

Cost Analysis Model for Syngas Production Cost Evaluation Using the Graphical User Interface

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Abstract An economic analysis of a bio-gasification facility requires an understanding of its syngas production cost. The objectives of this study were to develop a Cost Analysis Model (CAM) to determine the costs associated with syngas production at different production capacities. The CAM was developed using on a graphical user interface (GUI) programmed in Microsoft Visual Studio 2008 software, mathematical equations and validated using data from the local bio-gasifier at 60 Nm³h⁻¹ capacity. The cost analysis results showed that the syngas production unit cost decreased from \$0.543 Nm⁻³ to \$0.043 Nm⁻³ by increasing the production capacity from 60 to 1,800 Nm³h⁻¹. The economic analysis using the CAM showed better power relationship between production capacity vs. unit cost ($R^2 = 0.99$) than the relationship between production capacity vs production cost ($R^2 = 0.97$). It is generally suggested that the bio-gasification facility should run at a high production capacity in order to reduce the unit cost of syngas production. The CAM developed in this study could be a useful tool for economic analyses of syngas production at different capacities.

Keywords Bio-gasification, Cost analysis model, Economic analysis, Modeling, Syngas

1. Introduction

Biomass gasification system has been considered to be an energy option with high potential. It can be implemented on a smaller-scale for a more efficient utilization of biomass, which provides high-quality energy for rural areas [1]. Due to growing commercial and technological interests in the small-scale bio-gasification facilities, it becomes an important aspect of bio-energy [2, 1, 3]. In addition, the bio-gasification has received substantial attention from academia for the environmental benefits it can bring, such as low air pollution, low waste disposal, waste products re-use (feedstock), and valuable by-products [4]. In addition, the bio-gasification process should be economically reasonable for its successful implementation. Therefore, the economic analysis is essential when assessing the potential profitability of a bio-gasification system and optimizing the expenses associated with capital and operating costs [5, 6, 7]. Similar approach is essential for generating energy from sludge air-blown gasification [8].

Several hydrological and water quality models have been developed to evaluate agricultural and forest based crop production and their impact on hydrology [9, 10]. However, very limited computer-based models have been developed

for evaluating economics of the bio-gasification facilities.

Recently, an economic analysis has been carried out by using a computer-based model because it can improve the cost efficiency and accuracy of the economic analysis [11]. Most of these computer-based models, however, have been developed for engineers and scientists who are skilled and well-versed in spreadsheet programs [12, 13] or computer programming languages such as C++ [11]. As a result, general users (i.e. policy makers) unskilled in computer programming are not able to easily use the economic analysis models for developing the bio-gasification project strategies. The model developed by a graphical user interface (GUI) is one of solutions to this problem since the GUI provides general users useful tools to interface with the complex process models [14, 15, 16]. The GUI is a user-friendly graphical method that allows users to interact with a computer to conduct several tasks and a computer operating system that uses visual relationships and icons rather than text commands. Instead of issuing commands at a prompt, the users carry out desired tasks by using a mouse to select the pictorial buttons (icons) or lists of options displayed on a screen. Therefore, general users with limited computer knowledge can easily use the economic model developed using the GUI. The objectives of this study were: 1) to design and develop the cost analysis model (CAM) using the GUI for analyzing the micro-scale bio-syngas production unit cost, and 2) to apply it based on data derived from the bio-gasification system installed at Mississippi State University (MSU).

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Published online at <http://journal.sapub.org/ep>

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2. Materials and Methods

The general procedure of syngas production from the bio-gasification system includes steps such as feedstock preparation, biomass gasification, and syngas cleaning steps. For economic analysis, feedstock preparation is considered the starting point and the bio-syngas production output was considered as the ending point. The cost configuration of a bio-gasification facility includes many factors. These factors are affected by both external conditions, such as equipment type and size or operating time; and internal conditions, such as production cost. In this study, the production cost was divided into capital cost and operating cost. The capital cost involved equipment, installation, construction, equipment test run, tax, loan interest, insurance, overhead, and auxiliary costs. The operating costs were divided into variable and fixed costs. Variable costs involve the feedstock, operating labor, utility, waste treatment, and maintenance costs, while fixed costs include the general expense and contingency cost. The model design and model economic parameters are described below.

