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Exploration of Biomass for the Production of Bioethanol: "A Techno-Economic Feasibility Study of Using Rice (Oryza Sativa) Husk"

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Abstract
The increasing energy demand and fossil fuel dependency have increased interest in the bio-ethanol production in the recent years. The use of conventional saccharine and starchy materials for ethanol production is prohibitive since it is a threat to food security. As such, rice-husk poses to be of great value, providing a means to utilize waste. In this work, we assess the economic viability of bio-ethanol production from the rice-husk waste, which entails the capital and manufacturing cost estimation, and the profitability of this process. Further, cost optimization studies are carried in order to determine the material cost, government subsidy, and tax potential to maximize the overall financial benefit (i.e. ROI and net profit) of the bio-ethanol production. Findings from this work indicate that transforming rice-husk into bio-ethanol is not economically feasible due to the negative net profit (i.e. a loss on investment) obtained from its profitability analysis. Further studies indicate that the project is susceptible to the raw material cost, subsidy, and tax rate. The result obtained from the optimization studies indicate that if the rice husk sales as low as 1.38 US$/kg, and the Government introduce 25% subsidy and tax-free policy on the bio-ethanol production, the project will yield a net worth of US$ 5 million per annum, payback period of 5.5 years, and a return on investment of 16.1%. Therefore, this work recommends introducing a subsidy and tax-waiver policy for bio-fuel production in order to encourage the investors and promote cleaner fuels in the emerging nations.

Keywords: *Rice-husk; Bio-ethanol; Biomass; Optimization; Economic; Bio-fuels.*

1. Introduction
The world's energy demand depends on fossil fuels, which are finite and depleting, and could vanish in the next decades. In the recent years, the current environmental problems, energy requirements, and oil dependency have driven the need to devise an alternate energy source that is not petroleum-based and renewable [1, 2].

Disposal of solid waste is a widespread stinging problem to the world today, both in the developed and developing countries. Burning of biomass and other forms of biomass disposal emits the pollutants and particulate matter into the environment. In some instances, it can emit more pollutants than fossil fuel, leading to various environmental and human health issues if not appropriately contained [3–6].

Furthermore, there have been concerns and projections in the scientific world in the recent years involving modification of wastes produced, consumption patterns, and a significant increase in resource extraction regarding the destination of the solid waste generated and its relatively high potential toxic contents. It is worth noting that agricultural wastes constitute a significant percentage of annual waste disposal [7–10].

Renewable energy, especially bio-fuels, has caught the global industries' attention as possible solutions to the current energy demand [7, 11–13]. Among the available bio-fuel resources, bio-ethanol is an established efficient alternative. Bio-ethanol produced from non-edible biomass or lignocellulosic resources is a renewable and clean

source of energy. It is not dependent on the food industry, and is economically viable [11, 14, 15].
Literature reviews indicate that several research works have attempted to provide a potential solution to address the energy and fuel demand challenges. For instance, Sassner *et al*. [16] have evaluated the feasibility of using different biomass-based materials such as spruce, salix, and corn stover. They indicated the importance of a high ethanol yield and the necessity of utilizing the pentose fraction for ethanol production to obtain a good process economy, especially when salix or corn stover is used. Christiana and Eric [17] have identified that bio-ethanol production from cassava is only feasible in Nigeria, provided that the plant is sited next to the farm. This study indicated that distance from the raw material source to the plant was the key to the project's feasibility. Another study conducted by Oyegoke *et al*. [17] has indicated that 143 million liters of bio-ethanol per annum can be obtained from 402 metric tonnes of sugarcane bagasse. That is, 2.8 metric tonnes of sugarcane bagasse would always yield 1 million liters of bio-ethanol. Other research works are on the bio-ethanol production from molasses [18], combine sugarcane-bagasse-juice [19, 20], sorghum bagasse [5], and many others. In other cases, some research works have attempted to investigate the potential of transforming wastes into power instead of bio-fuels. Some of such works including Abbas *et al*. [21], Oyegoke *et al*. [22], Sobamowo and Ojolo [23], Mataji and Shahin [24] have explored the use of municipal wastes, sugarcane bagasse, other biomass resources, and wind energy, respectively, for the generation of power.

As a way to identify a feasible solution to the challenge of solid waste management and the promotion of green technology adoption (which would promote cleaner air) within the developing countries like Nigeria, in this work, we evaluated the techno-economic feasibility of transforming biomass like rice (*Oryza Sativa*) husk into a fuel-grade bio-ethanol. This work presents the potential of bio-ethanol substituting petrol using the parameters like the recent price of petrol and tax-rate. Subsequently, cost optimization is carried out in order to identify the potential conditions that can best promote the economic feasibility of establishing such a plant in Nigeria. The deductions presented in this work would provide information on the economic benefits that the green technology for fuel production would offer in the low-income nations like Nigeria. It would also go a long way in boosting the government and investors' morale towards investment in such a project.

2. Methods

2.1 Description of process analyzed

The rice-husk (feedstock) studied was reported to be averagely composed of 27.8% cellulose, 21.5% hemicellulose, and 20.3% lignin, in line with the literature. The detailed data for the composition is presented in table 1. The rice-husk at 180 kg/h (crushed, 25 ºC, 101.3 kPa) was liquefied using water at 90 kg/h (25 ºC, 101.3 kPa) in a mixer and heated in order to yield a stream with 121 ºC temperature, 1605 kg/h flow rate, and pressure of 101.3 kPa.

Table 1. Cellulose, hemicellulose, and lignin content in rice-husk.

Cellulose	Hemicellulose	Lignin	Reference
15–36	12–35	8–16	Saha & Cotta [25]; Saha & Cotta [26]
25-35	18-21	26-31	Rabemanolontsoa & Saka [27]
27.8	21.5	20.3	Average

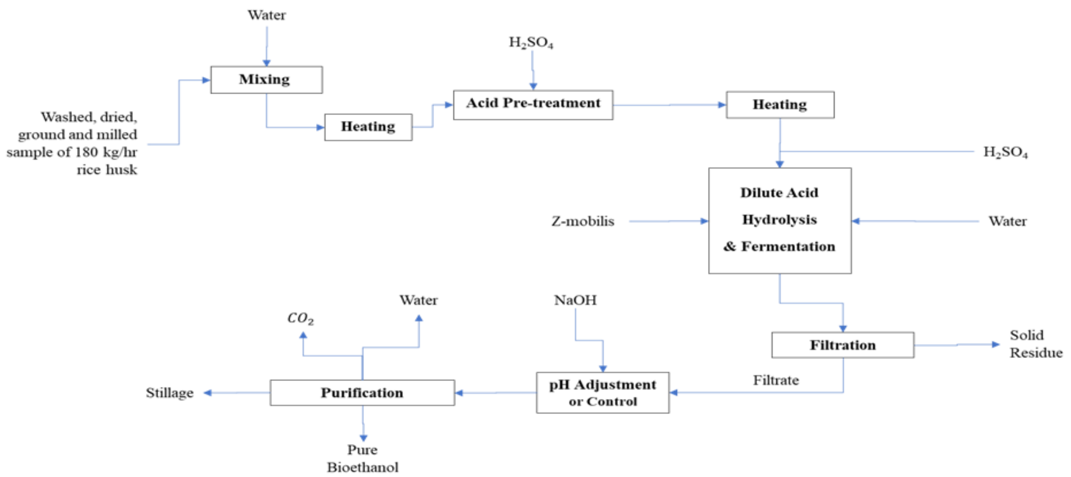

Figure 1(a). Block flow of rice-husk conversion into a fuel-grade bio-ethanol fuel.

