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Developing Modular Refineries in the Downstream Sub-Sector of the Nigerian Petroleum Industry

Olatona Temitope Olaniyi
A Dissertation Submitted to the School of Graduate Studies in partial fulfillment of the requirements for the award of degree of Master of Science (MSc) Petroleum Economics, Management & Policy) in the Department of Petroleum Engineering, Faculty of Engineering, University of Port-Harcourt

***Abstract* - The study commences with the modular refinery definitions, limitations, and comparative advantages to full-scale and provides answers to a few refining questions. At conception, did modular refinery make business sense; the study delves into the reasons and explains entire modular refinery processes. What are the available options, configuration, processes, and economic advantages of the atmospheric distillation unit.? The study explains reasons for refining margin instability outlook, any considerable factors to enhance refining margin by up to 20-25%. Why should an investor prefer modular refineries, national refineries? Feasibility study results, product yield analysis, configuration and upgradability of modular refinery, etc. Why the need for synergy between the modular refinery and full-scale. What is modular refinery complexity and how it does affect refining margins? What are the roles of refinery optimization, linear programming, benchmarking, bottom-line, and maintenances in tackling the refining complexity in modular refinery sustainable development? The study also presents the gap analysis between petroleum product demand and supply in Nigeria, as opportunities for the development of modular refineries with reference to the sub-optimum state of our domestic refineries. What are the challenges to the sustainable development of modular refineries in Nigeria? The study discusses further the legal framework, licensing procedures, types of business model, finance lenders, what economic factors there are for modular refinery, and spectacular benefits of modular refinery. The study has a six-stage methodology design, contains detailed financial analysis for a 10,000 bopd capacity modular refinery vis-a-vis the stimulated number of modular refineries to attain self-sufficiency in 2021. The results show relationships between crude oil price and gross margin model and refinery efficiency, gross margin relationship model. The research study enumerated critical roles of the government in modular refinery development, the need for refinery synergy is a prerequisite to becoming self-sufficient in PMS production for domestic consumption among other germane discussions**

Keywords: Modular refinery, refining margin, self-sufficiency PMS, domestic consumption, government roles

I: INTRODUCTION

1.1 Background to the Study

Historically, the first domestic refinery in Nigeria was developed and located in Portharcourt in 1965. Shell-BP saw an opportunity to so do in the domestic deficit as an incentive to develop the first refinery. The same refinery was later upgraded from 38,000 BOPD capacity refinery to 60,000 BOPD capacity refinery. Upon this milestone development, Nigeria was able to meet and exceed domestic demands for refined petroleum product. This brought Nigeria into the limelight as one of the oil producing-nations.

However, as the nation's population and economy continued to grow with possibility of the population growth rate exceeding the economic growth rate with resultant potential demand-supply gap shortfall, the country embarked on development of second refinery, a 120,000 BOPD capacity. The refinery was finished and commissioned in 1978 in Warri, bringing the total number of refineries to two. And with the two refineries, the country was able to adequately supply to meet the domestic demands.

In 1983, the third domestic refinery with 110,000 BOPD capacity refinery was built to augment production capacities. This was located in Kaduna. The third refinery notwithstanding, based on economic growth and attendant economic intelligence projected domestic demand may outpacing supply in 1989, Federal government appropriated another final investment decision to develop the fourth refinery in Portharcourt. This time around, the name plate capacity was about 150,000 BOPD capacity refinery to meet domestic demand, as the second refinery in Portharcourt. With the additional refinery in Portharcourt, the total number of domestic refinery was now four (4) as at 1989, with a combined production capacity of about 445,000 BOPD.

Beginning of 1990, the unexpected began to happen, the four domestic refineries combined capacities was no longer sustainable as they could not perform to their optimum. This was as a result, government interference, inadequate maintenances resulting in less capacity utilization, poor funding among many others. Unfortunately, this trend has persisted ever since despite all frantic efforts and budgets earmarked for turnaround maintenances, rather than getting better, performance has been on the downhill direction. In fact, the combined capacity utilization dropped to 6.1% in September, 2017 which represents a continuous drop from the average 13.7% in 2018 (Ogbon N, 2018).

In contrast to the contemporary, the domestic refineries are considered to have so much aged due to irregular maintenance and recently, statistics show production at a paltry level of 30% combined capacity equivalent to about

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1.6 billion liters of petroleum motor spirit (PMS), a lot less compared to an estimated 18.8 billion liters of PMS per annum required to meet the domestic demand in 2017.Apart from ageing, the continued decline in production capacity, among other, is what has led to introduction of modular refineries by the Federal government as part of the transformational agenda to exit the country from over dependence on imported refined fuels and to become self-sufficient and ultimately a net exporter.

Comparatively, modular refinery can be said to be less sophisticated compared to the conventional refineries. In addition to its comparative advantages, the word modular is because it can be setup on skid-mounted structure, otherwise known as, modules. The modular structure gives modular refinery its low investment capital, short payback period and relatively good margins and more, thus making modular refinery enticing to upstream and downstream operators. Modular refinery is much less capital intensive compared to conventional refinery, therefore making it a viable option in inaccessible location or rural areas, especially where diesel supply is inadequate to meet daily consumption demand.(Mcguire D, 2019). It is important to mention that modular refineries are available from 1,000 to 30,000 barrels of oil per day based on a study report by proshareng. (Brickstone P, 2019).

Furthermore, a modular refinery can further be differentiated as per their respective refined outputs,(Olumide A., 2017), that is, modular refinery with PMS and modular refinery with Diesel. Rather than having just one conventional refinery to meet the domestic demand of a region or country, in which any attacks or force majeure may cause a shutdown of the refinery inadvertently. The economic impact of the shut down on the region or country may be too harsh or worse still; the region or country`s economy may grind to a halt. Instead, it is therefore preferable to have several modular refineries in place of the just one conventional refinery, of which when one modular is shut down, the others may still be in operation to sustain the economy of the target group, thus zeroing or minimizing impact on economy(Detail Commercial Solicitor, 2018). Table 1.1shows the simplistic difference between a modular and conventional refinery

Modular refinery is simply an Atmospheric Distillation Unit (ADU) in Table 1.2. This is also known as Topping Plant.(MUHENDISLIK K, 2019). The simplest modular refinery yield is an Atmospheric Distillation Unit, otherwise known as Topping Plant.[1]It comprises of a crude oil distillation unit which operates a little above the atmospheric pressure (to produce gasoline, kerosene, and diesel and heavy diesel oil among other) and fluid catalytic cracking unit for conversion of heavy crude to light oil(Cenam Energy, 2019) at a much higher temperature (TIMTIANPCC, 2019). Kerosene, Jet fuel, distillate fuel oil such as diesel are generalized as middle distillates(Jechura J, 2018)optionally, hydro cracker may be required as an addendum to a modular refinery[2]to achieve a full conversion refinery.(Cenam Energy, 2019). Modular refinery has capability for producing a wide range of arbitrary petroleum product(Brickstone P, 2019) such as gasoline (aviation and motor gasoline, distillates (jet fuel, diesel, kerosene and fuel oil) and heavy fuel oil (asphalt, lubricants, waxes etc.); however, the refined product(s) from any modular refinery is informed by the force of local demand according to the refinery configuration(Brickstone P, 2019).

Similarly, a case study shows the gross profit margins from investment in conventional refineries have always been all-time low. The margins keep crashing [3]and does not mean well for oil marketers or refiners at large(Cunningham N, 2018). What this portends for modular-mini refiner may be so damning without a cushioning effect from the refining units. The modular refinery configurations of simple unit for diesel production to higher refinery complexity(ABarrelFull, 2014) ones are better-off in terms of margins for refiners in remote locations (Cenam Energy, 2019). Modular refinery competitive advantages such as ease of construction and few hours of commissioning and low interest charges play key role in this[4](Olumide A and Ayodele O, 2017)

Nigeria has had four (4) refineries since 1969 till date. Despite this, Nigeria remains mono-cultural economy and still so much depends on importation of 80% of current domestic demand to sustain the economy, a huge market for domestic refinery investments and expansion(Olumide A et al, 2017). The concern is not about the availability or non-availability of crude oil but rather inefficient and ineffective state of our refineries that operate below optimal capacity. In 2016, the local refineries capacity utilization was 12.85% and 16.59% in 2017[5].Beyond the comatose performance of the refineries,[6]the general failures of the refineries to operate up to the optimum refining capacity after repairs and major maintenances upon maintenances remains a debilitating impact on our economy(Petrobarometer, 2018).The only sustainable means to put an end to fuel importation[7]is green refineries. In a related report, (Nwaozuzu C, 2018) stated categorically that the country would need a minimum of 1.2 million bopd total refining capacity to attain self-sufficiency in meeting domestic demands for petroleum products and cater to smuggling across our porous border. However, optimism is high of Nigeria ability to transition from a net import to net export with the current upsurge in petroleum policies and dip in crude oil prices(Olumide A and Ayodele O, 2017). This is a huge opportunity for modular refinery promotion either as standalone or complementary to the conventional refineries (Olumide A and Ayodele O, 2017). No other reasons are tenable for the development and promotion of Modular-Mini Refinery in Nigeria now than before. In the contemporary, Nigeria is, therefore, considered for modular refineries and modular refineries are being recommended as a viable alternative(Ibikunle O,Adeyemi O.,Yusuf O and Akarakiri J, 2016).In my opinion, it is misplacement of priority and misconception of highest order to have suggested replacement of illegal refineries with modular refineries(Mamudu A,Okoro E,Igwilo K and Olabode O, 2018) just so to end illegal refineries, illegal refineries, also known as, artisanal refineries which obtain crude oil from vandalized pipelines.

(Maclean M & Steve.A, 2019) This also implies artisanal refineries cannot operate without oil theft and oil theft is oil sourced through stealing[8].

Having established the feasibility of modular refineries, of course, not as a replacement for illegal refineries but rather a vias able option to close the perennial gap between supply and demand for the petroleum products in the local market is imperative to mention that the viability or success of the development of modular refineries is not without attendant challenges that must be tackled or fought frontend. Two of the major challenges identified in this study are lack of adequate capital vis-a-vis technical know-how and incoherent licensing structure and idle licenses, just to mention a few. The regulatory body saddled with the responsibility of issuance of licenses will definitely need to retract the proceedings for companies with expired licenses. It makes no economic sense to have been licensed and allow the licenses to expire for whatever reason. As at this day, there are 43 licenses for both modular and conventional refineries, most of them have expired and only a few active licenses remaining[9] According to report, only about ten(10) have made commendable progress and been issued authority to construct (AtoC) license by DPR(EnergyMix Report, 2019).

1.2 Statement of the Problem

Domestic refineries in a state of disrepair: The urgent necessity for modular refinery development in Nigeria is a result of a major problem in the downstream sector of the oil and gas industry. It is a consequence of age-long negligence and inadequate maintenance culture of the existing four domestic conventional refineries. Although these refineries are acclaimed to be obsolete and suffered from perennial poor technical care which have responsible for sub-optimum, performances are often recorded. Even at that, perhaps they were optimum in performance and capacity utilization above 80%, they still would not be able to meet the domestic demand for petroleum products, a major concern, and gaps that must be filled

Supply-demand gap: Today, the Nigerian population growth is at such a level that refinery capacity can no longer match the domestic demand, hence the over-dependence and need for the importation of refined petroleum products to close up the gap already created remains unresolved, a problem that must be resolved urgently. Besides the supply-demand gap already identified, the government roles cannot be substituted with any other entity that may be, government must rise up to the occasion and do the needful, invest massively in infrastructure and equally participate in the modular refinery development through investment partnership or taking full ownership as a sign of business desperation and seriousness. It is in this view of the above problems that the following pertinent questions are presented as follows:

- What has crude oil price volatility got to do with refining gross margin? There is a need to estimate the relationship between the two aforementioned variables such that when there is a change in one, what is the corresponding change(s) in the other.
- Secondly, is there any relationship between refining capacity or efficiency and the refining gross margin?
- How many modular refineries will be required to meet the current domestic demands considering the current exponential population growth of the nation?
- Does the investment towards modular refineries give any guarantee of impressive returns, in terms of gross margins, on investment in a short term?
- What are the regulatory roles of the government towards modular refinery promotion and development?

1.3 Aim/Objectives of the Study

The aim is to conduct a research study on the 10,000 BOPD capacity modular refinery with the objectives of further analysis to show what the refinery product mix or yield and what each product yield percentage looks like refinery gain is applied. The ultimate goal is arriving at what are the requirements to attain self-sufficiency in production of PMS. What is the relevance of refining gross margins and of course the any possible relationship between gross margins, crude oil prices shocks and refinery efficiency?
In more specific terms, taking the study further, the following are the specific objectives of this study:

- To estimate any relationship between refining gross margin and crude oil prices volatility using a 10,000 BOPD modular refinery vis-à-vis, the relationship between refinery efficiency and refining gross margin
- To evaluate the number or quantity of 10,000 BOPD modular refinery(s) that will be required to meet the domestic demand for petroleum motor spirit (PMS) by the year 2021, using the 10,000 bpsd hydro-skimming modular refineries as a case study, at the least attaining self-sufficiency
- The result of the number of 10,000 BOPD modular refineries to attain self-sufficiency as above shall highlight the need for the possibility for a synergy between modular and full-scale refineries towards self-sufficiency before being a net exporter of petroleum products ,especially the PMS.
- To summarize what roles the host government needs to play in the development of modular refinery such as creating modular refinery clusters, among other equally important roles of government.

1.4 Significance of the Study

Within the confine of the assumptions made and stated facts, this study shall be of immense contribution and useful information towards the development of modular refineries in Nigeria.
The research study unequivocally will be explicit on the fact that modular refineries are established for domestic demands. Any efforts by its operators to export the products will compromise the real essence and defeat the purpose of

having modular refineries. It is expedient to state also that where priority is for production for exportation, full-scale conventional refineries are best suitable because of its larger capacity making it possible to spread the cost of production, hence a much-improved refining margin.

Secondly, the research study supports the idea of using modular refineries, however, must be in a large quantity to be able to meet the huge domestic demands. This buttresses the fact that self-sufficiency must be attained before net-exportation should be considered as per the transformational agenda of the federal government.

The understanding of the petro-economic aspect of the modular refinery is a necessity. This study is expected to provide prospective investors refiners with a hands-on set of information that may be relevant in making a final investment decision. Having comprehensive ideas of business model specially designed for modular refineries, the types of the financial institutions, investment fund sources set up purposely for an investment of this nature. In addition to this, an in-depth interpretation of the refining margin and the risk inherent in the oil price volatility.

Finally, government participation in the development of modular refineries is highly inevitable. You cannot continue to woo investors while you seat on the fence. Prominently, the government must have a mechanism for pricing crude oil for local refiners and at the same time, design a subsidy regime that varies with refinery capacity because the refining margin is sensitive to crude oil volatility and if not managed economically, the little profit margin may get eroded by increase in crude oil price.

1.5 Scope and Limitation of the Study

The research study is centered on the development of modular refineries in Nigeria petroleum industry and consequently, what roles the government must play to fast-track the development. The under-listed are the scope of this research study and a few limitations as identified as follows;

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- Most importantly, the research study estimates only the number of 10,000 bspd modular refineries needed to meet countries' domestic energy demand by 2021. This is due to the on-availability of analytical data such as the output yield from the other modular refineries' capacities. Needless to mention, required data about the possible product yield from other capacities of modular refineries were not readily available, so was restrained to only the 10,000 bspd capacity to estimate gross revenue, operating expenses, and feedstock cost.
- The research study emphasizes the 10,000 bopd capacity modular refinery for petroleum motor spirit (PMS) production, PMS being the most popularly demanded domestically. This is the basis for forecasting the domestic consumption by 2021just so to be able to estimate the quantity of modular refinery required to achieve self-sufficiency of the transformational agenda of the federal government.
- The prices of crude oil used for the research study analysis are mere assumptions on $55/bbl step-wise increment and not on any empirical data as there is no data available domestically. Similarly, refinery efficiency is on the basis of discretion, provided all other conditions remains the same(ceteris paribus).
- The forecast for PMS domestic consumption by 2021 was based on 2017 analytical data of 18.81 billion liter per year with 700 million liter per year increment for the next four year. The data from 2018 was still under debate thus remains inconclusive and 2019 is not out yet. The truth is Nigeria does not have a viable database and most estimations are politically motivated and so cannot be verified beyond their peripheral values.
- Refined product such as naphtha has no commercial value yet in Nigeria, they are being imported at a price. Of course, during the course of this study, to maximize the full benefits of distillates from modular refineries, a full conversion unit is a requirement, however, it is unfortunate, and our domestic refineries which could have offered the services of further distillation are in a state of comatose and so are incapacitated to do such. This thus implies the possible importation of naphtha if the volume is viable commercially.
- The research study is not so much delved into mini refineries and conventional refineries, just a few details about mini-refinery and differentiation from modular refineries. Nothing much is discussed on the requirement for the conventional refinery in combination with a modular refinery in meeting domestic demands.
- One more, the refinery maintenance is as important as the investment in it. The four domestic refineries are in a parlous state today as they were not properly maintained. However, this study digressed a little into the maintenance aspect of the modular refinery known as linear programming and optimization of the entire supply chain, just so to maximize profitability by reducing cost and eliminating wastages. However, there is more to be researched into regarding supply chain and linear programming.

II: LITERATURE REVIEW

2.1.0 Literature Review

However, for the purpose of extensive clarifications and provision for explanation on the importance of modular refinery sustainable development in Nigeria, and the roles of the government, this study took a dive into other relevant previous research works in the same downstream industry, the aftermaths of the reviews have been put together to provide readers an in-depth understanding of the background of this study, it is such a wide study. The reviews have contributed immensely as a source of insights into the new discoveries to close out the lapses observed. All through this study, it is clear that none of the previous articles or research works reviewed have all-in-one documents, at the least the minimum, the full details of both technical and economical requirements for investment in modular refineries vis-à-vis government roles in Nigeria. This is what this study has to offer the readers. However, the relevant literature review has been sub-divided into three parts as follows:

- The concepts about modular refinery with reference to the preference of modular to conventional refineries. Also reviewed is the modular refinery case studies and the process flow charts, the modular refinery configurations, the product-yield percentages and spectacular benefits of modular refineries.
- Still about modular refineries, this research study took a swipe at the complexities of refinery operations and its essence. What is the linear programming and optimization, reasons and applications of linear programming, how to integrate operating and planning information into the linear programming, salient points about linear programming as it applies to modular refinery. What are the inputs to run a linear programming and the expected output results? Refinery benchmarking and different types of maintenances for modular refineries
- The literature reviews will not be completed without reference to the state of oil refinery infrastructure in Nigeria, the current domestic supply and demand, the urgent need for modular refineries to address the demand shortfall. Even in addressing the gap, there are still some mis-conceptions about modular refineries as discovered in some of the related literatures, this needs urgent correction. The correction is one of the offerings of this study. This now takes the study reviews further into the modular refinery development in Nigeria with emphasis on what roles the government should play towards the development of modular refineries in Nigeria.

2.1.1 Concept about Modular Refinery

A modular refinery was also developed where local demands took precedent over the economic viability as modular refinery initially never made any economic sense to invest into, according to(Mcguire D, 2019). It was intended to make power available in remote rural locations and affordable by rural dwellers. An instance is where diesel supply was needed to run power plants in remote health-centers during emergencies such as surgical operations to save human life among other related applications. Modular refinery is much less capital intensive compared to conventional refinery, therefore making it a viable option in inaccessible location or rural areas, especially where diesel supply is inadequate to meet daily consumption demand.

