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Technical and Economic Viability of Ethylene and Propylene Production from Ethane Gas Recovered at the Atuabo Gas Processing Plant, Ghana

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Abstract

Ethylene, the main intermediate feedstock for petrochemical production, with diverse uses and significant consumption in Ghana, is imported for use despite the availability of raw materials for its production. This paper aims to assess the technical feasibility and economic viability of producing olefins like ethylene and propylene from recovered ethane gas at the Gas Processing Plant (GPP) in Ghana; to optimise Ghana's hydrocarbon resources. The steam cracking method of olefin production was chosen for this research after a review of pertinent literature and a general assessment conducted. The basis of this selection was its widespread use; thus, easily accessible facilities, comparably anticipated lower costs to be incurred, more stable products formed, and minimal environmental effects after comparison with the Oxidative Dehydrogenation of Ethane (ODHE) and Catalytic Ethane Dehydrogenation (EDH) methods. With the aid of Aspen Hysys Simulation Software V11, this paper was carried out by utilizing process simulation techniques to design an olefin production plant. Using the Aspen Process Economic Analyzer and Microsoft Excel Spreadsheet Application, cost estimation and economic analysis were conducted while applying standard investment decision criteria. Based on a successful simulation and results obtained with a Net Present Value of $19,343,264.87, an Internal Rate of Return of 27% and a Payback Period realized at year 3, the paper concluded that the venture portrayed technical and economic attractiveness.

Keywords: Ethylene, Olefins, Economic viability, Processing plant, Steam cracking

Introduction

Once only a great nuisance, commercial petroleum has become the critical lifeblood of the industrial world; with wars being waged for this carbon prize. The great hydrocarbon rush now causes producing countries' governments to reign by its value while consuming countries' economies are being subjected to its price.[1] With the emergence and increasing importance of natural gas, economies have invested in its production and consumption, not only because of its environmental friendliness but also because of the current and anticipated profit upswing; and Ghana's economy is no exception.[2] Ghana has sig- significantly optimised her gas resources by producing, processing and advocating for citizen use of natural gasresources for thermal power generation, combined heat and power by industrial companies, and liquefied petroleum gas as a replacement for cooking and other domestic purposes.[2]

The goal of this paper is to investigate the technical feasibility and economic viability of locally producing olefins such as ethylene and propylene, the main intermediate feedstock used to produce various petrochemical products; from ethane gas recovered at the Gas Processing Plant in Ghana.

The focus of such an investment is to optimise ethane gas, which currently has no distinct market in Ghana (and as a result, is comingled with methane gas to serve as lean gas), to produce olefins (ethylene and propylene) which have a considerable market and are presently imported for use by numerous companies.[3]

This paper seeks to explore and examine the industrial method(s) of large-scale olefin production from ethane gas; in order

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to select the most feasible and applicable method; to simulate an olefin production plant using recovered ethane gas conditions; and subsequently to conduct an economic assessment of the possible investment to determine profitability.

Statement of theory

Following its commercial discovery, the Ghanaian government, through the Environment Protection Agency, prohibited gas flaring except for emergency or short-term operating needs. In this vein, Ghana has used her natural gas resources from both regional and domestic sources for power generation, industrial power, and heating, as well as for residential activities such as cooking (Liquefied Petroleum Gas).

The Gas Supply Sources in Ghana are listed as follows and shown in Figures 1 and 2:

- Domestic (Indigenous) Source - Associated gas processed and recovered at the Gas Processing Plant upon receipt from the Jubilee and TEN Fields and non-associated gas from the Sankofa- Gye Nyame Field
- Regional Source - West African Gas Pipeline Company

As displayed in Figure 1, indigenous lean gas obtained from the Gas Processing Plant is transported to consumers through transmission pipelines for power generation and industrial purposes. Other gas products (LPG and Condensate) recovered at the plant, make their way to the final consumer via trucks from a loading gantry.

Ethane gas, as illustrated in Figure 3, represents 9% of products recovered at the Processing Plant. This percentage, equivalent to a daily volume of 10.811 MMscf currently, is comingled with the methane fractions and commercialized as lean gas to serve the purpose of power generation and industrial heating.