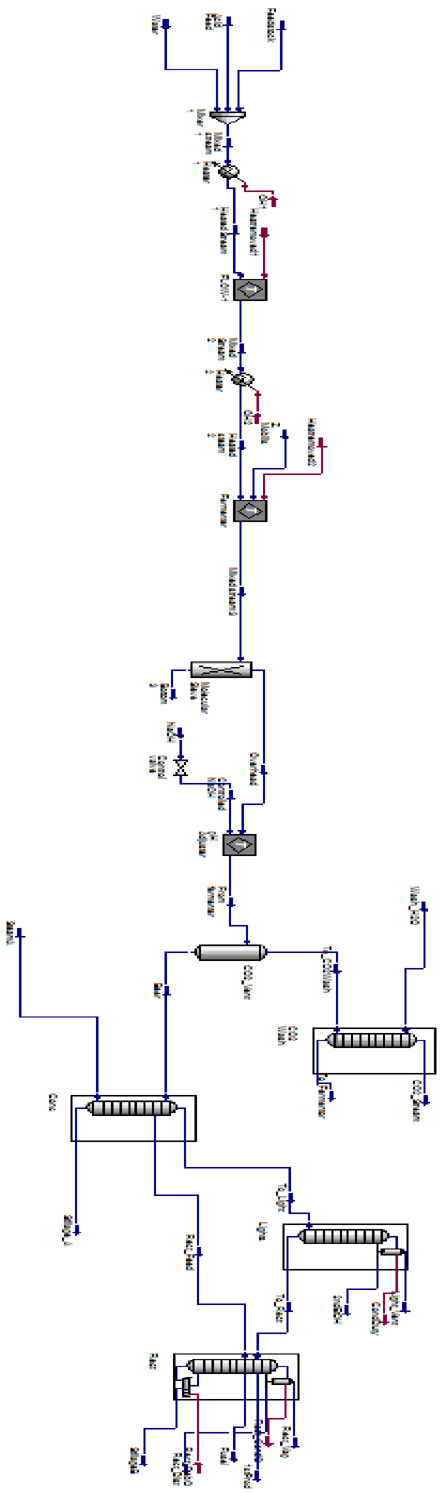

Figure 1(b). Process flow of rice-husk conversion into a fuel-grade bio-ethanol fuel.

The resulting heated mixtures were then fed into the acid pretreatment unit, where it was treated using a dilute sulfuric acid (charged in at 90 kg/h, 25 ºC, 101.3 kPa). The pre-treated mixture from this unit was re-heated in order to ensure that the temperature is up to the reaction temperature (121 ºC). The mixture was then charged into the dilute acid hydrolysis and fermentation unit (DAHF or reactor), where both the hydrolysis and fermentation processes were held simultaneously in the presence of dilute sulfuric acid (charged in at 90 kg/h, 25 ºC, and 101.3 kPa) and enzyme (charged in at 5.94 kg/h, 121 ºC, and 101.3 kPa with 91.68% water).

Reaction expressions/equations

Acetate → Acetic acid

Sucrose + H_2O → 2 Glucose

Cellulose + H_2O → 90 Glucose

Hemicellulose + H_2O → 64 Xylose

2 $NaOH$ + H_2SO_4 → Na_2SO_4 + 2 H_2O

Glucose → 3 Ethanol + CO_2

3 Xylose → 2 Ethanol + CO_2

The end-products obtained from the DAHF reactor were filtered in a filtration unit in order to remove the solid components (residue) from the raw bio-ethanol (filtrate). The raw bio-ethanol was channeled to the pH adjustment reactor, where NaOH was used in order to neutralize the filtrate's acidity. The neutralized bio-ethanol (product) from the pH adjustment reactor was cooled to 30 oC, and then sent to the purification section. Figure 1 represents the bio-ethanol production diagrammatically from rice-husk using simultaneous saccharification and fermentation using both the block flow diagram and the process flow diagram (from process simulation [28]).

In the purification section, CO_2 and the bio-ethanol present in the raw bio-ethanol were separated using the separators' network (comprising the absorption and distillation columns) from which CO_2 entered stage 4 of a 10-stage absorption column, where CO_2 was washed before being released into the atmosphere. Another absorption column with steam was used in order to remove stillage (water) from the bio-ethanol, yielding two products, a light product and a concentrated one. The light product was sent to a refluxed absorber, while the concentrated one was channeled to the distillation column, where the condenser pressure was set to 101.3 kPa. Also an overhead vapor rate of 69 kg/h and the bio-ethanol component mass fraction were specified. The liquid was fed into a distillation column consisting of 29 stages, and the feed entered stage 12. The condenser and reboiler pressures of the distillation column were 172.3 and 202.6 kPa, respectively. At the full reflux condenser, the reflux ratio of 1.241 and a 38940 kg/h flow rate were specified. The distillation column gave a

95% purity of bio-ethanol. The choice of this process for the transformation of rice-husk into a bio-ethanol fuel was made in line with the previous studies presented in the literature [29–31].

2.2 Analysis approach

A MATLAB-based Economic Analyzer Algorithm (MbEAA) developed by Oyegoke and Dabai [19, 20] was adopted for this work. The analysis provided details about the total capital investment, manufacturing cost, and profitability analysis in order to ascertain the economic feasibility of establishing or setting up the bio-ethanol plant. The total equipment cost reported as US$ 853,176 for the process modeling and simulation of the process in our previous studies [28, 32] was employed in this work.

2.3 Analysis of total capital investment and manufacturing cost

The total capital investment was estimated using the factorial method after estimating the total plant equipment cost. MbEAA was used in order to estimate the manufacturing cost. The factorial method was also adopted for the computation of the total capital investment of the two plants evaluated in this work and presented in table 2. The project parameters and other details (utility and material costs) employed in estimating the manufacturing costs for the plant are presented in table 3.

Table 2(a). Factors for estimation of project fixed capital cost.

Item	Process type (fluid-solid)
Purchase	1.00
Installation cost for equipment	0.39
Piping installation	0.31
Electrical installation	0.10
Instrumentation & control cost	0.13
Battery-limits building and service	0.29
Excavation and site preparation	0.10
Auxiliaries/Service facilities	055
Land survey & cost	0.06
Field & construction expense	0.25
Engineering & supervision	0.35
Contractor‘s fees, overhead, profit	0.05
Contingency	0.10
Working capital	0.05

Table 2(b). Equipment cost from our previous process simulation study [28, 32].

Description	C_0 (U$)	C_n (U$)
Mixer	450790.50	484977.40
Heater	11223.20	14304.50
Reactor	160602.90	205469.30
Column	1382.80	1769.20
Separator	75329.00	96373.10
Molecular sieve	1138.61	1225.00
Condenser	5911.66	6327.70
Reboiler	6996.28	7526.90
Cooler	27620.00	35203.10
Total cost	734694.95	853176.20

Table 3(a). Utility cost and cost of raw material for use of rice-husk for bio-ethanol.

Descriptions	Unit	Amount
Working time	h	24
Working days	d	365 (0.9)
Raw material	NGN/kg	500
Discount rate	%	10
Proposed product price	NGN/L	140
Exchange rate	NGN/US$	360
Tax rate/Interest rate	%/%	20/10
Economic project life	Year	25
Depreciation method	-	Straight line
Depreciation period	Year	10
Cost of raw material	NGN/kg	500.00
Unit price of sulphuric acid	US$/kg	0.40
Unit price of sodium hydroxide	US$/kg	0.30
Unit price of Z-mobilis	US$/kg	5.60
Cooling water price	US$/ton	5.71
Unit price of electricity	NGN/kWh	43.38
Total cost of equipment	US$	853,176

Table 3(b). Material flow report obtained from our previous process simulation study [28, 32].

Inlet material	Flow (kg/h)	Outlet Material	Flow (kg/h)
Sulfuric acid	90.00	Pure bioethanol	1789.45
Feedstock (rice-husk)	180.00	CO_2 and other light gases	67.8
Process water	810.00	Stillage	1281.86
Sodium hydroxide	90.000	Solid residue/wastes	285.00
Wash water	13.10		
Steam	2270.23		
Z. Mobilis	5.94		

Also some data adopted from our previous process modeling and simulation for the concerned process studied is presented in table 2(b), presenting the total cost of the equipment purchased, while table 3(b) presents the quality of material used in the process of transforming the rice-husk into the bio-ethanol fuel.

