



**BIOENERGY AND FOOD SECURITY
RAPID APPRAISAL (BEFS RA)**

User Manual

GASIFICATION



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BEFS Rapid Appraisal

Energy End Use Options Module

Rural Electrification Sub-Module

Section 1: Gasification

User Manual

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BEFS RA User Manual Volumes

- I. Introduction to the Approach and the Manuals
- II. Country Status Module
- III. Natural Resources Module
 - 1. Crops
 - Section 1: Crop Production Tool
 - Section 2: Crop Budget Tool
 - 2. Agricultural Residues
 - Crop Residues and Livestock Residues
 - 3. Woodfuel and Wood Residues
 - Section 1: Forest Harvesting and Wood Processing Residues
 - Section 2: Woodfuel Plantation Budget
- IV. Energy End Use Options Module
 - 1. Intermediate or Final Products
 - Section 1: Briquettes
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 - Section 3: Charcoal
 - 2. Heating and Cooking
 - Biogas Community
 - 3. Rural Electrification
 - Section 1: Gasification**
 - Section 2: SVO
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 - 4. Heat and Power
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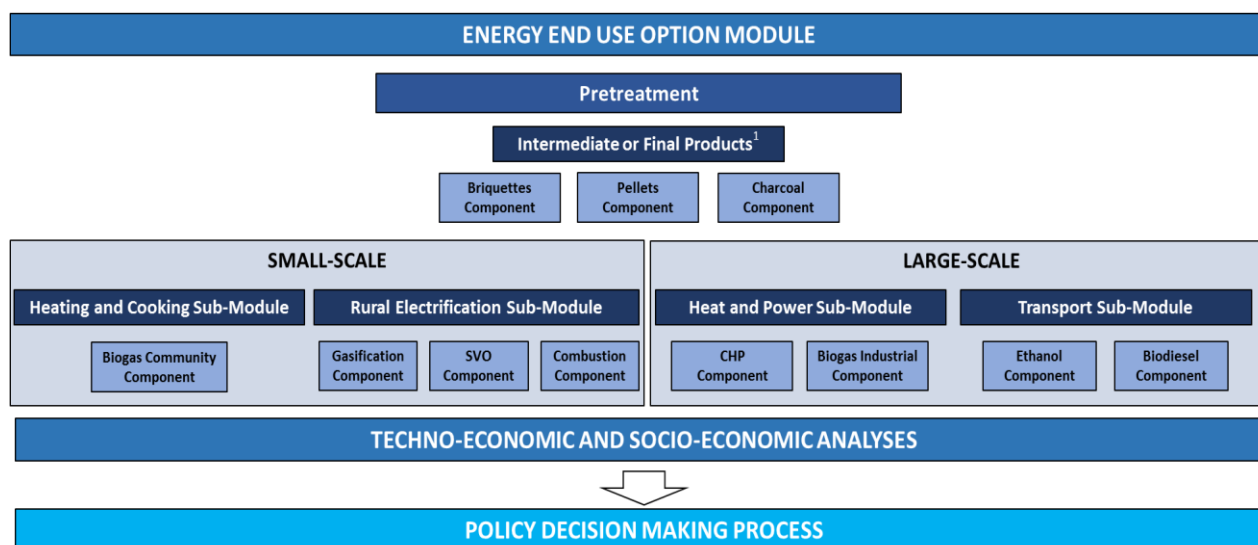
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1 Overview of the Energy End Use Option (End Use) Module

As explained in the general introduction of the BEFS RA training manual, the *Energy End Use Option* module is used to assess the techno-economic and socio-economic viability of different bioenergy production pathways. The module is divided into five sections, these are: Intermediate or Final Products, Heating and Cooking, Rural Electrification, Heat and Power and Transport. Each of the sub-modules includes a choice of components of analysis to assess the production of specific biofuels based on particular processing technologies, as depicted in Figure 1. This module builds up from the information generated in the *Natural Resources* modules in relation to feedstock. For a more detailed description of the module, refer to the general introduction of the training manual.



¹These products may be used either as final products for heating and cooking or as intermediate products in the rural electrification options of gasification and combustion.

Figure 1: The Structure of the Energy End Use Option Module

A general description of each of the sub-modules and their respective components of analysis are presented below. A more detailed discussion on each of the components of analysis will be provided in the respective user manual.

