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Monetization of Nigeria Coal by Conversion to Hydrocarbon Fuels through Fischer-Tropsch Process

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Abstract *Given the instability of crude oil prices and the disruptions in crude oil supply chains, this article offers a complementing investment proposal through diversification of Nigeria's energy source and dependence. Therefore, the following issues were examined and reported: A comparative survey of coal and hydrocarbon reserve bases in Nigeria was undertaken and presented. An excursion into the economic, environmental, and technological justifications for the proposed diversification and roll-back to coal-based resource was also undertaken and presented. The technology available for coal beneficiation for environmental pollution control was reviewed and reported. The Fischer-Tropsch synthesis bothering on the process chemistry and its advances into Sasol's slurry phase distillate process (sspdp) was reviewed. Specifically, the adoption of Sasol's advanced synthol process (sasp) and the slurry phase distillate process were recommended as ways of processing the products of coal gasification. The article concludes by discussing all the above-mentioned issues with regard to value addition as a means of wealth creation and investment.*

Keywords coal beneficiation, complementing-investment proposal, Fischer-Tropsch process, hydrocarbon fuels, monetization, process chemistry, value addition

1. Introduction

1.1. Monetization Concept

According to Peters and Timmerhaus (1981):

$$\$ + CH_2 = CH_2 + Cl_2 \rightarrow CH_2ClCH_2Cl + \$$$

$$\text{Dollars} + \text{Ethylene} + \text{Chlorine} \rightarrow \text{Ethylene dichloride} + \text{Dollars}$$

This concept will serve as the cornerstone of monetization of Nigerian coal by conversion to hydrocarbon fuels through the Fischer-Tropsch (F-T) process.

1.2. Justification for Coal Monetization

In recent times, the world has experienced a sudden growth in crude oil demand. China and the U.S. rank high in the growing demand for oil. A report from Cable News

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Network's (CNN's) World Business Today shows that China's economy is growing very fast; in 2003 it grew by 11%, and this year it is growing at 14%. This no doubt suggests growing demand for oil and, of course, increases in global oil prices. On September 13, 2004, CNN's Todd Benjamin (2004) reported that global oil prices have risen about 30% this year. In another news item, CNN's bizbar of September 30, 2004, reported that crude oil price breaks a milestone of US$50 per barrel in September 2004. This unabatable upsurge in prices of oil is believed to be stimulated partly by the present post-recession period. For example, Reed et al. (2004) express that, indeed, every recession since 1970 has been preceded by a sharp run up in oil prices.

The price mechanism of demand and supply, and also the fear of the global supply chain disruptions, are the likely causes of the upward push in oil prices. According to Palmeri (2004), there is no doubt that most of oil's huge price leap—up 40% in the past year to US$45 a barrel—is grounded in fundamental supply-and-demand issues; but how much of crude's big bounce is also because of speculation. Of course, speculation makes the world oil market nervous.

The volatility of the world oil markets is demonstrated by some disruptive events like war in Iraq, tax-evasion dispute in Russia, political-recall referendum in Venezuela, Hurricane Ivan disruption in the U.S., and resource control disturbance in the Niger Delta area of Nigeria.

Given the vulnerability of oil supply and prices to both artificial and actual disruptions, this paper will focus on an alternative fossil fuel that will reduce the world's dependence on petroleum crude oil. This involves using the Fischer-Tropsch process in the manufacture of synthetic crude oil from coal for complementing the natural petroleum crude oil.

2. Some Economic Aspects of Oil Dependence

The apparently unabatable increases in oil prices experienced recently in the world oil markets are rooted in the economics theory of demand and supply and also speculations. From demand-and-supply theory, price increase is a consequence of demand outpacing supply. Rapidly growing oil consumption in the world has given rise to oil demand outpacing oil supply. The factor responsible for this phenomenon is the recovery from global recession of the late 1990s. The Chinese and U.S. economies have recorded significant growths in oil demand. This standpoint is leaned on the following statements.