2.4 Profitability analysis

MbEAA was used in order to evaluate the profitability of the proposed plant. The investment criteria used including Return on Investment (ROI), Net Present Worth (NPW), Payback Period (PBP), Gross Income (GI), and Net Profit (NP) are all represented in equations 1 to 4.

$$GI = SP*V - COM \quad (1)$$

$$NP = GI*(1 - TR) \quad (2)$$

$$ROI = \frac{NP}{TCI} * 100\% \quad (3)$$

$$NPW = \sum \frac{(B_n - C_t)}{(1+r)^t} \quad (4)$$

where SP is the selling price, V is the quantity of production, n is the project life, r is the discount rate, t is the period, NP is the net profit, GI is the gross income, TCI is the total capital investment, TR is the tax rate, B is the benefit, and C is the cost in the project life’s cash flows.

2.3 Optimization studies

Multi-objective optimization studies were performed for the manufacturing cost using a response surface methodology (RSM) study approach with the Box Behnken (BB) design. The design matrix summary details are presented in table 4, indicating 3 factors and 2 response variables including the numbers of experimental runs and the factor levels involved in the studies.

Table 4. BB design matrix summary for optimization of NP and ROI.

Response	Name	Units	Runs	
Y1	NP	$	17	
Y2	ROI	%	17	
Factor	Name	Units	Low actual	High actual
A	RM	NGN/kg	200.00	800.00
B	SD	%	0.000	30.00
C	TX	%	0.000	30.00

Furthermore, in this work, we attempted to maximize the return on investment (ROI) and net profit (NP). These optimization studies were based on a rational investor's objective to maximize their returns from investing in a profitable project. The maximization objective was subjected to a set of given constraints including the raw material (RM) cost, government subsidy (SD) being minimized, and tax rate set being in a range of the boundary condition. The constraint and objective functions are presented in table 5.

Table 5. Optimization constraints and objectives in this analysis.

Name	Goal	Boundary condition	Lower weight	Upper weight	Importance
RM	maximize	200 ≥ RM ≥ 800	1.31001	1	3
SD	minimize	0 ≤SD ≤ 40	1	1	5
TX	is in range	0 < TX < 30	1	1	3
NP	maximize	-2.85E + 06 > NP > 2.22E + 06	1	1	4
ROI	maximize	-59.083 > ROI > 45.951	1	1	5

3. Results and discussion

3.1 Total investment estimation

Table 6 shows that the total plant cost of US$39,99,690.03 comprises a direct plant cost (US$2,499,806.27) and an indirect plant cost (US$1,499,883.76). These values mean that the direct plant cost constitutes 62.5% of the total plant cost with the indirect plant cost constituting the remaining 37.5%. Also the fixed capital cost of US$4,599,643.53, as expected, constitutes the bulk of the total capital investment of US$4,829,625.71 since significant amounts must be invested on the machines and other tools required for bio-ethanol production and capital goods by nature are costly, and they are expected to be used in the foreseeable future for production.

Table 6. Total capital investment of transforming rice-husk into bio-ethanol.

Description	Symbols	Unit	Amount
Direct plant cost	DPC	US$	2499806.27
Indirect plant cost	IPC	US$	1499883.76
Total plant cost	TPC	US$	3999690.03
Fixed capital cost	FCI	US$	4599643.53
Working capital	WC	US$	229982.18
Total capital investment	TCI	US$	4829625.71
Bio-ethanol production	nV	L	17719641.04
Capital per liter	CaPv	US$/L	0.27
Capital per liter	CaPv	NGN/L	97.2

The capital per liter of US$0.27 (Twenty-seven cents) (or NGN 97.20, i.e. ninety-seven naira and twenty kobos) was computed based on a bio-ethanol production of 17,719,641.04 L. This capital cost per liter is US$0.07 and 1.65 lower than that obtained by Oyegoke and Dabai [19, 20] and Ajayi *et al*. [5] for bio-ethanol produced from sugarcane bagasse-juice and sorghum bagasse, respectively, in Nigeria. This deduction shows that producing bio-ethanol from rice-husk is cheaper than producing it from sugarcane bagasse-juice and sorghum bagasse in Nigeria in terms of capital investment.

3.2 Cost of manufacturing estimation

Table 7 shows that the manufacturing cost of transforming rice-husk into bio-ethanol comprises raw material costs and operating labor. Taking the manufacturing cost and dividing it by the output of 17,719,641.04 L resulted in a cost of US$0.51 manufacturing per L.

Table 7. Manufacturing cost for transformation of rice-husk into bio-ethanol.

Description	Symbols	Unit	Amount
Raw material ($)	RM	US$	2767892.64
Operating labor ($)	OL	US$	54800.61
Direct manufacturing cost ($)	DMC	US$	6554407.15
Depreciation ($)	DP	US$	459964.35
General expenses ($)	GE	US$	1407023.98
Manufacturing cost ($)	COM	US$	9039516.51
Product (L)	Nv	L	17719641.04
Cost price ($/L)	CoPv	US$/L	0.51
Cost price (N/L)	CoPv	NGN/L	183.6

The manufacturing cost is once again $0.1, 0.13, and 0.32 less than that obtained by Oyegoke and Dabai [19, 20], Christiana and Okoli [17], and Ajayi *et al*. [5] for ethanol production from sugarcane bagasse-juice, cassava, and sorghum bagasse, respectively, in Nigeria. Hence, bio-ethanol production from rice-husk is cheaper in terms of the manufacturing cost than bio-ethanol production from sugarcane bagasse-juice, cassava, and sorghum bagasse in Nigeria.

3.3 Profitability analysis of plant

The selling price of bio-ethanol was chosen as 0.4US$/L (140 NGN/L) compared to that of petrol. This choice was made to reconcile the claim of bio-ethanol being a substitute for petrol. The high cost of petrol has contributed to a widespread poverty in Nigeria, and hence, a lower price of bio-ethanol would stimulate demand for bio-ethanol and contribute to reducing poverty in Nigeria. The price of bio-ethanol would ensure that bio-ethanol in its demand competes favorably with petrol in Nigeria. The initial investment analysis carried out for the plant showed that if the (bio-ethanol) product sells for 0.4 US$/L at an exchange rate of 360 NGN/US$ and a tax rate of 20% per annum, the revenue generated would be US$ 7.1 million per annum. The gross income would be US$-1.9 million per annum, resulting in a net loss of US$-1.5 million per annum. Return on investment for the plant was computed to be -31.51% (i.e. a loss on investment), as stated in table 8. These findings show that the revenue generated is less than the manufacturing cost, which results in a negative gross income (i.e. gross loss), negative net profit (i.e. net loss), and a negative return (i.e. loss) on investment.

Table 8 would appear to suggest that investment on the bio-ethanol plant is not profitable, and is certain to discourage investment on bio-ethanol production. This highlights bio-ethanol production as an expensive venture with the potential of significant loss on investment. This result was due to the absence of government subsidy to finance the production cost, as observed in table 8, where no subsidy was utilized. Similar kinds of infeasibility results were equally obtained for the profitability of utilizing sugarcane bagasse-juice, cassava, and sorghum bagasse for bio-ethanol production, as reported in the literature [5, 17, 19, 20], in Nigeria.

Table 8. Project profitability analysis for the bio-ethanol plant.