Modular refinery conception was premised on necessity for a refinery that can be put back in operational use quickly[10]after at most four (4) hours of cold start(KUAI Energy System), ease of mobility with minimum logistics requirements such as cranes, concrete floors and power station(Mcguire D, 2019). The short fall may be due to logistic problems or where fuel supplies are exorbitant.

Another concept is that modular refineries are never setup as standalones but rather as contingency or redundant system to existing full-scale conventional refineries. This is the most popular and best practices especially in Europe. In other places where there is no conventional refinery, a modular refinery is setup alongside a power plant to make a complete system where the output from the modular refinery is an input into the power plant. This is most common with independent power plant (IPP)(Nwaozuzu C, 2013)

Generally, refineries can be divided into three (3) classes of refineries. They are; mini refinery, modular refinery and conventional refinery which is the full-scale refineries. Each of the refineries are unique with their respective sizes and distinct capacity for the purpose of differentiation in terms of barrel of oil per day(bopd)[11]number of skids, and the number of hours required for commissioning (Mcguire D, 2019) as shown in Table 2.1. The higher the refining capacity, the higher the number of skids and the more the hours required for commissioning.

According to (KUAI Energy System, 2019), modular and mini refineries vary from 500; 625;1000;2000;3000;6000;10,000;12.000;15,000;20,000; and 30,000 refining capacity of crude oil per day. All the same,(Mcguire D, 2019) defines mini-refineries as ones with refining capacities from 1000 bopd and below. And a modular refinery as one that is built in modules mounted on skids. According to work scope on the (Federal Ministry of Petroleum Resources, 2017), a modular refinery shall not be more than 30,000 refining capacity, anything more than that shall be considered as a full conventional refinery. Another school of thoughts [12] says modular refineries can vary from 1,000 to 30,000 bopd capacity(Olumide A., 2017). And the conventional refineries are always from 30,000 bopd capacity and above. Meanwhile mini-refineries are range from 500-600 bopd or anything less than a thousand capacity,[13]and modular refineries are available from 1,000 to 30,000 barrels of oil per day based on a study report by(Brickstone P, 2019) . However, for the purpose of this study, the focus shall be on Modular Refinery, the word modular because; it can be setup on skid-mounted structure, otherwise known as, modules. And furthermore, a modular refinery can further be differentiated as per their respective refined outputs, (Olumide A., 2017), that is, modular refinery with PMS and modular refinery with Diesel.

2.1.2 Preferences for Modular Refinery to Full-Scale Refinery

1. Cash Outlay: Modular refinery is an asset that requires a huge capital expenditure to acquire especially a new modular refinery. It is a lot cheaper compared to its conventional refinery equivalent with same capacity. For a 100,000-bpd conventional refinery, it will require not less than $1.5 billion and above, while for three (3 x 30,000) bpd modular refineries[14] which is just about $750 million ($250 million per modular refinery). The price difference can be a lot less or more depending on the refinery complexity and capacity(Detail Commercial Solicitor, 2018).

2. Manufacturing Lead Time: Modular refineries are assembled at the manufacturing plant, transported as skids and setup at the field location while the conventional refinery is built from scratch to finish at the field location and this takes minimum of three years to eight years to deliver while modular refineries takes estimated 18 months to 24 months maximum, depending on the capacity[15], it is quite easy to construct and quality-controlled before delivery In the Nigeria case, where our refinery capacity is at all-time low, [16] modular refineries will be most suitable to quickly turnaround and increase the overall refining capacity of the nation just so to meet the domestic demand because of the short lead-time.(Detail Commercial Solicitor, 2018)

3. Upgradability: Modular refineries enjoy ease of improving the capacity whenever the need arises. A 10,000 bopd can be doubled or tripled within the shortest possible time[17], similarly, it does not take as much time to disassemble and relocate the entire modules to another location. These flexibilities to upgrade and ease to relocate are near impossible with a conventional refinery. Conventional refineries are permanent structures and to upgrade, there are factors of production that may limit the possibility and ease (Detail Commercial Solicitor, 2018)

4. Sustentation: It takes a lot, in terms of procedures, processes, guidelines and quality control to keep-up with the operations of a conventional refinery, same as the requirement for its maintenance. One of the greatest challenges of a conventional refinery is inadequate maintenance or irregular turnaround maintenances. These are the reasons for the sub-optimal capacity performance and poor utilization of the four (4) domestic refineries operated by the government. Meanwhile,[18] the modular refineries are easier to maintain and costs a lot less and less time. Manpower for the maintenance is few and the covered area is properly secured, less susceptible to external aggression and sabotage(Detail Commercial Solicitor, 2018)[STOP]

5. Investment Efficiency: The net cash flow(positive) analysis of an investment in a modular refinery[19] is estimated between 2-5 years (WREN, 2016) while the net cash flow in a conventional refinery is estimated 18 years and above(Olumide A and Ayodele O, 2017). This implies the return on investment in a modular refinery is quicker compared to conventional refinery.[20] Another determinant factor of how soon is the projected payback in investment in refinery is the capacity and complexity (Detail Commercial Solicitor, 2018)

6. Economic Impacts: In event of any emergency**,** rather than having just one conventional refinery to meet the domestic demand of a region or country, any attacks or force majeure may cause a total shutdown of the refinery inadvertently. The economic impact of the shut down on the region or country may be too harsh or worse still, the region or country`s economy may grind to a halt. Instead, it is therefore preferable to have several modular refineries in place of the just one conventional refinery or as a backup,[21]of which when one modular is shut down, the others may still be in operation to sustain the economy of the target group, thus zeroing or minimizing impact on economy(Detail Commercial Solicitor, 2018)

2.1.3 Case Study of Modular Refineries

Globally, the gross profit margins from investment in conventional refineries have always been all-time low. The margins keep crashing [22]and does not mean well for oil marketers or refiners at large(Cunningham N, 2018). In the last one decade in US, refining margin for motor gasoline has been on a decline according to a data analysis from EIA, Figure 2.1.

Also, worth noting is that from every single barrel of crude oil processed in a conventional refinery, the gasoline output is twice the diesel output, yet the margin from gasoline has been on the decline, should refiners then cease to refine for gasoline just so to favor other products such as diesel due to its advantageous price?(Cunningham N, 2018). What this portends for modular refiner may be so damning without a cushioning effect from the refining units. The modular refinery configurations of a simple unit to higher refinery complexity for diesel production (ABarrelFull, 2014) ones are better-off in terms of margins for refiners in remote locations(Cenam Energy, 2019). Modular refinery competitive advantages[23]such as ease of construction and few hours of commissioning and low interest charges play key role in this(Olumide A and Ayodele O, 2017). One or more 10,000 bopd for production of gasoline, diesel, kerosene and fuel oil where demanded, will not take more than one year and six months to commission with a principal of about 200 million us dollar.(Cenam Energy, 2019)

2.1.4 Modular Refinery Processes

By way of introduction,[24]refinery is a chemical transition of crude oil into fuels and other petro-chemical to satisfy customers demands(ABarrelFull, 2014). As much as there are different refineries (Olumide A., 2017), refineries have unique and different levels of complexities known as (Nelson Complexity) - the more the number of units the more the complexity.

Refineries also differ in terms of types of crude oil and different chemical transition process. An example is a Hydro-skimming refinery, it has no capability for cracking; their complexity unit is 2-3(ABarrelFull, 2014). The chemical transition processes are broken into five different units, most widely common in all oil refineries(TIMTIANPCC, 2019). The modular refinery units are as follows;

1. Fractionation Unit.[25]This is first separation of crude oil into fractions or distillate based on different boiling point prior further processing in other units(A Honey Well Company, 2017). Example of such unit is Atmospheric Distillation Unit or Vacuum Distillation Units. Gasoline, Automobile Gas Oil, AGO and Dual-Purpose Kerosene, DPK can be obtained during this process[26]. The modular refinery is simply an Atmospheric Distillation Unit (ADU) also known as Topping Plant.(MUHENDISLIK K, 2019). The ADU is a size of a container with varying refining capacity. The ADU can be used for production of automotive diesel, jet kerosene, naphtha and HFO.[27]Additional 6 to 8 ADUs can be setup in the same site location, linked together with flanges, i.e. adding-up the

units. The ADU comes in a complete package with all the requisite components and accessories with optional equipment such as de-salter, desulphurization and catalytic reformer[28].(MUHENDISLIK K, 2019)

2. Conversion Unit. This is dividing the fractions into hydrocarbons by either thermal or catalytic cracking(ABarrelFull, 2014). And combining through Alkylation and Polymerization and finally –re-arranging the hydro-carbon molecules with Isomerization Unit and Catalytic reforming Unit.(TIMTIANPCC, 2019)

3. Treatment process. This is getting the hydro-carbon ready to go as finished petroleum product. This is the process of removal of impurities and undesirable contaminants(TIMTIANPCC, 2019). This treatment can be carried out using physical filtration method or by using chemical, i.e., crude oil desalting, drying solvent de-waxing (ABarrelFull, 2014)etc.

4. Blending and Formulating. This is putting together hydro carbon fractions with additives to produce a finished product with specific quality and chemical composition for an improved performance.

2.1.5 Modular Refinery Flow Chart

Using as feedstock: Nigerian Crude Oil (API 36.25 and 1.3 PPM Mercaptan Sulphur). The feedstock is fed into the ADU as shown in Figure 2.2 which distills the crude into naphtha, kerosene, heavy diesel and some residue. Naphtha is supplied into the Naphtha Hydro Treatment (NHT) unit for producing a Reforming Stock which now goes into the Semi Regeneration Reforming(SRR) from where the final products as Petroleum Motor Spirit(PMS) and Liquefied Natural Gas (LNG) which are stored in separate tanks(Peiyangchem, 2019). The residue from the ADU passes through the VDU as shown in Figure 2.3 to produce Vacuum Gas Oil which is now fed into the Fluid Catalytic Cracking (FCC) unit. The dry gas outputs from both the FCC and ADU are both combined in the Hydrogen Generator. Similarly, FCC AGO plus ADU kerosene and Diesel are together discharged into the AGO Hydro Treating (DHT) unit to output the HT AGO and the eventual products are AGO and kerosene (DPK-Dual Purpose Kerosene) which are sent to their separate tanks for storage. The sulphur goes into the dry gas, LPG, gasoline and FCC fumes. The sour water and the sour gas (sulphur) must be purified by conversion into SO2 that is, detoxified before being flared and burnt off into the environment while the sour water is re-injected for electric desalting as shown in Figure 2.4.Note, the following products fuel oil, lubricating oil, waxes and asphalt cannot be produced from Modular Refineries.

2.1.6 Modular Refinery Refined Products

Crude oil is a composition of mix of hydrocarbons(KUAI Energy System, 2019).See Table 2.2.Modular refinery has capability for producing a wide range of arbitrary petroleum product(Brickstone P, 2019) such as gasoline (aviation and motor gasoline, distillates (jet fuel, diesel, kerosene and fuel oil) and heavy fuel oil (asphalt, lubricants, waxes etc.); however, the refined product(s) from any modular refinery is informed by the force of local demand according to the refinery configuration(Brickstone P, 2019). There are no two refineries which are similar, each has peculiar features. For knowledge's sake, heavy oil compared to light oil, is not as practicable with modular refinery except with special refinery configuration.(Cenam Energy, 2019).

In Nigeria market today, gasoline remains a high demand product and as such refiners are more geared toward refinery configuration for maximum gasoline production at the neglect of other associated petroleum product. According to (Brickstone P, 2019), 50% of total local demand is for gasoline sales while other distillate sales are about 30% of product demand. However, in developing nations where modular refinery is gaining momentum, there is a generic demand for both gasoline and distillates used in haulage and transportation businesses.

Over decades of improvement and evolution in the refinery industry, crude oil can now be processed to produce over 2000 individual petroleum products. And intermediate product can be further distilled to different products.(EIA, 2018). Examples of Liquefied Petroleum Gas(LPG) are ethane, propane and butanes. While an example of Gasoline is Naphtha. The middle distillate samples are kerosene, jet fuel and diesel and fuel-oil. Petroleum products are inclusive of the asphalt (road-oil) and petroleum coke, lubricants, wax, petrochemicals and sulphur etc. to mention but few. (EIA, 2018)

Gasoline is efficient for use in a spark internal combustion engine with an ability to compress and not ignite before spark ignition, while diesel is suitable in a non-spark internal combustion engine, with ability for self-ignite when in a compressed air ambience.(EIA, 2018)

2.1.7 Modular Refinery Product Yield Analysis

Crude oils are not created equal[29], they vary in density and categorized by API gravity values. All crude types have varying percentages of sulfur, nitrogen and metal contents(Jechura J, 2018).

Based on API gravity, crude is light if API>38^o; medium if 38^o> API>29^o; heavy when the 29^o> API>8.5^o; and very heavy if API<8.5^o. The higher the API value the lighter the crude oil and vice versa. Table 2.3 shows different refinery products distillated at different temperatures. The simplest modular refinery yield is an Atmospheric Distillation Unit, otherwise known as Topping Plant as shown in Figure 2.2. It comprises of a crude oil distillation unit which operates a little above the atmospheric pressure (to produce gasoline, kerosene, and diesel and heavy diesel oil among other) and fluid catalytic cracking unit for conversion of heavy crude to light oil[30](Cenam Energy, 2019) at a much higher temperature(TIMTIANPCC, 2019). Kerosene, Jet fuel, and diesel are generalized as middle distillates(Jechura J, 2018).

It is relevant to state that it is possible to combine differing crude types and feed into a modular refinery as shown in Table 2.4. This also may help to improve refinery yield, a significant economic impact and percentage of gasoline yield.(Cenam Energy, 2019). The petroleum products from the distillation unit is now a feedstock into the cracking unit at a higher temperature and pressure with a catalyst for further refining processes where the gasoil is further distilled to produce gasoline and distillate product. Now, the last refining stage is the coking unit, where the residue from the cracking unit(Fluid Catalytic Cracking Unit) is now thermally cracked into lighter product. The FCCU is one of the most important units in oil refinery(TIMTIANPCC, 2019). Optionally, hydro cracker may be required as an addendum to a modular refinery to achieve a full conversion refinery.(Cenam Energy, 2019)

2.1.8 Modular Refinery Configurations

The most modular-refinery configuration that makes most business sense is a combination of an atmospheric distillation unit (aka topping plant) and a catalytic reformer, the product of which is gasoline. However, for this combination, the feedstock is of necessity light sweet crude and probably condensates. The production of heavy fuel oil depends on market demands and economics. This is the first level of refinery process called distillation refinery.(Cenam Energy, 2019). The atmospheric distillation unit does have same capability as the vacuum distillation unit except that it operates at less atmospheric pressure.

The second level of refining process is called cracking refinery, also known as catalytic reformer unit(KUAI Energy System, 2019). At this level, the output product, that is, diesel and heavy fuel oil from the first level is now combined with some catalyst. This combination now serves as a feedstock into the second level to produce more of gasoline and distillate. Worthy of note, is the inclusion of this second level in any modular refinery increases the refinery complexity(Brickstone P, 2019). See Table 2.5.

The third level which is also the last is called coking refinery, that is, introduction of another unit called fluid catalytic cracking unit (FCCU). The very heavy residual output product from both the first and second level is now further cracked by feeding into a coker or hydro-cracker. This produces additional gasoline. The whole idea is to increase the total gasoline yield percentage from a barrel of crude oil, high-valued gasoline product. The yield from a hydro cracker increases refinery volumetric gain by 20 to 25% for gasoline from the residue. This stage is always a special request to add to modular-mini refinery, its inclusion makes a modular refinery to obtain a full conversion refinery, making an important contribution to refinery margin.(Brickstone P, 2019)

The configuration of any modular refinery is incomplete without units such as hydrogen sulphurization units for removal of sulphur-related impurities from distillates. DE salter is another unit designed for salt removal from crude oil before being fed into the ADU or VDU. While the splitter or stabilizers are designed to split crude oil into two products and finally, a flare system for burning off excess gas after refining processes.(KUAI Energy System, 2019)

A modular refinery can be upgraded into a full flexibility refinery (Mcguire D, 2019), comparable to a conventional refinery as shown in Figure 2.5. This is achievable by building and upgrading the modular refineries into three (3) phases as illustrated in Figure 3.

Phase One(1) has only a 30,000 bopd capacity of modular refinery and later upgraded with additional two, (2 X 30,000 bopd), thus making approximately 90,000 or 100,000 bopd with add-ons such as vacuum and hydrocracker units for full flexibility and conversion(Mcguire D, 2019) See Figure 2.6.According to(Nwaozuzu C, 2013) it is feasible to have 100,000 bopd capacity in modular refineries(3 or more combined).Interestingly, the net cash flow realized during phase one(1) can be re-invested to add another modular refinery until the desired capacity is attained.

For a government built modular refinery, a full conversion facility, which is a combination of catalytic reformers and naphtha Hydro-Treater, must be added just so to be able to produce petroleum motor spirit (PMS).(Nwaozuzu C, 2013).

The premier refinery in Nigeria in 1969 was a simple hydro-skimming plant of 32,000 bopd, which in today's technical parlance, may be regarded as a modular refinery by reason of its capacity. Later, it was expanded to 45,000 bopd with a catalytic plant just so to convert naphtha to higher research octane number and PMS with high value(Ogbuigwe T, 2017). Today, the then premiere refinery operates at 60,000 bopd capacity. One of the neighboring countries, Ghana, copiously started with a simple hydro-skimming plant of 28,000 bopd capacity (Ogbuigwe T, 2017) (modular refinery of sort) and increased to 45,000 bopd capacity with a fluid catalytic cracker to increase PMS production.[31]

However, as earlier stated in this research study, oil refinery business is generally low on return on investment, however, modular refinery specifically for diesel production is a reprieve with much improved return on investment. More benefits are accruable when two or more are combined. Installation of 2X 30,000 bopd with a budget of about 200 million usd within a year and half is a huge positive compared to a newly installed conventional refinery with 100,000 bopd capacities, refer to Figure 2.6**.**

It will suffice to mention that refinery business has been faced with age-long challenges such as the low ROI; these challenges have been responsible for its inadequacy and low economic level of industrial investment and near-zero re-investment in conventional refineries (Modular Refinery Margin Trend Analysis, 2015). However, without an in-depth feasibility study and economic understanding of operations of modular refinery, the venture may be regarded as futile and a wastage. However,(Soyode and Eheanacho, 2019) advocates for synergy between modular refinery and the full-scale.[32]

Private-owned modular refineries can be modelled for diesel, kerosene and fuel oil production only where residue from the refineries such as naphtha can further be refined in a government owned refinery for distillation of naphtha residue to produce petrol (PMS). The reason being that, hydro treater and catalytic converter may add to the cost of modular refinery set up, because they are too expensive.(Nwaozuzu C, 2013). Typically, the high percentage of residue from Nigeria crude cannot all be channeled for further distillation to produce fuel oil or petrol, so what the naphtha is finally used for is a source of concern as naphtha has no applications yet in the Nigeria market (Mamudu A,Okoro E,Igwilo K and Olabode O, 2018)

2.2 Complexity of Modular Refinery Operations

1. Crude Selection The success of any refinery in terms of margin is as good as the selection of crude oil which cost is about (70-90)% of the entire refinery operating expenses. Regrettably in the contemporary, a refinery can only buy crude on a contract basis (long term) and by spot-buying from the market(short Term), thus making crude selection extremely impossible. Crude oil price volatility is another factor that affects crude oil selection; however, the decision of crude selection is such that is complex and as such must be well planned for and optimized on a long term.

