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# THE ROLE OF EFFECTIVE AND EFFICIENT PRODUCT LIFE CYCLE ENGINEERING IN SUPPORTING SUSTAINABLE DEVELOPMENT IN AFRICA USING COAL IN NIGERIA AS A CASE INSTANCE

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## ABSTRACT

This study examined potential benefits of coal through improved and efficient technology life cycle in supporting sustainable development in most developing parts of the world. The aim of this study was to reveal various products that can be obtained from coal and its sustainability property. The need for coal to clean transportation fuel will not seize as long as the pressure on oil price remains high. In addition, the location of the world's oil and gas resources and their availability to consumers is a major concern, and import dependency is a considerable part. Coal on the other hand offers security of supply benefits and possesses a particularly broad geographic resource distribution where it is present in more than 70 countries worldwide and currently mined in 50 of those countries. Coal users can benefit from utilising their own indigenous resources, or by accessing affordable coal in a well-established market from a wide variety of countries and suppliers. Even taking into account the costs of transformation, coal-derived fuels can provide a hedge against the volatility of oil prices and facilitate greater economic independence through the stabilisation of demands on foreign currency reserves. This study revealed that coal can produce products such as ammonia & Urea, methanol, olefin, natural gas, and dimethyl ether in commercial quantities. In addition, since, the carbon dioxide produced in the coal chemical processing is of high concentration and high pressure, it was found to be helpful in capturing and utilization of other products such as urea, acetic, potassium carbonate and underground fire extinguisher. Hence, giving priority to deploying captured carbon dioxide to the coal chemical industry and power plants for boasting electricity generation will aid economic and environmental development. These findings explore the benefit of effective and efficient product life cycle engineering in encouraging sustainable development around the globe.

## Introduction

Coal mining has been performed around the world throughout history and has continued to play vital part in economic activity. Today, coal is the largest primary source of energy used for the generation of electricity around the world. The use of coal is coupled to major environmental impacts, which include the release of carbon dioxide, a greenhouse gas emission which is responsible for climate change and global warming [1], and the influence of water use on flows of rivers and consequential effect on other land-uses [2]. In order to reduce these environmental impacts, there is a trend among coal dependent industry to operate according to the highest environmental standards, which can be formalised through certification [3].

Nigeria is endowed with vast reserves of solid minerals, including precious metals, stones and industrial minerals. The country was a major exporter of tin and coal in the early 1970s. However, activities in this sector belly flopped considerably when crude oil production began to take the centre stage, and became a major source of foreign exchange for the country. The restoration to democracy in 1999 revealed the need to diversify the revenue base of the country.. Consequently, a new national focus and strategy on mining evolved such that in 2007, the Nigerian Minerals and Mining Act (the Act) was enacted to invigorate the Nigerian mining industry. There are over 40 different types of minerals spread across the country, including gold, barite, bentonite, limestone, coal, bitumen, iron ore, tantalite / columbite, lead/zinc, barites, gemstones, granite, marble, gypsum, talc, iron ore, lead, lithium, silver, etc. However, not all the minerals aforementioned are available in commercial quantities. As part of the strategies to reform the sector, the Ministry of Mines and Steel Development (MMSD) has identified seven (7) strategic minerals, namely, Coal, Bitumen, Limestone, Iron Ore, Barites, Gold and Lead/Zinc for priority development as further discussed below.

## Coal

Coal can be defined as a sedimentary rock that has the ability to burn, usually formed by decomposition of plant matter; it is a complex substance that can be found in many forms. Coal is divided into four classes namely: anthracite, bituminous, sub-bituminous, and lignite. Elementary analysis revealed empirical formulas such as $C_{13}H_{97}O_9NS$ for bituminous coal and $C_{240}H_{90}O_4NS$ for high-grade anthracite. Nigerian coal was found apposite for boiler fuel, production of high caloric gas, domestic heating, briquettes, formed coke and the manufacture of a wide range of chemicals including waxes, resins, adhesives and dyes.

Coal can be found in the central, middle-east and south east regions of the country such as Anambra, Kogi, Benue and Enugu States. A reasonable estimate in these regions is put at about a total of 396 million metric tonnes, while the unproven reserves are predicted to be in the region of 1,134 million tonnes.

The Nigerian government has since perceived the need to reawaken the country's coal mining subsector, which could provide fuel for power generation and domestic use. Consequently, the coal resources were marked out into ten prospective blocks and placed for bidding by companies with proven financial and technical competence.

## Statement of the problem

The current upswing in oil prices has triggered renewed worldwide interests in different energy resources. Coal, which has been the subject of much attention because of the many environmental concerns resulting from its Sulphur and ash content and significant carbon footprint, is expected to play a key role in the rapidly growing economy in countries such as China, India, Canada and even the US. It is clear that the world will have to rely on more efficient and clean coal technology where the most probable option is to convert coal into high quality, clean burning transportation fuel. Moreover, countries such as Venezuela and Colombia has keyed into the advantages of coal and its new resources thereby reinvigorating the industry in these nations. Coal without doubt has a significant role to play in the provision of alternative fuels globally and it is the most affordable of the fossil fuels and widely distributed around the world even in most parts of Nigeria. Coal benefits from a well established global market, with large number of suppliers. It should be interesting to note that the production of liquid fuels from coal will not require vast land resources or cause competition with food production as the case with crude oil. The advantages of new resources production from coal ranges from availability, affordability and sustainability. However, Nigeria coal resources have not been optimally explored and this enhances the potentials of the coal industry in the country especially now that coal can yield various bye- products which are commercially viable with regards to economic, environmental and societal sustainability. Hence, the need to study the product life cycle of coal and it ability to support sustainability in Nigeria becomes very essential.

## Objectives of the study

The objective of this study was to reveal;

1. The production route of ammonia & Urea from coal
2. The production route of methanol from coal
3. The production route of olefin from coal
4. The production route of natural gas from coal
5. The production route of dimethyl ether from coal

## Literature Review

According to [4], the potential for 5 (five) coal conversion projects (coal to Y) for the production of fuels and primary products for the petrochemical industry.

