the environment. These options could satisfy the hard constrains which most countries are facing in order to protect the environment and human health.

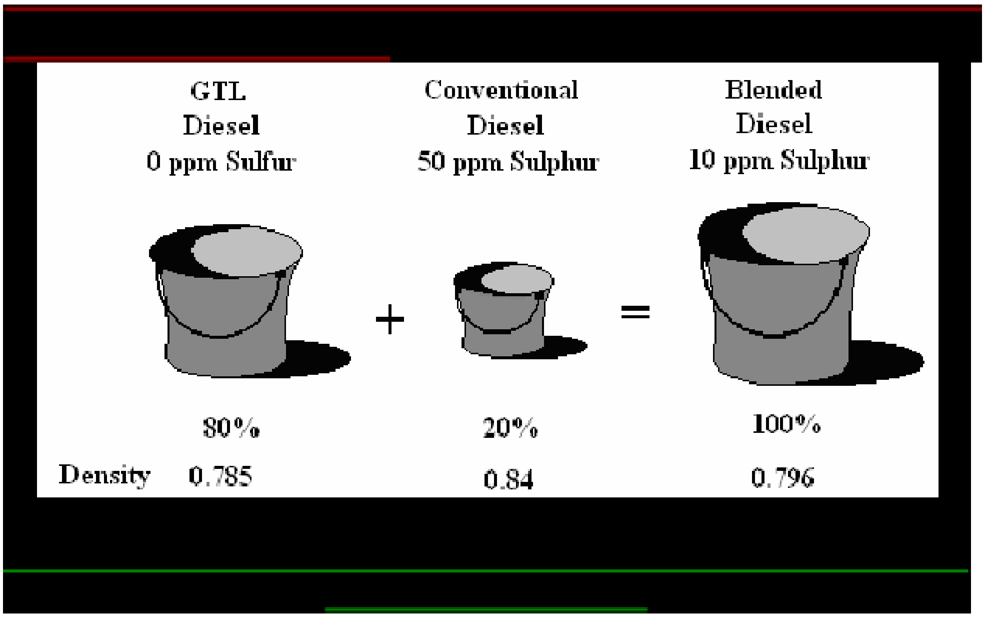

Figure 3. Blended product of conventional diesel and GTL diesel (Source: Al-Shachi, 2006)

The differences between the specifications of the diesel product from the GTL technology and product from the petroleum refineries are shown in table 1. This is based on tight stipulation of the European and American government's standard.

Table 1. Comparisons of various countries diesel specification and GTL diesel

Specifications	EU diesel	US diesel	GTL diesel
Sulphur max (ppm)	50	15	0
Density (kg/m^3)	820-845	876	790
Cetane number	51	40	>70
Poly Aromatic max (wt%)	11-2	N/A	0
Distillation max (^{o}C)	340-360	338	340
Cloud point (^{o}C)	0	0	-15

5. Reduction in CO_2 emission

For an accurate comparison of all alternatives considered in combating flaring and reducing effect to the environment, Branco et al (2009) applied some equation to estimate emission of refinery unit and GTL plant. Equation 7 can be used to estimate flare emissions (EM_{flare}) as a result of burning of AG instead of venting:

$$EM_{flare} (tCO_2/m^3_{of\ NG}) = F \times (\eta_{flare} (\%) + 1 - \eta_{flare}(\%) \times GWP_{CH4}) \times P_{CH4}(\%) \quad (7)$$

Where:

$F = V_{NG} (m^3) \times LHV_{NG} (kj/m3) \times$ Emission factor (EF_{CO2} in tCO_2/TJ) $\times 10^{-9}$

LHV_{NG} = Lower heating value

EM_{flare} = Emissions of flare

P_{CH4} = Percentage of CH_4 in the NG

GWP_{CH4} = Global warming potential of CH_4 for 100 years on a mass basis

V_{NG} = Volume of NG

η_{flare} = Efficiency of flare

Reduction of emissions of CO_2 could be obtained by converting the gas flare to other useful product. The CO_2 emission from GTL plant (EM_{GTL}) can be calculated by using equation 8, for each m^3 of natural gas consumed.