Not only will olefin (ethylene and propylene) production from the recovered ethane gas readily provide ethylene for the fifty-two (52) identified importers of ethylene in Ghana,[4] but also ensure the durability of turbines of power producers, who represent about

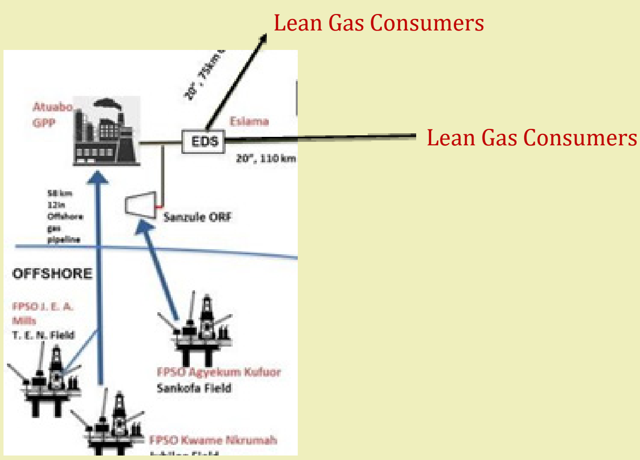

Figure 1: Ghana's indigenous gas infrastructure layout.[4]

Figure 2: West african gas pipeline network (WAPCo, 2023).

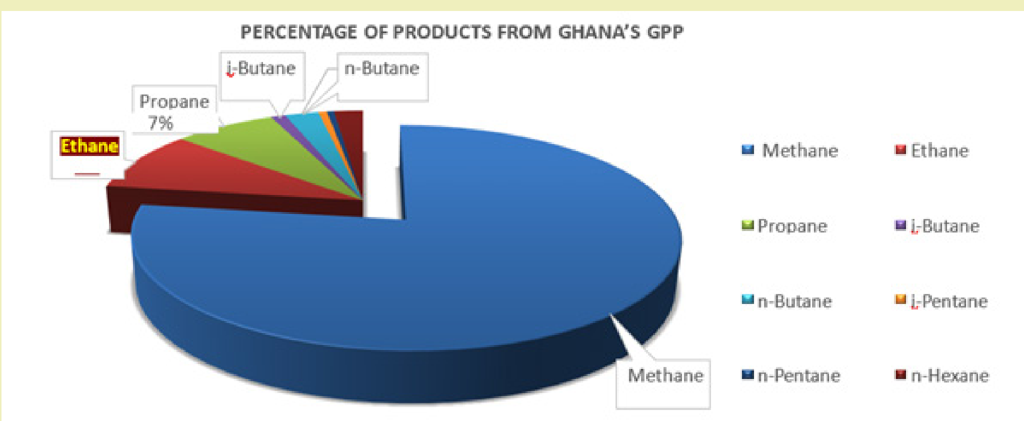

Figure 3: Percentage composition of products from Ghana's GPP.

84% of lean gas consumers in Ghana; and whose facilities have been designed to utilize methane gas of specified heating value (1110 – 1135 Btu/SCF) for power generation.

This step will also be an attempt to minimize imports of the various polymers of ethylene for the myriad of purposes they serve in packaging, health, oil and gas processing, agriculture, and various other sectors of the Ghanaian economy Figure 4.

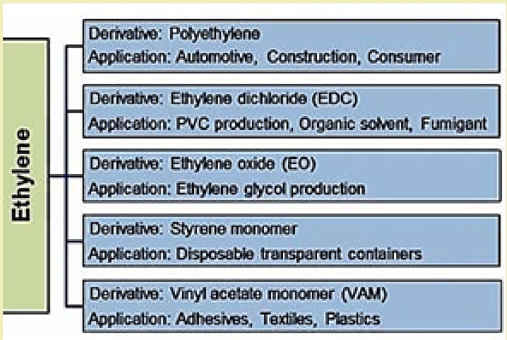

Figure 4: Key chemicals based on ethylene.[3]

Existing Methods of Ethylene Production from Ethane Gas

The discussion as follows compares the Steam Cracking Method, Catalytic Ethane Dehydrogenation, and Oxidative Dehydrogenation of Ethane (ODHE) methods:

Steam cracking

Steam cracking is a petrochemical process in which saturated hydrocarbons are broken down into smaller, often unsaturated, hydrocarbons. It is the principal industrial method for producing lighter alkenes (olefins), including ethylene and propylene. In steam cracking, a gaseous or liquid hydrocarbon feed like ethane or naphtha, is diluted with steam and then briefly heated in a furnace up to a temperature of about 850°C in the absence of oxygen. After this cracking temperature has been reached, resulting in the formation of unsaturated hydrocarbons (ethylene, propylene, butadiene, etc), the gas is quickly quenched to stop the reaction in a transfer line exchanger. Steam cracking produces a wide product distribution, however, the products formed in the reaction depend on the composition of the feed, the hydrocarbon-to-steam ratio, cracking temperature, and furnace residence time. Light hydrocarbon feeds (such as ethane, LPG, or light naphtha) give product streams rich in lighter alkenes, including ethylene, propylene, and butadiene.[5] Cryogenic distillation is employed to obtain pure ethylene from the cracked gas after undergoing a series of compression, drying, and sweetening stages.[6]