**Table. 1: Coal conversion routes (CTY) products, LHVs and main applications**

| CTY products | | LHV [MJ/kg] | Examples of application |
|---|---|---|---|
| MET | Methanol | 19.9 | Petrochemical base for MTO process<br>Motor fuel |
| DDME | Dimethyl ether, direct and indirect route | 28.4 | Motor fuel (LPG blending required)<br>IDME Petrochemical base for DTO process |
| IDME | | | |
| FTD | Fischer-Tropsch diesel | 44.0 | Motor fuel<br>(Standard diesel blending required) |
| SNG | Synthetic Natural Gas | 50.0 | Stationary heating applications<br>Power generation |

As given in Table 1, each product has a number of different final applications, possibly requiring additional downstream conversion and conditioning steps. For each coal conversion route, a plant design was developed, considering a grass root complex able to operate in a standalone mode with only coal, raw water and start-up power available at plant boundaries. The plant was set to a generic location in North America [4]. Each conversion route has the same input feed, namely 4 Mt/a of coal. Coal requirements for utilities and power block have to be added to this amount. The primary aim of the development study was to perform a comparison of product output, utility requirements, and technical costs.

Sustainability is viewed as an increasingly important requirement for human activity, making sustainable development a key objective in human development. At its core, sustainable development is the concept that social, economic and environmental concerns should be addressed simultaneously and holistically in the development process [5]. Sustainability has been applied to many fields of endeavour, including engineering, manufacturing and design. Manufacturers are becoming increasingly concerned about the issue of sustainability. For instance, recognition of the relationship between manufacturing operations and the natural environment has become an important factor in the decision making among industrial societies. Achieving sustainable development is in general a challenging and complex undertaking, involving such factors as technology and engineering, economics, environmental stewardship, health and welfare of people and the communities in which they live and work, social desires, and government strategies and policies. Making manufacturing sustainable requires balancing and integrating economic and environmental societal objectives, supportive policies and practices. Furthermore, relevant, meaningful, consistent and robust information on sustainable manufacturing must be available and utilized by organizations and their managers if sustainability is to improve in manufacturing [5]. Sustainability entails the ability to endure or survive, which has significant ramifications. For instance, sustainability describes the productivity and diversity over time of biological systems, from an ecological perspective, and the potential for long-term welfare, from a human perspective. The latter depends on the wellbeing of the natural world, including the responsible use of natural resources and disposal of wastes [6]. Various models have been designed for implementing sustainability in manufacturing by improving the sustainability of manufacturing. Recently, frameworks for sustainable manufacturing, production and supply chains have been put forth and modeling and optimization tools have been developed ([7]; [8]; [9]; [5]). [10], proposed an environmental health and safety technology engagement model that illustrates the potential for implementing sustainability objectives during the development of a product or process. This model includes three phases: research, development and commercialization. A significant time period, often lasting years, is normally involved in designing a new manufacturing product or process. [10], argued that their model showed that the potential for implementing sustainability objectives differs with the time and phase of development. Manufacturing engineers and designers need to recognize this dependence to integrate sustainability effectively into processes or products. [10], explained that rather than considering only the environmental factors at one point in the product or process development cycle, a long-term commitment over the entire design process, from early research to process development, is usually more effective for integrating sustainability into manufacturing. Sustainability can be addressed in each of the three phases of the model: (a) Research: The first significant opportunity to influence the design process for sustainability is during the research phase at the pre-competitive level. At this phase, specific sustainability requirements and not-yet regulated concerns can be evaluated and examined, e.g., energy and resource use, pollution and climate change impacts. Early evaluation helps to ensure appropriate attention to sustainability at a time when it can be affected greatly, e.g., research can focus on solving manufacturing environmental issues. (b) Development: During the development phase, effort to improve environmental performance is focused on system design and equipment selection using appropriate methods and tools, e.g., design for environment, environmental footprint assessment, and life cycle analysis. Collaboration with vendors helps promote environmental improvements. The potential for modifications that enhance sustainability characteristics is high during this phase. (c) Commercialization: The efforts introduced during the development phase are extended and refined during commercialization activities, and involve cooperation with suppliers, vendors and customers.

**Table 2: Model for potential for implementing sustainability in manufacturing**

| **Phase** | **Development phase** | **Potential for modification** | **Time before commercial manufacturing** | **Cost benefit of proper decision** |
|---|---|---|---|---|
| 1 | Research | Low-medium | Long | Low |
| 2 | Development | Medium-high | Medium | Medium |
| 3 | Commercialization | Low-medium | short | High |

*Based in part on model of [10].

[10], illustrates the potentials of the model using Intel, a semiconductor equipment company that strives to build sustainability into its products and processes prior to commercialization. Intel operates under a two-year model for new product development, alternating between silicon manufacturing technology for one year and microprocessor architecture the next year. The model proposed by [10], introduces a new manufacturing process technology in the first year, allowing, for instance, reductions in semiconductor size and the subsequent manufacture of more semiconductors on a single wafer or placement of more transistors in an equivalent space. In the second year, this model introduces a new chip architecture or design with the same manufacturing technology. Each step provides the opportunity to establish objectives and strategies to reduce environmental impact, and Intel has worked with suppliers of semiconductor manufacturing equipment and materials to improve the environmental performance of various technologies using this approach. Speaking on the importance of sustainability from the view of manufacturing company practices, [5], emphasized the need for manufacturing companies to holistically incorporate sustainability into their practices. Practices that would be helpful include: improved measuring and monitoring of sustainability indicators by companies, company policies and governance that focus on sustainability, improved efforts to control a company's environmental impact, establishing a sustainability-supportive company culture and working conditions, enhancing awareness of sustainability among suppliers and customers, responding to their requirements and measures, and engaging the community to promote sustainability. In addition, [5], stressed that significant collaborative research is needed in industry and academia in the fields of sustainability, manufacturing, design, engineering and environmental impact. Also, there is grave need for more detailed, comprehensive and robust data to support environmental impact and sustainability assessments, and measures across the overall product life cycle. Such data need to be standardized where feasible to aid en-

hanced monitoring and exploration of the manufacturing system.