$$EM_{GTL} (tCO_2/m^3_{of\ NG}) = EF_{NG} (tCO_2/m^3) \times \eta_{GTL} \quad (8)$$

The efficiency of GTL plant (η_{GTL}) is described in equation 9. To increase efficiency means more products output and decrease in fuel consumption and feedstock.

$$\eta_{GTL} = \text{Energy of syncrude } (MJ/m^3_{of\ syncrude})/\text{Energy of natural gas } (MJ/m^3_{of\ NG}) \quad (9)$$

Assuming a GTL plant of natural gas consumption of 1,780m^3 (74,005MJ NG) is to produce 1m^3 of synthetic crude. The volume of Syncrude contains an equivalent of 37,325MJ.

$\eta_{GTL} = 0.50$, this shows consumption is approximately 50% of energy from natural gas to produce syncrude.

Research conducted by Branco et al (2009), estimated that total emissions from GTL plant of capital cost of US$ 127,000,000 is 0.001258811 tCO_2 during one year. This reduces the emissions during flaring up to 40%.

6. Possibility of using GTL technology in Nigeria

GTL plants are perfectly suited for natural gas rich countries, especially where the reserves are underutilised or where large amounts of AG are flared during conventional oil production. Gas flaring in Nigeria was reduced from roughly 49.8% in 2000 to fewer than 26% in 2006 (NNPC, 2009). This was accomplished through increase use of AG locally. GTL will permit development which could lead to complete eradication of flaring in Nigeria and this can easily be achieved by improved technology to use stranded gas in remote gas fields. Most of the Nigerian gas fields, whether produce associated or non-associated, are in remote fields. Remote or stranded gases are best process and commercialise with GTL technology. These conditions can make it easy to invest in GTL technology because of sufficient feedstock gas to the plant. Two projects have been approved by the government to converts Nigerian AG into liquid fuels. The first plant is located in southeast of Lagos, own by South Africa company (Sasol limited) and Chevron. This project started 2005 and expects to be in operation by the year 2012. The second project which is supposed to be located in Olokola, western Nigeria is still under evaluation.

This development will increase the oil revenue of the country, as well as protect the local and the global environment. It will also go a long way to reduce the electrical power problem of the country and increase middle petroleum products. Burning of huge quantities of AG is due to lack of the treatment facilities and this behaviour is expected to continue for the next years, if possible technology suitable is not applied.

Nigeria is suffering from very big shortages in electrical power generation and delivery. This shortage is due to several reasons, political and technical. A considerable percentage of electrical power currently generated in Nigeria is produced by burning various liquid fuels including diesel oils, heavy and residual oil. This dependence on liquid fuels for power generation results in loss of oil exports and source of revenue. The rising electrical demand in Nigeria will create pressure on the electric production, transmission capacity, and fuel production and delivery infrastructure. For this reason GTL diesel is being considered for use in new electric power generation. Electricity generation sector is expected to rise in production in the nearest future. There are also shortages and delivery problems of products throughout the country. Production of liquid fuel through GTL will also make easy transport and prompt delivery of products.

6.1. Potential market of GTL

Presently, Nigeria is suffering from huge shortages in the production of petroleum products, especially the light and middle distillates. These shortages are due to the low production capacity of the old fashioned petroleum refineries. Nigeria needs at least 695,000bbl/d of light and middle distillates to balance present local consumption of liquid fuels, while all the local refineries produce less than 380,000bbl/d. The differences in local consumption could be covered in several ways like importing, building at least two new big oil refiners, or investing in natural gas by building GTL project.

Unlike liquefied natural gas (LNG), GTL products are sold on the spot market. It does not require long term sales and purchase agreements. Currently, GTL has a very small market share in Nigeria, but the market potential for GTL products can essentially be considered unlimited. Given the superior quality and marketability, it is perhaps only a matter of time before GTL production becomes a formidable industry (Stanley, 2009). It can be achieved without the cost of modifying vehicle or installing much new infrastructures.

7. Process challenges and cost of GTL plants

In most optimization activities the focus is always on the question of capital and operating costs. Capital investment for installation of a GTL plant is a limiting factor, though the operating costs are coming down steadily (Al-Shachi, 2006). GTL plant is only economical when the cost of products from syngas is lower or equal to crude oil refining products. Studies conducted in different operating company's shows that capital cost is the main dominant of GTL plants (see Figure 4); feed and operating costs also constitute an important portion.