2. Crude Transportation Having secured a supply contract for crude oil or perhaps on spot-buying, of next importance is transportation cost from supplier to the refineries. However, for modular refineries, the drive is to site refinery within proximity of crude oil source so as to maximize margin by saving cost of transportation.

3. Crude Processing The crude on arrival at the refinery must be carefully examined for its contents, value and condition before being processed. It is not an easy task to process the crude to maximize the dollar per barrel value. The refinery process is highly sophisticated today than before and environmental impact must also be given due consideration.

4. Product Demand The product quality, product demand and product prices are the motivation for crude processing. The more the grades of the products, the more the complexity of the operations and the more complex the supply chain management becomes[33]. (Raghav O.P, 2006)

2.2.1 Reasons for Refinery Operations Optimization

The deal is all about making optimum decision between value addition satisfactions to the end-users of refined products and maximizing profitability on the side of the refinery operators. While the end-user is concerned about the fuel economy when used in their vehicles, the operators are much more focused on the complexity of refining processes such as how to optimize purchase of appropriate crude oil, optimize a contract deal on a short and long term basis for supply of crude, optimizing the right crude oil mix, correct additives and blends where necessary, use of most effective technologies for refining, optimize utilization of the assets, optimize inventory management, optimize capacity utilization etc. All of these and many more operational activities are the reasons for the complexity and dynamism in the systems. All the same, any business decision must comply with the business strategic objectives at the corporate level. The refiners have a decision to make between the complex activities and customer satisfaction and margins. The decision is such a complex one to take, hence the need for optimization of the many-sided objectives within the supply chain of the business. Below is a table of many-sided decision to optimize.(Raghav O.P, 2006). The optimization necessity is such that requires a lot of hard work yet an opportunity for margins improvement

2.2.2 Optimization and Linear Programming

Optimization is making the best possible decision within the boundaries of limitations and flexibility. Linear programming (LP) is a mathematic way of solving mathematic equations with a solution, subject to linearity conditions. This is applicable for refinery operations planning and provides generic most profitable solution to refinery operation. The word linear is algebraic and satisfies two mathematical conditions which are additivity and proportionality while the word programming implies planning only. Therefore, linear programming means mathematical expression to represent planning and operations as mathematical variables and then solving the mathematical expression to obtain a favorable value between maximum and minimum plan. The LP model is an excellent economic assessment system to managing entire supply chain toward maximum profit.(Micheal A,T). The linear programming is now mathematical modelling software that is used to optimize multiple operations and planning, see as shown in Figure 2.7. It is a useful device to equate crude oil to product.[34]The objectives of linear programming are to optimize product value, to optimize material cost and to optimize refinery variable cost at the limit of the defined constraints(EKT Interactive, 2019).

2.2.3 Integrating Operating and Planning Information

Refineries have three levels of juxtaposing processes and operating data as shown below:

Level 3: The Planning Level. These are foundational to refinery operations, such as the assumptions on which the refinery operations are built upon

Level 2: The Plant Level. The outputs are required for daily operational instructions to achieve optimization result.

Level 1: Distributed Control System. See Figure 2.8

2.2.4 Refinery Planning and Optimization

This is introduction of supply chain management, that is, all about the inflow and selection of crude oil and other related additives, outflow of numerous refined petroleum products and the entire refining processes involved in conversion of raw materials into a finished good must be well coordinated in such a manner as to adding value to customer and optimize profitability(Linear Program Modelling).

Typically, a refinery supply chain is a combination of factory activities from selection, purchase and mobilization to the refinery, refining processes, off-take of refined product and transportation and marketing the product to final consumer. Crude selection does impact on transportation cost, and it also determined by the refinery configuration, capacity and limitations and of course, crude oil volatility.(Micheal A,T). The money-involved and management of refinery supply chain is such that is complex and thus requires a form of software application which uses Linear Programming technique.

2.2.5 Modular Refinery Benchmarking and Maintenances

It is a comprehensive audit of the plant on a bi-annual basis to determine and evaluate those criteria for profitability. The refinery profitability criteria are as follows: CAPEX, OPEX, Utility and Maintenance Expenses and Asset & Overhead Costs.The audit results are ranked in order of performance from top to bottom, with the top being the best in that order.(EKT Interactive, 2019).

Refineries are designed to run every day of the week, every month of the year and year-on-year without any down time or non-productive time. However, such a continuous operation deserves a well-programmed maintenance schedule without interrupting on-going operations. There are different scheduled maintenances carried out on refineries, they are as follows:

- Preventative maintenance is carried out while the plant is still in operation. It is for the efficiency and reliability of the refinery, and is done on a regular basis.
- Breakdown maintenance is carried out when there is a fault or breakdown and the plant has to shut down for the maintenance. However, breakdown maintenances are noted on the to-do list for actions during a unit or entire refinery maintenance. Today, there is a computer-based system, called Mechanical Work Order (MWO), for organizing maintenance and keeping record of all maintenance works carried out on the plant.
- Turnaround maintenance (TAM) is done once in 3-5 years. It is a huge cost. During TAM, refinery capacity can be upgraded by debottlenecking. It is important to also capture the possibility of emergency TAM when the unexpected happens.

  Turnaround Maintenance is an integral part of planning and operation of refineries, without which, the refineries are bound to perform below expectation and may eventually experience total collapse or shut down[35]. This has been the case with the nation`s domestic refineries, as back-to-back governments have failed to do the needful. Although, records have it that funds are budgeted for TAM as at when due, nonetheless, there has been no commensurate performance increase from the refineries (Adejoke N, Akinbode & Abel O., 2019).

  Lately, the following expenditures have been on record spent on the local refineries: $300 million, $57 million, $200 million and about N264 billion had been expenditure on just maintenance and yet NNPC looking forward to another TAM to **gulp** about $1.8 billion,(Adejoke N, Akinbode & Abel O., 2019)

2.2.6 Linear Programming Software Activation and Bottom-Line

Refinery operations require adequate planning which impacts on refining margins. Generally, the following are some of the refinery plans for which a specific Linear Programming model is developed

- **Weekly Plans**: Type of Crude, Duration of Operation and Product Supply and Demand
- **Monthly Plan**: Crude Purchase at Spot Price and Product Demand Operations
- **Annual Plans**: Turnaround Maintenance, Annual Budget and Crude Purchase Contract
- **Strategic Plans**: Business Expansion and Integration Strategy

The refinery linear programming software as a planning, scheduling and testing of crude is available for sales from separate numerous vendors, however, it must be configured to suit a refinery operations and planning. A few vendors are as follows in Table 2.6.

A typical Linear Programming (LP) describes the entire configuration of the refinery, inclusive of the redundant system. A model has both the variable data as used in cases of eventuality and fixed or structural data which represent the physical reality. Items as cost, prices, raw materials, product demands can be represented as variable data. All the data representation makes it possible input a problem or case scenario, from which several case results are generated and one is considered the optimum case result. (Linear Program Modelling).

A generic LP model is in form matrix while the users see as table of data for creating the matrix, an example is 1500 rows, 3500 columns, 1500 equation, 1500 constraints and 5000 variables(Linear Program Modelling). The model has timeframes for different operations planning duration as follows:

- Annual planning (1x4 quarter),
- Quarterly planning (1x3 months) and
- Monthly planning (1x4 weeks)
- Other Raw material and Crude Oil Prices, Minimum and Maximum Availability
- Refine Product Selling Price: Minimum and Maximum Demands for individual product
- Refinery Capacity
- Inventory Count: Minimum and Maximum Storage Capacity
- Quality Assurance and Control Requirements

The first stage is the conversion of the input data into variable and mathematical equations which are later transformed into matrix by LP matrix generator. The output of the LP matrix generator is now transformed by the optimization algorithm or program to a combination to give the optimum margin in addition to the financial statement. The output result is in excel format

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The refining margin can improve by 15-20% simply by application of Linear Programming model(Linear Program Modelling). However, the bottom line is in the use of experienced hands. Human being is a repository of knowledge and as such their roles as human who understand linear programming cannot be substituted or exchanged for the most sophisticated computer system in the world. Computers still require humans to operate.

2.3 State of Refinery Infrastructure in Nigeria.

The first refinery installation built in Nigeria was built by Shell in 1965. The refinery has 38,000 bopd refining capacity and later on; the refinery was acquired by the Nigerian National Petroleum Corporation. And between 1976 and 1989, additional three (3) refineries were built in Port-Harcourt (old and new ones), Warri and Kaduna; to make it four (4) refineries of 445 kbopd total capacities.[36]Port-Harcourt new has installed capacity of 150,000 bopd, Warri installed capacity is 125,000 bopd, Kaduna `s installed capacity is 110 000 bopd and Port-Harcourt old installed capacity is 60,000 bopd(OPEC, 2018).

Ever since 1989, there have been no new refineries built in the country, making the country a net importer of refined petroleum products just so to meet domestic demands.[37]Just recently, NDPR, Ogbelle, using modular-mini refinery Topping configuration, added 1000 bopd refining capacity, making total installed refining capacity in Nigeria 446,000 bopd. The table of downstream refinery activities is summarized in Table 2.7(Nigeria Oil and Gas Industry Annual Report, 2017)

Despite this, Nigeria remains mono-cultural economy and still so much depends on importation of 80% of current domestic demand to sustain the economy, a huge market for domestic refinery investments and expansion (Olumide A., 2017). The concern is not about the availability or non-availability of crude oil but rather inefficient and ineffective state of our refineries that operate below optimal capacity.

In 2016, the local refineries capacity utilization was 12.85% and 16.59% in 2017[38]. Taking a look at the Kaduna refinery, the refinery was not in operation for the most of 2017 except in January and August and no record of operation in November and December of 2016. Port Harcourt refinery, although was a bit stable continuous operations in 2017(Petrobarometer, 2018) except in August 2017 when shut down for a periodic maintenance, but still not at the expected optimal level of operations. The September operation was the lowest in the 2017. Warri refinery was down throughout the last two months of 2016. The total capacity of the refineries declined to as low as 6.1% towards the end of September 2017,the lowest in years, compared to a prolonged drop from the average value of 13.7% in 2016(Petrobarometer, 2018).

Beyond the comatose performance of the refineries the general failures of the refineries to operate up to the optimum refining capacity after repairs and major maintenances upon maintenances[39]remains a debilitating impact on our economy.(petrobarometer, 2018).[40]According to one NNPC former CEO, (Akpieyi J, August 9,2018), were the four (4) refineries operating at full capacity of 445,000 bopd, they would not still be able to meet the domestic demand (Nigeria Oil and Gas Industry Annual Report, 2017) This shortfall as a matter of necessity, calls for more refineries to be built with enough capacities to make up for the supply gap[41]. The only sustainable means to put an end to fuel importation is green refineries. In a related report, (Nwaozuzu C, 2018) stated categorically that the country would need a minimum of 1.2 million bopd total refining capacity to attain self-sufficiency in meeting domestic demands for petroleum products and cater to smuggling across our porous border. However, optimism is high of Nigeria ability to transition from a net import to net export with the current upsurge in petroleum polies and dip in crude oil prices(Olumide A and Ayodele O, 2017). This is a huge opportunity for modular refinery promotion either as standalone or complementary to the conventional refineries(Olumide A., 2017). Nigeria is the only country.(Ibikunle O,Adeyemi O.,Yusuf O and Akarakiri J, 2016)in the world with insufficient refining capacity[42].Hence, the urgent need for Modular Refinery promotion to fill in the supply gap[43] created due to country`s inability to meet its domestic energy demands.

Refineries in the country operate at low utilization rate, sub-optimal capacity of about 15% of total installed capacity (Soyode and Eheanacho, 2019)due to obsolescence of the infrastructure, and failure to carryout regular maintenance and poor management model, (Mordor Intelligence, 2019)among others, are the reasons for despicable state of domestic refineries in Nigeria[44]

2.3.1 Modular Refinery Mis-conceptions in Nigeria

The modular refinery has long existed in the industry, but seems nascent development in the Nigeria context. [45]Modular refinery was first introduced to complement conventional refinery in event of inadvertent shutdown or breakdown, just to ensure un-interrupted supply of petroleum product(Mamudu A,Okoro E,Igwilo K and Olabode O, 2018). Therefore, Nigeria is long overdue for the modular refineries to complement the sub-optimum conventional refineries in the country. Nigeria is therefore considered for modular refineries and as recommended as a viable alternatives(Ibikunle O,Adeyemi O.,Yusuf O and Akarakiri J, 2016).It is therefore, a misplacement of priority and misconception of highest order to have suggested replacement of illegal refineries with modular refineries(Mamudu A,Okoro E,Igwilo K and Olabode O, 2018) just so to end illegal refineries.

Illegal refineries,(Maclean M & Steve.A, 2019) also known as, artisanal refineries obtain crude oil from vandalized pipelines which implies artisanal refineries cannot operate without oil theft and oil theft is oil sourced for through stealing[46]. Besides, one key policy of the current administration is using modular refineries to stop stealing of crude for illegal refineries. The illegal refineries are so illegal cause of the dubious means of sourcing crude oil, through pipeline vandalism and illegal bunkering. The spate of pipeline vandalism has been on the increase in the recent past, in spite of our probable solutions such as militarization of the entire Niger delta region and several other attempts to step down the tide have failed to deliver the mandate.(Boris O.H, 2015). Joint Task Force decimated over 4,349 illegal refineries in 2012. In a similar operation by the JTF, 36,584 drums of refined product from illegal refineries were annihilated, 638 pumping machines and 326 outboard engines seized and decimated. And another 2.24 million liters of diesel burnt off by the men of the Nigerian Security and Civil Defense Corps in Delta(Audu L.O, 2016). The illicit business of illegal oil bunkering (Nwaozuzu C, 2013) keeps thriving because there are ready black markets where the illegal oils such as diesel especially are exchanged for money[47]. The number of motor trucks loading from such refineries is countless.(Audu L.O, 2016).

According to United Nations Security Council, (Noah B and Evans C, 2013)an estimated $2.8 billion has been lost through illegal oil deals in 2017, translated to about 100,000 barrels per day-$3-$8 billion per year(22 million barrels of crude stolen in 6 months[48].

The existence of the black markets can be alluded to be consequence of petroleum products supply gaps which in turn is the fall out of the sub-optimum refineries in the country. The earlier the government can fix the rot in the refining value chain, the earlier the illegal oil deals can be halted.[49]This is purely not an un-economic problem. If satellite deployment to trace illegal oil bunkering has not been successful to halt the shady business, I do not foresee modular refinery development being able to. (Reuter, 2019). Therefore, upgrading of illegal local refinery to modular refinery is not feasible(Boris O.H, 2015). If the problem of illegal bunkering is not nipped at the bud, the illegal acts may perpetuate even with modular refineries as well.

Needless to mention, illegal refineries have no correlation with modular refineries at all. Going by the definition, illegal refineries have no basis for an upgrade, so cannot be upgraded to modules let alone refineries. Illegal refineries are mere collection of metal drums for boiling stolen crude oil to high temperatures and the steam from boiling crude collected as diesel, in adulterated form, for sale. This has no engineering design basis or technicality to warrant upgrade to modular refineries. As earlier discussed, modular –mini refineries are modules built in factories, transported in skids and setup at the site location.

According to (Boris O.H, 2015)several attempts to curb pipeline vandalism vis-a-vis oil theft have failed.[50]Therefore, to stop the ugly incidences, the approach will require multi-dimensional joint efforts by all the stakeholders, as this is a crime against the economy.(Mamudu A,Okoro E,Igwilo K and Olabode O, 2018).

To curb oil theft and illegal bunkering, the host communities must be engaged, without which all efforts will continue to prove abortive.[51]Relevant laws implementation and enforcement such as the miscellaneous offences act must be taken more seriously; the effect will go along way to stop oil theft in Nigeria(Noma Garrick, 2018)

Modular refinery is capable of succeeding or complementing conventional refineries. Examples of Modular refineries location in Africa and beyond are as follows: 1000 bopd modular Atmospheric Distillation Unit in Australia,35,000 bopd Tanta Atmospheric Distillation Refinery at Cairo,7000 bopd Wadi Feran Atmospheric Distillation located on the Red Sea in the Gulf of Suez, 23,000 bopd Sogara Hydro-Skimming Refinery in Gabon, 23,000 bopd Indenni Refinery Zambia has all units apart from the fluid catalytic cracking unit and 21000 bopd Coraf(Pointe Noire) refinery Congo has all the units etc. none of the aforementioned examples were setup to solve the issues of illegal refinery or used for an upgrade of the same. These are areas of successful sustainable and proven applications.(Mamudu A,Okoro E,Igwilo K and Olabode O, 2018)Therefore, modular refinery can solve the contemporary problems in Nigeria refinery industry and liberate Nigeria from committee of petroleum-importing nations to becoming a net exporter[52].

Modular refinery can be setup easily, making it also not difficulty for expansion within the shortest possible time and saving cost of pipelines infrastructure.[53]By so doing, it increases the possibility of using modular refinery for solving perennial problems of our moribund refineries.(Udonne J.D and Akinyemi O.P, 2018)

2.3.2 Challenges to Development of Modular Refinery in Nigeria

1. Lack of Adequate Capital and Technical Know-How

On a short to medium term basis, (Olumide A., 2017) modular refinery development remains one of the viable alternatives, if not the only option, towards the transformational agenda of making the country self-sufficient in domestic demand and becoming net exporter of petroleum products[54]. On a long term, a conventional refinery sounds suitable for a densely populated country as Nigeria, yet, the country seems not financially buoyant and remains economically unstable to embark on such a capital project. How much capital required remains a deterrent to embark on such a project. Successive governments have made umpteen efforts towards revamping the refining industry through turn-around maintenances, all to no avail, mere political statements for winning elections. These have been recurrent decimal in the successive administrations. The entire failed efforts now seem a loophole for looting illicit fund, so much have been budgeted by successive governments, claimed expended and yet the refineries remain comatose. Nobody seems to be accountable and economic financial crime commission lacks the will power to prosecute such inconsistences. After several failures by successive governments, the erstwhile state petroleum minister,[55]announced an alternative funding plan to resuscitate the countries' refineries through a third part financier(Market Report, 2018). The whole system is shrouded in secrecy and cast doubts on the veracity of the new planned intention to finance, since past investments have not yielded expected result, why still same old way go.

This calls for a paradigm shift to a more pragmatic approach such as the modular refinery, which is cost effective, the cost of which will not require much credits from financial institution, upgradable and quick turnover. For an example, the capital required for a conventional refinery of 100,000 bopd capacity is about $1.5 billion, while a 24,000 bopd is just in the neighborhood of $250 million. It could be a lot less than this amount, depends on the modular refinery capacity, making the fund easily accessible with not much security requirement. Modular refinery project is easier to capitalize.(Ogbuigwe T, 2017) More discussion on project finance will be delved into under the methodology. Furthermore, 7 out 35 private refinery licensees passed the technical and financial capacity audit carried out by ministry of petroleum resources in 2012. One of the root causes of paucity of funding is the over-bearing nature of the federal government through regulations. These have added to the unknowns and associated risks and as a consequence, have forestalled flow of foreign direct investment, according to Nigerian Extractive Industries Transparency Initiative (NEITI).