Catalytic ethane dehydrogenation

In steam cracking/pyrolysis, the formation of side products such as aromatics and light gaseous hydrocarbons is unavoidable, although sustainable at high temperatures. The side processes involved in the formation of by-products reduce the efficiency of ethylene production. Catalytic ethane dehydrogenation over oxide or supported-metal catalysts allows for ethylene production at lower temperatures than pyrolysis of ethane. The reaction, however, is endothermic and thus, a high temperature and low pressure of ethane must be used in this process for high ethane conversion.

Platinum, Pt and Palladium, Pd-containing systems are common catalysts for selective hydrocarbon dehydrogenation. At low temperatures, ethane conversion over noble metal catalysts occurs. However, unsaturated Pt may induce side processes such as ethane hydrogenolysis and subsequent polymerization to coke which are undesired.[6]

Oxidative Dehydrogenation of Ethane (ODHE)

Oxidative dehydrogenation of ethane (ODHE) has been discovered to be an appealing alternative for producing ethylene that does not require internal heat input. It has been reported that molten alkali chlorides such as LiCl, KCl, NaCl, Li-K- Cl, Li-Na-Cl, Li-Sr-Cl, and Li-Ba-Cl supported by Dy_2O_3/MgO can produce ethylene with a yield of nearly 75%. However, this process can result in a variety of Cl-containing by-products that are considered environmentally hazardous and incur additional costs of treatment. Deactivation of catalysts (a temporal or permanent loss of active sites) also remains one of the major constraints of the ODHE method.[6]

Method of Selection for Ethylene Production in Ghana

Catalytic Ethane Dehydrogenation and Oxidative Dehydrogenation of Ethane, although they exhibit high selectivity to ethylene due to catalysts used, face significant catalyst deactivation due to the unstable nature of catalysts; resulting in excessive downtime for catalyst activation/replacement; and excessive environmental hazards due to the production of Chlorine-containing by-products which in turn incur high additional costs of removal.[7] The products formed during steam cracking are highly affected by the composition of the feed and in this case, ethane gas (a more specific feed), which limits the issue of low selectivity. For this investigation, steam cracking is selected due to its wide usage and thus, readily available facilities, comparative environmental safety and anticipated lower cost to be incurred.

In the proposal this paper presents, the concept of ethylene production from ethane gas employed by Carbide and Carbon Chemicals Corporation, the first firm to produce ethylene from light hydrocarbons (predominantly ethane) is applied. The company, now a subsidiary of Dow Chemicals, owned a small plant in Clendenin, West Virginia, that separated natural gasoline from raw natural gas. The gasoline, which at room temperature is a liquid, was sold as fuel.

However, the remaining liquids derived from natural gas, consisting mostly of ethane and propane, found no ready markets, so the company installed processing units and a furnace to convert them into more valuable products. The furnace began operating in 1921 to produce ethylene[8] Figures 5,6.

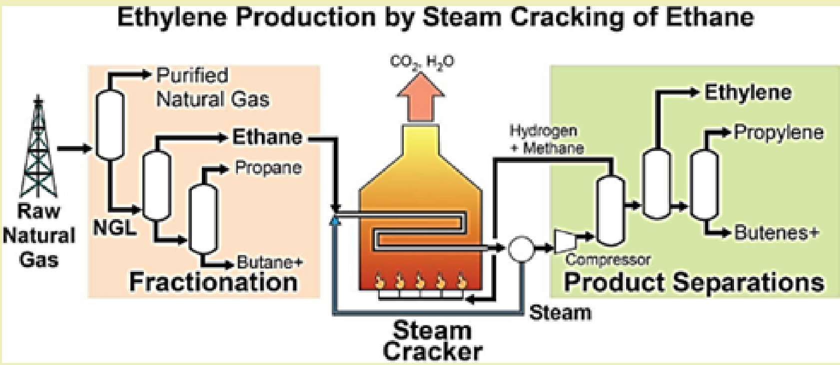

Figure 5: First ethylene production plant from ethane gas-operations schematic.[8]

Hydrogen	4.1
Methane	5.0
Acetylene	0.4
Ethylene	52.8
Ethane	32.6
C3H4's	0.03
Propylene	1.2
Propane	0.2
sum C4's	1.9
sum C5s	0.4
sum C6's	0.9
sum C7's	0.1
sum C8's	0.1
sum C9's	0.01
sum C10's	0.2

Figure 6: % Fractions of expected products from the cracking process.