2.1. Model Design

The cost analysis model (CAM) for the syngas production from the bio-gasification system was developed using Microsoft Visual Studio 2008 software [17]. The CAM was designed to control the computer hardware system interface with the GUI (Fig 1). The CAM structure allows users to create input and view output displayed on a screen by the GUI. Inputs to the CAM were categorized into capital and operating costs parameters. A mathematical modeling approach was used to estimate each cost components in the model.

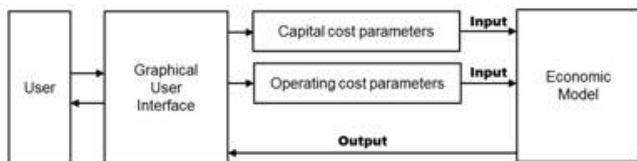


Figure 1. Structure of the Cost Analysis Model (CAM)

In addition, the CAM included functions for saving and downloading data. The CAM output results can be saved and compared with different scenarios. The function of par chart was applied to analyze the cost composition. As shown in figure 2, the CAM consists of six icons: Home, Data, annual capitol cost (Cac); annual operating costs for labor and feedstock (Cao#1); annual operating costs for electricity, waste treatment, maintenance, general expense and contingency expense (Cao#2); and syngas production unit cost (Cup). These icons lead to each slide for cost input and output. Each icon button was designed using the form designer generated code. In addition, the tooltip code was used to help add the text notes on the interface. As the mouse moves to the text area, the related text note is displayed. The home page of the CAM was designed with icon buttons for easy movement to other pages (fig. 2). In order to help data

collection and comparison, the data storage system was established (fig. 3). The data page included the area of saved data output and file name input. Three buttons: “SAVE”, “OPEN” and “DELETE” indicates the data processing for different files. The help page of the CAM provides users information on various terminologies, mathematical equations, and techniques used in the CAM (fig. 4).

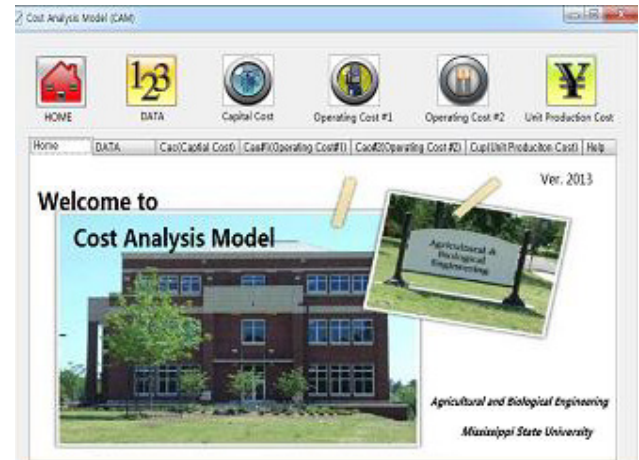


Figure 2. Home page of the Cost Analysis Model (CAM)

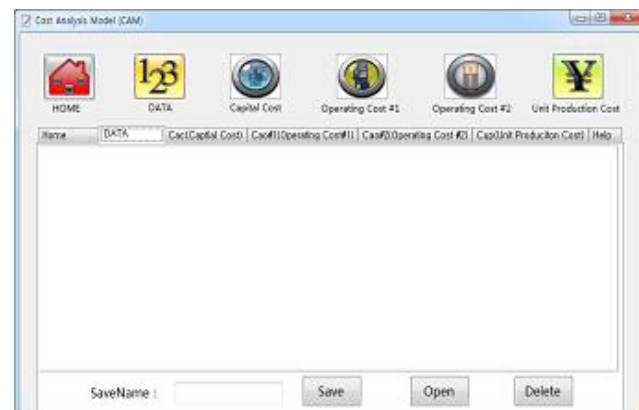


Figure 3. Data page of the Cost Analysis Model (CAM)