Some proponents (Mamudu A,Okoro E,Igwilo K and Olabode O, 2018) who are advocating for upgrade of artisanal refineries to modular refinery also are hopeful that operators of the illegal refineries should have adequate capital from the business of illegal refinery operations as to invest in modular refinery. Some investigations[56]revealed that the operators of illegal refiners realizes between about $12,800 and $64,000 per week, which is a lot less compared to start-up capital required for modular refinery(Audu Liberty Oseni, 2016). While some others allude that refinery owners make 2 million naira ($6500 equivalent) a month from producing petrol and diesel – the later sought by hotels and shops(Ulf Laessing, 2017). Both revenues from the different sources can never be sufficient for investment in modular refineries, the more cogent reason for government interventions and other financial institutions.Ed Johnson (CEO Sirius Petroleum) alluded poor financial return, for failure by most investors to commit fund into the refining business, as government reluctance to deregulate the downstream sector[57]and to provide a new template for pricing mechanism for crude oil for modular refiners make the business less remunerative(Nwaozuzu C, 2015).

2. Idle Licenses and Structure

Federal government initiated the modular refinery development in 2002. With license to establish (LTE) issued to 17 out of 18 interested investors, after due diligence in 2004. Unfortunately, the licenses were revoked by DPR due to some bottlenecks prior to commence construction on the part of the investors. Upon the revocation,[58]DPR opted to review the guidelines and framework with incentives for modular refineries investors. This now led to new proposals for 39 modular refineries and 6 conventional refineries with total capacity of 1.35 million bopd.(Punch Newspaper, August,2018). Despite the motivations from DPR, still 18 companies lacked proof of fund, while some other licenses were left to expire within the time frame, leaving only 20 licenses in date. Undoubtedly, expired licenses and failure to commence construction by the licensees within the time-frame may have impacted adversely on the Federal Government forecast to start to export fuel by Q4, 2019, reason for issuance of import duty exoneration for 3 modular refineries.(EnergyMix Report, 2019) There is still more rooms for as many more refineries, just so to achieve domestic self-sufficiency vision. DPR will definitely need to stage a come-back opportunity for companies with expired licenses. And in addition, a lot more improvements to the licenses issuance and stages, none should be licensed until due diligence on technical know-how and financial capacity stages are completely passed. It makes no economic sense to have been licensed and later become expired or invalid for whatever reason. License should be the last to come upon satisfactory preliminary stages. The word license in this context seems ambiguous; it should rather be properly termed to avoid confusion. The consequence is that the numbers of idle licenses are now more than the active ones. Generally, once a license is issued, the project risk level is eliminated and it gives an impression of prospect and that the project is as good as ready for execution, which is not the matter under this scenario. According to the qualification requirements (Federal Ministry of Petroleum Resources, 2017), there are 3 stages of licensing which are as follows in order of issuance[59];

1.License to Establish (LTE). 2. Authority to Construct, (AtoC). 3. License to Operate (LTO).

Each stage must be satisfied before procession to the next. The stages are adequate and may remain but will prefer being called another name rather than license. The last stage which is the license to operate should be the only stage where license is issued to avoid the confusion created with many idle and expired licenses.

As at this day,[60]there are 43 licenses of both modular and conventional, with many idle licenses and only a few active licenses (about 10) have made commendable progress and thus issued authority to construct (AtoC) license by DPR(EnergyMix Report, 2019).

They are as follows:

- 5000 bopd capacity modular-mini refinery in Imo by Waltersmith Refining and Petrochemical Company Limited in a Joint Venture with National Content Development and Monitoring Board in a $10 million equity stake. Operation to commence[61] Q2, 2020.(Olusola Bello, 2019)
- 20,000 bopd capacity modular-mini refinery in Delta by Clairgold Oil & Gas Engineering Limited
- Two 5,000 bopd capacity modular-mini refinery in Rivers by Niger Delta Petroleum Resources. Currently at completion stage (EnergyMix Report, 2019).
- 7000 bopd capacity modular-mini refinery in Kwale, Delta State
- 6000 bopd capacity modular-mini refinery in Cross-River by Dee Jones

- 20,000 bopd capacity modular-mini refinery in Delta by Energia Limited
- 20,000 bopd capacity modular-mini refinery in Delta by Southfield Petrochemical & Refinery Limited
- 100,000 bopd capacity Conventional Refinery in Rivers by Starex Petroleum Refinery Limited
- 250,000 bopd capacity Conventional Refinery in Rivers by Petrolex.

2.2.3 Regulatory Legislative Framework for Modular Refinery

1. Petroleum Act (1969): The power to issue licenses to construct refineries,[62]from the conception to commission stage, is an exclusive reserve of the Petroleum Resources Minister(Petroleum Act (1969) Section 3). What that implies is that the minister has got the authority to monitor and control refinery activities such as how much to pay for the licenses, the validity period of the licenses, the different stages of the refinery, refinery sizes, configuration, complexity, crude oil supply, product evacuation and petroleum product percentage to push into the market and of course, the price(s) of refined products[63].

2. Hydrocarbon Oil Refineries Act (1965): Under this Act[64], it is a criminal and illegal to refine crude oil without the requisite approval(The Hydrocarbon Oil Refineries (1965) Section 1). This is the declaration of illegality on refining of crude oil without the approved license. For every refinery that is established, there must be an refiner`s license to refine crude oil in the refinery. The refiner`s license is issued by the Custom Service Board in appreciation of the assumptions to base the refinery upon.(The Hydrocarbon Oil Refineries Act (1965) Section 2)

3. Department of Petroleum Resources (DPR) Refinery Guideline for Establishment of Hydrocarbon Processing Plant 2007: There are guidelines and procedures[65]necessary for the different levels of approvals prior to issuance of licenses to start work.(Federal Ministry of Petroleum Resources, 2017)

2.3.4 Licensing Procedures for Modular Refineries

1. Specific Licensing Process for Modular Refineries: This is the abstract of what are specifically needed to construct and operate a modular refinery, inclusive of application and licensing fees as captured in the DPR refinery guidelines. These are specific guidelines requirements and there is no ambiguity and they must be followed. There are three stages of application which are; License to Establish, Authority to construct and finally, License to Operate. Each of the stages is not open ended, there is a time limit for each stage for a licensee to close out each stage without which the license may expire and licensee may lose the application fees

2. Generic Licensing Criteria for Modular Refinery: This is a summary of the general conditions for the settlement of modular refineries, they are as follows:

3. Modular Refinery Capacity Design: A modular refinery ranges from (5000 – 30000) BPD capacity(Federal Ministry of Petroleum Resources, 2017).Any design above 30,000 bpd shall be increased to a full capacity of a conversion refinery[66]

4. Location of Modular Refinery: A modular refinery or Modular Refinery Cluster must be sited as closest as possible to a marginal field or oil producing oilfields for supply of crude oil, without necessarily passing through pipelines, to the modular refinery(s). The number of modular refinery or cluster in a location will depend on the production capacity of the location, just so as not to over-utilize the infrastructure or cause environment pollution above the acceptable threshold.

5. Documentations Required of Investment Partners: When there is a consortium or a group formed to undertake the investment in Modular Refinery, the Nigeria partner must be duly registered in Nigeria with evidence and the foreign partner must show evidence of foreign registration. However, the two parties must also present a letter of memorandum of association and understanding with other related documents that can be used as legal tenders

6. Proof of Financial Capacity: As proofs and compliance to fiscal regime, the consortium must supply their audited accounts, tax certificates, and financial reports for three consecutive years. The source of fund and all the other documents as mentioned earlier must be verifiable.

7. Compliance with Community Affairs, Safety, Health, Environment and Security (CASHES): Potential investor must be able to display their policy(s) covering the following scopes such as health, safety and environmental (HSE) policy, management of change(MOC) system, community, and social and corporate responsibility plans

8. Nigeria Content Policy: Potential investor must provide their local content policy: The policy must explain intent and intentions to hire and develop local talents with the aim of transferring technical knowledge and wherewithal

9. Strictness to Technical Specification: All the technical requirement and guidelines for design, construction and operation of Modular Refinery must be fully complied with and strictly adhered to.

10. Age of Modular Refinery to be imported: All newly fabricated modular refinery within DPR specification are allowed, however, for any used modular refineries older than ten years from the date of manufacturing is disallowed. Same goes for a modular refinery not older than 15 years but has never been in operation before is also allowed for importation

11. Fiscal Benefits for Modular Refineries: All modular refineries imported into the country, having met importation conditions, are eligible to all the six (6) tax benefits as stated in the Company Income Tax Act, under section 39[67].

1. Eligibility to tax-exempt first three(3) years tax with additional two(2) years renewals

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2. In lieu of tax-exempt as above, eligibility to additional 35% investment allowance

3. Capital allowance is available after the tax-exempt duration as below;

- additional spending on additional asset is eligible to annual allowance up to 90 percent, with 10 percent retention
- an additional capital allowance of 14 percent without prejudice to the asset value

4. Where investment in modular refinery is domiciled in foreign exchange or the value of imported machinery is above 30 percent of the equity share of the capital structure, the company shall be eligible for tax-exempt.

5. Refiners are advised to seek approval of Petroleum Minister before loan application; such interest payable on such loan shall be eligible for tax deduction.

6. The tax-exempt date shall start counting from the day of production commencement as witnessed by the ministry of petroleum resources.

2.4 Business Models for Modular Refineries

Empirically,[68]modular refineries remains best alternatives on account of less financial significance required in its development compared to full conversion units.(Marine and Petroleum, 2019). Although, most paramount is avoiding margin shortfall,[69]which makes refining margin an inevitable consideration in refinery business(Marine and Petroleum, 2019). However, (Olumide A,Ayodele O, 2017)there are only two industry-recognized and economical ways of modelling a modular refinery business deal[70].

Generally, modular refineries are predominantly set up to meet domestic demands owing to their locations proximity to crude oil source, either with an existing local refinery or land marginal fields[71].While conventional refineries, by virtue of its capacity, are set up for both domestic and international demands.(Olumide A,Ayodele O, 2017). However, the current supply-demand gap can be filled through massive investment in both the conventional and modular refineries. The upcoming Dangote Refinery is sited close to the Atlantic Ocean just for ease of meeting international demands which is more profitable for the foreign investors in the business model. Hence the more cogent reason to focus on the aggressive development of modular refineries through public-private partnership across the entire nation, government subvention and support arekey to the success. It is high time the modular refinery road map was re-developed and its implementation followed to letters to meeting domestic demands for petroleum products and possibility of becoming a net exporter. In view of this, the intent for recommendations for modular refineries shall be for production of gasoline (PMS) and diesel (AGO)

1. Old Model: This is based on a partnership agreement between an upstream company and an oil marketer. An oil marketer is an individual or firm that buys refined petroleum products and resells to end users while a marginal field operator provides the feedstock[72].Both parties agree on a sharing formula for the proceeds from sales transaction. The sponsors are liable should the agreement fail to deliver returns on investment as forecasted(Olumide A,Ayodele O, 2017).

2. Special-Purpose Vehicle (SPV) Model: In this scenario, the oil marker and upstream operator act as project sponsors, create a project company and project finance which is specifically setup to undertake the modular refinery plant. The new project company assets suffer should the project fail. The project finance comes from both. Equity is capital contributed to fund the project company by sponsors.

Two, debt is money borrowed from a financial institution.[73]Project sponsor are inadequate financially, so need financial institution to leverage upon, reason for the debt(Proshare Economy, 2019). Equity can be inform of loan or banking instrument from a financial institution.[74]Ultimately, project sponsors are always looking forward to an impressive dividend and increase on their shareholding (Proshare Economy, 2019).[75]The project sponsors returns-on-equity comes as dividends and capital gains. The creditors are financial institution and get paid back with interest plus initial capital. The number of project sponsor may be as many as possible, that is, without number, they could be a third party company, government agents, individuals, banks can be a project sponsor or even an association of private-public partnership can be formed to be a sponsor(Olumide A,Ayodele O, 2017).

2.4.1 Project Finance Lenders for Modular Refinery

Lenders also can be as many as possible, no end to the numbers. They are the creditors and risk takers. There are a number of creditors out there and different banking instruments depending on project size, project location, project risks and project equity holders. A few of the creditors are as follows:

1. Commercial Banks These are banks with international footprints and huge capital base. They participate in project feasibility study just to be certain the project risks are practically mitigated or zeroed, if possible. Commercial banks also assign a representative consultant to superintend the project execution and management, ensure execution is done as per textbook. This is because modular refinery projects involve taking a huge risk and huge capital is needed.[76]Commercial banks can merge to create a cartel, an association of banks from different international background. The idea of which is to deter host government from unholy interference for a political reason. Host government will have to respect the cartel and respect the diplomatic relations among the member countries involved.(Proshare Economy, 2019)

2. Export Credit Agency (ECA). These are financial institutions that provide financial support to domestic companies` international export operation and similar activities(Adam B, 2019). ECAs do not have any governmental contribution, so are not subject to host country political manipulations. A modular refinery project is eligible as the whole plants such as the modules and skids are manufactured in developed countries and shipped into the country. It is an-import-orientated business. The technology is available for importation. In view of this reason, project sponsor approach Export Credit Agency for subvention or credit as the case may be. ECA examples are Export-Import (Ex-Im) Bank of USA and Nigeria Export-Import (NEXIM) of Nigeria.(Proshare Economy, 2019)

3. Multilateral Agencies These are financial institution established between governments of two or more nations or between different levels of government in same country[77].Their sources of funding is from different governments of nations and the fund is disbursed in form of guarantees or loans for projects in developing countries.(Proshare Economy, 2019). In several case studies, multilateral agencies provide project funds on the basis of merit. They also ensure government and government parastatal will not short-change the project.(Proshare Economy, 2019). Prospective investors are often confronted with what investment decision between a modular refinery and conventional refinery. The answer is easy, modular refinery has low investment capital, short payback period and relatively good margins and more, make modular refinery enticing to upstream and downstream operators[78]. Firstly, upstream company's partnership in modular refinery business will beyond the usual business of crude oil production for sale, will improve their net cash flow by getting additional value from processed crude oil. And similarly for a downstream company,[79]it is an opportunity to reduce their exposure to foreign exchange instability on their customary business by focusing on domestically refined product to replace imported fuel. Modular refinery development is a win-win for all stakeholders across the entire value chain.(Olumide A,Ayodele O, 2017)

2.4.2 Modular Refinery Economics

Generally, there are four (4) fundamental requirements to run a successful and sustainable refinery business. They are as follows;

- Available Crude Oil Type: Crude oils are identified with their respective API with respect to their density; the lighter the crude, the higher the API value.(Olumide A,Ayodele O, 2017)In paradox, heavy crude oil gives more yields but with lower value, necessitating further distillation and more cost, while light crude gives high value product, ready for sale, and do not require further distillation[80]
- Refinery Configuration which is related to the refinery complexity
- Type of Refined Product
- Quality of Refined Product

In terms of economics, for an improved refining margin, refiners must find a balance between cost of production and selling prices of refined products(Olumide A,Ayodele O, 2017). Therefore, a refiner must aim at efficiency at all time, there is no way to influence price of crude, it's based on international market determinants or spot price mechanism, therefore, the refiner is only left to minimize operating cost and other related operating expenses.(Aveva`s Refining Operations mangement, 2018).The supply chain management is an integral part of the business that must be optimized and structurally planned for sustainable profitability[81]-[82]. Although, aforementioned are generic to all refineries, needless to mention, each refinery is sophisticated and unique in its entirety[83].

For references are Tables 2.8, Table 2.9 and Table 2.10of modular refinery configuration analysis with due consideration for the following assumptions according to(Olumide A,Ayodele O, 2017)

- Modular refinery sited close to either an existing refinery or crude oil source
- The feedstock is Nigerian Bonny Light
- Crude oil price is $54 Per Barrel
- Bank Loan Interest Rate is approximately 17.3%
- Refinery Utilization Rate is 60%

2.4.3 Spectacular Benefits of Modular Refinery

1. **Climate Change Alleviation** Modular refinery will serve to mitigate the climate change, in the nearest future in the Niger Delta region of the country[84] .This revelation was an outcome of a brainstorming session on local solution to climate change, at University of Nigeria, Nsukka. Although, modular refinery is a new development in the Nigerian oil and gas space(Ejike I.O, 2018), yet in comparison with illegal and local refineries as shown by (Bucke & Mauverney, 2008). The ease of maintenance of modular refinery makes it an instrument of reducing climate change effect. Modular refineries will use as much space as full conversion, besides, the maintenance expenses is a lot reduced[85]. Giving job opportunities to village restive youths will increase infrastructure security since the community youths will be kept busy at the modular refineries location as against the happenings with conventional refinery
2. **Independent Power Producers (IPP)** These are non-government power plant built and licensed by the Federal government. And over sixty licenses have been issued for more power stations to be built around the country (Nwaozuzu C, 2019). The power generated from IPP is transmitted to the National Grid is for onward transmission and eventual distribution to homes, industries and market places. Modular refineries are sustainable and reliable sources of cheap power to IPP all over the globe. The fuel from modular refineries is readily available to energize power plants for generating additional power supply. This increases the cumulative power capacity from IPP(Techmodular Inc USA, 2017)
3. **Additional Stream of Revenue** If and when taxes are levied, taxes from modular refiner will add to the stream of revenues for the state and local government, that is, source of internally generated revenue, thus creating an ambience for small and medium scale businesses to sustain and grow.(Techmodular Inc USA, 2017)

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4. **National Economic Empowerment** The resultant effect of modular refinery is in closing the gap between the rich and the poor, creating jobs and making many rich. It is therefore indispensable for a sustainable national development and improving the standard of living in oil communities(Techmodular Inc USA, 2017).

III: RESEARCH METHODOLOGY

3.1 Research Design

As part of the research study, below is the model providing guidance into the data gathering and analysis of data just so to arrive at the intended study objectives. The research design is a mixed research methodology as it blends both the qualitative and quantitative data collection and analysis together under this study, the result of which will be used to establish the research objectives. The research design has five (5) broad stages which are as follows:

- **Stage One:** This is all about gathering relevant data and classifying the research data by putting them in perspective according to the research study objectives. It describes the different sources of data such as the wholesale prices of petroleum products and the assumptions under consideration as deemed necessary for the research study. The data used for the research study are both primary sources, that is, from legalized authentic documents sources and the secondary sources are as published or reported .An example of assumption is the exchange rate for USD to Naira, see Table 3.1
- **Stage Two** At this stage, the data gathered are collated for data analysis just so to make sense of the data in accordance to the objectives of the research study. The following are the data analysis done; firstly, in order to evaluate any relationship between crude oil price and gross margin at constant refinery efficiency, see table 3.2 to 3.4 as below. (Note: crude oil price is about 80-85% of total cost of production), and secondly, estimating any relationship between refinery efficiency and gross margin at a constant crude oil price, see Table 3.5 to 3.7 as below. These two estimates are done using the four different scenarios as per the methodology design.