Description	Notations	Unit	Amount
Subsidy	Sub	%	0
Exchange rate	X	NGN/US$	360
Tax rate	TR	-	0.20
Cost price	CoPv	US$/L	0.51
		NGN/L	183.65
Sales price	SPv	US$/L	0.40
		NGN/L	145.00
Revenue	R	US$	7,137,077.64
Gross income	GI	US$	-1,902,438.87
Net profit	NP	US$	-1,521,951.09
Return on investment	ROI	%	-31.51

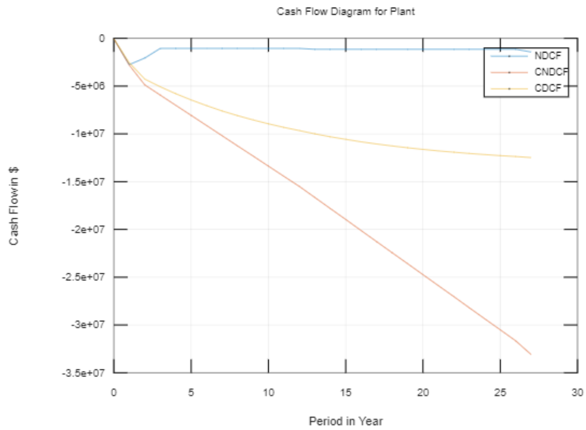

Figure 2. Cash flow diagram for production of bio-ethanol from rice-husk.

Figure 2 shows the project's net present worth as unfavorable with a negative internal rate of return and an interest rate greater than the internal rate of return. Hence, the project is shown as non-viable and non-profitable. In other words, it is not in the interest of the producer to invest on bio-ethanol production given the present conditions while incurring a loss on the project. Despite the paying interest charges, the producer is made worse off with his wealth's value before the project declining significantly after embarking on the project.

3.4 Net profit and return-on-investment modeling

3.5.1 Screening of model for fitness for response (NP and ROI) prediction

(a) Analysis of variance

The study of the results presented in table 9 for net profit (NP) indicated a linear, two-factor-interaction (2FI), quadratic model, and cubic would best predict that NP is < 0.0001, 0.0133, < 0.0001, and < 0.0001, respectively.

Using a 95% confidence level, it was identified that both linear, two-factor-interaction (2FI), quadratic model, and cubic model have the potential for a good NP prediction, based on the analysis. However, the best model selected after the analysis was the quadratic model. The quadratic model's choice is on account of firstly the p-value of the F-statistic of the model, which indicates that the model in addition to the linear model and cubic model are valid models. The second reason for choosing the quadratic model is that it provides the least sum of squares of all the possible models, which is a further major consideration for determining a model's potential in order to give a good prediction.

Table 9. NP model's ANOVA for production of bio-ethanol from rice-husk

Source	Sum of squares	DF	Mean square	F-value	Prob > F
Mean	2.559E + 012	1	2.559E + 012		
Linear	2.666E + 013	3	8.886E + 012	184.97	< 0.0001
2FI	4.009E + 011	3	1.336E + 011	5.98	0.0133
Quadratic	2.203E + 011	3	7.342E + 010	155.60	< 0.0001
Cubic	3.303E + 009	6	5.505E + 008	7.418E + 009	< 0.0001
Residual	0.074	1	0.074		
Total	2.984E + 013	17	1.755E + 012		

Table 10. ROI model's ANOVA for production of bio-ethanol from rice- husk.

Source	Sum of squares	DF	Mean square	F-value	Prob > F
Mean	1097.09	1	1097.09		
Linear	11428.60	3	3809.53	184.97	< 0.0001
2FI	171.89	3	57.30	5.98	0.0133
Quadratic	94.43	3	31.48	155.58	< 0.0001
Cubic	1.42	6	0.24	6.366E+007	< 0.0001
Residual	0.000	1	0.000		
Total	12793.42	17	752.55		

Further evaluation of the results presented for return on investment (ROI) in table 10 indicate that the linear, two-factor interaction (2FI), quadratic and cubic model, respectively, have the potential for a good prediction of ROI as p-values of < 0.0001, 0.0133, < 0.0001, and < 0.0001 were obtained in respect of all the models, and all the three have the least sum of squares of all possible models considered, 1.42, 94.43, and 171.89, respectively.

(b)Model statistics summary

Table 11 presents the model statistics summary. The model's goodness of fit was checked by the determination coefficient (R^2), which indicated the proportion of variation in the outcome variable explained by the model. In this case, the value of the quadratic model's determination coefficient is (R^2 = 0.9999) and indicates that the model does not explain only 0.01% of the total variations. The determination coefficient is the highest of all the models in table 11. Although all four models have coefficients of determination above 0.95, indicating all the models have a perfect fit, the value of the adjusted determination coefficient for the quadratic model [Adj (R^2) = 0.9997] is also very high in supporting the quadratic model's high significance. The result obtained and tabulated in table 11 above the quadratic models was considered as the best with the smallest value of prediction error sum of squares (PRESS) with a value of 4.866E + 010.

Table 12 presents the model statistics summary. The result shows that the quadratic model has the highest R2 with a value of 0.9999, indicating that RM, SD, and TX can explain a 99.99% variation of ROI. Therefore, the quadratic model was selected as the best, with the smallest value of PRESS with 20.86.

Table 11. NP model's statistics for production of bio-ethanol from rice-husk.

Source	Std. Dev.	R-squared	Adjusted R-squared	Predicted R-squared	PRESS
Linear	2.192E + 005	0.9771	0.9718	0.9545	1.242E + 012
2FI	1.495E + 005	0.9918	0.9869	0.9669	9.039E + 011
Quadratic	21722.65	0.9999	0.9997	0.9982	4.866E + 010
Cubic	0.27	1.0000	1.0000		+

Table 12. ROI model's statistics for production of bio-ethanol from rice-husk.

Source	Std. Dev.	R-squared	Adjusted R-squared	Predicted R-squared	PRESS
Linear	4.54	0.9771	0.9718	0.9545	532.28
2FI	3.10	0.9918	0.9869	0.9669	387.51
Quadratic	0.45	0.9999	0.9997	0.9982	20.86
Cubic	0.000	1.0000	1.0000		+

3.4.2 Analysis of selected model for NP and ROI predictions

(a) Analysis of variance for NP model

The selected quadratic model obtained for NP from the use of response surface study approach using the Box Behnken design yields:

NP = +5.00274E + 005 - 4842.91199 * RM + 71419.28884 * SD - 3812.05424 * TX - 5.58114E - 003 * RM2 + 1017.80594 * SD2 - 1.87259 * TX2 - 1.94026E - 014 * RM * SD + 48.48660 * RM * TX - 1019.58252 * SD * TX (5)

Moreover, the NP's prediction displayed model indicates the contribution of the various parameter via the use of their coefficients. It was identified that the variables like RM, SD, TX, SD2, RM * SD, and RM * TX were highly significant, while the other variables like RM^2, TX^2, and RM * SD were found to be insignificant.

Looking at the analysis of variance (ANOVA) for the NP model in table 13, the first step after determining the model vector is to estimate the statistical significance of model coefficients of variables. A significant variable is essential in predicting the outcome variable, while an insignificant variable has no relevance in predicting the outcome variable. Therefore, following ANOVA, the coefficients that are found statistically insignificant should be removed from the model. The P-values determined the significance or insignificant of each coefficient. The P-values lower than 5% indicated that the coefficient of a variable in the model was significant; otherwise, it was not significant. Based on the P-values, the first-order effect of all variables (A, B, and C) with a p-value of $0.0001 < 0.05$, the quadratic effect of B^2 with a p-value of $0.0001 < 0.05$ and two-level interaction of A and C (or AC); and also two-level interaction of B and C (or BC) are significant with a p-value of 0.0001 < 0.05, respectively. Other variables did not have statistically significant coefficients (since P-values were greater than 0.05), and as such, were eliminated from the model in order to reduce the noise present in the NP model and aid improvement in the prediction of the model. The insignificant variables eliminated from the improved NP model were, therefore, A^2, C^2, and AB.