Cracking Reactions and Products

C2H6→ CH3* + CH3*	Initial reaction
CH3* + C2H6 → CH4 + C2H5*	Hydrogen abstraction
C2H5*→C2H4+H*	Propagation
H* + C2H6 →CH4 + C2H5*	
C2H5*+C2H5*→C2H10	Termination
H* + C2H5* → C2H6	
H* + CH3* → CH4	
H* + H* → H2	

Description and Application of Equipment and Processes

Aspen HYSYS, developed by AspenTech was used to create the design of the proposed ethylene production plant. After completion of the simulation, cost estimation was conducted using the Aspen Process Economic Analyzer (APEA) and data from the US Department of Energy. These costs were recorded using the Microsoft Excel Spreadsheet Application and further analysed.

The Process Simulation employed the Peng Robinson and SRK Fluid Packages; as feed streams and expected products were hydrocarbon in nature. Upon selecting individual equipment making up the entire proposed plant and defining their compositions as well as all material and energy streams, the simulation was run successfully. For some components, an N+1 redundancy was employed to ensure system availability in the event of component failure.[7]

The proposed design to be displayed in the next section consists of:

- Inlet Filter Separators to extract any entrained solid particles and moisture components from the feed gas;
- The cracking section which primarily undertakes preheating of the feed ethane to about 120°C by steam, subsequent heating to the incipient cracking temperature of averagely 600°C in the convection section, and further to cracking temperatures of about 850°C in the radiation section by fired tubular reactors. Afterwards, the cracked gas is cooled briefly by a Transfer Line Exchanger. A schematic of the cracking process is shown in Figure 7.

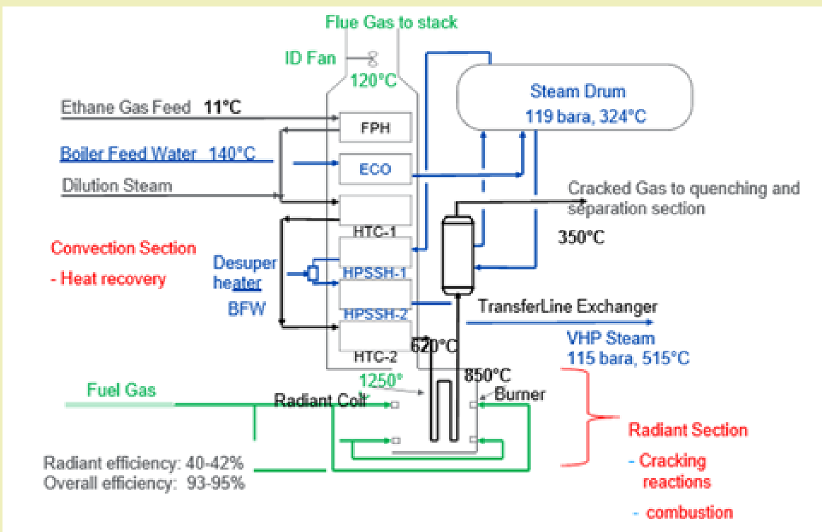

Figure 7: Cracking furnace layout.

- The quenching section which employs the quench tower for drastic cooling of the cracked gas to about 180°C;
- A series of five turbine-driven centrifugal compressors to compress the quenched gas ahead of fractionation;
- An acid gas removal unit consisting of a caustic scrubber to extract acid gases in order to prevent the formation of ice and hydrates;
- A dryer after the last stage of compression removes moisture and prevent ice and hydrates formation.
- A series of fractionation towers (depropanizer, demethanizer, deethanizer, C2 and C3 splitters) for the recovery of ethylene, propylene, and by-products; and

Refrigeration of products.[8,5,10]

Presentation of Data and Results

Find as follows, the proposed design of the ethylene production plant with components discussed in the previous section of this paper; Subsequently in this section, data pertaining to plant economics and assessments are provided.

Unreacted and product ethane and propane streams recovered from the C2 and C3 splitters are recycled by transporting them to the inlet of the Thermal Cracking Furnace.