Companies find themselves confronted with increasing internal and external complexities. Increase changes in markets, legislation, technologies, and customer demands have a particularly strong influence on the complexity of their surrounding environment. In many industries, such as the electrical, electronics industry, and also in many supplier industries, more and more actors, products (product variants), product accompanying services, and legislative regulations emerge within the globalized market. At the same time, social and legal requirements regarding a change toward sustainable development forces industries to increase effectiveness, reduce emissions, avoid hazardous substances and to decouple the economic growth and the primary resource consumption on the long-term view. As an example, some countries strive to increase national resource productivity, which includes optimizing the use of primary resources and promoting the use of secondary raw materials by promoting a recycling society [11]. [12], argued that to cope with future challenges with respect to sustainable development, an integrated view of different sustainability-related and life cycle-related research disciplines (engineering, industrial management, social science, chemistry, etc.) is necessary. Pre-conditions for coming to terms with the increased complexity and the emerging research approaches are on the one hand a frame of reference which enables orientation, and on the other hand transparency for the integration of differentiated approaches. [12], emphasized the need for company models and management frameworks to link different disciplines; this is to uncover interdependencies, and to promote the integration of disciplines and methods of production. In order to depict the different life cycle phases of products and to classify corresponding life cycle objectives and activities, life cycle management approaches have been developed by several researchers. At present, life cycle management ([13]; [14]; [15]; [16]), closed-loop supply chain management ([17]; [18]), and life cycle planning [19], are more and more topics of research. [20] noted that considering the product life cycle phases, the approaches start with life cycle design and engineering ([19]; [21]) and end up to product life cycle management and end-of-life management with an information-oriented view on the product life cycle. While some researchers focus on the life cycle of primary goods (e.g. washing machines, cars, etc.) and address environmental issues like design for environment (DFE) or life cycle assessment (LCA), other researchers focus on the life cycle of production equipments (e.g. machine tools, robots, etc.) and address topics like life cycle maintenance or spare part management in order to maximize resource productivity. As these rather different life cycle approaches have to be synergistically incorporated by companies within their operations, these approaches in terms of frameworks, disciplines, and methods have to be contemplated considering the mode of operations of companies [22]. Nowadays manufacturing companies are facing diverse economic (e.g. shorter product life cycles, rising product variant diversity, increasing production volume fluctuations, rapid changing technologies, financial crisis) but also enormous environmental (e.g. climate change, resource depletion) and social challenges (e.g. aging personnel). Therefore, besides traditional economical production objectives (e.g. cost, time, quality), environmental driven objectives (e.g. low CO2 emissions) have become strategically relevant for manufacturing companies. Altogether, it is necessary to strive towards harmonising the requirements of sustainable development with the needs of manufacturing [23]. Doubtlessly, manufacturing processes play an essential role regarding economic success and environmental impact. Production processes consume raw materials and transform them into products and wanted or unwanted by-products using energy as input. While one part of the resources is used for creating value and embodied into the form and composition of products, another part is wasted in terms of losses, heat and emissions. Manufacturing systems predominantly influence the environmental outcome and therefore represent the major potential to minimise the environmental performance of a company [24]. Thus, designing and improving manufacturing systems while advantageously integrating economic, ecological and social goals becomes an essential strategic objective of manufacturing companies nowadays ([25]; [26]; [27]). It is clear, that an isolated consideration of traditional economic variables is not sufficient anymore. In fact, Sustainable Manufacturing is the new necessary paradigm for manufacturing companies which involves the integration of all relevant dimensions for all technological and organisational measures within the normative, strategic and operative production management. Production process is a set of interrelated activities such as value creating and supporting activities like transformation, combination, transport, control, measure or storage [28], which transforms inputs into outputs. [29], explained that inputs to a process are generally outputs of other processes and complex technical products are typically made in multistep production process chains as logically linked sequence of successive or parallel single processes (and associated activities) over time with one common goal of bringing out a defined output (one or several final products) at the very end. These processes and process chains involve technical equipment and personnel, which form manufacturing systems as specific designated areas for production and, on a higher level of aggregation, factories. Systems engineering efforts are very concerned with technical direction and management of the process of systems definition, development, and deployment, or systems management ([30]; [31]). The aim of systems engineering is to ensure that correct systems are designed and not just those system products are correct according to some potentially ill-conceived notion of what the system should do through adopting and applying the management technology of systems engineering (Fiskel, 1998). Appropriate metrics to enable efficient and effective error prevention and detection at the level of systems management and at the process and product level will result in systems engineering products that are "correct" in the broadest possible meaning of this term. To ensure that correct systems are produced requires that considerable emphasis be placed on the front end of each of the systems engineering life-cycles. Systems engineers are concerned with the appropriate definition, development, and deployment of systems. These comprise a set of phases for a systems engineering life-cycle [30]. There are many ways to describe the life-cycle phases of systems engineering processes. Each of these models, and those that are outgrowths of them, are comprised of the three phases of definition, development, and deployment. For pragmatic reasons, a typical life-cycle will almost always contain more than three phases. Generally, they take on a "waterfall" like pattern, although there are a number of modifications of the basic waterfall, or "grand-design life-cycle," to allow for needed incremental and evolutionary development of systems. [32], argued that sustainability is a quality that permits to preserve, to keep and to maintain something. It is argued that when something is sustainable, it is able to be kept. In the past, the term was mainly environmentally-oriented, such as the quality to sustain the environment. However, in current literature, sustainability is defined with three dimensions: environmental, social, and economical; often adding a forth one, technological. Engineering is identified to be a key driver of human development and viewing the role of technology in human development, engineering is the key driver of technology based human development which is leveraging on a extensive collaboration from many individual disciplines (i.e. industrial, mechanical, electrical, etc). Henceforth, Sustainable Engineering can be defined as the way of applying engineering for sustainability purposes. According to [33], as global sustainability indicators is clearly showing current patterns of mass production of cheap goods, over consumption of products with a short use cannot be evidently sustained. Evidently, sustainability has a social responsibility impact, but its attainment is a matter of practical implementations: sustainability can be achieved through optimization of the use of resources along the product lifecycle, while retaining the quality of products and services, but optimization and quality of product related processes are strongly based on the use of information. To this end, product lifecycle management is being viewed as a very important approach for achieving a more sustainable way of work and life, a more sustainable development, manufacturing and use. Speaking on product life-cycle, [34] noted that life-cycle assessment is a methodology for evaluating the environmental loads of processes and products during their whole life-cycle. The assessment includes the entire life-cycle of a product, process, or system encompassing the extraction and processing of raw materials; manufacturing, transportation and distribution; use, reuse, maintenance, recycling and final disposal [35]. Life-cycle assessment has become a widely used methodology, because of its integrated way of treating the framework, impact assessment and data quality [36]. Employed appropriately, Life-cycle assessment examines environmental inputs and outputs related to a product or service life-cycle from cradle to grave, which is from raw material extraction, through manufacture process, usage phase, reprocessing where needed, to final disposal. The origin of life-cycle reasoning was attributed to the US defence industry where it was employed to consider the operational and maintenance costs of systems [37]. This has become a costing technique known as Life-Cycle Accounting or Life-Cycle Costing. The first appearance of life-cycle assessment in its current modern environmental understanding was in a study held by Coca-Cola to quantify the environmental effects of packaging from cradle to grave where emphasis at that time was primarily on solid waste reduction, rather than on environmental emissions or energy use [38]. As observed by [39] that life-cycle assessment has been widely used in the building sector since 1990, and is an important tool for assessing buildings, it is less developed than in other industries, including perhaps the engineering and infrastructure sector. The building industry, governments, designers and researchers of buildings are all affected by the trend of sustainable production and eco-green strategies. The importance of obtaining environment-related product information by life-cycle assessment is broadly recognized, and is one of the tools to help achieve sustainable building practices.