After the elimination of noise/insignificant variables, as explained above, the improved model was found to be in the following form:

$$NP = +5.01657E + 005 - 4848.52590 * RM + 71420.04491 * SD - 3868.48156 * TX + 1017.76405 * SD2 + 48.48660 * RM * TX - 1019.58252 * SD * TX \quad (6)$$

However, among the significant model variables, going by their respective signs, it was found that the RM, TX, and SD * TX variables contributed negatively, while SD, SD2, and RM * TX contributed positively to the NP change. The negative contribution of RM and TX to NP highlights the adverse effects of the high and rising raw material costs and high taxes on profitability. High raw material costs and taxes increase the production costs, and as the high cost and taxes are transferred to the customers, demand would be discouraged, and loss would result. The adverse effect of SD*TX highlights that higher taxes would be charged to finance subsidies given to the bio-ethanol producers by the Government, which would negatively affect business profits, and consequently, profitability.

Table 13. Analysis of the selected NP model before elimination of the insignificant terms.

Source	Sum of squares	DF	Mean square	F-value	Prob > F
Model	2.728E + 013	9	3.031E + 012	6423.25	< 0.0001
A (RM)	1.311E + 013	1	1.311E + 013	27792.99	< 0.0001
B (SD)	1.354E + 013	1	1.354E + 013	28696.40	< 0.0001
C (TX)	4.650E + 010	1	4.650E + 010	98.53	< 0.0001
A2	1.016E + 006	1	1.016E + 006	2.154E - 003	0.9643
B2	2.197E + 011	1	2.197E + 011	465.49	< 0.0001
C2	7.457E + 005	1	7.457E + 005	1.580E - 003	0.9694
AB	0.000	1	0.000	0.000	1.0000
AC	1.904E + 011	1	1.904E + 011	403.56	< 0.0001
BC	2.105E + 011	1	2.105E + 011	446.11	< 0.0001
Residual	3.303E + 009	7	4.719E + 008		
Pure error	0.000	1	0.000		
Cor Total	2.728E + 013	16			

Table 14 shows the analysis of the selected model after elimination of the insignificant variables. The result obtained indicated that the linear effect RM (A), SD (B), and TX (C) had a significant effect on NP with a p-value < 0.05, for the quadratic effect B^2 had a significant effect on NP, while the interaction effect AC and BC had a significant effect on NP with a p-value of 0.0001, respectively. Looking at the model mean-squares for all the sources in table 14, it can be seen that B(SD) was found to have the highest value. This finding implies that among the sensitive factors (like A, i.e. RM and C, i.e. TX), B(SD) happens to be the most sensitive factor that can significantly affect NP.

(b) Analysis of variance for ROI model

Here, the selected quadratic model obtained for ROI from the use of the response surface study approach using the Box Behnken design yields:

$$ROI = +10.35914 - 0.10028 * RM + 1.47878 * SD - 0.078949 * TX - 1.14145E-007 * RM2 + 0.021074 * SD2 - 3.85385E - 005 * TX2 + 1.66667E - 008 * RM * SD + 1.00394E - 003 * RM * TX - 0.021111 * SD * TX \quad (7)$$

Similarly, the NP prediction model indicates the contribution of various variables to ROI as measured by the variables' coefficients. In other words, the coefficients of variables give the marginal effects of variables on ROI. The study of these coefficients revealed that RM, SD, TX, SD2, RM * SD, and RM * TX were highly significant, while the other variables like RM^2, TX^2, and RM * SD were found to be insignificant.

Table 14. Analysis of the selected NP model after elimination of the insignificant variables.

Source	Sum of squares	DF	Mean square	F-value	Prob > F
Model	2.728E + 013	6	4.546E + 012	13756.91	< 0.0001
A (RM)	1.317E + 013	1	1.317E + 013	39856.47	< 0.0001
B (SD)	1.354E + 013	1	1.354E + 013	40983.67	< 0.0001
C (TX)	4.649E + 010	1	4.649E + 010	140.69	< 0.0001
B2	2.203E + 011	1	2.203E + 011	666.50	< 0.0001
AC	1.904E + 011	1	1.904E + 011	576.21	< 0.0001
BC	2.105E + 011	1	2.105E + 011	636.97	< 0.0001
Residual	3.305E + 009	10	3.305E + 008		
Pure error	0.000	1	0.000		
Cor Total	2.728E + 013	16			

Table 15 gives the results of an analysis of the selected model before elimination of the insignificant variables. The result in this table showed that the linear effect of RM (A), SD (B), and TX (C) had a significant effect on Return on Investment (ROI) with a p-value of 0.0001, respectively. Also the quadratic effects of B^2 were significant in the statistical analyses with a p-value of 0.0001. In table 14, the coefficient of interaction between A and C (or AC) was found to significantly affect ROI, with a p-value of 0.0001. Also the interaction between B and C (or BC) was found to have a significant effect on ROI, with a p-value of 0.0001. The interaction between AB had no significant effect on ROI with a p-value of 0.9696. The quadratic effects of A^2 were insignificant in the statistical analyses with a p-value of 0.9647. A^2, C^2, and AB were insignificant and thus removed to reduce the noise present in the ROI model for the model prediction to get improved.

After elimination of the noised/insignificant terms, the improved ROI model was found to be in the form presented in equation 8:

$$ROI = +10.38734 - 0.10039 * RM + 1.47880 * SD - 0.080110 * TX + 0.021073 * SD2 + 1.00394E-003 * RM * TX - 0.021111 * SD * TX \quad (8)$$

Further evaluation of the significant model terms, going by their respective signs, it was unveiled consistently with the findings from determining NP obtained in equation (6) and also the earlier model specification for ROI in equation (7) that the RM, TX, and SD * TX variables contributed negatively. In contrast, SD, SD2, and RM * TX contributed positively to the change of ROI.

Table 15. Analysis of the selected ROI model before elimination of the insignificant variables.

Source	Sum of squares	DF	Mean square	F-value	Prob > F
Model	11694.92	9	1299.44	6422.89	< 0.0001
A (RM)	5622.61	1	5622.61	27791.61	< 0.0001
B (SD)	5805.31	1	5805.31	28694.68	< 0.0001
C (TX)	19.93	1	19.93	98.51	< 0.0001
A2	4.251E - 004	1	4.251E - 004	2.101E - 003	0.9647
B2	94.16	1	94.16	465.44	< 0.0001
C2	3.159E - 004	1	3.159E - 004	1.561E - 003	0.9696
AB	0.000	1	0.000	0.000	1.0000
AC	81.64	1	81.64	403.53	< 0.0001
BC	90.25	1	90.25	446.09	< 0.0001
Residual	1.42	7	0.20		
Pure error	0.000	1	0.000		
Cor Total	11696.34	16			

Table 16 gives an insight into the analysis of the selected model after elimination of the insignificant terms. The result in table 15 showed that the linear effect of RM (A), SD (B), and TX (C) had a significant effect on ROI with a p-value of 0.0001, respectively. Also the quadratic effects of B^2 were significant in the statistical analyses with a p-value of 0.0001, while the coefficient of interaction between A and C was found to have a significant effect on ROI with a p-value of 0.0001. Also the interaction between B and C was found to significantly affect ROI, with a p-value of 0.0001. Therefore, all variables in the ROI model following the elimination of insignificant variables are statistically significant in light of their p-values, respectively, being less than 0.0001. All variables, therefore, have strong relevance in predicting ROI in equation (8) above. From the results presented in both tables 14 and 16 for the model's mean-square for all the sources, it can be seen that B(SD) emerges to have displayed the highest value. These findings indicate that among the sensitive factors (like A, i.e. RM and C, i.e. TX), B(SD) is the most sensitive factor that significantly affects NP and ROI. This deduction indicates that the government subsidy has to be introduced for the producer to enjoy growth in their project returns; else, it would be challenging to earn a good return for selling bio-ethanol at the same price as petrol.

Table 16. Analysis of the selected ROI model after elimination of the insignificant terms.