*V-100 A/B -Filter Separators, CV and VLV-Valves, CGC-Cracked Gas Compression, STG- Stage

* T1, M1 and MIX 100 represent pipe spools

Plant Economics

With individual costs of equipment and installation generated as presented in Appendix A and estimation of other costs conducted with cost components provided in Appendix B, find as follows, a summary of the plant economics Figure 8.

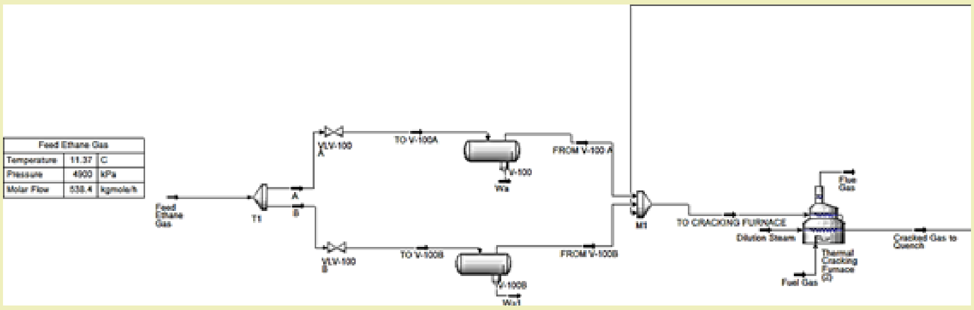

Figure 8: Proposed ethylene production plant design.

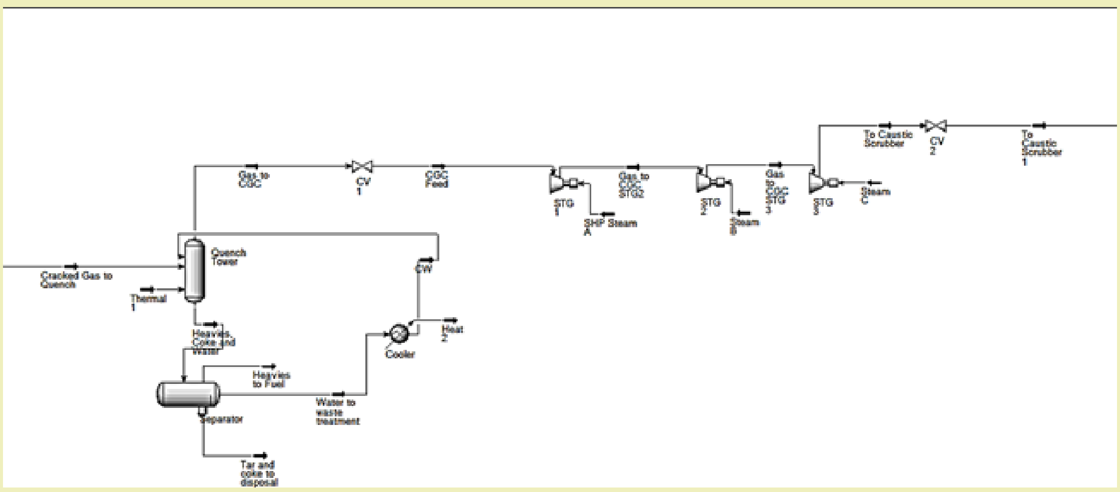

Figure 8: Proposed ethylene production plant design (Continued).

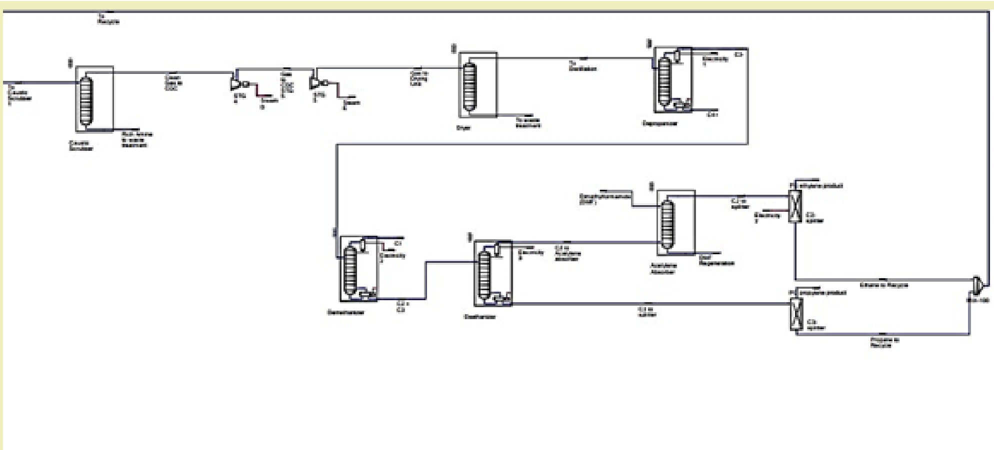

Figure 8: Proposed ethylene production plant design (Continued).