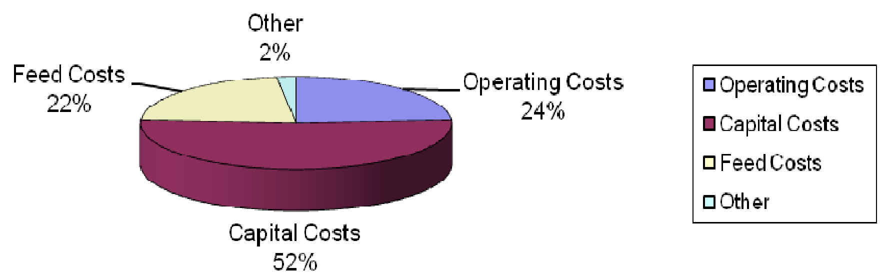

Figure 4. Typical GTL plant cash flow (Source: Al-Shachi, 2006)

The capital cost for project with plant capacity of 30,000bbl/d is between \$30,000 and 20,000bbl/d. As stated in Stanley (2009), the costs of Sasol´s GTL plant in Qatar were estimated to be between \$20,000 and \$25,000. Presently, this cost is almost double compare to refinery project of the same capacity. According to Salomon (1998), he suggested that there is high possibility to lower or reduce the cost of GTL plant to less than \$13,000bbl/d (sited in Stanley, 2009). With these, more research and development in GTL technology is very likely to downtrend the overall capital expenditure in future.

The cost improvement defined in Roberts report (1999) is fully and adequately incorporated into this study. Due to immature nature of the investment in Nigeria, the analysis made some assumption on the improvement cost of GTL. This will not reflect exact economic information of GTL project in Nigeria. It only based on credible information of existing projects around the world. Cost of improvement can be described mathematically by the equation 10 below.

$$C_n = C_1 n^b \quad (10)$$

C_n = cost of the nth unit
C_1 = cost of the first unit
n = number of unit being estimated
b = exponent equal to the log of improvement curve rate divided by log of 2
b = ln 0.738/ln2.0 = -0.438 (cost improvement rate for organic chemical is 73.8% and GTL processes are included in organic chemical production industry).

Assumed the capital cost of first plant is $25,000 bbl/d, the cost for the second plant of equal capacity would reduce to $18,450bbl/d, according to equation 10.

$C_n = 25,000 * 2^{-0.4383}$

The return on investment on GTL is highly linked to the proximity of market and depends on project locations. According to Usman (2007), the average GTL products price is between $12 and $30 (Diesel- $30/bbl, Naphtha- $25, LPG-$12). In most cases, this price remains constant for several years. Revenue from GTL is based on selling price of each product produced. The return on investment (ROI) is calculated as follow:

ROI = profit/total annual cost x 100%

Payback period of investment can be determined from:
Fixed capital investment (F_{ic}) *divided by annual cash flow* (A_{cf}) after tax (F_{ic}/A_{cf}).

To determine GTL investment, one of the most important aspects is internal rate of return and economic evaluation. The performance and return cost of GTL plants considered in this study have been identified and found to be successful in previous investigations and research (e.g., Bao, 2010; Stanley, 2009). Assuming that the investment cost of GTL plants is 10.8 billion dollars, total production income is 4.3 billion and price per gallon is 2.09 billion.

ROI = 4.3 - 2.09/10.8 *100% = 20%

The process is profitable and strongly dependent on the plant capacity, the increase in size of the plant also increases the profit. Based on past research, the payback period of GTL technology in Nigeria is highly appreciable. From this study, the proposed Escravos GTL plant that will soon be on stream in Niger Delta region seems to be financially viable and economically attainable. Summary of some existing commercial development of GTL applications are listed in table 2.