> *This year China will suck up 830,000 barrels a day more oil than last year, the IEA estimates, accounting for a third of world demand growth. As their incomes boom, the Chinese are buying cars even as the government rushes to build more roads to accommodate all the new traffic. Switching manufacturing from the West and Japan to less efficient facilities in China just adds to the nation's thirst for oil.* (Reed et al., 2004. p. 40)

Also, Reed et al. (2004) further reports that the U.S. also continues to defy predictions as the economic recovery chugs along and Americans continue to buy gas-guzzling vehicles and energy-gobbling McMansions; in the second quarter, America's demand for oil grew by 3.5%, the biggest gain since 1999.

However, the suddenness of the demand growth for oil may be a source of concern. In this regard, over more than a decade, the relatively stagnant demand for oil at relatively low prices undermined the efforts of oil-producing countries at developing new oil reserves. For example, between 1985 and 2000 (Figure 1) the average annual price of Nigeria's Bonny light crude was below US$20 per barrel, while Nigeria's daily average export of crude oil stood at 1.5 million barrels per day (mb/d) for 1985–2000 (Figure 2). Without a promise of at least 15% return on investment, oil-producing companies, the operators of oil production joint ventures, hesitate at committing investment funds for new reserves in producing countries. This no doubt accounts considerably for the lack of spare capacity to contain the rapidly growing global oil demand. Thus, oil low prices (Figure 1) and virtually stagnant oil demand (Figure 2) are attributable as the factors restraining profit-driven investors from developing new oil reserves that would have provided spare capacities to cushion the present growth in oil demand. The overall effect is the emergence of speculative world oil markets currently being experienced that are vulnerable to psychological disruptive threats like political crises and agitation down to serious supply outages resulting from war, anarchy, and weather crunch.

Over the years, the Organization of Petroleum Exporting Countries (OPEC) has been imposing production cuts on members to prop up oil prices and prevent glut. Apparently, this is aimed at meeting the 15% returns that will attract and motivate oil-producing companies into investing in new ventures. OPEC's problem of spare capacity suggest that its measures of production cuts over the years have not actualized the objective of developing new oil reserves which the world could lean on in periods of demand growth and scarcity.

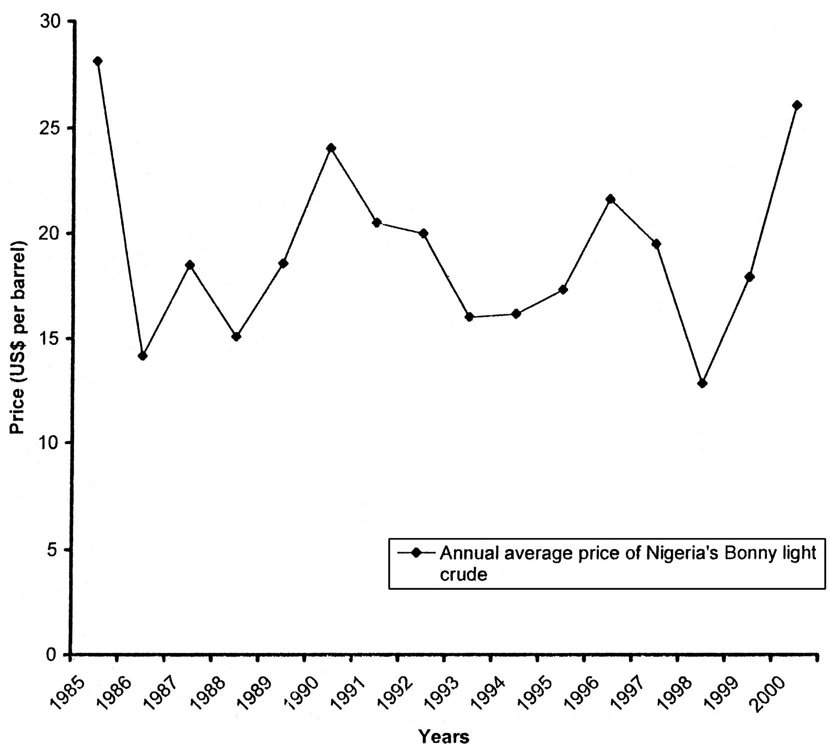

Figure 1. The graph of annual average price of Nigeria's Bonny light crude (US$ per barrel) over time (years). (*Source*: A plot of values collected from Central Bank of Nigeria, CBN [2000:133] Statistical Bulletin, Vol. 11, No. 2. Abuja: CBN Research Department, December.)