Figure 4. Help page of the Cost Analysis Model (CAM)

The annual capital cost in the model was determined as the sum of annual investment cost and annual loan interest cost. The large investment cost can be paid as a part of production cost each year instead of being charged at one time [18]. Thus, the costs of equipment and construction could be

depreciated for their economic lifetimes. In this study, a straight line depreciation method, which considers the actual purchase cost for the asset to reduce the value over time, was used. In this study, the annual capital cost, the equipment costs, construction cost, loan interest cost, annual operating cost, feedstock cost, annual feedstock consumption cost, annual syngas yield, annual working hours, utility cost, electricity consumption cost, labor cost, waste treatment cost, maintenance cost, general expenses, contingency cost, and annual unit cost of bio-syngas production were calculated by using equations and assumptions described in the previous literatures [19, 20, 21, 18, 13, 11].

2.2. Model Economic Parameters

Economic parameters or values were used when calculating the syngas production unit cost based on the data measured from the 60 Nm³h⁻¹ of the bio-gasification capacity installed at MSU. In addition, an economic analysis was carried out based on one working shift. Economic parameters used in the CAM are presented in table 1.

Table 1. Economic parameters used in the model [22, 18, 11, 12, 13]

Parameter	Value
Purchase cost of existing bio-gasification equipment (Cex)	\$42,000
Production capacity of an existing power facility (Pc_ex)	60 Nm ³ h ⁻¹
Depreciation rate of equipment cost (Rdec)	0.1
Depreciation rate of construction cost (Rdec)	0.05
Loan rate (Rloan)	0.9
Loan interest rate (Rintr)	0.04
Building cost factor (Fbud)	0.25
Equipment installation cost factor (Finsta)	0.2
Equipment test run cost factor (Ftst)	0.1
Property insurance cost factor (Finsu)	0.005
Property tax cost factor (Fctax)	0.004
Construction overhead cost factor (Fovh)	0.02
Auxiliary cost factor (Faux)	0.15
Electricity price (Pel)	\$0.0718Kw ⁻¹ h ⁻¹
Labor cost (Rlabo)	\$16h ⁻¹
Feedstock price (Pfsto)	\$35ton ⁻¹
Number of employees (m)	1
Repairing rate (Rrepa)	0.03
General expenses rate (Rgen)	0.1
Contingency rate (Rcontig)	0.1

3. Results and Discussion

This study developed and validated the CAM using available economic data from the bio-gasifier at MSU at 60 Nm³h⁻¹ capacity. Further the model was applied at different capacities to quantify syngas unit cost of the bio-gasification system. Figure 5 shows the results of the annual capital cost analysis including annual equipment cost, annual construction and annual loan interest. The total annual capital cost was \$8,345. Of capital cost, the annual equipment cost (Ceq) was the largest part (50%), while

annual loan interest cost (Cainstr) and construction cost (Ccon) accounted for 32% and 18%, respectively, as presented in figure 6. In the Cao#1 (fig. 7) and Cao#2 pages (fig. 8), the feedstock cost (\$1,433), labor cost (\$33,280), utilities cost (\$576), waste treatment cost (\$16), maintenance cost (\$2,179), general expenses (\$3,748), and contingency cost (\$3,748) were computed. The annual operating cost was \$44,982 (fig. 8). The analysis of operating cost composition showed that labor cost accounted for the largest part of the operating capital cost at 74%, followed by general expense (8%), contingency (8%), maintenance cost (5%), feedstock cost (3%), utility cost (1%), and waste treatment cost (less than 1%), as shown in figure 9.