Table 2. GTL existing technology

Plant	Syngas	Fischer-Tropsch	Catalyst	Capacity (bbl/d)
Shell (Malaysia)	ATR (O_2)	Slurry phase	Fe, Co	50,000
Sasol (South Africa)	POX (O_2)	Fixed bed	Co	120,000
Mobil (Qatar)	ATR (O_2)	Slurry phase	Co	>50,000
Syntroleum (Australia)	ATR (air)	Fixed bed	Co	<10,000
Rentech (USA)	SR	Fixed bed, Slurry	Fe	<5,000

Source: Abdel-Kreem et al, 2009

7. Future of GTL industry in Nigeria

This technology would appear to be a viable and alternative future promising solution to eradicate gas flaring in Nigeria and clearer energy. It is also committed to sustainable fuels. The major natural gas project in Nigeria is LNG, with introduction of GTL industry will provides another means of producing nations diversify gas resources beyond gas market. GTL development by finding an innovative ways of meeting future social and environmental friendly will attract more investment than LNG because of its many products output and provide more occupational and economic benefits

For this technology to work in Nigeria, it will also give commercial application to coal gasification. This is another route to produce syngas through GTL technology. Figure 5 illustrate how syngas produce from three source, though coal to fuels is not presently economical attractive (example is Sasol plant in South Africa). With time, it will become commercially viable and provide opportunities to promote local growth especially in Nigeria that have abundant coal resources.

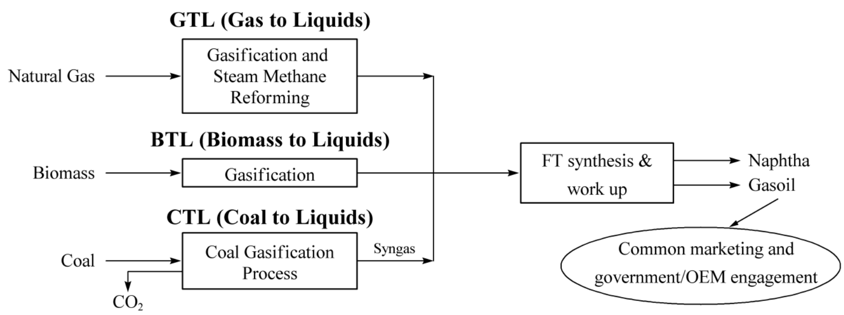

Figure 5. Potential routes to clean fuels based on FT technology (Source: Idrus and Heng, 2004).

8. Conclusion

In this research work, it has been observed that Nigeria has adequate reserves of associated and non-associated gas for the development of the country. Despite the relatively large reserve of this resource, environmental consequences response is weak and has yielded poor results. Gas flaring through the production of oil and gas has brought multiple environmental effects and limited economic growth to Nigeria. Basically, the government has failed to ensure that the companies comply with regulations meant to promote sustainable economic development and suitable environment. The situation has worsened by the lack of effective political leadership to address the problem.

There are strong indications that the implementation and effects of government regulations to abate gas glaring completely is still suspect. Supplementary effort needs to be done to turn down the gas flare burning stack in Nigeria. Though, various commitments and attempts have been made to phase out the practice since 1969. Some of it requires re-injection of AG, export as LNG, domestic consumption for electricity generation and other industrial use purposes of natural gas are existing project in the country. However, flaring remained unabated because of few utilization of AG. Most of the existing projects rely on non-associated gas while unused AG is flared.

The evidence from these research findings show that, Nigerian government should not expect total elimination of gas flaring and venting until the successful creation of AG utilization that would be beneficial to local consumption. And would possibly help to preserve an energy resource that is currently being lost and improve environmental challenges.

This study has discovered that the ability to eradicate AG flares and put an end to the process lies in the Fischer-Tropsch based technology. This will transform the burden of stranded AG into valuable resource to improve the environment and increases the country´s revenues. GTL process is a well proven technology that can use existing infrastructure without additional investment. The products specifications comply with the present and future tight standards which of the same standard that legalized by global regulation to protect environment, and the public health.

GTL industry does not affect the established or existing industries for gas processing, it should be seen as opportunity to produce different products that are easier to handle, export and more widely used locally. It is an option for moving stranded AG to market place and help in resolving the problem of shortages of petroleum products suffered by Nigerian refineries. Subsequently expansion of GTL processes would lead to cost saving. It can be clearly concluded that except gas utilization projects in the country are totally engaged in AG usage, all the projects are bound to suffer the same environmental concern. Investment in GTL could contribute to a substantial reduction of gas flaring).

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