The Total Required Delivered Price estimated to be used as a benchmark for the pricing of the ethylene product obtained was found to be USD/mt 821.95.

Estimated Revenue

Applying the current average prices of ethylene and propylene,[6] estimated revenue is summarized as follows Tables 1,2:

The expected Total Daily Revenue to be obtained from the sales of ethylene and propylene was estimated at USD 210,948.26 and yearly revenue at USD 73,146,309.51. This was obtained by applying the current average prices of ethylene and propylene and the expected product recovery. A 5% allowance was given to cater for Turnaround periods.

Table 1: Ethylene production plant economics.

ETHYLENE PRODUCTION PLANT ECONOMICS		
Plant Capacity		
Daily	195.14	(mt/d)
Annual (95%)	67664.32	(mt/y)
Gas Consumption		
Per metric ton	98.06	MMBTU
Per day	19134.8	MMBTU
Ethane Volume (1,770 Btu/scf)	10.81	MMSCFD
Feed Gas Needed (20 years)	74971.64	MMSCF
Capital Investment		
Battery Limits	$20,864,974.00	USD
Offsite	$7,302,740.90	USD
Owner's Project Costs	$5,633,542.98	USD
TOTAL FIXED INVESTMENT	**$33,801,257.88**	USD
Production Cost		
Ethane gas ($8/MMBTU)	784.46	US $/mt
Utilities, chemicals	15	US $/mt
Variable Costs	**799.46**	US $/mt
Fixed Costs (labour, maintenance, over- heads)	**10**	US $/mt
Total Cash Costs	**809.46**	US $/mt
Depreciation (10% of TFI)	**2.5**	US $/mt
Total Cost of Production	**811.96**	US $/mt
Return on Investment (before tax) 20% of TFI	**5**	US $/mt
Required Plant Gate Price	**816.96**	US $/mt
Shipping (20% CAPEX)	**5**	US $/mt
Total Required Delivered Price	**821.95**	US $/mt

Table 2: Estimated revenue accrued from sales.

ESTIMATED REVENUE		
Plant Capacity		
Daily	195.14	(mt/d)
Annual (95%)	67664.32	(mt/y)
Ethylene	**Average Price**	
Per metric ton	$1,060.00	$
Daily Revenue	$206,846.94	$/d
Yearly Revenue (95%)	$71,724,176.19	$/y
Propylene	**Average Price**	
Per metric ton	$997.00	0
Daily Revenue	$4,101.32	$/d
Yearly Revenue (95%)	$1,422,133.32	$/y
TOTAL		
Daily Revenue	**$210,948.26**	**$/d**
Yearly Revenue (95%)	**$73,146,309.51**	**$/y**

Economic Analysis

With a discount rate of 20% applied, the Net Present Value was calculated to be USG19,343,264.87, the Internal Rate of Return at 27% and the Payback Period expected at year 3. Supporting graphs are provided as follows Figures 9,10.