Source	Sum of squares	DF	Mean square	F-value	Prob > F
Model	11694.92	6	1949.15	13756.28	< 0.0001
A (RM)	5647.11	1	5647.11	39854.88	< 0.0001
B (SD)	5806.76	1	5806.76	40981.62	< 0.0001
C (TX)	19.93	1	19.93	140.65	< 0.0001
B2	94.43	1	94.43	666.44	< 0.0001
AC	81.64	1	81.64	576.18	< 0.0001
BC	90.25	1	90.25	636.95	< 0.0001
Residual	1.42	10	0.14		
Pure error	0.000	1	0.000		
Cor Total	11696.34	16			

3.5. Results of multi-objective cost optimization studies

The project objective was to maximize profit, and consequently, the bio-ethanol producer would like to realize as much profit as possible, given the cost constraints facing the bio-ethanol production. Further, in light of subsidies having the potential to support huge costs of bio-ethanol production but having a cost in terms of the tax charged to the producer, the profit-maximizing producer would minimize subsidies and minimize tax charges. Hence, the optimal production level for the producer of bio-ethanol from rice-husks, given the producers' objective to maximize profit, is explored. NP and ROI, respectively, compute profit, and within the set constraints presented for the raw material (RM) cost, government subsidy (SD) intervention potential, and tax rate (TX), as earlier presented in table 4.

Here, the map in figure 3 displays the different optimization solution spaces from which the proximity of the solution space to the set target was measured as the desirability. Space or region that displayed the highest level of desirability (0.53) emerged as the optimum solution to the problem.

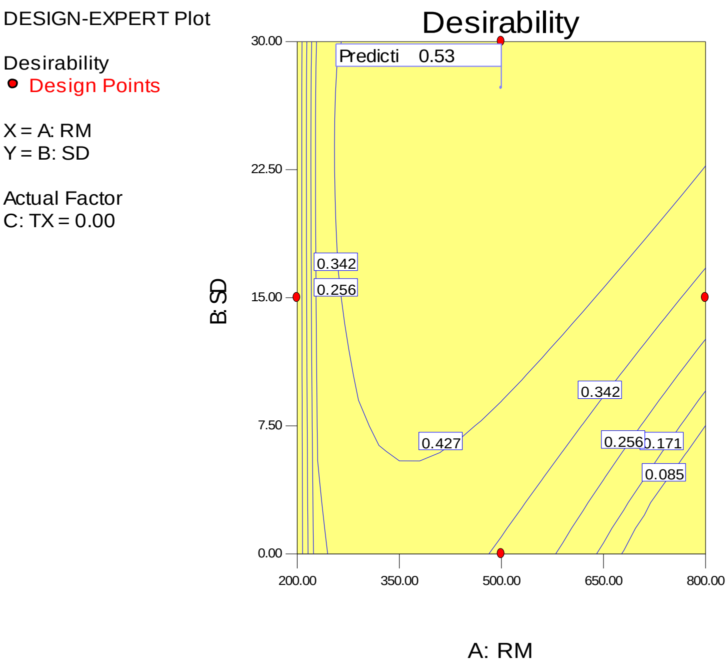

Figure 3. A map indicating the optimal solution region in variables of desirability.

The details of the optimal point (desirability with a value of 0.53), identified where the solution to the optimization problems exists, is displayed in figure 4. These results shown in figure 4 present the optimum conditions (subsidy, tax, raw material cost) that would yield a maximum profit (NP and ROI) in the bio-ethanol production. The results obtained from this work presented in the figure indicate that for a producer to benefit from this bio-ethanol project, the rice-husk purchase cost (RM) is 499.90 NGN/kg (maximum), the government has to provide a minimum subsidy of 24.82%, and a tax-free policy has to be adopted for the bio-ethanol production in the developing nations like Nigeria. The zero-tax charged on the bio-ethanol production would stimulate the bio-ethanol's significant production, and the government subsidy would significantly support the production costs. Further, the consumer would certainly benefit in terms of lower prices since the production cost is substantially lower due to subsidy, and the customer has not transferred any tax burden via the price of the produced bio-ethanol.

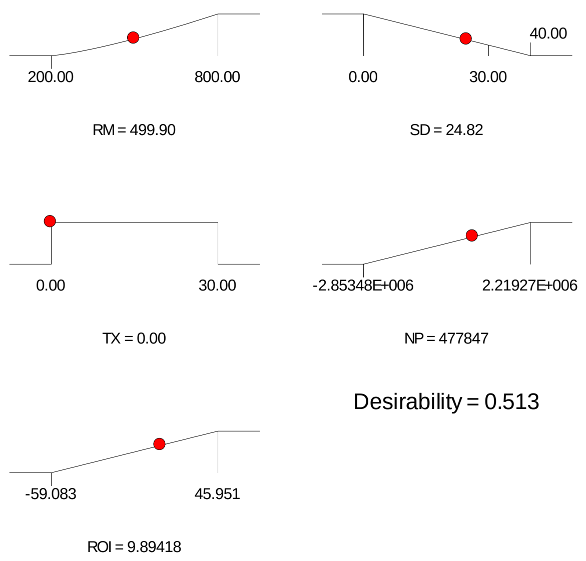

Figure 4. The optimal condition for the optimization problem.

The solution to the optimization problem presented in figure 4 indicates that if the optimal conditions identified are embraced, and the chances of yielding benefit packaged worth of 9.89% ROI and a net profit (NP) of US$ 477,847 per annum. The return on investment of 9.89% is relatively high and represents a healthy return for the investor.

The consistency of the results reported in table 17 for the validated output (obtained from the use of the developed prediction models and the optimal prediction (obtained from the optimization studies) for ROI and NP in equations 6 and 8, respectively) was found to have recorded an insignificant deviation of 1.01%. The two results would equate each other when both are rounded off.

Table 17. Validation analysis for the optimal condition obtained.

Number	RM	SD	TX	NP	ROI
Optimal predicted	499.85	27.28	0.00	783562.00	16.22
Validated output	499.85	27.28	0.00	775673.99	16.06
Deviation				7888.01	0.160
Error (%)				1.01	1.01

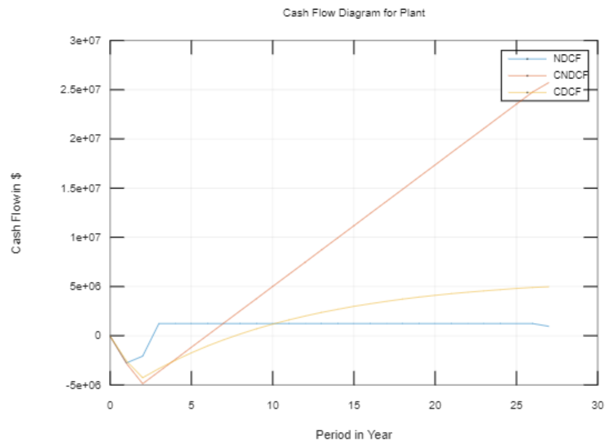

Figure 5. Cash flow diagram for optimal solution obtained.

Furthermore, the result obtained from the studies for optimal situation indicates that it would take about 5.5 years (payback period) in order to recoup the investment, and the net present worth after the project life (25 years) would be about 5 million dollars (NPW), which was deduced from the cumulative discounted cash flow trend line displayed in figure 5 to the study. The payback period of 5.5 years is relatively short and would ensure that the borrowed funds are re-paid in the shortest possible time, while the investor would enjoy his investment over the remaining 19.5 years.