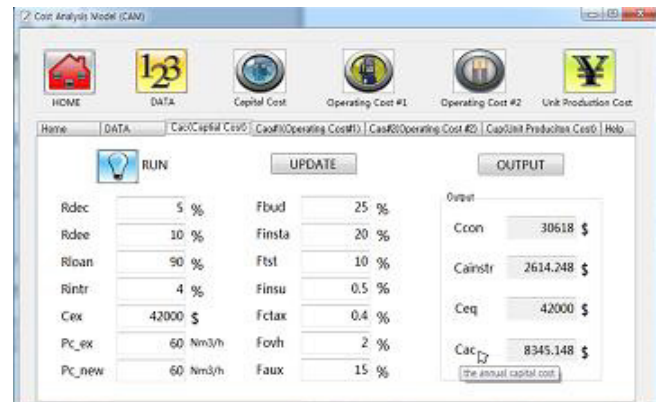


Figure 5. Cac page showing the information for capital cost analysis at a 60 Nm³h⁻¹ capacity

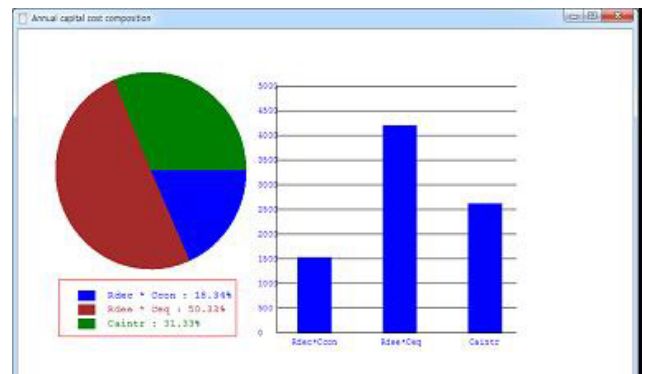


Figure 6. Annual capital cost composition at a 60 Nm³h⁻¹ capacity



Figure 7. Cao#1 page showing the information for operating cost analysis at a 60 Nm³h⁻¹ capacity



Figure 8. Cao#2 page showing the information for operating cost analysis at a 60 Nm³h⁻¹ capacity

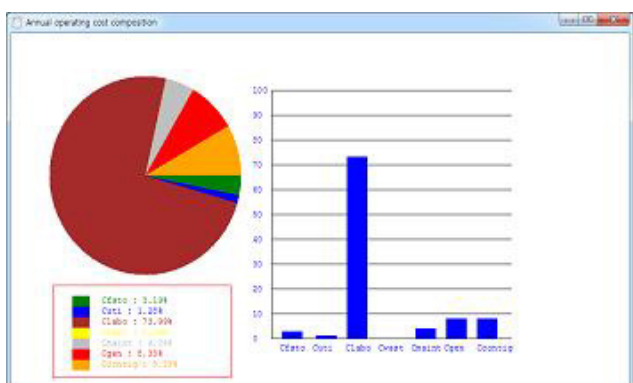


Figure 9. Annual operating cost composition at a 60 Nm³h⁻¹ capacity

Based on cost input and output associated with the annual capital and annual operating costs, annual total production costs and annual syngas production unit costs were computed (fig. 10). Annual production cost at a 60 Nm³h⁻¹ capacity was \$53,327, while the syngas unit cost was \$0.543 Nm⁻³. Operating costs accounted for 84% of the annual syngas production cost, while capital costs were 16%. The annual production cost composition shows that the labor cost, which was the largest portion (74%) of the annual operating cost, was 62% of the annual production cost (fig. 11). The equipment cost, which was the largest portion of annual capital cost, was the second highest percentage (8%) in the annual production cost, followed by the general expense (7%), contingency cost (7%), loan interest cost (5%), maintenance cost (4%), construction cost (3%), feedstock cost (3%), and utility cost (1%). These results indicate that the labor and equipment costs have a relatively large impact on the syngas production cost. Thus, stabilizing the labor and selecting a suitable bio-gasification facility are very important in reducing the syngas production cost and improving the economic feasibility.