## Coal conversion routes (CTY)

Apart from coal combustion for electricity generation, coal can be converted through gasification, resulting in a hydrogen rich synthesis gas (syngas). The obtained syngas can in turn be converted to a series of products, ranging from fuels to input feeds for the petrochemical industry. This type of coal conversion is commonly referred to as Coal to Y or CTY conversion [4]. A CTY conversion plant is generally made up of three distinct sections, namely the coal gasification section, the syngas conditioning section, and the product synthesis section. Acid gas removal units (AGRs) are located in the syngas conditioning section, used for capturing the $CO_2$ stream. We shall then discuss below the routes of coal conversion and the various products that can be obtained from coal.

**Carbon capture and storage (CCS)**

Carbon capture and storage (CCS) is a green house gasses (GHG) emissions reduction option which consists in capturing $CO_2$ at its emission source and its transportation to and injection into a suitable geological structure. It includes three distinct steps:

(a) $CO_2$ capture: There are three generic capture processes for coal power plants, namely post-combustion, pre-combustion and oxy-fuel combustion capture. Similar applications exist for production plants such as cement kilns, alloy smelters, or CTY plants.

(b) Compression and transportation: Once separated, the $CO_2$ is compressed, and transported to a suitable geological storage site, either by truck, train, barge or pipeline.

(c) Storage: $CO_2$ is injected into a suitable geological storage structure, such as saline aquifers, depleted oil & gas fields, or used for enhanced oil recovery (EOR).