  The annual revenue analysis covers the entire product-mix yield from the 10,000 bopd capacity refinery, their respective expected product yield and conversion of the yield in barrel to liters per annum, and application of the refinery gain. Refinery gain is the amount by which total volume of product is greater than the volume of input crude oil. Finally, the analysis on application of wholesale prices of petroleum products per liter basis as below gives us the annual revenue in billions of naira. See the entire framework structure of the methodology design in Table 3.1.
- **Stage Three:** The target here is to estimate the required number of a 10,000 bopd modular refinery that would be required to meet domestic energy demand in 2021. Here is a more streamline data analysis and forecast of PMS consumption from 2018 to 2021 based on available veritable data of PMS consumption in 2017. The forecast is extended just so to estimate what PMS consumption would be in 2021, using an assumption that the annual rate of PMS consumption is pegged at 700 million liters. At the end of which, the annual PMS consumption at the end of 2021 is arrived at.
- **Stage Four:** This is the forecast of domestic PMS consumption in 2021 based on the assumed population growth and available data and the evaluation of estimated PMS Yield from 10,000 bopd Modular Refinery at ADU 100% Efficiency. Using the analyzed data from the 10,000 BOPD modular refinery product yield when the refinery efficiency was 100%, with emphasis on the PMS production, the result of the PMS production as 2810 bbl. /day to estimate the total production of PMS per year at 334 operating days per year

  The two results are computed to estimate the number of modular refinery(s) that will be required to meet domestic demand in 2021. Below is the methodology research design table or framework as in below Table 3.1
- **Stage Five:** This is a financial statement of profit and loss analysis. It is a snapshot of total revenue, annual operating expense as may be incurred. This is not cast in stone, it is a matter of experience and how well the organization finances could be managed. Below is the methodology research design table or framework as in Table 3.1

Stage One: Research Data Sources	**Data Gathering:** ▪ Primary Sources (OPEC ASB, NNPC etc. ▪ Secondary Sources (WREN-Consulting) **Data Analysis Assumptions:** ▪ Operating Days: 334 Days Per year. ▪ Exchange Rate is 1$ to N305 ▪ Crude Oil Benchmark Price at $55/bbl. ▪ Whole sales prices for petroleum products etc.

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Stage Two: Research Data Financial Analysis	**Basis of Total Annual Revenue Analysis** **Product Yield Analysis of a 10,000 BOPD Modular Refinery** ▪ Petroleum products such as PMS, AGO, HHK etc. ▪ Each product Yield Percentage in BPSD ▪ Conversion of Product Yield in Bbl. to Liters **Financial Analysis Scenarios** ▪ Relationship between Crude Oil Price and Gross margin (Scenario I and II) ▪ Relationship between Refinery Efficiency and Gross Margin at Constant Crude Oil Price. (Scenario III and IV)
Stage Three: Research Data PMS Consumption Analysis	**Analysis of PMS Consumption in 2017** **Forecast of PMS Consumption (2018-2021)**
Stage Four: Estimate PMS Consumption by 2021	**Using PMS Product Yield from a 10,000 BOPD Modular Refinery** ▪ Estimate PMS Consumption by 2021 ▪ Estimate Modular Refinery Yield for PMS Production ▪ Estimate No. of Modular Refinery for Self Sufficiency
Stage Five: Profit & Loss Projections	**Basis of Total Annual Revenue Analysis** ▪ Gross Margin (Cost due to Crude Oil Price Only) ▪ Net Margin Percentage (Operating Expenses and Cost)

Table 3 1Research Study Methodology Design

3.2 Nature/Sources of Data: Primary and Secondary

The primary data for the research study are sourced from the official links of relevant popular and veritable organizations such as OPEC, NNPC Annual Statistical Bulletins etc. while the only secondary data used under this study is from WREN Consulting (a service provider of modular refinery solution). All the data sources are as articulated below as follows:

- National Bureau of Statistics Petroleum Products Consumptions Statistics in Nigeria[86]
- OPEC and NNPC Annual Statistical Bulletin, 2018[87] OPEC Oil Prices from 1960-2019
- National Petroleum Energy Demand and Petroleum Product Forecasts from 2014 – 2020 (US Department of Energy, Energy Information Agency, EIA) are the sources of data for the Energy Planning and Foresight Analysis Methodology [88]
- Data on Nigeria`s Gross Domestic Product (GDP) in Purchasing Power Parity and Energy Intensity[89]
- The Petroleum Products Pricing Regulatory Agency (PPPRA)[90]
- WREN Consulting Limited

3.3. Methods of Data Analysis and Assumptions

The methods of data are partly quantitative and partly qualitative. Quantitative in the sense of objectivity, reliability and generalizability of the data sources, the study results and established relationship between variables will always follow same trends irrespective of the researchers and variations the data are subjected to. And qualitative as the secondary source of data is purely based on a feasibility study conducted

In order to estimate the relationship between crude oil price and gross margin at constant refinery efficiency, the following data analysis procedures are followed; with reference to the 10,000 BOPD Modular Refinery, the output from the refinery is a function of the refinery efficiency, the higher the efficiency the more is the product output. Based on this fact, and then calculated the revenue from each product to estimate the total annual revenue. The refinery expected operating days is 334 days in a year. The total revenue put into considerations the refinery efficiency and the refinery factor which the amount by which total volume of output product is greater than the input crude oil. The final result shows the total annual revenue. However, to estimate the gross margin, the total crude oil cost is minus from the total revenue to give the gross margin or profit (simply from total revenue from total cost to give gross profit.) There after the gross margin percentage is estimated by finding the ratio of the gross margin in the total annual revenue. The same procedure is followed when the crude oil cost is varied up or down, this automatically varies also the total revenue either up or down without any changes to the refinery efficiency. There is a trend-line pattern to define a relationship between oil price changes and gross margin

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In similar step-wise procedures, to estimate the relationship between refinery efficiency and gross margin at a constant crude oil price, the following are the steps: When the refinery efficiency is increased, the refinery is expected to increase its product percentage and vice versa with the crude oil price remaining the same. That is, more product, the more the total annual revenue. However, this does imply that changes in refinery efficiency will have corresponding changes in the total annual revenue and of course, corresponding changes in the gross margin. The variation as a result of changes between refinery efficiency and gross margin also gives a trend-line pattern. And the interpretation is such that is relevant to the petroleum economics of modular refinery as to how a refiner or local operator can find a balance between cost of production and the selling prices of products. This is still on the basis of a 10,000 BOPD Modular Refinery.

In terms of the estimation for the quantity of a 10,000 BOPD modular refinery to attain self- sufficiency, the data analysis method is in two steps.

The first step is to analysis further the PMS consumption in 2017. Statistic has shown that PMS consumption rate per year is about 700 million liters per year. This statistical reference is based on the estimated population growth of the country. Therefore, knowing PMS consumption in 2018, it is a lot easier to forecast what the consumption would be like in four years' time, ,that is, 2021. The second step is analysis of data from a 10,000 capacity modular refinery using PMS product yield percentage at full refinery efficiency and applied refinery factor to give the total PMS in barrel that is produce able from the modular refinery, all things being equal such as 334 operating days etc. Having done that, it is therefore possible to estimate PMS production in liters per annum (conversion from barrel). The outcomes of the two steps when dividing the result of the first step by the result of the second step will give the total number of modular refinery (a 10,000 BOPD capacity) that will be required to attain self-sufficiency domestically

The following are some of the assumptions taken into due consideration during the research and data analysis study as follows:

- The four domestic refinery capacity (445,000 bpd operating at zero utilization) ,
- The modular refinery works 334 days per year based on 10,000 bpsd refinery technology
- One(1) Barrel of Oil is approximately equivalent to 159 liters
- Modular Refinery operate 334 Days Per year.
- Exchange Rate is 1$ to N305, special rate for oil and gas importer and exporter.
- Crude Oil Benchmark Price at $55/bbl.
- And whole sales prices for petroleum products

IV: RESULTS AND DISCUSSION

For ease of understanding, results and discussion chapter is all about the presentations of collected data in tabular forms, the different comprehensive financial data analysis carried out during the course of the study and of course, the findings and the results obtained from the analysis. Foremost of the analysis is the financial analysis to estimate any relationship between refining margins and crude oil volatility using a 10,000 bpsd Hydroskimming Modular Refinery as a case study. Furthermore, there is another financial analysis to observe the relationship between refining margins, crude and the refinery efficiency. Undoubtedly, crude oil price changes do affect refining margin dependent on whether the price increases or otherwise. Under this consideration, there are two separate scenarios where crude oil price is varied and the corresponding changes gross refining margin are observed at relatively same refinery efficiency. There are also another two scenarios where refinery efficiency is varied and the corresponding results over the refining margins are observed at the same crude oil price of $55 per barrel. The net margin estimations is as a result of further estimation with inclusion of operating expenses in addition to the crude oil cost under the profit and loss projection. The research study emphasis is more on the gross margin rather than the net margin; this is because crude oil cost is about 80% of the total cost.

However, one of the most important aspects of this research study, is the estimation done to arrive at the number or quantity of 10,000 bpsd Hydro skimming modular refineries that will be required to, at least, meet domestic demand for PMS in 2021, PMS being the most popularly demanded among the petroleum products spectrum. The evaluation is based on the estimated PMS consumption by 2021 and the PMS output yield per annum from a 10,000 bpsd Hydro skimming modular refinery. Needless to mention, also is the financial analysis of the modular refinery of same capacity and the last but not the least, the critical roles of government towards a sustainable development of modular refinery in 2021.

4.1 Presentation of Data in Table

Yield	Temperature Range	Product Yield in %	Product Yield in (bpsd)	Yield in Liter Per Year at 100% ADU Eff.
LPG	< 59 °F	0.98	98	5,204,388
Light Gasoline	(55-175 °F)	4.25		
Light Naphtha	(175 – 300 °F)	13.73	2810	149,227,860
Heavy Naphtha		10.12		
	(300 - 400 °F)			
ADK	(400 - 500 °F)	13.28	1328	70,524,768
AGO	(500 - 650 °F)	22.69	2269	120,497,514
Residue Fuel Oil	(300 - 400 °F)	34.95	3495	185,605,470

Table 4 1 A 10,000 bpsd Hydro-skimming Modular Refinery Output Yield Per Liter Source:(Ogbon N. O., 2018)

Yield	**Yield in Per Liter**	**ADU Efficiency at 90% (liters/year)**	**Refinery Gain Factor x 1.0714 (liters/year)**
LPG	5,204,388	4,683,949	5,018,383
Light Gasoline Light Naphtha Heavy Naphtha	149,227,860	134,305,074	143,894,456
ADK	70,524,768	63,472,291	68,004,213
AGO	120,497,514	108,447,763	116,190,933
Residue Fuel Oil	185,605,470	167,044,923	178,971,931

Table 4 2 A 10,000 bpsd Hydroskimming Modular Refinery Yield per Liter per Year Output Source

Product Yield	**Prices N/liter**	**Prices $/Liter**
LPG	130	0.426
Gasoline (Petrol-PMS)	135	0.443
Household Kerosene (HHK)	185	0.059
AGO(Diesel)	185	0.059
Fuel Oil	70	0.229

Table 4 3Wholesale Prices of Petroleum Products. Source: (EIA, 2018)

Product Yield	**Refinery Gain Factor x 1.0714 (liters/year)**	**Prices N/liter**	**Annual Revenue (N)**
LPG	5,018,383	102	511,875,066
Gasoline (Petrol-PMS)	143,894,456	135	19,425,751,560
Household Kerosene (HHK)	68,004,213	180	12,240,758,340
AGO(Diesel)	116,190,933	180	20,914,367,940
Residue Oil	178,971,931	70	12,528,035,170

Scenario I: Refinery Efficiency at 90% and Crude Oil Price at $55/bbl.	
Total Annual Revenue in Naira	N 65,620,788,076
Total Annual Revenue in Dollar	$ 215,150,125
Annual Cost of Crude Oil at $55/bbl. in Naira	N 56,028,500,000
Annual Cost of Crude Oil at $55/bbl. in Dollar	$ 183,700,000
Gross Margin Per Annum in Naira	N9,592,288,076
Gross Margin Per Annum in in Dollars	$ 31,450,125
Gross Margin %	**14.62%**

Scenario II: Refinery Efficiency at 90% and Crude Oil Price at $65/bbl.	
Total Annual Revenue in Naira	N 65,620,788,076
Total Annual Revenue in Dollar	$ 215,150,125
If the annual cost of crude oil increases to $65/bbl.: (10,000 bpd x $65/bbl. x N305/$ x 334 days/annum)	N 66,215,500,000
Gross Margin Per Annum in Naira	**-N 594,711,924**
Gross Margin %	**-0.91%**
Scenario III: Refinery Efficiency at 90% and Crude Oil Price at $35/bbl.	
Total Annual Revenue in Naira	N 65,620,788,076
Total Annual Revenue in Dollar	$ 215,150,125
If the annual cost of crude oil increases to $65/bbl.: (10,000 bpd x $35/bbl. x N305/$ x 334 days/annum)	N 35,654,500,000
Gross Margin Per Annum in Naira	N 29,966,288,076
Gross Margin %	**45.7 %**

Yield	**Yield in Per Liter**	**ADU Efficiency at 95% (liters/year)**
LPG	5,204,388	4,944,169
Light Gasoline Light Naphtha Heavy Naphtha	149,227,860	141,766,467
ADK	70,524,768	66,998,530
AGO	120,497,514	114,472,638
Residue Fuel Oil	185,605,470	176,325,197

Product Yield	**Prices N/liter**	**Prices $/Liter**
LPG	130	0.426
Gasoline (PMS)	135	0.443
Kerosene(HHK)	185	0.059
AGO(Diesel)	185	0.059
Fuel Oil	70	0.229

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Product Yield	Refinery Gain Factor x 1.0714 (liters/year)	Prices N/liter	Annual Revenue (N)
LPG	5,297,182	102	N 540,312,564
Gasoline (Petrol-PMS)	151,888,592	135	N 20,504,959,920
Household Kerosene(HHK)	71,782,225	180	N 12,920,800,500
AGO(Diesel)	122,645,985	180	N 22,076,277,300
Residue Oil	188,914,816	70	N 13,224,037,120

Scenario IV: Refinery Efficiency at 95% and Crude Oil Price at $55/bbl.	
Total Annual Revenue in Naira	N 69,266,387,404
Total Annual Revenue in Dollar	$ 227,102,910
Annual Cost of Crude Oil at $55/bbl. (345 Days/Annum)	N 57,873,750,000
Annual Cost of Crude Oil at $55/bbl.	$ 189,750,000
Gross Margin Per Annum in Naira	N 11,392,637,404
Gross Margin Per Annum in in Dollars	$ 37,352,910
Gross Margin %	**16.5%**

Table 4 4. Financial Analysis Scenarios

Daily PMS Consumption 2017:	51.5 million Liters
Annual PMS Consumption,2017:	51.5 million x 365 Days = 18.8 billion liters
Average PMS Consumption Rate (Per Year)	700,000,000 million liters Per Year
Tota; PMS Consumption (4 Years)	2,800,000,000
Annual PMS Consumption by 2021	21,597,500,000 liters

A 10000 BOPD Modular Refinery PMS Production	= 2810 bbl./Day * 159 Liters* 334 Days =149,227,860 Liters/Year
Therefore, Number of 10,000 Capacity Modular Refinery	= 21,597,500,000/149,227,860 =145 (10,000 BOPD Modular Refineries)

Table 4 5 Analysis of PMS Consumption in 2017-2021 Source:(NBS, 2018)

Profit and Loss Projection

Year	**Year 1($)**	**Year 2($)**	**Year 3($)**	**Year 4($)**	**Year 5($)**
Total Revenue	215,150,125	215,150,125	227,102,910	227,102,910	227,102,910
Feedstock Cost	183,700,000	183,700,000	189,750,000	189,750,000	189,750,000
Gross Margin	**31,450,125**	**31,450,125**	**37,352,910**	**37,352,910**	**37,352,910**
Gross Margin %	**14.6%**	**14.6%**	**16.5%**	**16.5%**	**16.5%**

Operating Expenses and Cost[91]

Salary(s)	786,253	786,253	933,823	933,823	933,823
OPEX	1,258,005	1,258,005	1,494,116	1,494,116	1,494,116
Interest	6,000,000	4,200,000	2,400,000	600,000	0
IBT	23,405,867	25,205,867	32,524,971	34,324,971	34,924,971
Income Tax	0.00	0.00	0.00	0.00	0.00
Net Income	23,405,867	25,205,867	32,524,971	34,324,971	34,924,971
Net Margin	**10.9 %**	**11.7 %**	**14.3 %**	**15.1 %**	**15.3%**

Table 4 6. Profit and Loss Projection and Operating Expenses and Cost

4 .2 Data Analysis

With reference to Table 4.5, on the average, within three years, between 2016 and 2018, the amount of consumed petroleum in liters is about 51.5 million liters of petroleum per day according to PPPRA(PPPRA, 2018) and NBS(NBS, 2018). This makes the annual consumption at 18.81 billion liters, see Table 4.5. However, by 2021, with the PMS consumption growth at the rate of 700 million liters per year, it implies that four years after, the annual PMS consumption in 2017 would increase by 2.8 billion liters. This now put the annual PMS consumption by 2021 at of 21.6 billion liters that is (18.81 billion plus 2.8 billion liters).

Table 4.1, Table 4.2, Table 4.3 and Table 4.4in sequence explain the production of PMS and AGO etc.from Bonny Light crude type using 10,000 bpsd Hydroskimming Modular Refineries(Ogbon N. O., 2018) with operating days of 334 days per year[92]. As earlier mentioned in this research

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work that distillation yields depend on refinery complexity and capacity, therefore, according to(Mcguire D, 2019), it can be said to also vary from refinery to refinery as each refinery is unique in its entirety[93]**.** The tables 4.1, 4.2 and 4.3 represent the breakdown of Bonny Light crude oil as feedstock into the 10,000 bpd capacity Hydroskimming modular refinery. The output yield is in yield per liter for each constituent product with respect to the refinery efficiency and refinery gain factor. These are the basis for arriving at the annual gross revenue and gross margins, Table 4.4.

The crude oil cost is a variable that depends on the total refinery capacity, foreign exchange rate, price of crude oil in the international market and number of days of refinery in operation per year. With all that put together, there are four scenarios for examination by simply varying the refinery efficiency with crude oil price to arrive at different gross margins. These variation and results have economic implications for the refiner, therefore must be able to reach a compromise between production costs and selling prices of products. Below are explanations of the financial analysis scenarios with reference to Table 4.4:

Scenario I: However, as shown in the above tables, the first scenario, when the refinery efficiency was about 90% and crude oil price was $55 per barrel, the annual gross income was $215,150,125 at 14.6% gross margin percentage, all at the foreign exchange rate of N305 per dollar.

Scenario II: However, as shown in the above tables, the second scenario, when the refinery efficiency was about 90% and crude oil price was $65 per barrel, the annual gross income remains at was $215,150,125, however, the gross margin percentage is now at negative 0.91% gross margin percentage, all at the foreign exchange rate of N305 per dollar. Better still, at $35 crude oil price, the gross margin percentage has increased to 45.7% at same refinery efficiency of 90% as can be seen below

Scenario III: The third scenario, when the refinery efficiency was about 90% and crude oil price has increased to $35 per barrel, the annual gross income remains at $215,150,125which translates to 45.7% gross margin percentage. This scenario compared to scenario I also verifies the claim the less is the crude oil price, the more is the gross margin

Scenario IV: This scenario in comparison to scenario I shows relationship between changes in refinery efficiency and gross margin at same crude oil price. This scenario shows that refinery efficiency, increased of95% while the feedstock price remains at $55 per barrel, the annual gross income at the same $215,150,125, and the gross margin percentage has increased to 16.5% compared to when the refinery efficiency is at 90%, the gross income is still at $215,150,125 but with a resultant changes in the gross margin percentage at 14.6%. This validates refining margin improvement with optimum refinery efficiency, the higher the efficiency, the much improved is the refining margin.