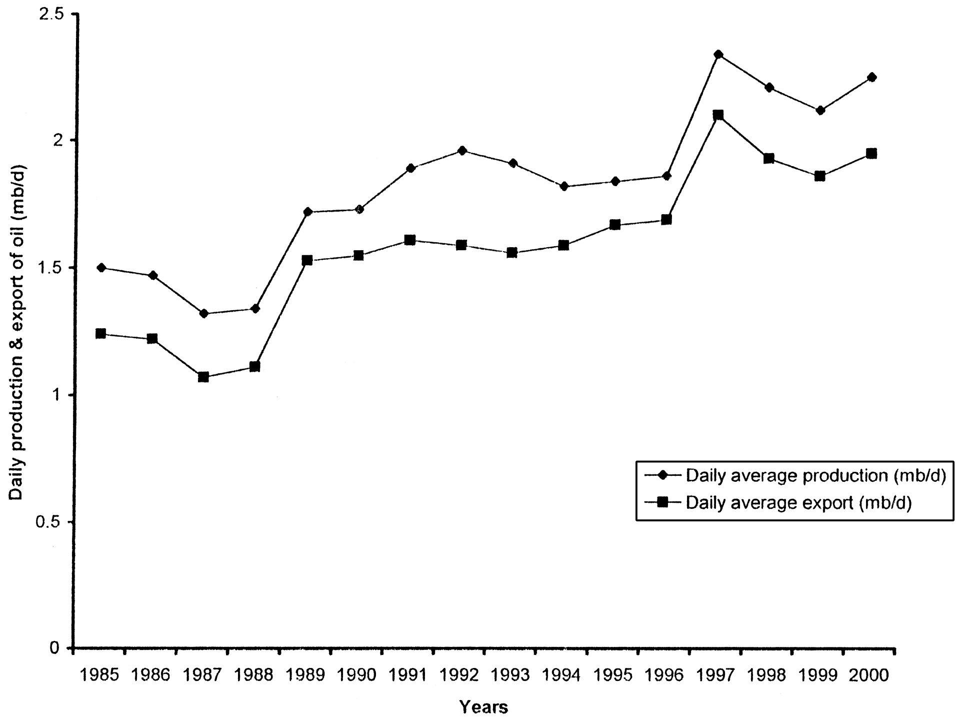

Figure 2. The plot of Nigeria's daily production and export of crude oil (mb/d) versus time (years). (*Source*: Graphed from data obtained from Nigeria National Petroleum Corporation, NNPC [2000:44 and 73] Annual Statistical Bulletin.)

One of the approaches to abating the problems of oil scarcity is to enhance global coal reliance and utilization, thereby reducing the global pressure and dependence on crude oil.

3. Enhancing Coal Utilization

Coal utilization for the manufacture of synthetic hydrocarbons and motor fuels is not as popular as petroleum-crude oil usage. To complement the petroleum resource with coal, the objects are (1) suggest the roll back to coal to synthetic crude manufacture which had existed for years, and (2) contribute toward popularizing coal to synthetic hydrocarbons conversion. These no doubt would be of great promise to coal-rich countries and petroleum-poor economies, thereby easing the pressure on crude oil markets.

Nigeria is fortunate to be richly endowed with coal reserves, just as she is with oil/gas resources. We now examine Nigeria's coal resource and its utilization rate, with a view to monetizing it, and Nigeria's fuels imports, with a view to substituting the importation with motor fuels made locally from coal.

3.1. Coal Reserve in Nigeria

High-grade coal deposits are available in over 13 states of Nigeria. Managing Director, Nigerian Coal Corporation, Iwu (1998) writes that the estimated coal reserve in Nigeria

Table 1
Life of Nigeria's coal reserves at Nigeria's and South Africa's production rates

Country	Coal reserve, tonnes	Nigeria's 1998 production rate, tonnes	South Africa's 1998 production rate, tonnes	Life of reserve at 1998 production rate, year
Nigeria	2.7×10^9	18,500	—	145,946
South Africa	2.7×10^9	—	50×10^6	54

Source: Iwu (1998); FOS (2001); Sasol (2000).

is over 2.75 billion metric tonnes and that in over 76 years of coal mining in Nigeria only about 25 million tonnes have been exploited mainly from the Enugu Coal Mines. Table 1 below describes and summarizes coal reserves in Nigeria in terms of the depletion years at both Nigeria's and South Africa's rates of production.