**Coal Conversion Technology and $CO_2$ Emissions**

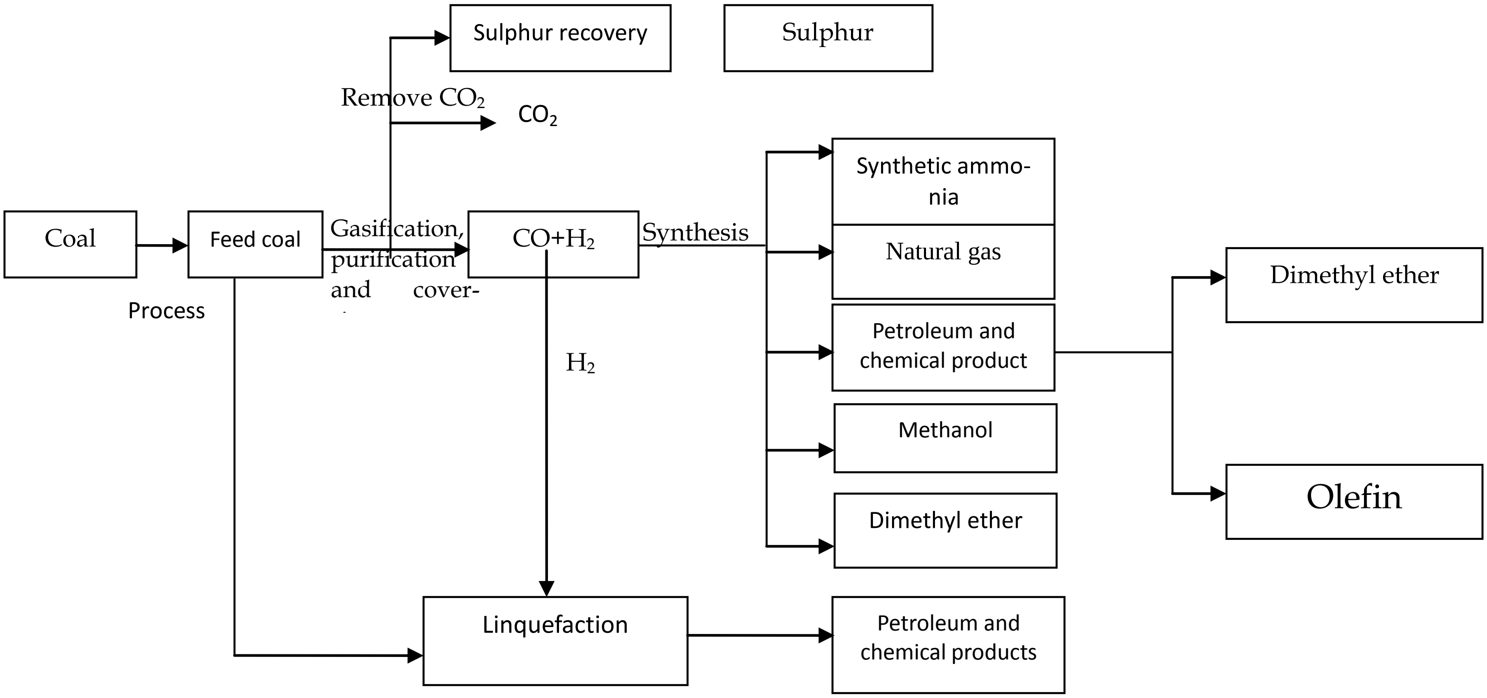

Figure 1: Routes conversion of coal to other products

## Ammonia and Urea Production from Coal

The products on which the life –cycle assessment will be performed are the products at the gate of the coal conversion plant. The considered system begins with the coal mining process, followed by its transportation to the coal conversion plant. The conversion unit is split into three parts, namely the coal gasification part, the $NH_3$ synthesis part, and the carbon capture and storage part. Power is supplied to the gasification unit by a power block (integrated gas combined cycle (IGCC)), on which carbon capture is applied as well [40].

The comprehensive coal consumption in ammonia production is 1.3~1.7 tons of standard coal correlatives per ton of $NH_3$; a level of below 1.5 tce/t $NH_3$ can be actualize if technology permits. The volume of carbon dioxide emission is about 2~2t/t$NH_3$ and can be utilized in the production of urea and the recovery of sulphur thereby decreasing the carbon dioxide emission to about 0.71 t/t. Hence, the utilization of the emission will reduce the hazard of carbon dioxide to the environment which implies contributing to sustainability of the environment.

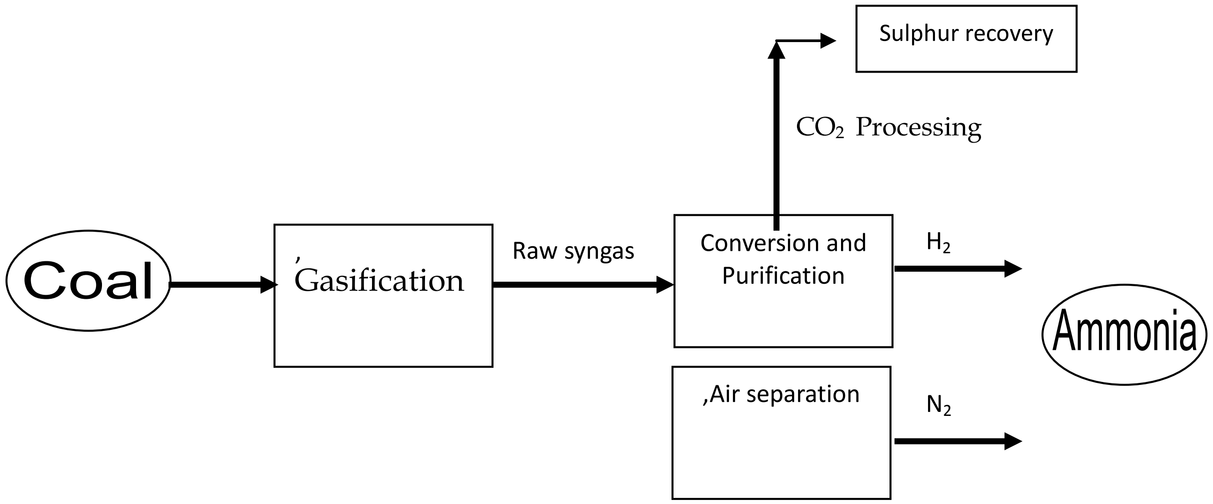

Figure 2: Route conversion of Coal to Ammonia production

## Methanol Production from Coal

The products on which the life –cycle assessment will be performed are the products at the gate of the coal conversion plant. The considered system begins with the coal mining process, followed by its transportation to the coal conversion plant. The conversion unit is split into three parts, namely the coal gasification part, the Methanol synthesis part, and the carbon capture and storage part. Power is supplied to the gasification unit by a power block (integrated gas combined cycle (IGCC)), on which carbon capture is applied as well [40].

The comprehensive coal consumption in methanol production is about 1.42~1.59 tons of standard coal proportionate per ton of methanol. Energy conversion efficiency can be up to 43~48%, or even in some large projects. In addition, $CO_2$ emission are 2.37~3.52 tons of carbon dioxide per ton of methanol (0.119~0.176t/GJ), among which 0.079~0.117 tons are discharged in the processing of chemical products such as $K_2CO_3$, acetic thereby reducing $CO_2$ emissions to about 0.040~0.059 tons which goes to the public process. Hence, this process of utilization of the $CO_2$ emission encourages sustainability of the environment.