4. Conclusions

Lignocellulose resources are the most promising feedstock for bio-ethanol production in environmental sustainability and food security as they do not antagonize food crops and animal feeds. In this work, we showed that agricultural waste such as rice-husk could be used as a feedstock or substrate for bio-ethanol production. This work unveiled the enablement of promoting a sustainable environment as waste could be transformed into a useful form while ensuring that the agricultural output could meet the society's

needs beyond just providing food for consumption. Besides, selling at a reduced price than petrol, bio-ethanol would further ensure that the Nigeria's present energy poverty is reduced.
In this work, we established that 17.7 million liters (1789.45 kg/h) of bio-ethanol could be produced from 1,478.25 metric tons (180 kg/h) of crushed rice-husk at a capital investment of 0.27 US$/L (97.2 NGN/L) and a manufacturing cost of 0.51 US$/L (183.6 NGN/L). The plant would yield 18.0 million liters of bio-ethanol from the processing of 1478 metric tons of crushed rice-husk with a capital of US$4.8 million and a manufacturing cost of US$9.0 million per annum.
Also from the profitability analysis, this work showed that the plant would generate a revenue of US$7.1 million, a gross loss of US$1.9 million, and a net loss of US$1.5 million, yielding a 31.51% loss on investment. The analysis outcome indicated that the process would not be viable and non-profitable based on this work’s project parameters. The findings implied that the revenue for the sale of bio-ethanol (at the current petrol selling price rate) would be less than its manufacturing cost, resulting in a negative gross income (i.e. gross loss), negative net profit (i.e. net loss), and a negative return on investment (i.e. loss on investment). A negative return on investment is a disincentive (or discouragement) for investment at the expense of high energy poverty due to the high cost of petrol, a competing commodity for bio-ethanol. This work indicated that among the factors involved (like A, i.e. RM and C, i.e. TX), B(SD) happened to be the most sensitive one, which implied that for the producers to enjoy growth in their returns, the subsidy had to be introduced; else, it would be challenging to earn a good return for selling the bio-ethanol at the same price with petrol.
However, a process cost optimization was carried out in order to ascertain the best and most effective conditions that would yield a positive return. Findings from this work show that if the rice-husk sales for as low as 499.85 NGN/kg (1.388 US$/kg) coupled with 25 % government subsidy and tax waiver on the sale of bio-ethanol, this production would yield a high gross profit, good net profit, and favorable investment return. The benefits were estimated to be a net worth of US$5 million per annum, a payback period of 5.5 years, and a return on investment of 16.1% (as shown in table 17, and figures 4 and figure 5). For the maximum utilization of the plant, the optimization conditions are the best-operating regions that make the bio-ethanol project feasible.
Conclusively, this work has ascertained that bio-ethanol is not just a cleaner and efficient fuel than petrol; it can also be sold at the same price as petrol or even cheaper and still yield a good profit. Hence, the investment on bio-ethanol from rice-husks is highly recommended based on the significant benefits to the society, provided the optimization conditions hold, especially that of government subsidy and zero tax, all of which must be given consideration.
Further investigations should be carried out in order to investigate the exergy and energy analysis of the proposed plant in order to ascertain the plant energy and exergy efficiency. Further investigations into the use of other biomass resources for bio-ethanol and other biofuels like bio-diesel and bio-gas can be considered.