At the 1998 production rate in Nigeria (Table 1), the current coal reserve will last for the next 145,946 years. Incredible duration! This suggests gross under-utilization. However, at South Africa's rate of coal production (50×10^6 tonnes), Nigeria's present coal reserve will deplete in the next 54 years (Table 1).

Also, Figure 3 shows the trend of coal production from 1986 to 1998. The declining trend of the coal production level (Figure 3) suggests the gradual abandonment of coal development and utilization in preference for oil/gas development.

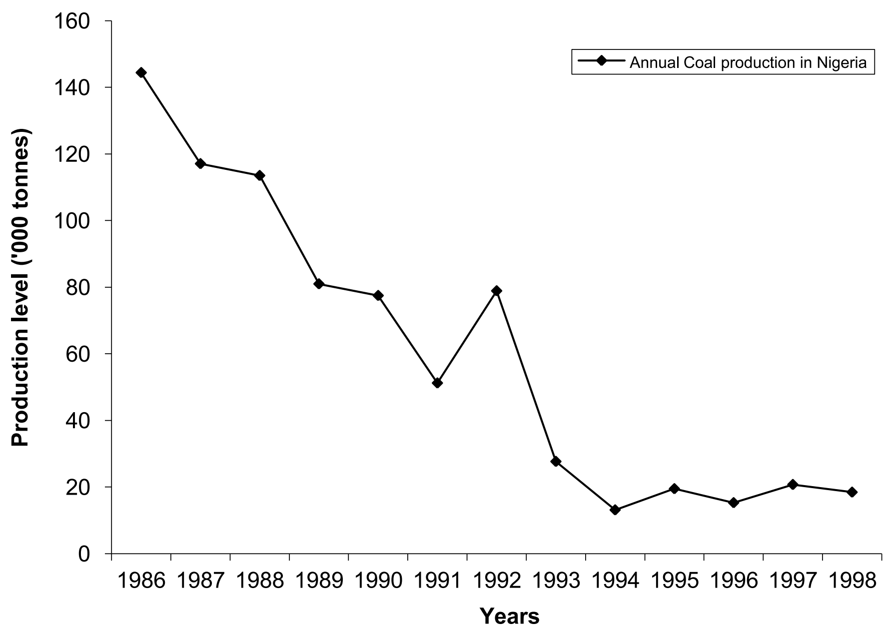

Figure 3. The graph of Nigerian coal production over the years ('000 tonnes). (*Source*: Graph data compiled from FOS [1991:203], [1994;226], [1996:287], and [2001:407] Annual Abstract of statistics.)

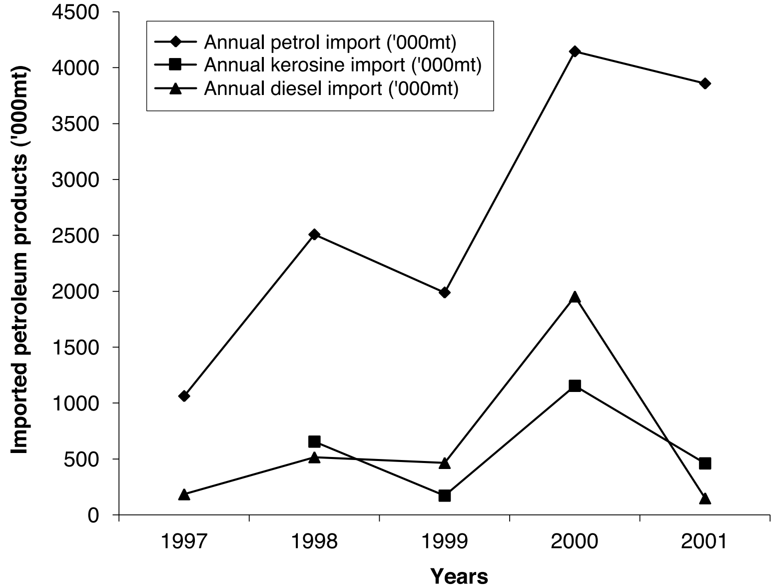

Figure 4. The plots of Nigeria's imported petroleum products for 1997–2001 (thousand metric tonnes, '000mt). (*Source*: The plots of data obtained from NNPC [2001:73] Annual Statistical Bulletin.)