Using the GUI-based CAM developed in this study, the syngas unit costs at different production capacities (60, 120, 240, 480, 960 and 1,800 Nm³h⁻¹) were analyzed with the scenario of one working shift mode. The results from this

study showed the power relationship ($R^2 = 0.99$) between production capacity and unit cost (Fig. 12). The annual syngas production unit cost reduced from \$0.543 Nm⁻³ to \$0.043 when production capacity increased from 60 to 1,800 Nm³h⁻¹. The power relationship of the production capacity vs unit cost was determined better ($R^2 = 0.99$) than the relationship between production capacity vs production cost with slightly decreased R^2 value of 0.97 (Fig. 13). It is generally suggested that the bio-gasification facility should run at a high production capacity in order to reduce the unit cost of syngas production.

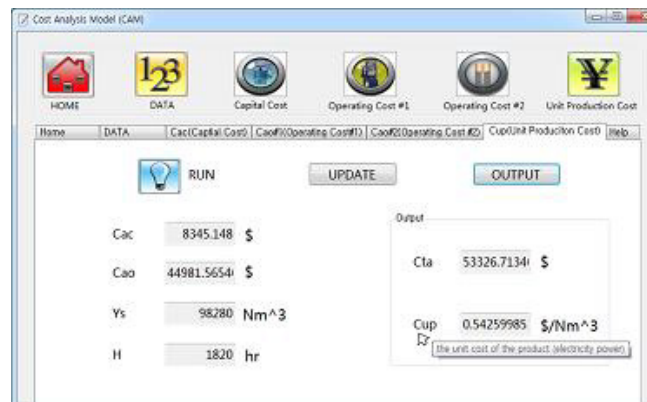


Figure 10. Cup page showing the information for syngas unit cost analysis at a 60 Nm³h⁻¹ capacity

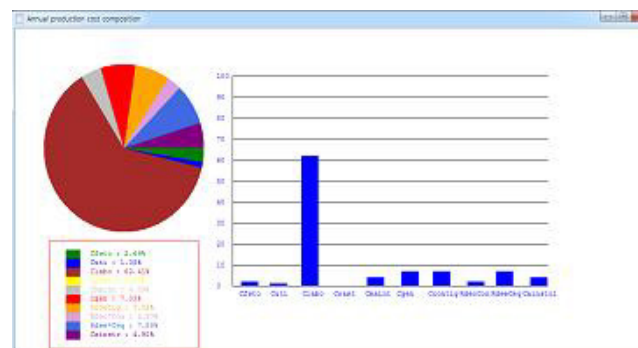


Figure 11. Annual production cost composition at a 60 Nm³h⁻¹ capacity

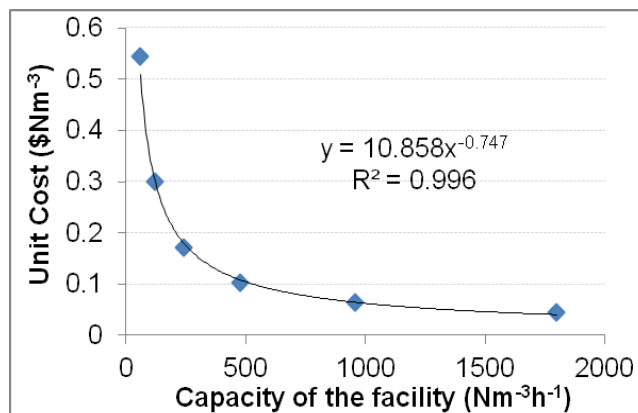


Figure 12. Production capacity (Nm³h⁻¹) vs unit cost (\$Nm⁻³)

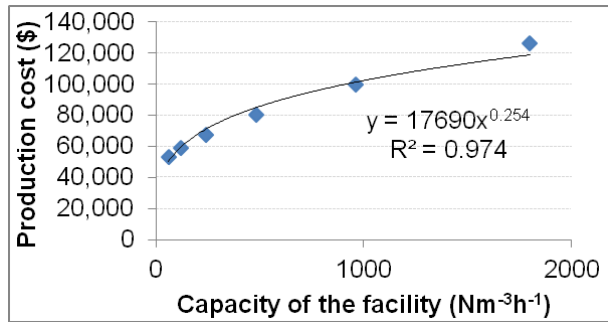


Figure 13. Production capacity (Nm^3h^{-1}) vs production cost (\$)