5. Appendix

MATLAB Code for Economic Analysis of Rice-Husk Transformation into Bio-Ethanol

```
clc
clear all
%developed by T. Oyegoke, ABU Zaria Nigeria
%toyeseoyegoke@gmail.com, or Oyegoketoyese@gmail.com
X=input('exchange rate (N/$)=')
%ESTIMATION OF TOTAL CAPITAL INVESTMENT
A=input('raw material cost (N/kg) =')
B=input('wage (N/month) =')
D=input('subsidy (%) =')
%E=input('sellprofit (%) =')
C=input('tax (%) =')
%Using Factorial Method for Fluid-Solid Processing and Grass
%Root Plant With Reference to Table 17 in Max S.P. & Klaus %D.T.(1991), "Plant Design
%Economics for Chemical Engineers", %Fourth Edition, page 183.
%Purchased Cost of Equipment Delivered (PCE)
```

```
PCE=input('enter total equipment cost ($) =')
%DIRECT PLANT COST
f(1) = 1.00*PCE; % Purchased Cost of Equipment (PCE)
f(2) = 0.39*PCE; % Installation Cost for Equipment
f(3) = 0.31*PCE; % Piping Installed
f(4) = 0.10*PCE; % Electrical Installed
f(5) = 0.13*PCE; % Instrumentation & Control Cost
f(6) = 0.29*PCE; % Battery-limits building and service
f(7) = 0.10*PCE; % Excavation and site preparation
f(8) = 0.55*PCE; % Auxiliaries/Service Facilities
f(9) = 0.06*PCE; LD = f(9); % Land Survey & Cost
%Total direct plant cost (DPC)
f(10) = sum(f(1:9)); DPC = f(10);
%INDIRECT PLANT COST
f(11) = 0.25*DPC; % Field & Construction Expense
f(12) = 0.35*DPC; % Engineering & Supervision
%Total Indirect Plant Cost (IPC)
f(13) = sum(f(11:12)); IPC = f(13);
%Total Direct & Indirect Plant Cost (DIPC)
f(14) = DPC+IPC; TPC = f(14);
%OTHER PLANT COST
f(15) = 0.05*TPC; % Contractor‘s fees, overhead, profit
f(16) = 0.10*TPC; % Contingency
%Total fixed-capital investment
f(17) = TPC+f(15)+f(16); FCI = f(17);
CapCostGen=0; %Capital for power generation(if available)
%Working Capital
f(18) = 0.05*FCI; WC=f(18);
%Total Capital Investment for this project estimated as TCI
TCI = FCI+f(18) % Total Capital Inves'tment

%COST OF MANUFACTURING ESTIMATION (COM)
%Working Hours
h=input('working hour in h/day =')
%Annual Working Days
d=input('working days in d/year = ')
%Cost of Raw Material
s=A;
%Amount of minimum wage
w=B;
%Dollar conversion factor
x=X;
tol=0.0001; km=1000; COMo=50500; err=0.02; k=0;
while err>tol & k<km
COM=COMo;
%DIRECT MANUFACTURING COST (DMC)
%Raw Material (RM)

% ===== Feedstock cost
SGq = 180 %input('Feedrate or quantity in kg/h')
%SG = quantity * unit price * hr * days
m(1) = SGq*(s/x)*h*d; %Feedstock (SG) Annual Cost in $
SG = m(1)

% ===== Material cost 1
EZup1 = 0.4; %input('Unit price of material 1 in $/kg=')
```

```
EZq2 = 90 %input('Quantity of material 1 needed in kg/h=')
%5% for shipping fee
%RM = quantity * unit price * hr * days
m(2) = EZq2*EZup1*(1+0.05)*h*d; % Annual Cost (EC) in $

% ===== Material cost 2
EZup11 = 0.3 %input('Unit price of material 2 in $/kg=')
EZq22 = 90 %input('Quantity of material 2 needed in kg/h=')
%5% for shipping fee
%RM = quantity * unit price * hr * days
m(3) = EZq22*EZup11*(1+0.05)*h*d; % Annual Cost (EC) in $

% ===== Other Material cost 3
EZup123 = 5.6 %input('Unit price of material 3 in $/kg=')
EZq223 = 5.940 %input('Quantity of material 3 needed in kg/h=')
%5% for shipping fee
%RM = quantity * unit price * hr * days
OMC(1) = EZq223*EZup123*(1+0.05)*h*d; % Annual Cost (EC) in $
% ===== Annual Raw Material Cost in $
m(4) = sum(m(1:3))+sum(OMC(1));
RM = m(4);

%Operating Labor (OL)119
%Assumptions made here are:
%Each unit has an operator per shift
%No of Shift is 2
%OL = no of shifts * unit wage * months * no of units
nPS=9; %No of processing steps
nNPS=3; %No of non-processing steps
nOL=(6.29+31.7*nPS^2+0.23*nNPS)^0.5;
m(5)= 2*(w/x)*(d/365*12)*nOL; % Annual Operating Labour Cost in $
OL = m(5);
%Direct Supervisory & Clerical Labor (DS)
m(6) = 0.12*OL; %with reference to Richard et al.(2004)
DS = m(6);
%Utilities Cost (UT)
%The utilities are Water & electricity
% ===== Cooling water cost
WAup = 10.71 %input('Cooling water price in $/ton = ')
WApw = 12.23 %input('Process Water in kg/h = ')
WAww = 13.1 %input('Wash Water in kg/h = ')
m(7)=(WApw+WAww)*h*d*WAup*1620.5/1179; %Water cost (WA)
WA=m(7);
% ===== Electricity cost
EPup = 43.38 %input('Unit price of electricity in =N=/kWh = ')
%sourced from PHCN
EPq = 433 %input('kWh will be needed per hour for plant')
m(8)=(EPup/x)*EPq*h*d; %Electrical power (EP) cost
EP=m(8);
% ===== Waste treatment
%Type: Primary Treatment
WTm = 18.3% input('Amount of Waste in m3/h')
WTg = WTm*4.; % Amount of Waste in gal/m
WTbc = 282.1; % Bare Cost
WTn = 1.0758; % Cost Index (n)
% CE Cost Index for 2016 is 567 and 610 is 2019
```

```
% Reference Seider & Seader (2011)
m(9)=WTbc*(WTg^WTn)*610/567; %Waste Treatment Cost
WT=m(9);
% ===== Utilities Cost
UT=sum(m(7:9));
%Maintenance & Repair (MR)
m(10)=0.03*FCI;%with reference to Richard et al.(2012) range(0.02-0.10)
MR=m(10);
%Operating Supplies (OS)
m(11)=0.13*MR;%with reference to Richard et al.(2012) range(0.10-0.20)
OS=m(11);
%Laboratory Charges (LC)
m(12)=0.12*OL; %with reference to Richard et al.(2012) range(0.10-0.20)
LC=m(12);
%Patents & Royalties (PR)120
m(13)=0.02*COM; %with reference to Richard et al.(2012) range(0.0-0.06)
PR=m(13);
%Direct Manufacturing Cost
DMC=RM+OL+DS+UT+MR+OS+LC+PR;
%FIXED MANUFACTURING COST (FMC)
%with reference to Richard et al.(2004)
%Depreciation
m(14) = 0.1*FCI; DP = m(14);
%Local taxes
m(15) = 0.02*FCI; LT = m(15);
%Insurances
m(16) = 0.002*FCI; IS = m(16);
%Plant Overhead (PO)
%With Reference to Richardson & Coulson (2005): PO = 0.5-1.00 of OL
m(18)=0.6*(OL); PO=m(18);
%Fixed Manufacturing Cost
m(5) = sum(m(14:18)); FMC = m(5);
%GENERAL EXPENSES(GE)
%Administration cost
m(20)=0.177*OL+0.009*FCI; AC=m(20);
%Distrbution & Selling Cost
m(21)=0.10*COM; DC=m(21);
%Research and Development Cost
m(22)=0.05*COM; RD=m(22);
%General Expenses
GE=sum(m(20:22));
COMF=0.28*FCI+2.73*OL+1.23*(UT+WT+RM);
err=max(abs((COMF-COM)/COMF));
k=k+1; COMo = COMF;
end
%Land
LD=f(9);
%Cost of Manufacturing with discount
COM=COMo
%Cost of Manufacturing without discount
COMd=0.18*FCI+2.73*OL+1.23*(UT+WT+RM)
%Production Rate =1789.45kg/h
nM=1789.45*h*d; %kg/year and density is 0.796kg/L
nV=nM/0.79618; %L/year
%Cost of producting 1L product will be COM/nV
CoPv=COM/nV %$/L
```

```
%Subsidy of government
Sub=D/100;
%Selling price for ethanol
SPv=input('selling price of your product in $/L =')
NCv=SPv*x; %=N=/L
%INVESTMENT PROFITABILITY ASSESSMENT
%Revenue (R)
SubPay=Sub*SPv/(1-Sub)*nV;
R=SPv*nV+SubPay %from Sales of Product in $/year
%Gross Income (GI)
GI=R-COM
%NET PROFIT
%Tax Rate
TR=C/100
%Net Profit in '$'
NP=GI*(1-TR)
%Using the results of the below variables from the above calculation:
FCI; WC; DP; LD; R;
COMd; COM; TR; CapCostGen;
%Project life
p=25; %in years
%discount rate using straight line discounting method
r=0.10; % 10%
%Year
y=[0:1:p+2]';
%Investment
I=[LD,0.6*FCI,0.4*FCI+WC,zeros(1,p)]';
I(p+3,1)=LD+WC;
%Depreciation
rt=(FCI+CapCostGen)/DP; %years;
dk=[0,0,0,DP*ones(1,rt),zeros(1,p-rt)]';
%Investment after depreciation
Id=zeros(3+p,1);
Id(1)=FCI;
for i=2:3+p
Id(i)=Id(i-1)-dk(i);
end
size(Id); %for checking dimension of matrix consistency
%Annual revenue generation
Rv=R*[zeros(1,3), ones(1,p)]';
%Non-discounted Cash Flow
Income=(Rv-COMd*[zeros(1,3),ones(1,p)]'-dk).*(1-TR)+dk;
NDCF=Income-I
%Cummulative Non-discounted Cash Flow
CNDCF=zeros(3+p,1);
CNDCF(1)=NDCF(1)
for i=2:3+p
CNDCF(i)=CNDCF(i-1)+NDCF(i);
end
%Discounted Cash Flow
DCF=zeros(3+p,1)
dr=(1+r)*ones(3+p,1);%
size(dr);
for i=1:3+p
DCF(i)=NDCF(i)/(dr(i).^y(i));
end
```

```
size(DCF);
%Cummulative Discounted Cash Flow
CDCF=zeros(3+p,1);
CDCF(1)=DCF(1)
for i=2:3+p
CDCF(i)=CDCF(i-1)+DCF(i)
end
%plotting the graph
figure(1)
plot(y,NDCF,y,CNDCF,y,CDCF)
xlabel('Period in Year')
ylabel('Cash Flow in $')
title('Cash Flow Diagram for Plant')
legend('NDCF','CNDCF','CDCF')
grid on
%
%Payback period in years
PBP=interp1q(CNDCF,y,(LD+WC))-2
DPBP=interp1q(CDCF,y,((LD+WC)/(1+r)^p))-2
%Non-discounted Net Present Worth
NNPW=CNDCF(end)
%Discounted Net Present Worth
NPW=CDCF(end)
%Rate of Return on Investment
ROI=NP/TCI*100
IRR=10*(-NNPW/(NPW-NNPW))
%Cost Estimation
%For Non-Discounted Cash Flow
NCC1=NDCF;
for i=1:(3+p)
if NCC1(i)<0;
else NCC1(i)=0;
end
NCC=sum(NCC1(1:(3+p)));
end
NCC1;
Ncost=abs(NCC);
%For Discounted Cash Flow
CC1=DCF;
for i=1:(3+p)
if CC1(i)<0;130
else CC1(i)=0;
end
CC=sum(CC1(1:(3+p)));
end
CC1;
Dcost=abs(CC);
%Benefit Estimation
%For Non-Discounted Cash Flow
NBB1=NDCF;
for i=1:(3+p)
if NBB1(i)>0;
else NBB1(i)=0;
end
NBB=sum(NBB1(1:(3+p)));
end
```

```
NBB1;
Nbenefit=abs(NBB);
%For Discounted Cash Flow
BB1=DCF;
for i=1:(3+p)
if BB1(i)>0;
else BB1(i)=0;
end
BB=sum(BB1(1:(3+p)));
end
BB1;
Dbenefit=abs(BB);
%Benefit/Cost Ratio
B_C_ratio_NDCF=Nbenefit/Ncost
B_C_ratio_DCF=Dbenefit/Dcost
```

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