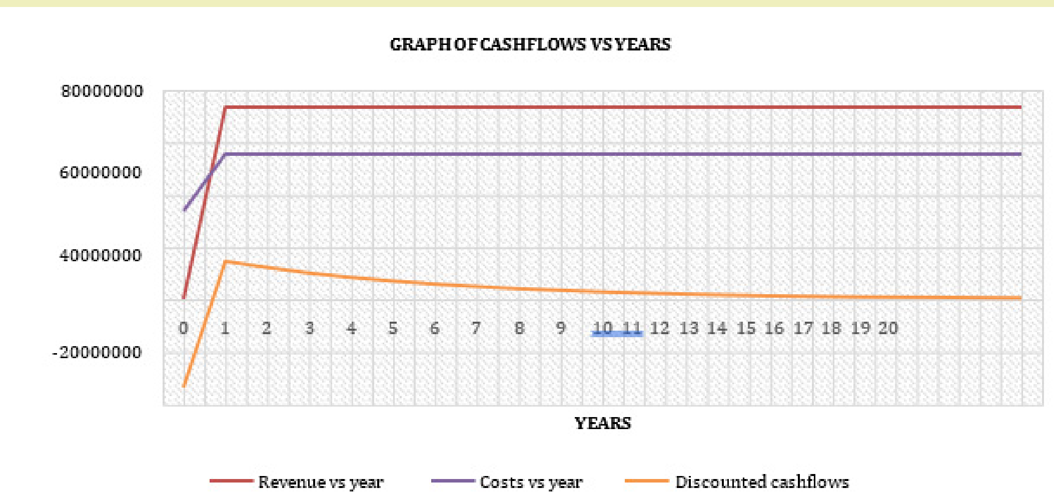

Figure 9: A graph relating the cashflows to the years.

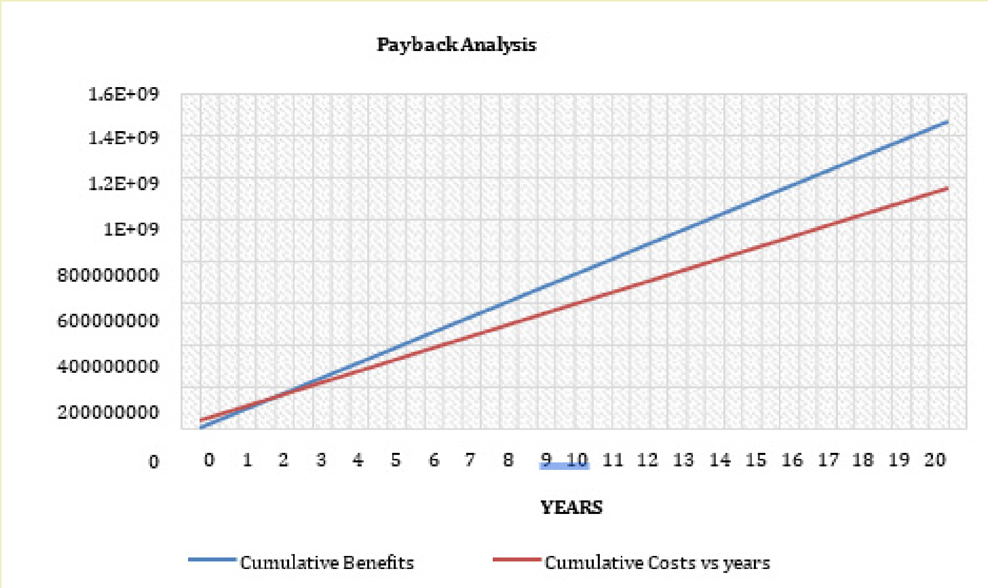

Figure 10: Payback analysis graph.

Conclusion

After a literature review, general assessment, method selection, process simulation and subsequent analysis using investment decision criteria, it is concluded that;

- The steam cracking method is currently the most feasible method of ethylene production to be possibly executed in Ghana with the proposed plant design illustrated in Figure 7.
- By employing the NPV investment decision criteria, ethylene production in Ghana is determined to be a viable venture.
- With an investment worth USD 33,801,257.88 as Total Fixed Investment and USD/mt 821.95 Total Required Delivered Price, a Net Present Value of USD $19,343,264.87 an Internal Rate of Return of 27% would be realized at the end of 20 years with profit realization starting at year 3.
- Investment into this venture will aim at reducing the dependency of our local petrochemical production companies on imported ethylene, generating income for the country, providing employment, and providing leaner gas for the power-generating companies.

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Conflicts of Interest

Regarding the publication of this article, the authors declare that they have no conflict of interest.

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Appendix

Appendix 1

Summarised equipment and installation

Name	Equipment Cost [USD]	Installed Cost [USD]
Dryer	160000	208000
Deethanizer	425000	552500
STG 5	500000	650000
Thermal Cracking Furnace	4500000	5850000
Depropanizer	425000	552500
Separator	250000	325000
V-100	749000	973700
STG 4	500000	650000
C3- splitter	225000	292500
Quench Tower	3375000	4387500
C2- splitter	225000	292500
STG 3	500000	650000
Acetylene Absorber	29600	38480
STG 1	500000	650000
STG 2	500000	650000
Caustic Scrubber	29600	38480
V-100B	749000	973700
Demethanizer	425000	552500
Cooler	20000	26000
VLV-100 B	473890	616057
VLV-100 A	473890	616057
Pipelines	3850000	5005000
SCADA	1000000	1300000
Valves	1750000	2275000
TOTAL COST	$16,049,980.00	$20,864,974.00

Appendix 2

Components of capital investment

The capital investment for a petrochemical plant is typically divided into three major components: Battery Lim- its Costs, Offsite Costs and Owner's Project Costs. The sum of these components is known as the Total Fixed Investment (TFI) for the petrochemical plant (Anon, 2010).