When the bio-gasification capacity increased from 60 to $1,800 \text{ Nm}^3\text{h}^{-1}$, the composition of annual production cost changed. As shown in figure 14, the feedstock cost was the largest portion of the annual production cost at the capacity of $1,800 \text{ Nm}^3\text{h}^{-1}$. The percentage of feedstock cost (24%) in the annual production cost was eight times greater than that (3%) in operating at a $60 \text{ Nm}^3\text{h}^{-1}$ capacity (fig. 14). This is because the amount of feedstock for producing syngas increased as the production capacity increased, resulting in an increase in feedstock cost. The percentage of equipment cost also increased from 8% to 18%. However, the percentage of labor cost decreased from 62% to 18% since the amount of labor did not change, which means that labor cost was consistent. Labor cost was the largest part of operating and the total annual production costs when micro-scale bio-gasification facility is operated at low capacity (e.g. $60 \text{ Nm}^3\text{h}^{-1}$). The percentage of labor cost can be reduced by operating the bio-gasification facility at higher capacity, whereas the percentage cost of the feedstock can be increased when operating bio-gasification facility in the higher capacity. Since the labor cost included different pay rates and insurances of employees (e.g. facility manager, shift operator, lab technician etc.), the CAM was simplified to input an average labor rate ($\$16\text{h}^{-1}$). The percentage of utility cost, waste treatment cost, maintenance cost, equipment cost, and construction cost increased when the production capacity increased, whereas general expenses and contingency costs decreased. These results shows that a bio-gasification capacity for syngas production affects the annual production cost composition as well as the unit cost of syngas production.

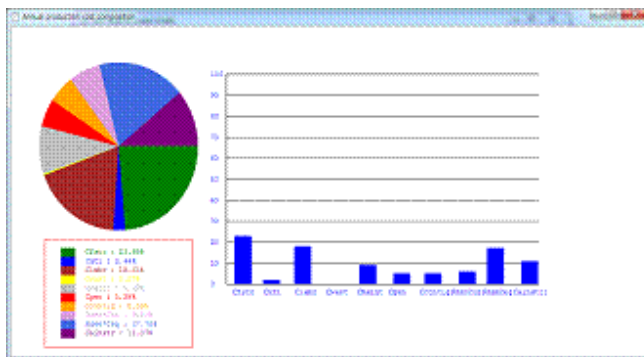


Figure 14. Annual production cost composition at a $60 \text{ Nm}^3 \text{ h}^{-1}$ capacity

4. Conclusions

The graphical user interface (GUI) CAM model was developed and initially validated using economic data available at MSU for the $60 \text{ Nm}^3\text{h}^{-1}$ capacity bio-gasifier. The CAM was further applied to assess syngas production unit costs at different capacities. Each cost component and syngas production unit cost changed when the bio-gasification production capacity increased. The cost analysis results showed that the syngas production unit cost decreased from $\$0.543 \text{ Nm}^{-3}$ to $\$0.043 \text{ Nm}^{-3}$ by increasing the production capacity from 60 to $1,800 \text{ Nm}^3\text{h}^{-1}$. The power relationship of the production capacity vs. unit cost was determined the better than the relationship between production capacity vs production cost. It is suggested that the bio-gasification facility should run at a high production capacity in order to reduce the unit cost of syngas production. The model developed and demonstrated in this study can be used to assess economic analysis of similar bio-gasification facilities at different capacities.

ACKNOWLEDGEMENTS

This material is based upon work performed through the Sustainable Energy Research Center at Mississippi State University and is supported by the Department of Energy under Award Number DE-FG3606GO86025; Micro CHP and Bio-fuel Centre.

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