3.2. Nigeria's Fuels Import

The declining trend of the coal production level (see Figure 3) suggests the gradual abandonment of coal development and utilization in preference for oil/gas development. With a daily consumption of about 30 million liters of petroleum products, Nigeria may be said to be a big petrol-consuming nation. Much of the fuels are imported to supplement local refinery output. Figure 4 shows the rising pattern of annual tonnages of imported petroleum products for 1997–2001.

With the deregulation of the downstream sector of the Nigeria's petroleum industry, it is highly likely that more petroleum products will be imported as import restrictions and controls are removed.

However, the development of a process plant that would utilize the huge coal reserves (see Table 1) to produce 4,144, 1,155, and 1,953 thousand metric tonnes of synthetic petrol, kerosene, and diesel, respectively (see Figure 4), will no doubt diversify the fuel source, reduce over-dependence on crude oil, and create jobs and wealth for Nigeria.

In this regard, with the huge commercial-scale coal reserve in Nigeria, we present the application of Sasol's expertise in the conversion of coal into synthetic hydrocarbon fuels.

4. Sasol's Coal to Synfuels Conversion Process

The fundamental process in Sasol's coal to motor fuels conversion is rooted in Fischer-Tropsch (F-T) technology. The F-T process entails the production of motor fuels from syngas, a pre-determined mix of CO and H_2 derived from coal. Shreve and Brink (1977) writes that the largest F-T plant is one in South Africa built by M. W. Kellogg Company.

Crouch and Cline (2003) states that the Sasol process for producing diesel and naphtha from coal-derived gas has been one of the longest continuing operations.

4.1. Sasol Process Outline

The process sequences of the Sasal's coal to synthetic fuels and chemicals manufacture are coal gasification, gas purification, Sasol Advanced Synthol (SAS) Reaction, and Sasol Slurry Phase Distillate (SSPD) reaction. SAS is a distinct high temperature F-T process innovated by Sasol for a one-step conversion of synthesis gas (syngas) into a synthetic form of crude oil and assorted chemical streams made up of olefins, propylene, ethane, methane, ketones, etc. SSPD is another distinct Sasol's evolved low-temperature F-T process involving one-step conversion of syngas into waxy crude oil, liquid petrochemical, and gas streams. The outline of these process steps are depicted in the simplified flowsheet below.

4.2. Chemistry of Sasol Process

4.2.1. Chemistry in the Gasifier. When coal is subjected to high pressure and temperature in excess of 1,000°C in the gasifier (Figure 5), where steam and oxygen are charged in raw gas made up of H_2, CO, CO_2, CH_4, H_2S, and N_2 is produced. The chemical equations representing the principal reactions are given below.

Reaction of coal with steam: At very high temperature, the following endothermic reaction occurs.

$$C_{(s)} + H_2O_{(g)} \rightarrow CO_{(g)} + H_{2(g)}; +\Delta H \quad (1)$$

At lower temperature in the gasifier, the following reaction takes place.