Battery limits costs

These include the installation costs of all the equipment and hardware within the main processing blocks of the plant (referred to as the Battery Limits) that are necessary to convert the process feedstock into the finished product. They also include the fees paid to the technology supplier and to the EPC (engineering, procurement, and construction) contractor for design, engineering and construction.

Offsite costs

Any systems and hardware required in addition to the equipment within the battery limits, such as:

- Storage tanks for feedstock, products and any by-products
- Steam generation units (unless specifically recovered from process streams, as in an ammonia plant)
- Cooling water systems, including treatment
- Boiler feed water and process water supply and treatment systems
- General utilities, such as plant air, instrument air, inert gas, fire water system, etc.
- Site development including roads and walkways, parking, railroad sidings, wharfs, mooring systems, etc.
- Auxiliary buildings
- Environmental control systems such as aqueous and organic waste treatment, incineration, etc.

Depending upon the type of process plant and site conditions, Offsite Costs can range from 30 to 100 per cent of the Battery Limits cost. For example, the Offsite Costs for a green field site in a remote location will be substantially more than that for a developed US Gulf Coast location.

Owner's project costs

During the engineering, construction, and start-up phases of the plant, the owner also has costs that are generally capitalized. Items that typically fall within this category include:

- The Owner's project team reviews, monitors, and approves the EPC contractor's progress and performs preliminary planning studies, environmental reviews, or equipment inspections.
- Initial hiring and training of plant operating personnel
- Interest during construction on any construction loan
- Initial charges of raw materials, catalysts, and chemicals
- Contingency for project scope changes and unforeseen start-up costs

The owner's Project costs will also depend upon the nature and location of the project. Typical values range from 15 to 40 percent of the combined Battery Limits and Offsite Costs.

Total fixed investment

The sum of Battery Limits, Offsite and Owner's Project Costs is known as the Total Fixed Investment (TFI) for the petrochemical plant.

Components of production costs

The Production Costs of an operating plant are typically divided into a series of categories that include:

- Variable Costs
- Fixed Costs
- Cash Cost of Production
- Depreciation
- Total Cost of Production
- Return on Capital Investment, and
- Required Plant Gate Price

Variable costs

These are incurred and directly related to the volume of production (i.e., the sum of the costs of feedstock and raw materials, catalysts & chemicals, and utilities minus any by-products or co-product credits that can be sold as part of the revenue stream). These costs are essentially constant per unit product output over the operating rates of the plant from around 50 to 100 per cent of design production.

Fixed costs

Fixed costs are independent of production volume. They include costs for operating labour, maintenance labour & supplies, labour burdens, general plant overheads, insurance and property taxes. Fixed costs are constant on an annual basis and, therefore, they will increase per unit product output as production volume decreases from 100 per cent of design.

Cash cost of production

The sum of Variable and Fixed Costs is commonly known as the Cash Cost of Production. This represents the total out-of-pocket costs that an owner incurs in running a plant.

Depreciation

While not an actual out-of-pocket expense, depreciation of the capitalized costs, including all of the hardware, equipment and buildings associated with the plant, is typically included in estimating the total cost of production. There are various methods used to account for this charge depending upon corporate philosophy, accepted accounting standards, and the tax codes of the country where the facility is located. Typically, for feasibility study purposes, depreciation is based on a straight 10-year life of the Total Fixed Investment.

Total cost of production

Adding depreciation charges to the Cash Cost of Production gives what is commonly referred to as a Total Cost of Production.

Return on capital investment

The project analysis typically includes a profit element to determine what selling price is necessary in order to achieve a certain return on the capital investment. This will vary from company to company depending upon the financial criteria used to evaluate petrochemical projects. Again, for feasibility study purposes, using a 20 per cent before-tax return on the Total Fixed Investment is indicative of the average historical profitability of petrochemical projects. Note that this is equivalent to an after-tax internal rate of return (IRR) of approximately 10%, assuming a tax rate of 40%.

Required plant gate price

Adding the Return on the Total Fixed Investment to the Total Cost of Production gives the Required Plant Gate Price. This requires an estimate of the annual volume of production, which is often assumed as 95%, allowing some downtime for maintenance.