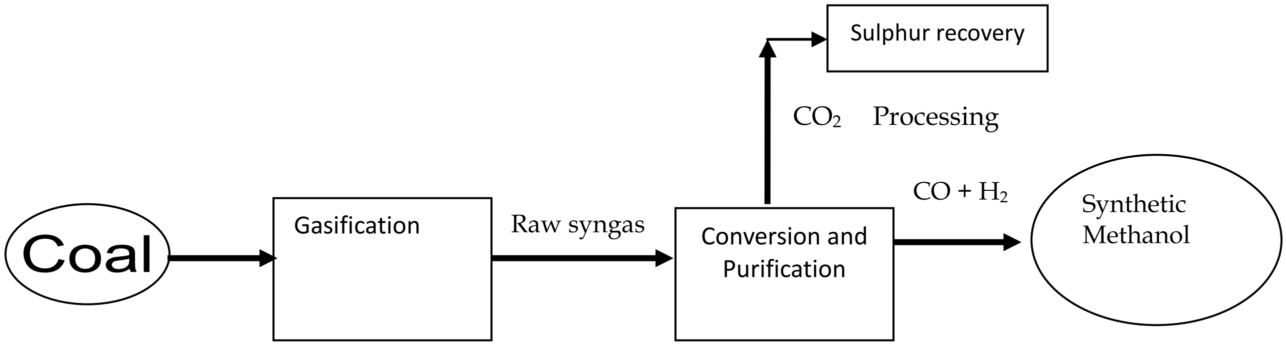

Figure 3: Route conversion of Coal to Methanol production

## Dimethyl Ether Production from Coal

The products on which the life –cycle assessment will be performed are the products at the gate of the coal conversion plant. The considered system begins with the coal mining process, followed by its transportation to the coal conversion plant. The conversion unit is split into three parts, namely the coal gasification part, the dimethyl ether synthesis part, and the carbon capture and storage part. Power is supplied to the gasification unit by a power block (integrated gas combined cycle (IGCC)), on which carbon capture is applied as well [40].

The comprehensive coal consumption for dimethl ether production is about 2.18~2.40 tons of standard coal equivalent per ton of dimethyl ether. Energy conversion efficiency can range about 41~45%. The $CO_2$ are about 3.8~5.48 tons of carbon dioxide per ton of dimethyl ether (or, 0.133~0.190t/GJ), among which 0.090~0.129 tons are discharged in the processing of chemical products such as potassium carbonate, acetic and sulphur thereby minimizing the $CO_2$ emission to about 0.043~0.061 tons in the public process. Hence, this process of utilization of the $CO_2$ emission encourages sustainability of the environment.

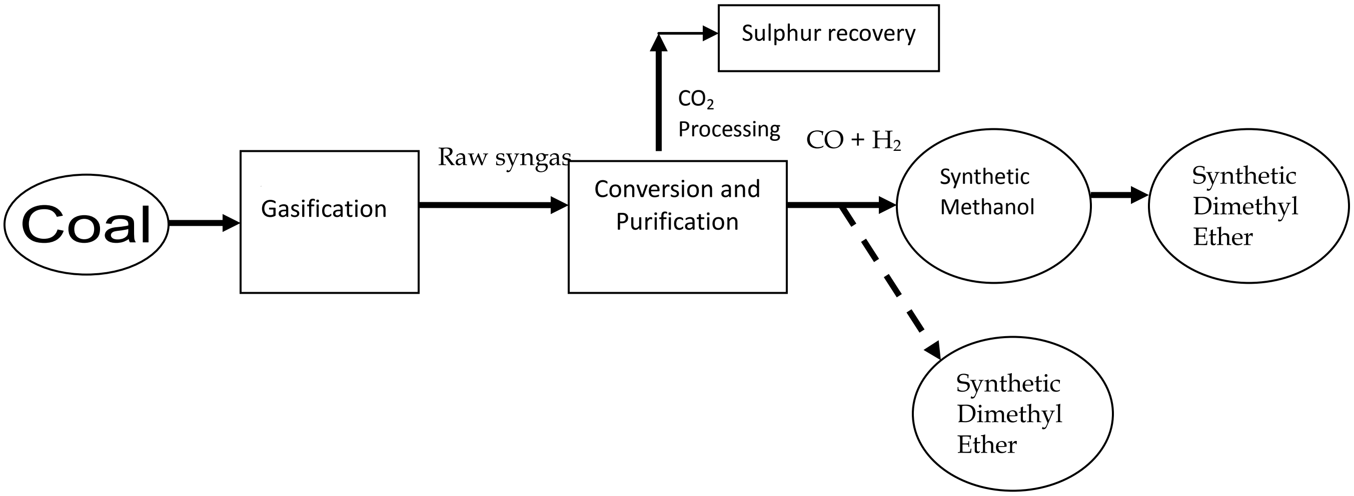

Figure 4: Routes conversion of Coal to Dimethyl Ether production

## Olefin Production from Coals

The products on which the life –cycle assessment will be performed are the products at the gate of the coal conversion plant. The considered system begins with the coal mining process, followed by its transportation to the coal conversion plant. The conversion unit is split into three parts namely, the coal gasification part, the Olefin synthesis part, and the carbon capture and storage part. Power is supplied to the gasification unit by a power block (integrated gas combined cycle (IGCC)), on which carbon capture is applied as well [40].

The comprehensive coal consumption is about 4.2~5.20 tons of standard coal correlative per ton of olefin. The $CO_2$ are about 6.40~9.15 tons of carbon dioxide per ton of olefin, among which 4.27~6.10 tons are discharged in the processing of chemical products such as $K_2CO_3$, acetic thereby reducing $CO_2$ emissions to about 2.13~3.05 tons which goes to the public process. Hence, this process of utilization of the $CO_2$ emission encourages sustainability of the environment.

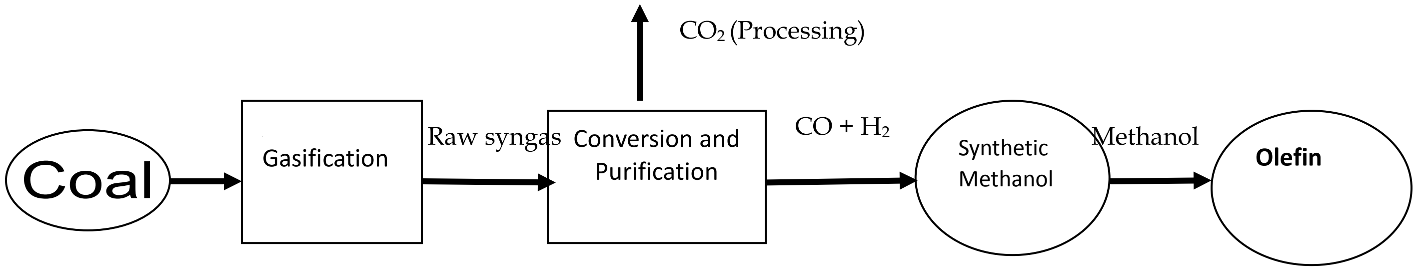

Figure 5: Route conversion of Coal to Olefin

## Direct Liquefaction of Coal

The products on which the life –cycle assessment will be performed are the products at the gate of the coal conversion plant. The considered system begins with the coal mining process, followed by its transportation to the coal conversion plant. The conversion unit is split into three parts, namely the coal gasification part, the liquefaction synthesis part, and the carbon capture and storage part. Power is supplied to the gasification unit by a power block (integrated gas combined cycle (IGCC)), on which carbon capture is applied as well [40].