$$C_{(s)} + 2H_2O_{(g)} \rightarrow CO_{2(g)} + 2H_{2(g)}; +\Delta H \quad (2)$$

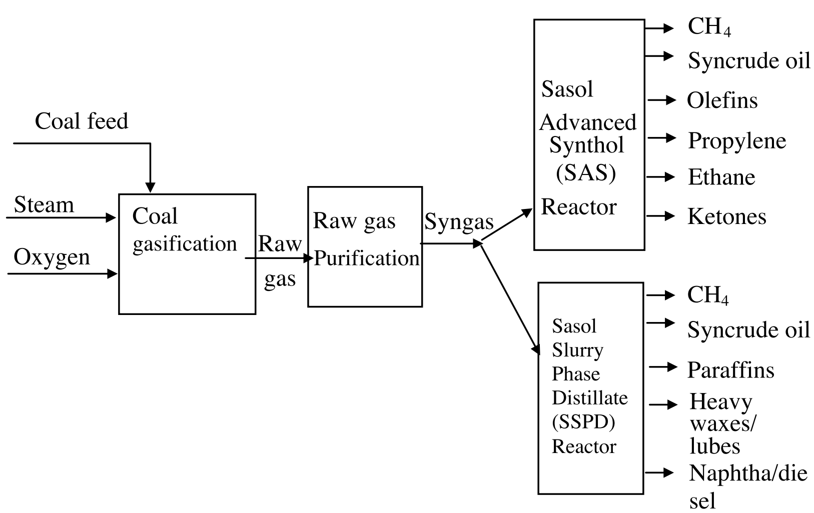

Figure 5. Simplified Sasol process flowsheet. (*Source*: Sketched from Sasol [2003:20-21] Sasol facts.)

Reaction of coal with oxygen: An exothermic reaction which adds heat that helps to sustain gasification process occurs

$$C_{(s)} + O_{2(g)} \rightarrow CO_{2(g)}; -\Delta H \tag{3}$$

Subsequently another endothermic reaction also occurs

$$C_{(s)} + CO_{2(g)} \rightarrow 2CO_{2(g)}; +\Delta H \tag{4}$$

To ensure that H_2:CO ratio of 2:1 needed for the F-T conversion is available, the shift conversion reaction is necessary

$$CO_{(g)} + H_2O_{(g)} \rightarrow CO_2 + H_2 \tag{5}$$

Other likely minor reactions that produce impurities may be represented by the following equations:

$$C_{(s)} + 2H_{2(g)} \rightarrow CH_{4(g)} \tag{6}$$

$$S_{(s)} + H_{2(g)} \rightarrow H_2S_{(g)} \tag{7}$$

$$2C_{(s)} + 3H_2 \rightarrow C_2H_{6(g)} \tag{8}$$

$$N_{2(g)} + 3H_{2(g)} \rightarrow 2NH_{3(g)} \tag{9}$$

These impurities, including N_2, are removed during the purification process (see Figure 5) to yield synthesis gas (syngas). Physical gas absorption systems are employed for scrubbing and removal of impurities.

4.2.2. Chemistry in the SAS Reactor. The syngas (Figure 5) is charged into the SAS reactor where hydrogenation of CO takes place under temperature and pressure in the presence of a fluidized iron-based catalyst. The product is a broad spectrum of hydrocarbons in the range of C_1 to C_{20}. The chemical equations which may represent this reaction (Oguejiofor, 2004) are:

$$nCO_{(g)} + 2nH_{2(g)} \rightarrow C_nH_{2n(1)} + nH_2O_{(g)} \tag{10}$$

$$nCO_{(g)} + (2n + 1)H_2 \rightarrow C_nH_{2n(1)} + (2 + n)H_2O_{(g)} \tag{11}$$

The hydrocarbon products are liquefied by cooling to yield separate hydrocarbon fractions and cuts.

4.2.3. Chemistry in the SSPD Reactor. In the low temperature SSPD reactor (Figure 5) the feed of syngas is reacted at temperatures between 350–230°C, lower than in the SAS reactor in the presence of circulating fluidized cobalt catalyst. Catalyzed hydrogenation reaction takes place and yields linear-chained hydrocarbon wave (the synthetic equivalent of crude oil). The simplified reaction (Sasol, 2002) is

$$CO_{(g)} + 2H_{2(g)} \rightarrow –CH_2–_{(l)} + H_2O_{(g)} \tag{12}$$

The products are separated by cooling and liquefaction and subsequently the products are upgraded.

These two processes are demonstrations that Sasol is currently the leading driver and operator of the F-T technology.