4.3 Discussion of Findings/Results

This sub topic covers the data analysis results, interpretations and implications as applicable to the 10,000 bpsd hydro skimming modular refinery financial analysis with focus on the gross and net refining margin as well as the estimation the number of the modular refinery that will be required for PMS production to meet immediate domestic demand in 2021, the aim of which is to attain self-sufficiency. The last and not the least, the roles of government as it relates to the findings uncovered by this research study.

4.3.1 Refining Margin of the Hydro skimming Modular Refinery

From the above financial analysis Table 4.4, two things are critical:

Firstly, the annual revenue which depends on the wholesale prices of the entire products-mix, from the refinery. The annual revenue remains same provided the variables such as the refinery efficiency and feedstock price are same and vice-versa. However good that may sound, when the crude oil price increases from $55 per bbl. to $65 per bbl., for the 10,000 bopd capacity modular refinery, the gross margin decreases and becomes negative. Same reaction is expected when the crude oil prices decreases, the gross margin percentage increases. This establishes a linear relationship between crude oil prices and the gross margin while the refinery efficiency remains the same. Below shows the plot of the annual average crude oil price from 1980 to 2019 against the estimated gross margin percentage as estimated. According to the plot, there is a linear relationship between crude price and refining gross margin percentage as in Figure 1.1.

The interpretation of the plot Figure 1.1 is as follows;

- It implies an inverse linear relationship between the crude oil price and the gross margin percentage
- It also implies that for a 10,000 bopd Hydro skimming modular refinery, there is a limit to how much the crude oil can increase and still remains profitable. In other words, gross margin becomes negative at an increased crude oil price. The increased oil price may be profitable for a conventional refinery due to its vantage economies of scale but not same for a modular refinery; continued increase in oil price will impact negatively on modular refinery.

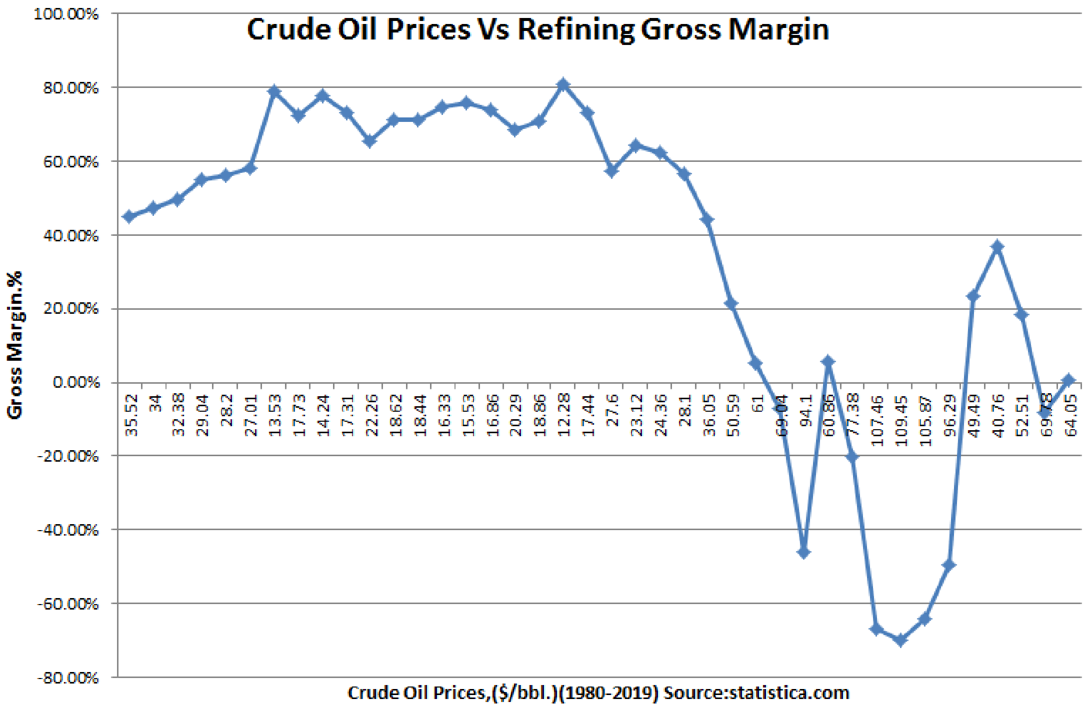

Figure 1 1 Plot of Linear Relationship between Crude Oil Price and Refining Gross Margin

Furthermore, for the same 10,000 bopd Hydro skimming modular refinery, when the crude oil price is about $65 per dollar, the gross margin becomes negative at the value of 0.91%. This implies that for the modular refinery capacity under consideration, crude oil price at and above $65 per barrel, the refining gross margin is at a loss. This buttresses the point that when the crude oil is not properly managed, the refining gross margin becomes unprofitable, Table 4.4.

Based on this research study analyses, at about $65 per bbl. of crude oil, nobody will ever invest or operate at zero or less than zero profit margin, let alone a negative margin. This is the more reason for government intervention to guarantee sales of crude at a cheaper price compared to the international market spot price. It is expedient to work out the local pricing mechanism at a favorable price with the upstream operator and local refiners. In addition, products from such subsidized crude oil prices must be monitored and never allowed to go beyond the border, where there is possibility for selling at high price.

Another point of discussion is the variation between the refinery efficiency and the gross margin, see scenario Table 4.8for the generated values for the variation between refinery efficiency and estimated gross margin using the developed model according**.** While Figure 2.9shows the plot of the linear relationship between the refinery efficiency and gross margin**.** The gross margin increases with higher refinery capacity and the relationship is as interpreted as below:

- In terms of refinery efficiency against gross margin, there is a direct linear relationship between refinery efficiency and refining margin. The higher the refinery efficiency, the higher the refining margin and vice versa, ceteris paribus. According to this research study, at maximum 100% refinery efficiency, the gross margin is about 20.6%, all things being equal. This validates that refining margin remains all time low for modular refinery, not motivating enough for interested investors.
- Worth mentioning is that refinery efficiency must be at all time at maximum and sustained throughout the operating life of the modular refinery. This research study shows that at anything below 80% refinery efficiency, the gross margin goes negative, all things being equal.

4.3.2 Financial Analysis of the Hydroskimming Modular Refinery

Operating Revenue The investment capital was USD 100 million at interest rate of 13.2 %. The refinery capacity utilization is 90% in Year 1 and Year 2 while the capacity utilization is now increased to 95% in Year 3, Year 4 and Year 5 as estimated below. Similarly, for the 3rd, 4th and 5th Years, the maintenance days have been optimized to 345 days per years as against the 334 days from the first two years of operations. Generally, the operating cost is based on percentages, that is, about 70% of projected gross margin is earmarked for cost of feedstock with acceptance criteria of plus or minus 2.5%, while the salary takes about 4% and operating expenses is always about 2.5% of the gross margin respectively as also projected. The end of the financial analysis, the profit and loss account show that the net margin ranges between 11 and 15%. With the margin mathematics, the margin percentage can vary depending on a lot of other factors of production and the operators.

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According to (Olumide A,Ayodele O, 2017), modular refinery margin varies with modular refinery capacity which is synonymous to internal rate of returns (IRR). Reference to Table 2.9 & Table 2.10, when the modular refinery capacity was 3000 bpd, the IRR was 10% and at 7,000 bpd, the IRR rose up to 31% and at 20,000 bpd, IRR became 48%. In terms of margins, another comparative analysis between a 20,000 and 30,000 bpd modular refineries show 6% and 12% margins respectively. Some additional assumptions have been taken into consideration for the analysis on the operating expenses. The refinery efficiency has increased from 90% to 95% after the first two years of operations, owing to lesson learned and international best practices. The crude oil price and whole sale prices of the petroleum product remain same over the same years under consideration.

4.3.3 Number of Modular Refinery Required for PMS Supply by 2021

As already estimated, the 10 kbpsd Hydroskimming modular refineries produces 143,894,456 liters per year of PMS at 90% refinery efficiency and PMS production of 149,227,860 liters per year at 100% refinery efficiency..

Nigeria imports refined petroleum products to meet up with the increasing domestic demands. In 2017, Nigeria PMS daily average consumption was 51,534,246 liters per day, totaling 18.81 billion liters per year[94]. Furthermore, analysis shows[95]that consumption of PMS increases at the rate 700 million liters per year, which now implies that after four years, the PMS consumption is expected to have increased by 2.8 billion liters with increase in a sustained population rate at 2.67(United Nations, 2017). By 2021,[96] the expected PMS consumption may be 18.8 billion plus 2.8 billion to give total of 21,597,500,000(Ogbon N. O., 2018).

It therefore implies, Nigeria will require: 21,597,500,000 \ 149,227,860 = 145 of 10,000 bpd capacity modular refineries). This is just the number of 10,000 bpd capacity modular refineries that will be required to meet country`s domestic demand for petrol, popularly known as PMS in 2021. The implication is if the number is realistic or feasible. Yes, it is feasible only on a long term, with government active involvement and participation. Although, the numbers is on the high side and may constitute environmental nuisance. Modular refineries cannot be alternatives to full-conversion unit, contrary to (Ibikunle O, 2016), they can only either be complementary or supplementary, they cannot be an outright replacement. There must be a synergy between modular refineries and conventional full-scale refineries.

4.3.4 Governments Roles towards a Sustainable Development of Modular Refinery in Nigeria

1. Government Protection from Imminent Threats and Collapse Ideally for refinery business, the profitability threshold is low. Economics of scale plays a key role here, as conventional refineries are better able to spread cost and manage expenditure. Therefore, modular refineries may be confronted with threats from large scale refineries from outside the countries and may end up being shut down permanently if government will not protect local refiners[97].History has it that larger percentage of modular refineries in Europe did collapse due to crude oil price volatility (low profitability during high crude oil price and vice versa), compounded by stiff competition from conventional refineries for profitability and threats(Ogbuigwe T, 2017)

2. Necessity of Government Participation The capital-intensive nature for a modular refinery is such a humongous amount of fund which a local illegal refiner cannot afford. This necessitates government participation either by equity holder or sole sponsorship. Truthfully, these illegal refiners lack the financial capability and skills to make such investment decisions. Government at different levels should be encouraged to participate, if every state invests in a modular refinery each, there is an assurance of minimum 36 modular refineries to be built in the country and that may spring board the realization of the country`s domestic demand self-sufficiency(Nwaozuzu C, 2018). The model must be implemented to letters which stipulates a private–sector led partnership with some measures of equity from state government and state agents with the private investor as the majority shareholder and technical operator of the joint venture.(Federal Ministry of Petroleum Resources, 2017). There are stipulated three levels of investors` categories: private sector of Nigerian-decent with technical and financial capacity; public-private partnership from foreign companies, state and local government, communities and NGOs etc. and artisans with vocational skill which can be converted to technical skill shall be considered as equity holders.(Federal Ministry of Petroleum Resources, 2017)

3. Price Regulation and Regulatory Bodies Adjustment by Government Price regulation, also known as ceiling, is government-made phenomenon. This happens when the prices of refined petroleum products are regulated, fixated by way of subsidy[98]. The subsidized price is always below the market equilibrium price, the market forces are not permitted to determine what prices the products should sell. The implication is quantity supplied of the petroleum product is less to the quantity demanded, hence creating a supply gap(Ilewumi D, 2019). Undoubtedly, government subside is a setback to speedy development and recovery of the refinery industry. According to (Punch Newspaper, August,2018) government must allow free flow of products at a deregulated price for refineries to develop as it should with domestic demands. Needless to mention that, NDPR Ogbelle modular refinery produces diesel only. This is the only operational modular refinery in the country till date simply owing to the fact diesel has been fully deregulated. The downstream sector must be fully de-regulated for prospective private investment to thrive. Apart from price regulation, there has been contentious argument over the effectiveness of the numerous regulatory bodies in the refining sector, resulting in uncertainties in regulation(Brickstone P, 2019)

3. Menace of Oil Pipeline Sabotage and Vandalism Oil pipelines lack adequate surveillance security and of course, vulnerable to frequent attacks and vandalism. Recently reports have it that attacks on pipelines have increased drastically of recent. There were just about 57 incidents in 1998 and ten years after, the incidents had plummeted to 2500 incidents. In 2018 alone, Shell records showed 128 oil spills incidents as a result of sabotage, two times more than the record in 2017 and all-time highest since 2014(Noah B and Evans C, 2013). Since all these incidents, government has continued to make frantic efforts to address the issues and root causes, (Okoli C, 2019),one of the efforts was deployment of satellite radar system to track pipelines for vandalism, and however, these ugly situations have persisted, rather than trending downward, it keeps on multiplying. This trend portends imminent danger to national security and economy of the nation[99] . Again, May, 2019, 60 separate incidents were recorded and in June, it increased to 106 incidents, that represent 77% pipeline vandalism increase across pipeline reticulated formation(Femi A and Kingsley J, 2019). Cumulatively, between January and June, 2019, 22 million barrels of crude oil have been stolen with possibility to increase twice by December, 2019. These are facts based on reality on ground. If this is allowed to continue unresolved, it will not mean well for modular refinery project development, construction and operations in the country and ultimately deter potential investors(Femi A and Kingsley J, 2019). In view of these, government needs to beef up security with zero tolerance and eliminate the uncertainties and instabilities brought about by the saboteurs. Vandalized pipelines to be repaired and replaced where the pipes are in disrepair.

4. Infrastructural Improvement Government needs to invest much more in infrastructures in addition to the existing pipelines such as rail system to enhance supply of crude and product transportation to end users. The shallow water ways must be dredged for easy passage oil tankers without going aground. The rail system, water-way dredging in addition to the pipeline network will eliminate the bottlenecks as a result of logistics hiccups. Badges can be used where oil tankers are not feasible. All these and more are capital intensive projects that the government must undertake to incentivize both the local and foreign investors.(Brickstone P, 2019) . This idea makes modular refinery location such that must be located very close to source of crude oil, therefore infrastructural improvement shall be done on case-by-case basis (location and refining capacity)

5. Regular Supply of Crude Oil The government must guarantee refineries access to feedstock regularly with interruption.(Nwaozuzu C, 2013). The government should be able to sustain the supply for a few years after commissioning of the modular refinery, and if possible, the supply may be extended throughout the life of the modular refinery operation. Due to the low margin characteristics of modular refineries, therefore, the refineries must always be in operations every day of the week and every month of the year to the maximum utilization capacity except on maintenance period. The refinery cannot afford to shut down due to non-availability of crude, it will impact adversely on the already low-margin.

The major threat to regular feedstock is insecurity. Government proposal for supply of 60% crude oil to domestic refiner must be reviewed up-ward to reflect 100%, not more, not less(Nwaozuzu C, 2015).Once license to establish is issued by DPR, there is a follow up agreement for supply of 60 percent crude oil from NNPC, the balance of 40 percent comes from where? this is imperious and needs urgent redress by the Federal Government. Government must make crude oil available 100% of the time and similarly makes crude oil supply flexible by engaging third part contractors, backward integration with upstream operators, to participate in the supply chain instead of PPMC only and the contractual terms and conditions must be adhered to without fail.

This aspect of the supply chain can be contracted out to avoid government bureaucracy and unnecessary delays. Although, modular refineries are situated within the proximity of crude oil source, this reduces the challenges of regular supply of crude oil and in this case, partnership between the refiner and oil operator is enhanced. More often than not, the expense incurred when crude oil is transported or pipelined from its source to the refinery is completely eliminated with modular refinery making it more economically practicable(Brickstone P, 2019)

6. Free Economic Zone/Port Modular refineries must be located in the free zones to reduce investment cost. This will serve as an incentive from government to attract more investor. Free zones market products enjoy tax concessions (no corporate or personal income tax) to encourage more economic activities. Custom interferences are limited, zero custom duty. The same model was used in establishing US export-oriented refineries which produced special products should also be adopted for modular refinery by creating oil and gas free zones in oil-producing state.(Brickstone P, 2019)

7. Upgrade of Modular Refinery Government must also invest in modular refineries with the hydro treater and catalytic converters, both of which are required for full conversion. The full conversion increases refinery yield and eventual profitability.(Mamudu A,Okoro E,Igwilo K and Olabode O, 2018)The idea is cost-saving for private-owned modular refineries which may not be equipped for full conversion cause of the high cost of purchase(Nwaozuzu C, 2013). However, the whole idea is to transport residue such as naphtha from private-owned refineries to government refineries which has been adequately equipped just so to further distillate the residue and produce more petrol. The same model similarly suggests both the private and government owned refineries to setup within same locality to avoid unnecessary spending on cost of transportation(Nwaozuzu C, 2013). This model creates synergy between government and private investor, while the private investor is saving cost on full conversion facility, the government is able to meet domestic energy demand.

8. Crude Oil Subsidy and Tax Exemption. Since crude oil sells at the international market price and the selling price have all the associated cost factored into the pricing, hence, the selling price is in us dollars. Government cannot charge international spot prices for crude oil meant for domestic refining and consumption, otherwise, investors will prefer to setup refineries in developed countries rather than Nigeria(Nwaozuzu C, 2015).If the same government subsidizes a few ECOWAS countries and a few traders, this is the more reason to offer subsidy to domestic modular refiners and cease subsidizing refined products. However, Government should not only offer subsidy on crude oil, they also must put control and monitoring measures in place to ensure the crude is refined to obviate diversion of subsidized crude oil(Nwaozuzu C, 2015).It is more expedient to subsidize local production than imported products.

In addition, (Nwanze K., 2019) crude oil price volatility is so critical and must be put into consideration for modular refiners[100]. It may be not too lucrative to sell crude oil at the international market price in the local market, by way on incentivizing the local refiners; the price of crude oil should be subsidized. This will definitely boost the already low margin business of refinery. Rather than subsidizing the petroleum products, it is a welcoming development for crude supply to modular refinery to be subsidized.

According to OPEC`s view of perspective of pricing petroleum products, OPEC countries are developing countries, where citizen`s per capital income is very low, local labor rate is a lot less than what is charged at the international level. And ultimately[101], natural resources belong to the citizens and their benefits should come in subsidies(Nwaozuzu C, 2019).

9. Government Off-Taker Assurance and Purchase of Naphtha Residue Government must sign an agreement with the modular refinery operators to buy-off the refined products and their residue such as naphtha and further process into petrol as the process of full conversion (naphtha hydro treater and catalytic reformers) is another cost which may increase the startup cost of modular refinery. Naphtha or gasoline as it is popularly called, forms about 18-42% of products and there is no market yet for naphtha in Nigeria, therefore, the need to further distillate to produce petrol. Government being part of the model will have to guarantee purchase and the modular operator must guarantee sales. The provision must be taken care of in the agreement, similar to off-take provision in gas-master plan contract. There must be a willing seller and a willing buyer. In this case,it is expedient modular refineries are sited close to government conversion units (conventional refinery) so as to cut cost of transportation of naphtha form respective modular refinery. If not properly managed, the cost of transportation may erode the profitability (Nwaozuzu C, 2013). Besides aforementioned, Off-taker Contract: This contract must be in place as this is used as a loan security to access funding.