The comprehensive coal consumption is 2.57~3.01 tons of standard coal equivalent per ton of coal in direct liquefaction of coal; energy conversion efficiency stands at 50~58%. The $CO_2$ are about 4.14~6.85 tons of carbon dioxide per ton of oil product (or, 0.096~0.157t/GJ), among which 0.067~0.110 tons are discharged in the recovery of sulphur and processing of chemical products such as $K_2CO_3$, acetic and underground fire extinguisher thereby reducing $CO_2$ emissions to about 0.029~0.047 tons which goes to the public process. Hence, this process of utilization of the $CO_2$ emission encourages sustainability of the environment.

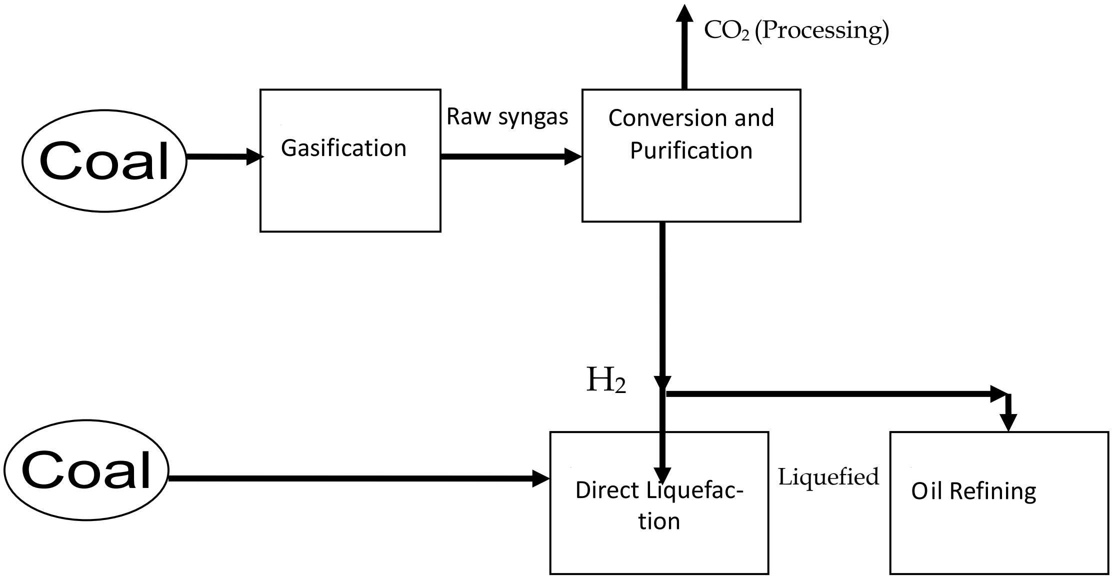

Figure 6: Route direct liquefaction of coal for oil refining

## Indirect Liquefaction of Coal

The products on which the life –cycle assessment will be performed are the products at the gate of the coal conversion plant. The considered system begins with the coal mining process, followed by its transportation to the coal conversion plant. The conversion unit is split into three parts, namely the coal gasification part, the liquefaction synthesis part, and the carbon capture and storage part. Power is supplied to the gasification unit by a power block (integrated gas combined cycle (IGCC)), on which carbon capture is applied as well [40].

The comprehensive coal consumption is 3.24~3.87 tons of standard coal correlative per ton of coal in indirect liquefaction of coal; energy conversion efficiency stands at 38~43%. The estimated $CO_2$ emissions are about 5.52~8.49 tons of carbon dioxide per ton of oil product (or, 0.128~0.197t/GJ), among which 0.085~0.131 tons are discharged in the recovery of sulphur and processing of chemical products such as $K_2CO_3$, acetic and underground fire extinguisher thereby reducing $CO_2$ emissions to about 0.043~0.066 tons which goes to the public process. Hence, this process of utilization of the $CO_2$ emission encourages sustainability of the environment.

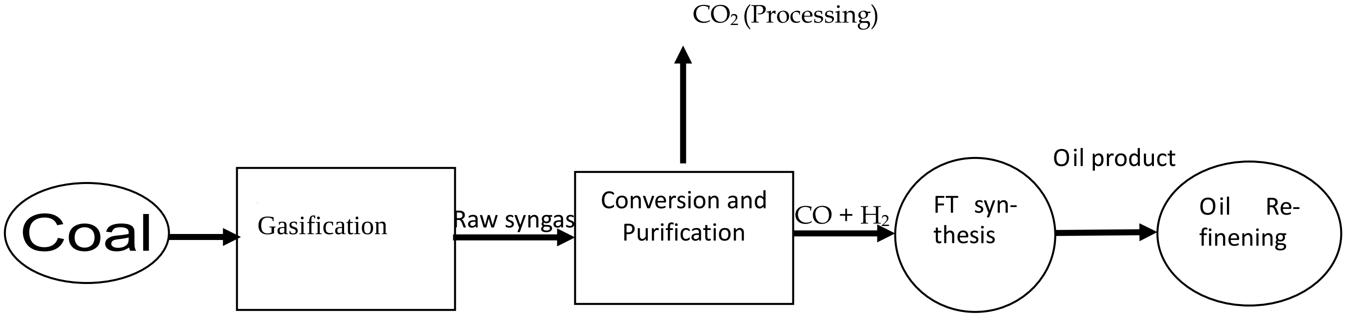

Figure 7: Route indirect liquefaction of Coal for oil refining

## Natural Gas from Coal

The products on which the life –cycle assessment will be performed are the products at the gate of the coal conversion plant. The considered system begins with the coal mining process, followed by its transportation to the coal conversion plant. The conversion unit is split into three parts, namely the coal gasification part, the natural gas synthesis part, and the carbon capture and storage part. Power is supplied to the gasification unit by a power block (integrated gas combined cycle (IGCC)), on which carbon capture is applied as well [40].