5. Coal Monetization Model

With over 2.75 billion metric tonnes of coal reserve currently available in Nigeria, and Sasol's expertise in coal to synthetic fuel conversion, coal-monetization model may be simply represented as

$$\text{Investment Fund} + C_{(s)} \xrightarrow[\text{Conversion of CO \& } H_2]{\text{Gasification \& catalytic}} C_nH_{2n(l)} + \text{Investment Return}$$

Despite the huge quantities of cheap coal in Nigeria, this monetization model may result in motor fuels at higher costs than conventional hydrocarbon source. According to Crouch and Cline (2003) while coal is recognized as a cheap source of carbon, it suffers from a poor hydrogen to carbon ratio; the result is a high unit cost for the product which was unable to compete with oil-based alternatives.

5.1. Cost Reduction Alternatives

Some cost-reduction alternatives that would minimize the high unit cost of hydrocarbon products from coal, make coal-based hydrocarbon products competitive, stimulate investments in coal in coal-rich countries like Nigeria, and on the other hand reduce pressure on petroleum are stated below.

1. Avoidance of mono-product process for coal to motor fuel conversion and manufacture.
2. Use of catalysts in hydrogenation of CO. Example SAS and SSPD reactors are Sasol's innovation in catalytic conversion of syngas to synfuels in an economical manner.
3. Introduction of parallel processing streams like hydrogenation, methanation, and NH_3 synthesis giving rise to multiple chemical and fuel products that would overwhelm the costs and promise lucrative earnings.
4. Where natural gas is readily available, products of natural gas reforming could complement products of coal gasification. A representation for this may take the following form.

$$\text{Investment in coal/natural gas} + nCO_{(g)} + 2_nH_{2(g)} \xrightarrow[\text{Conversion}]{\text{Catalyst}}$$

$$C_nH_{2n(l)} + nH_2O_{(l)} + \text{Investment returns}$$

The model that integrates all the cost-reduction alternatives into one as depicted below will ensure flexibility in raw materials usage, multiple processing, and promising returns (Figure 6).

5.2. Actualizing the Model and Concept in Nigeria

This article has shown that Sasol is the world leader in F-T technology that is based on coal conversion to motor fuels. The Nigerian Coal Corporation in partnership with the Ministry of Solid Minerals development should take the lead in entering into joint venture project with Sasol organization for the purpose of exploiting the huge coal reserves in Nigeria for the manufacture of liquid hydrocarbon fuels and chemical products. This is the way to make good the huge quantities of coal reserves, estimated at over 2.75 billion metric tonnes, of which annual production is less than 0.01% of total reserves per year.

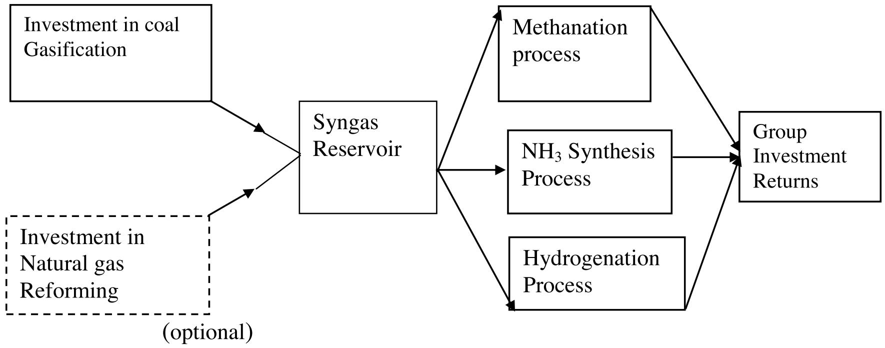

Figure 6. Integrated unit cost minimization concept.

Conclusion

Sequel to the high cost of crude oil at the world oil market (over US$40 per barrel for over 5 months), there is a need to ease the global pressure on crude oil dependence through diversification. One credible alternative is to maximize the utilization of large quantities of high quantity and cheap coal reserves available in Nigeria. Sasol organization has the clean technology for motor fuels manufacture from coal.

Therefore, the major thrust in the management of Nigeria's abundant coal reserves will be for the Nigerian Coal Corporation to enter into a joint venture project arrangement for an accelerating exploitation of Nigeria's coal for motor fuels manufacture.

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