10. Synergy between Landowners and Local Government[102]The ownership of petroleum resources(Collins A.I, 2017)was vested in the federal government right from the first piece of laws according to the colonial administration of 1946 and dated back to era of colonialism. Although, there is no ignorance in law as some land owners still holding to their belief of ownership of land and its content to any depth, however, by way of compensation, the Federal government must obtain the endorsements of both the state and local governments where the modular refineries shall be located,, their support is a necessity and their involvement as partners will contribute immensely to the success of the modular refineries[103].

Similarly, by way of incentivizing the land owners, the money value of their land or lease from the land can either be considered as investment by the land owners for which returns will be paid or as a debt for payment over a specified period of time for twenty years or more with the agreement of the state or local government. (Nwaozuzu C, 2015)

11. Building Modular Refinery Clusters Modular refineries clusters may be a solution to the problem of additional cost incurred to transport residue of naphtha from a local modular refinery to government conversion unit for processing. Clustering is a system of channeling a residue from one unit to other where it will serve as feedstock for another. Clustering connects a topping unit in a field location to hydro-skimming unit in another field location and possible connection to a conversion unit owned by government in another location(Angela C, 2019)[104].By way of incentivizing investors in modular refineries, government can take up this project of interconnecting modular refineries, by so doing, it makes the government a stakeholder in the entire refinery revolutionary business and confidence of government protection. The cost of establishing clusters cannot be compared to investment in laying pipelines(Angela C, 2019)

V: SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary.

The research study identifies the simplest form of modular refinery as an atmospheric distillation unit, also known as, Topping Unit. The study goes further to give insight into the modular refinery processes using the hydro-skimming refinery unit which has a higher refinery complexity compared to the atmospheric distillation unit. The highlight of modular refinery is such that in terms of cash outlay, the investment capital is relatively low; payback period is also low, short lead time, upgradability features etc. However, one major concern about Modular Refinery is that the refining margin is all-time low except some drastic measures are taken to improve the situation.

The study similarly looks reason behind crude oil selection. The type of crude oil will determine the product yield percentage, that is, the product yield analysis is based on the API values of the crude oil type, as different crude oil types have propensity to produce different percentages of same petroleum products. Topping plant yield is not same as yield from cracking unit and coking units. Cracking can increase

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volumetric unit by 20-25% for gasoline from residue from a topping unit. Understanding of refinery complexity is an essential knowledge to prospective refiner as this is about crude oil selection,

For optimum performance, modular refineries must be maintained on a regular basis to avoid incessant breakdown or eventual shutdown of the system. However, the following such as benchmarking, bottom-line definitions are key to optimum performance and the different types of maintenance there is. Benchmarking is the compulsory bi-annual audit and evaluation of criteria for profitability. Today, mechanical work-order (WMO) is a software-based system to structure and keep records of maintenance. There are preventive maintenance carried without necessarily shutting down the plant while breakdown maintenance require shut down of plants and the last of its kind, is the turnaround maintenance, undertaken every 3-5 years at interval. While Bottom-Line is the use of experienced hands in the day-to-day running operations of the refinery, especially a requirement for linear programming modelling using some software such as the Honeywell Hi-Spec Solution.

The research learning has another section on the state of the country`s refinery structure. The summary captures the four domestic refineries in terms of feedstock, capacity and petroleum products. The total refinery capacity is 445,000 bpd as per the nameplate. Despite, Nigeria remains a mono-cultural economy with dependency on importation of refined product to the tune of 80% of the current domestic demands. However, green refineries such as modular refineries have been identified and recommended to put an end to fuel importation in expectation to transforming the country to becoming self-sufficient or net exporter. Therefore, modular refineries by its applicability are like “a square peg in a square hole”.

The study argues opinions in some previous literatures suggesting upgrade of illegal refineries by modular refinery. This study is of a differed opinion, it is misplacement and misconception to suppose illegal refineries can be upgraded to modular refineries. This is premised on the fact the illegal refineries are mere metal drums used for boiling crude oil and the steams are collected in a containers as diesel(impure form of diesel). The system has no basis of engineering and as such cannot be upgraded to a modular refinery. Modular refineries are in modules built in factories, transported and set up at sites. These are two parallel lines and so are incoherent for any consideration. The study concludes illegal refineries as an economic problem that requires also an economic and purely un-technical approach.

The study also identifies a few current challenges confronting development of modular refineries. The number one is the lack of adequate capital and technical know-how. Though the initial investment capital is relatively low, yet so huge that local investors cannot afford to provide, vis-à-vis, the technology is still alien to us thus so much reliance on foreign partners cooperation and willingness to allow its importation. The other challenge is the issues with licensing structure and issuance. The word license is ambiguous, one assumes once licensed there should be no reason for failure to execute or operate. There are a lot more expired licenses than the active ones. License issuance should be granted after due diligence has been passed and investors` show of evidence of capital base as against the current practice which is premised on ability to purchase licensing forms .This trend must be reversed if we will ever see the sustainable development of modular refineries in Nigeria.

The Modular refineries have got speculative advantages which have been captured in the course of the in-depth study. They are climate change mitigation, in the sense and hope that modular refineries, illegal refineries will lose patronage and soon get wiped out of existence. Once the existences of illegal refineries which have contributed adversely to environmental pollution are no longer sustainable, the overall impact may imply climate change alleviation. Another advantage, it is a relatively cheap power source to Independent Power Producer as practiced across the globe, just to mention a couple.

The study on closing out this section, discuses economics of business models for modular refineries. There are just two industry-recognized and economical ways of modelling a modular refinery business and locating close to existing refinery, marginal field or within proximity of source of crude oil. There are a few finance lenders setup for modular refinery; they are commercial banks, Export Credit Agency (ECA) and Multilateral Agencies.

The roles of government cannot be over looked if modular refineries must be developed in Nigeria. The numerous roles of the government in ensuring development of modular refinery in Nigeria are essential and key. Largely, government core responsibility is protection of life and properties and creating an enabling environment for thriving economic growth. However, most pertinent in the development of modular refineries is government participation, crude oil pricing template for local refineries. Automatically, the development of modular refineries will nip in the bud the menace of pipeline vandalism and illegal refineries. Government must show seriousness by building modular refineries in cluster to facilitate development. 100% supply of crude oil to domestic modular refineries by government is inevitable. At the same time, government must demonstrate willingness to invest in Modular Refineries requirement to upgrade to full conversion as the population continues to out-grow domestic demands. These are just a few to mention from the study.

5.2 Conclusion

5.2.1 Firstly, the research study (first three scenarios) has estimated the relationship between crude oil price volatility and gross margin. The result shows an inverse linear trend line relationship between the crude oil price and gross margin. The higher the crude oil price, the lower the gross margin and vice versa. The relationship also reveals that, for a 10,000 bopd capacity modular refinery, if the crude oil prices is at $65 per barrel, the entire refining margin may become negative thus eroding the profitability, ceteris

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paribus. This is hypothetical however; it's a statement of fact, that crude oil prices must be regulated for modular refiners for profitability sake.

5.2.2 Secondly, on the basis of the annual revenue estimation done, the forth scenario compared to scenario one evaluation reveal the a direct linear relationship between refinery efficiency and the gross margin. This implies, the higher the refinery efficiency, the higher the operating gross margin. This validates claims by case study on mini-modular refinery feasibility study by IEA. That the refinery must be in optimum operations at all times. In view of this, the operating refinery efficiency must be sustained high at all times, contrary to that, the profitability may be eroded. There is a level of refinery efficiency below which profitability becomes negative, therefore, modular refinery must operate above the minimum level regularly and always.

5.2.3 This study has proven using a 10,000 bopd hydro-skimming modular refinery to produce PMS for domestic consumption, a total number of about one hundred and forty five (145) modular refineries of same capacity will be required to attain self-sufficiency in domestic PMS demand and supply, that is, using only the 10,000 bopd capacity modular refinery without any contribution or output from the domestic conventional refineries. The number is huge and this calls for a synergy between full scale and modular refineries if self-sufficiency must be attained.

5.2.4 As part of the synergy, the roles of government cannot be over-emphasized. Without involvement, participation and investment by the government, development of modular refinery may remain a mirage. Government must exercise political will to invest in building modular refinery clusters to network all the refineries, (both modular and domestic conventional) together in clusters, just so to ease crude oil supply and refined product evacuation. They must be ready to invest in cluster infrastructure development and incentivize. Similarly, government needs to revise all the existing policies and guideline to reflect the realities on ground and address the pressing issues that will encourage massive development of modular refineries.

5.3 Recommendations

The study is an eye-opener to many realities about modular refinery and on this note, the following recommendations are being proposed as explained thus:

The role of government is so critical that massive investment from the side of government is inevitable. They must invest in building modular refineries, not as a competitor but rather a demonstration of fate and strong believe in the modular refinery development towards self-sufficiency and becoming a net exporter if possible.

To maximize the advantages of modular refineries, government needs to invest in some expensive equipment for possible conversion of modular refineries into full scale ones soa s to maximize product yield percentage, leaving such in the hand of the local operator, may be an unnecessary financial and not in the interest of modular refinery development..

Government can also derive more economic benefits from development of modular refinery by ensuring all modular refinery operators participate in the Independent Power Producer (IPP) projects. As at today, only a few IOC are participating in the IPP, the idea must be extended to modular refineries operators. This will definitely improve their business profit margin

Similarly, the idea of supply of 60% crude to plant is not in the interest of the government. Firstly, where are the operators expected to source for remaining 40% crude to operate refineries? This is an avenue to perpetuate pipeline vandalism as it is a common knowledge that refineries are expected to operate all year round, and year on year without any break. Due to lack of crude supply, can cause a major loss to the operator and that will eventually kill the business in a short time. Government must be willing to make provision for crude oil supply non-stop. Government also should enter into an off-take agreement to evacuate petroleum products as soon as available.

5.4 Contribution to Knowledge

Indeed, the research study has been able to estimate the number of modular refineries for the country to achieve self-sufficiency which is about one hundred and forty five of a 10,000 bpsd hydro skimming modular refinery. The number is pretty high and seems unachievable within the short term period. This implies, development of modular refineries alonemay not suffice to meet the millennium goal of self-sufficiency, however, the combined synergized efforts of both the modular refineries and full-scale refineries would be much needed to meet the current domestic demands for petroleum products. Now, this is a clarion call to both the private and public partnership to drive the development of modular refineries and full-scale refineries alike, if the country must meet the economic development of the nation.

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	Modular Refinery	**Full-Scale Refinery**
Refining Capacity	Between 1000-30,000 bopd	30,000 bopd and Above
Manufacturing	Mounted on skids	Fabrication on site.
Configuration Installations	Topping Plant or Hydro-Skimming Plant	Combination of Topping,Cocking,Cracking,Hydro-Skimming
Products Ranges	Gasoline, Naphtha and lights	All ranges of product
Crude Types	Heavy Crude	All Crude Types
Flexibility	Easy to add more modules	Rigid except by Turn around Maintenance

Table1.1 Basic Comparison between Modular Refinery and Conventional Refinery [105] **Source**(Ibikunle O et al , 2016)

Equipment Requirement for 500 BPD Capacity		
Quantity	**Capacity (Units)**	**Description**
1	500	Crude Distillation Unit (CDU)
1	500	De-Salter

Table1.2 Equipment Needed for Mini Oil Refinery **Source** (Peiyangchem, 2019).

Mode	**Capacity (BPD)**	**Power (Kw/d)**	**Fabrication Period(months)**	**Area (Acre)**	**No. of Skids**	**Weight(Kg)**
MR10	1000	150	5	1	5	120,000 Kg
MR30	3000	200	5	2	7	160,000 Kg
MR50	5000	275	6	2	8	200,000 Kg
MR100	10000	350	6	3	11	375,000 Kg

Table1.3 Register of Modular Oil Refinery [106] **Source** (Peiyangchem, 2019)

Mode	Capacity (BPD)	Power (Kw/d)	Fabrication Period(months)	Area (Acre)	No. of Skids	Weight(Kg)
MR2	200	75	4	1	4	50,000 Kg
MR5	500	100	4	1	4	80,000 Kg

Table2. 1 Register of Mini Oil Refinery[107] **Source** (Peiyangchem, 2019)

Capacity	No. of Skids	Commissioning Hours
150	2	24
1000	3	48
3000	5	96
6000	8	168

Table2. 2 Standard Sizes Offerings **Source:** (Mcguire D, 2019)

Off Gas	LPG	Gasoline	Kerosene	Diesel	HFO	Asphalt
2%	2%	18%	7%	21%	20%	29%

Table 2 2 Heavy Crude Oil Products **Source** (KUAI Energy System, 2019)

Off Gas	LPG	Gasoline	Kerosene	Diesel	HFO	Asphalt
2%	4%	47%	10 %	23%	18%	3%

Table 2 2 Light Crude Oil Products [108] **Source** (US Department of Energy Source (Energy Information Agency, 2014)

Product	LPG	Light Naphtha	Heavy Naphtha	Kerosene	Diesel	Residual Fuel Oil
Temperature(^{0}F)	<85	85-200	200-350	350-450	450-650	1050+

Table2.3 Methodology and Specification Guide.[109]**Source**(The Eagle Ford Marker October 2012)**.**

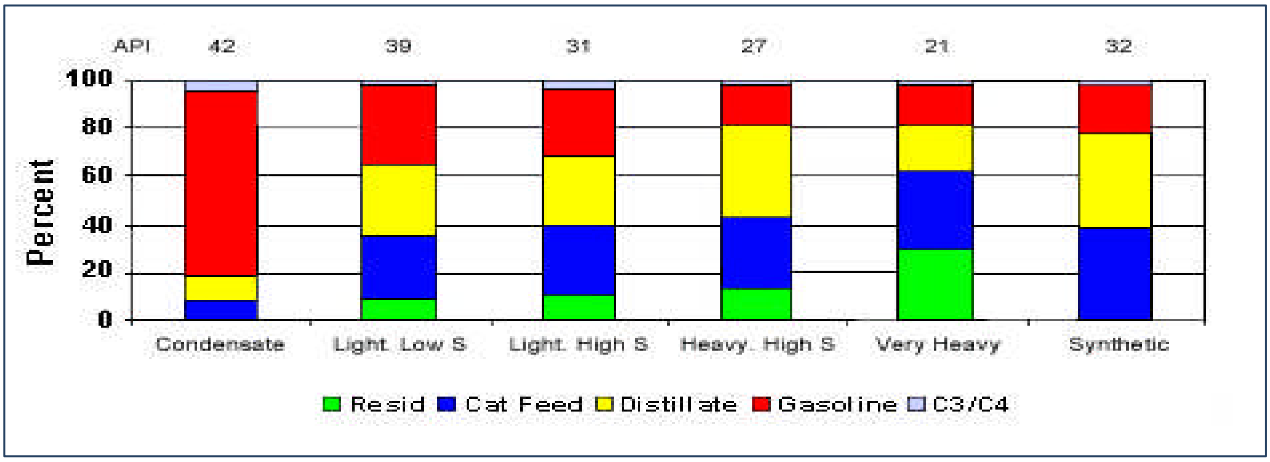

Table 2.4 Comparison of Modular-Mini Refinery Yield by Crude Oil Type Source (Cenam Energy)

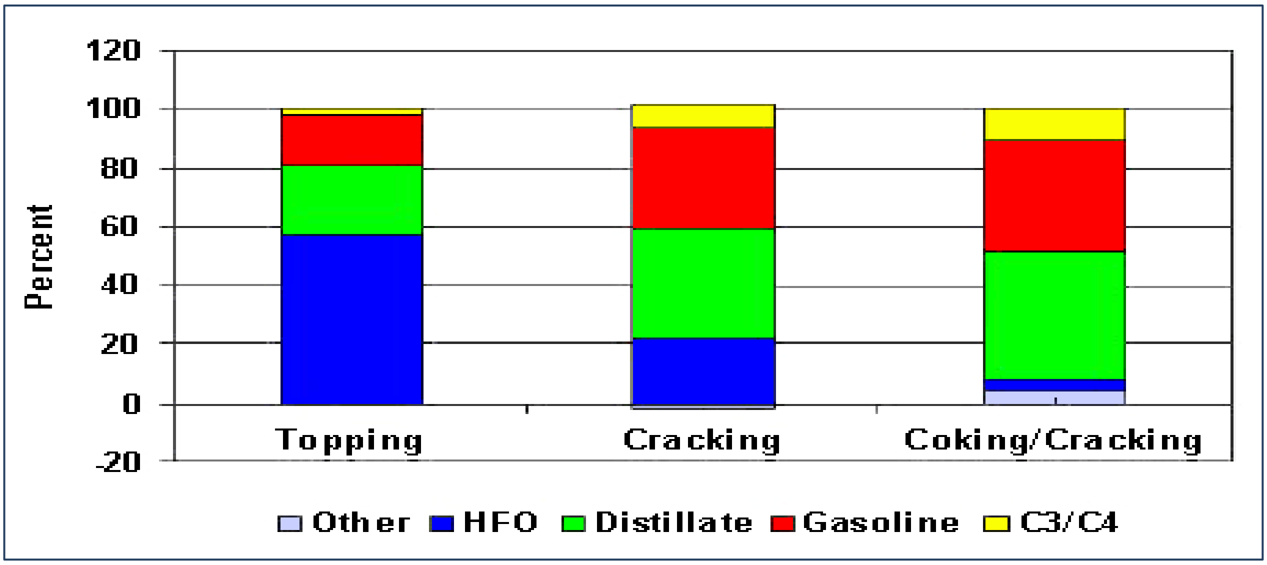

Table 2.5 Comparison of Yield by Refinery Type (Heavy Crude Oil Example) Source (Cenam Energy)

Vendor	Linear Programming Software
Haverly	GRTMPS-Generalized Refining Transportation Marketing Planning System
Aspentech	PIMS-Process Industry Modelling System
Honeywell Hi-Spec Solutions	Refinery & Petrochemical Modelling System

Table2.6 Linear Programming Model Software Vendors **Source** (Refinery Planning and Optimizations Using Linear Programming)

Process Unit	Kaduna Refinery	Portharcourt Refinery (New)	Portharcourt Refinery (Old)	Warri Refinery	Niger Delta Pet. Resource	Total
Configuration	Conversion	Conversion	Hydro skimming	Conversion	Topping Unit	
Feedstock	Escravos, Ughelli Blend, Basra, Urals	Bonny Light	Bonny Light	Escravos, Ughelli Blend	Ogbelle	
Products	Fuels, Petrochemicals	Fuels	Fuels	Fuels, Petrochemicals	Diesel	
Crude Distillation	110,000.	150,000	60,000	125,000	1000	446,000

Table2.7Summary of Domestic Refineries **Source** (Nigeria Oil and Gas Industry Annual Report, 2017)

Refinery Configuration Analysis	Full-Scale Refinery	Modular Refinery for PMS Production	Modular Refinery for AGO Production
Capacity (bpd)	200,000	30,000	20,000
Initial Capital (USD)	7 Billion	187 Million	92 Million
Revenue(USD)	3 Billion	413 Million	291 Million
Payback Period(Years)	18	8	2.6
Refining Margins	13%	6%	12%