The comprehensive coal consumption is about 1.97~2.25 tons of standard coal equivalent per cubic kilometres of natural gas; energy conversion efficiency stands at 55~63%. The $CO_2$ emissions are about 3.2~5 tons of carbon dioxide per cubic kilometres of natural gas (or, 0.086~0.145t/GJ), among which 0.057~0.097 tons are discharged in the recovery of sulphur and processing of chemical products such as $K_2CO_3$, acetic and underground fire extinguisher thereby reducing $CO_2$ emissions to about 0.029~0.058 tons which goes to the public process. This is actualisable because the $CO_2$ produced in the coal chemical processing are of high concentration and high pressure which is helpful in capturing, recovery and utilization of other chemical products; however, priority can be given to deploying captured $CO_2$ to coal chemical industry and power plants for power generation.

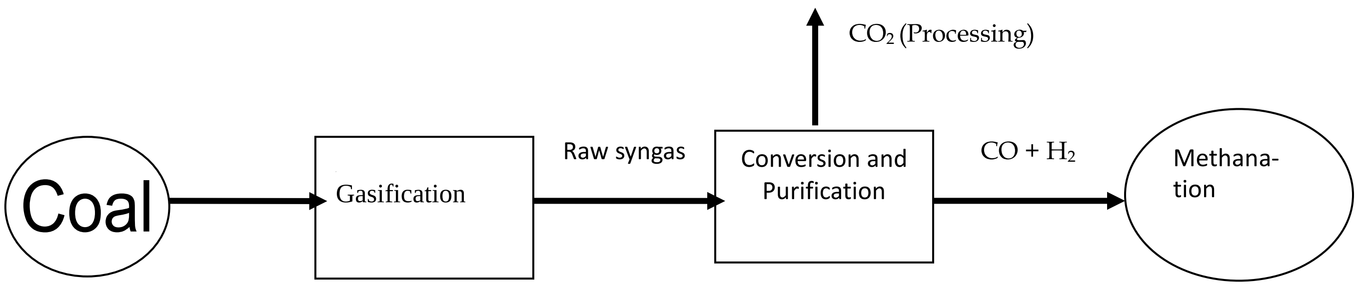

Figure 8: Route conversion of Coal to Natural gas

## Life cycle inventory (LCI)

Based on the previously defined scope, the data collected for the different lifecycle steps will be presented in the following sections.

## Mining

In order to extract coal from the ground, a mining step is required. For this LCA, an average North-American underground mine has been considered [40]. Electricity, heat, and diesel requirements for mining operation are included. A specific coal type has been considered for the internal study [4].

## Transportation

As the coal mine and the production plant are not located on the same site, transportation of the coal to the conversion plant is required. It is assumed that the distance between mine and process plant is 100 km. The transport system used is freight train transportation, assuming average diesel and electricity consumption [40].

## Conversion process, utilities and power block

All green house gases (GHG) emissions and fresh water requirements were taken into account. All energy requirements for the conversion process and utilities are assumed to be covered by the power block [4]. Due to the relatively low number of start-ups (around once every 3 years), only emissions occurring during the regular operation phase were considered [40].

## Conclusion

This study examined potential benefits of coal through improved technology in most developing parts of the world. Coal is the world's fastest growing energy source and has been set to continue on this path in the future [41]. With new resources of coal being identified in countries such as Mongolia, Botswana, and production so far increasing rapidly in Venezuela and Colombia; the need for rebirth of the coal industry in Nigeria becomes essential. The need for coal to clean transportation fuel will continue as long as the pressure on oil price remains high. Commercially it was found that methanol-to-gasoline (MTG) technology, coupled with established commercial coal gasification and methanol technologies, provides an economically competitive and low risk option for the production of clean gasoline from coal. The methanol-to-gasoline route for coal conversion also provides the additional flexibility for directly applying the technology to extend the product slate and flexibility of existing methanol plants.

In addition, the location of the world's oil and gas resources and their availability to consumers is a major concern, and import dependency is a considerable part. Countries and governments may feel an elevated level of risk if over-dependent on one particular fuel source or on imports from one particular region; particularly if the region is an unstable one where risks may change frequently. Coal on the other hand offers security of supply benefits and possesses a particularly broad geographic resource distribution where it is present in more than 70 countries worldwide and currently mined in 50 of those [42]. Coal users can benefit from utilising their own indigenous resources, or by accessing affordable coal in a well-established market from a wide variety of countries and suppliers. Even taking into account the costs of transformation, coal-derived fuels can provide a hedge against the volatility of oil prices and facilitate greater economic independence through the stabilisation of demands on foreign currency reserves. Finding from this study showed that coal can produce products such as ammonia & Urea, methanol, olefin, natural gas, and dimethyl ether in commercial quantities. In addition, since, the CO2 produced in the coal chemical processing are of high concentration and high pressure, it was found to be helpful in capturing and utilization of other products such as urea, acetic, potassium carbonate and underground fire extinguisher. Hence, priority can be given to deploying capture of the $CO_2$ to storage technologies in the coal chemical industry and power plants for boasting electricity generation which stands as one of the major infrastructural challenges facing the Nigerian government. These findings explore the benefit of effective and efficient product life cycle engineering in encouraging sustainable development around the globe. However, from the observation made in this study, we advocate for the revitalization of the coal industry in Nigeria and the encouragement of private partnership in the sector for generating the commercial aspect of the industry especially in the area of natural gas production and power generation in Nigeria.

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