Table2.8 Summary of Modular Refinery Economics **Sources:(Cenam Energy, 2017)**

Capacity(bpd)	Cost (USD)	NPV (USD)	IRR	Payback (Years)
20,000	92 Million	242 Million	48%	2.6
10,000	55 Million	116 Million	38%	3.3
7,000	44 Million	78 Million	31%	3.9
5,000	38 Million	52 Million	22%	5.1
3,000	29 Million	27 Million	10%	7.4

Table2. 9 Analyses of Modular Refinery Economics (AGO Product) Sources: (Cenam Energy, 2017)

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Modular Refinery Analysis (AGO-Diesel) cont`d Capacity(bpd)	PMS	Kerosene	AGO	Residue	Naphtha
20,000		97,498,800	250,711,200	243,747,000	97,498,800
10,000		48,749,400	125,355,600	121,873,500	48,749,400
7,000		34,124,580	87,748,920	85,311,450	34,124,580
5,000		24,374,700	62,677,800	60,936,750	24,374,700
3,000		14,624,820	37,606,680	36,562,050	14,624,820

Table210Analysis of Modular Refinery Economics **Sources:**(Cenam Energy, 2017)

Year	TotalAnnual Revenue (Naira).	Refinery Efficiency (%)	Crude Oil Price ($/bbl.)	Crude Oil Cost (Naira)	Gross Margin (Naira)	Gross Margin %
2019	65,620,788,032.51	0.9	64.05	65,247,735,000.00	373,053,076.00	0.57%
2018	65,620,788,032.51	0.9	69.78	71,084,886,000.00	**5,464,097,924.00**	-8.33%
2017	65,620,788,032.51	0.9	52.51	53,491,937,000.00	12,128,851,076.00	18.48%
2016	65,620,788,032.51	0.9	40.76	41,522,212,000.00	24,098,576,076.00	36.72%
2015	65,620,788,032.51	0.9	49.49	50,415,463,000.00	15,205,325,076.00	23.17%
2014	65,620,788,032.51	0.9	96.29	98,090,623,000.00	**32,469,834,924.00**	-49.48%
2013	65,620,788,032.51	0.9	105.87	107,849,769,000.00	**42,228,980,924.00**	-64.35%
2011	65,620,788,032.51	0.9	107.46	109,469,502,000.00	**43,848,713,924.00**	-66.82%
2010	65,620,788,032.51	0.9	77.38	78,827,006,000.00	**13,206,217,924.00**	-20.13%
2009	65,620,788,032.51	0.9	60.86	61,998,082,000.00	3,622,706,076.00	5.52%
2008	65,620,788,032.51	0.9	94.1	95,859,670,000.00	**30,238,881,924.00**	-46.08%
2007	65,620,788,032.51	0.9	69.04	70,331,048,000.00	**4,710,259,924.00**	-7.18%
2006	65,620,788,032.51	0.9	61	62,140,700,000.00	3,480,088,076.00	5.30%
2004	65,620,788,032.51	0.9	36.05	36,724,135,000.00	28,896,653,076.00	44.04%
2003	65,620,788,032.51	0.9	28.1	28,625,470,000.00	36,995,318,076.00	56.38%
2002	65,620,788,032.51	0.9	24.36	24,815,532,000.00	40,805,256,076.00	62.18%
2001	65,620,788,032.51	0.9	23.12	23,552,344,000.00	42,068,444,076.00	64.11%
2000	65,620,788,032.51	0.9	27.6	28,116,120,000.00	37,504,668,076.00	57.15%
1999	65,620,788,032.51	0.9	17.44	17,766,128,000.00	47,854,660,076.00	72.93%
1998	65,620,788,032.51	0.9	12.28	12,509,636,000.00	53,111,152,076.00	80.94%
1996	65,620,788,032.51	0.9	20.29	20,669,423,000.00	44,951,365,076.00	68.50%
1995	65,620,788,032.51	0.9	16.86	17,175,282,000.00	48,445,506,076.00	73.83%
1994	65,620,788,032.51	0.9	15.53	15,820,411,000.00	49,800,377,076.00	75.89%
1993	65,620,788,032.51	0.9	16.33	16,635,371,000.00	48,985,417,076.00	74.65%
1992	65,620,788,032.51	0.9	18.44	18,784,828,000.00	46,835,960,076.00	71.37%
1991	65,620,788,032.51	0.9	18.62	18,968,194,000.00	46,652,594,076.00	71.09%
1990	65,620,788,032.51	0.9	22.26	22,676,262,000.00	42,944,526,076.00	65.44%
1989	65,620,788,032.51	0.9	17.31	17,633,697,000.00	47,987,091,076.00	73.13%
1988	65,620,788,032.51	0.9	14.24	14,506,288,000.00	51,114,500,076.00	77.89%
1987	65,620,788,032.51	0.9	17.73	18,061,551,000.00	47,559,237,076.00	72.48%
1986	65,620,788,032.51	0.9	13.53	13,783,011,000.00	51,837,777,076.00	79.00%
1985	65,620,788,032.51	0.9	27.01	27,515,087,000.00	38,105,701,076.00	58.07%
1984	65,620,788,032.51	0.9	28.2	28,727,340,000.00	36,893,448,076.00	56.22%
1983	65,620,788,032.51	0.9	29.04	29,583,048,000.00	36,037,740,076.00	54.92%
1982	65,620,788,032.51	0.9	32.38	32,985,506,000.00	32,635,282,076.00	49.73%
1981	65,620,788,032.51	0.9	34	34,635,800,000.00	30,984,988,076.00	47.22%
1980	65,620,788,032.51	0.9	35.52	36,184,224,000.00	29,436,564,076.00	44.86%

Table 4 7 Relationship Between Crude Oil Prices and Refining Gross Margin for a 10,000 bopd Capacity Modular Refinery

Total Revenue	Crude Oil Cost	Gross Margin	Refinery Margin,%	Gross Margin,%
72,911,986,702.79	57,873,750,000.00	15,038,236,702.79	100%	20.63
72,182,866,835.76	57,873,750,000.00	14,309,116,835.76	99%	19.82
71,453,746,968.73	57,873,750,000.00	13,579,996,968.73	98%	19.01
70,724,627,101.71	57,873,750,000.00	12,850,877,101.71	97%	18.17
69,995,507,234.68	57,873,750,000.00	12,121,757,234.68	96%	17.32
69,266,387,367.65	57,873,750,000.00	11,392,637,367.65	95%	16.45
68,537,267,500.62	57,873,750,000.00	10,663,517,500.62	94%	15.56
67,808,147,633.60	57,873,750,000.00	9,934,397,633.60	93%	14.65
67,079,027,766.57	57,873,750,000.00	9,205,277,766.57	92%	13.72
66,349,907,899.54	57,873,750,000.00	8,476,157,899.54	91%	12.77
65,620,788,032.51	57,873,750,000.00	7,747,038,032.51	90%	11.81
64,891,668,165.48	57,873,750,000.00	7,017,918,165.48	89%	10.81
64,162,548,298.46	57,873,750,000.00	6,288,798,298.46	88%	9.8
62,704,308,564.40	57,873,750,000.00	4,830,558,564.40	86%	7.7
61,975,188,697.37	57,873,750,000.00	4,101,438,697.37	85%	6.62
61,246,068,830.34	57,873,750,000.00	3,372,318,830.34	84%	5.51
60,516,948,963.32	57,873,750,000.00	2,643,198,963.32	83%	4.37

59,787,829,096.29	57,873,750,000.00	1,914,079,096.29	82%	3.2
59,058,709,229.26	57,873,750,000.00	1,184,959,229.26	81%	2.01
58,329,589,362.23	57,873,750,000.00	455,839,362.23	80%	0.78
54,683,990,027.09	57,873,750,000.00	3,189,759,972.91	75%	-5.83
51,038,390,691.95	57,873,750,000.00	6,835,359,308.05	70%	-13.39
47,392,791,356.81	57,873,750,000.00	-10,480,958,643.2	65%	-22.12
43,747,192,021.67	57,873,750,000.00	-14,126,557,978.3	60%	-32.29
36,455,993,351.40	57,873,750,000.00	-21,417,756,648.6	50%	-58.75
32,810,394,016.26	57,873,750,000.00	-25,063,355,983.7	45%	-76.39
29,164,794,681.12	57,873,750,000.00	-28,708,955,318.9	40%	-89.62
25,519,195,345.98	57,873,750,000.00	-32,354,554,654.0	35%	-104.293
21,873,596,010.84	57,873,750,000.00	-36,000,153,989.2	30%	-118.966
18,227,996,675.70	57,873,750,000.00	-39,645,753,324.3	25%	-133.639
14,582,397,340.56	57,873,750,000.00	-43,291,352,659.4	20%	-148.312

Table 4 8Relationship Between Refinery Efficiency and Gross Margin for a 10,000 bopd Capacity Modular Refinery

Product	**Output Yield, (Liters)**	**Gain Factor x1.0714**	**Efficiency,% 90%**	**Wholesale (N/Littre)**	**Revenue (N)**
LPG	5,204,388	5575981.303	5018383	102	511,875,083.63
PMS	149,227,860	159882729.2	143894456	135	19,425,751,598.29
ADK	70,524,768	75560236.44	68004213	180	12,240,758,302.50
AGO	120,497,514	129101036.5	116190933	180	20,914,367,912.94
Residual FO	185,605,470	198857700.6	178971931	70	12,528,035,135.15
				TR	65,620,788,032.51
Assumptions: Crude Oil Price at $55/bbl for 345 Days Per Annum FX @N305/$				**Cost Crude**	57,873,750,000
				GM	7,747,038,032.51
				GM%	11.81%

Table 4 9How to Estimate Gross margin Percentage

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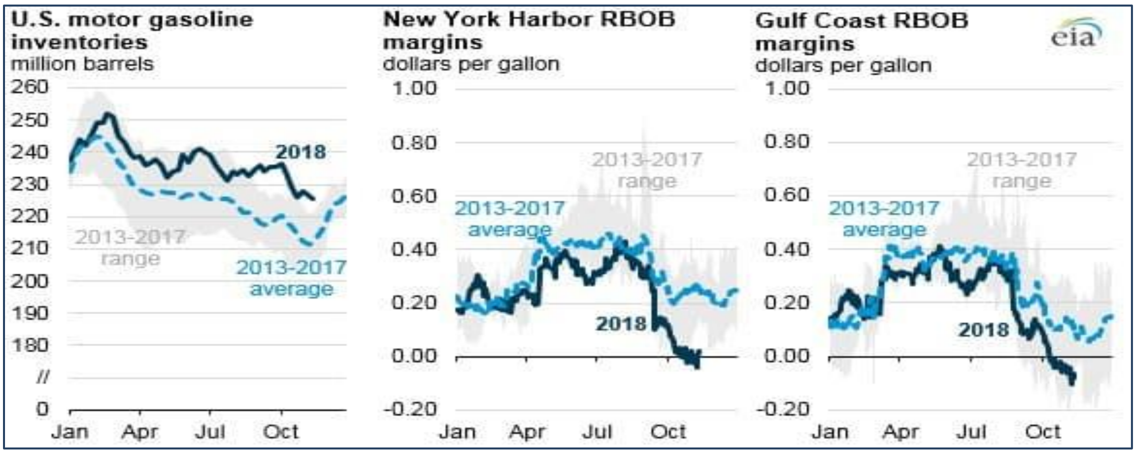

Figure 2.1Refining Margin in the Middle Source: (Cunningham N, 2018)2

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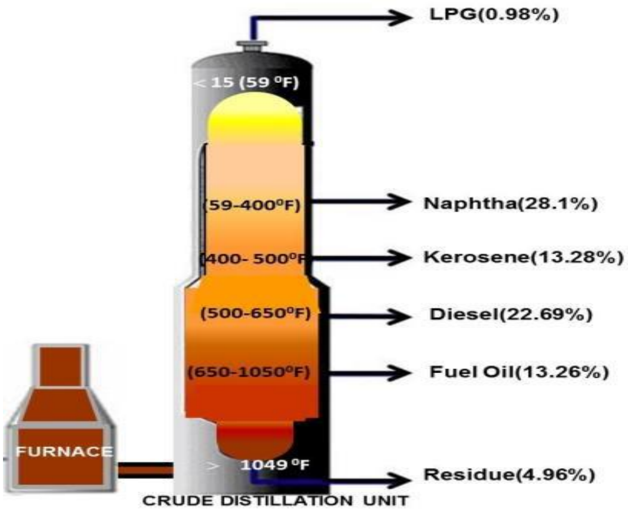

Figure 2.2 Topping Refinery Configuration and Yield Source:(Ogbon N. O., 2018)[110]

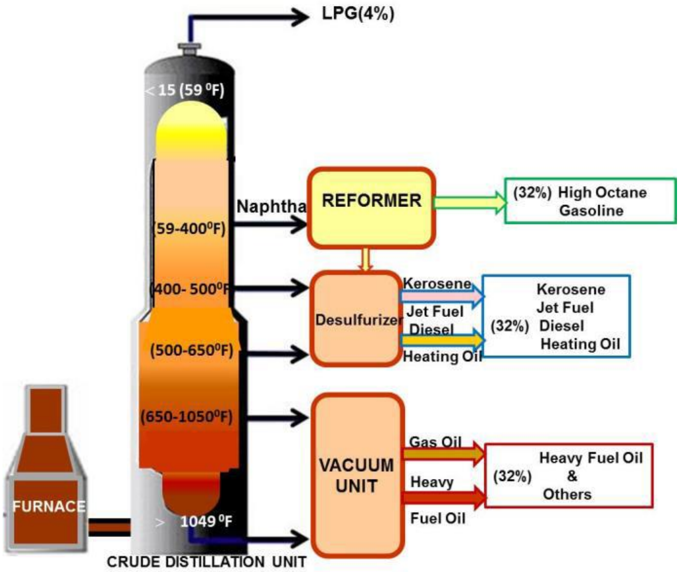

Figure 2.3 Hydro-skimming/Topping Refinery Configuration and Yield Source:(Ogbon N. O., 2018)[111]

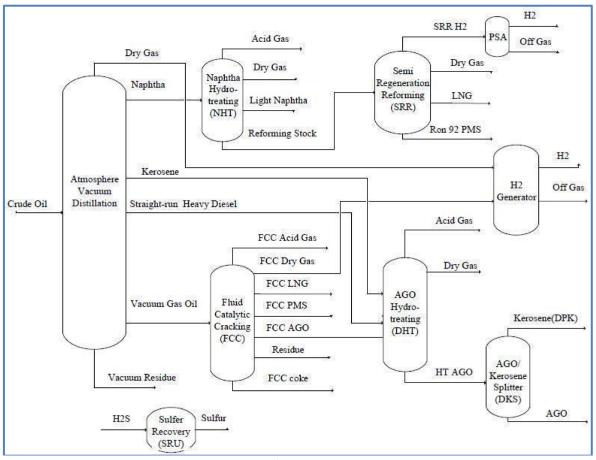

Figure 2.4. Modular Refinery Process Flow Chart Source (Peiyangchem, 2019)

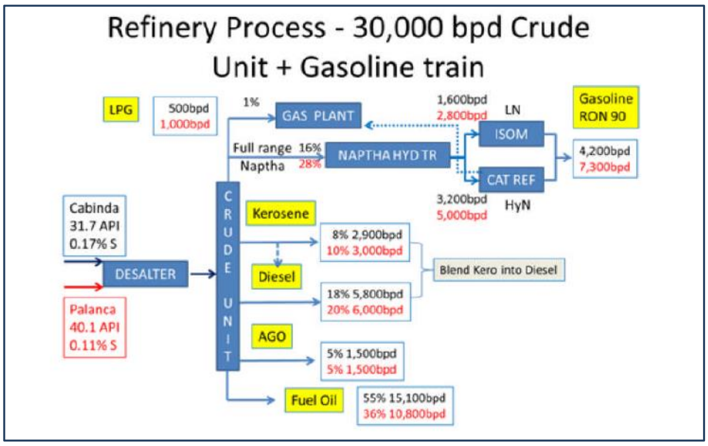

Figure 2.5 Typical Modular Refinery Configuration with Two Mixtures of Crude Oil Type Source(KUAI Energy System, 2019)

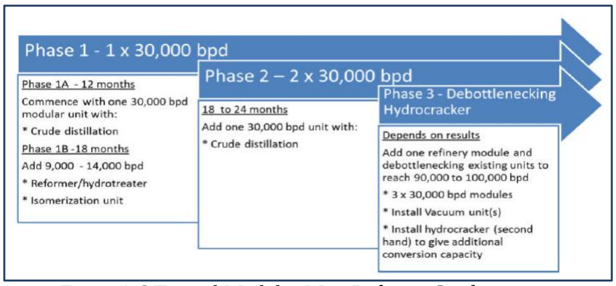

Figure 2.6 Typical Modular-Mini Refinery Configuration Source(KUAI Energy System, 2019)

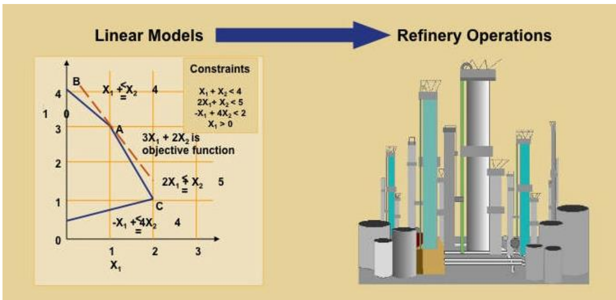

Figure 2.7 Linear Programming Model and Optimization: Source Linear Programming Model by (Micheal A,T)

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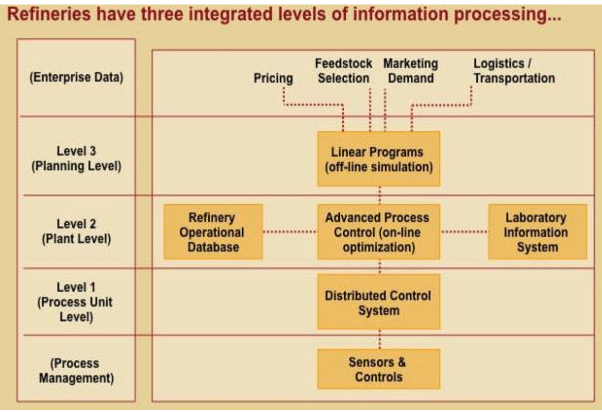

Figure 2.8 Integrated Levels of Information processing Source Linear Programming Model by (Micheal A,T)

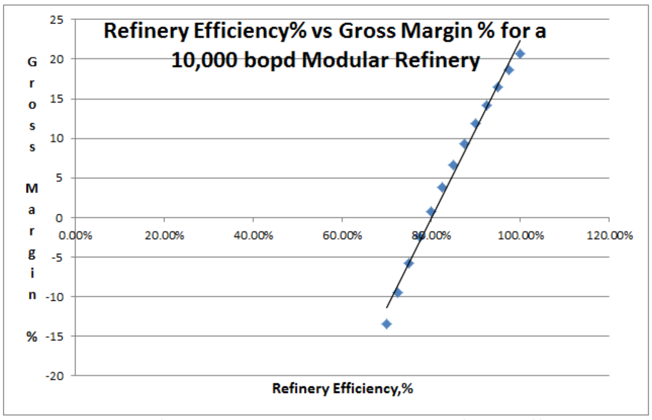

Figure 2.9 Plot of Log-Linear Relationship Betw Refinery Efficiency and Gross Margin

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