The **Intermediate or Final Products** sub-module is used to assess the viability of producing briquettes, pellets and charcoal. The **Briquettes/Pellets** components are used to evaluate the potential to develop the production of biomass briquettes/pellets to supply energy for heating and cooking in rural and urban households. The objective of the analysis is to generate information on production cost, biomass requirements and financial viability and social parameters to help users in their decision to promote briquette/pellet production in the country. The **Charcoal** component is used to compare existing charcoal production technologies with improved and more efficient technologies. The aim of the analysis is to assess the required upfront capital cost of the improved technologies, the financial viability from the standpoint of charcoal producers and the social and environmental benefits that improved technologies can trigger when compared to existing charcoal production technologies. The results generated by the analysis inform on potential barriers for the uptake of the improved charcoal technologies by producers and help define how to effectively disseminate their introduction.

The **Heating and Cooking** sub-module is used to assess the viability of producing biogas at the community level. The **Biogas Community** component is used to evaluate the potential to develop biogas production from livestock manures at the household and community levels and compares three different types of technologies. The component generates information on: 1) the amount of biogas that can be produced based on manure availability, 2) the size of biodigester needed to harness the energy, 3) the installation cost of three types of biodigester technologies. The component also provides financial social and economic parameters to help the user understand the potential opportunities and the requirements needed for deploying biogas technology in their countries.

The **Rural Electrification** sub-module is used to assess the viability of supplying electricity from local biomass resources in remote areas without access to the electric grid. The sub-module is comprised of three decentralized-based technology pathways for electrification, these are: gasification, use of straight vegetable oil (SVO) and combustion. The results from this sub-module generate estimates of the cost of electricity generation and distribution, calculates the financial viability of electrification and informs on the associated social and economic outcomes for each alternative technology pathway. The **Gasification** component analyses the partial burning of biomass to generate a gas mixture that is subsequently combusted in gas engines to produce electricity. The **Straight Vegetable Oil (SVO)** component builds on from the Crops component in the Natural Resources module. It assesses the potential to substitute diesel with SVO in generators to produce electricity. The **Combustion** component assesses the burning of biomass to produce steam which drives a turbine to produce electricity.

The **Heat and Power** sub-module is used to assess the viability of the production of electricity and heat from local biomass resources. The sub-module is comprised of two decentralized-based technology pathways for electrification and heat, these are: CHP (cogeneration) and biogas industrial. The results from this sub-module generate estimates of the cost of electricity/heat generation and distribution, calculates the financial viability of electrification/heat and informs on the associated social and economic outcomes for each alternative technology pathway. The **CHP (cogeneration)** component examines the potential for the simultaneous production of electricity and heat from a biomass source, allowing the user to analyse a factory integrated production or a standalone operation for pure grid electricity generation. The **Biogas Industrial** component evaluates the potential to develop a biogas-based industry for electricity, heat, CHP or upgraded biogas. This is done by using waste water, high moisture solids, low moisture solids or a combination of these. All technology pathways are based on simple and readily available technologies that can be easily adaptable to remote rural areas.

The **Transport** sub-module is used to assess the viability of producing liquid biofuels for transport, namely ethanol and biodiesel. The analysis builds on the results generated from the Natural Resources' components in terms of feedstock availability and the crop budget. The tool covers ethanol and biodiesel. In the ethanol sections the users can assess the potential for developing the ethanol industry in the country. Likewise in the biodiesel section, the potential for developing the biodiesel industry is assessed. The analyses generates results on the cost estimates for the production of the selected biofuel based on feedstock origin, i.e. smallholder, combination smallholder/commercial or commercial, and according to four predefined plant capacities, namely 5, 25, 50 and 100 million litres/year⁴. The results also consist of information on economic feasibility and socio-economic parameters. In this component,

⁴ The selection of the predefined plant capacities is based on a review of relevant literature; please see the Transport manual for further details.

the user has the option to include into the assessment a GHG emissions analysis that covers the whole supply chain of the selected biofuels.

Another option for the user is to utilise the **Pretreatment Calculator** prior to using the Energy End Use tools⁵. This allows the user to calculate the additional costs of pre-processing the biomass selected in order to obtain the specific conditions required for the final biomass conversion for energy end use.

2 The Gasification Component

The *Gasification Component* is designed to assist the user in evaluating the potential to develop biomass gasification to supply electricity in rural areas without current access to electricity and where extension of the national grid is not feasible. The boundary of the gasification analysis is shown in Figure 2. The tool is based on extensive literature reviews. The detailed assumptions and calculations used to develop the tool are provided in the Annex.

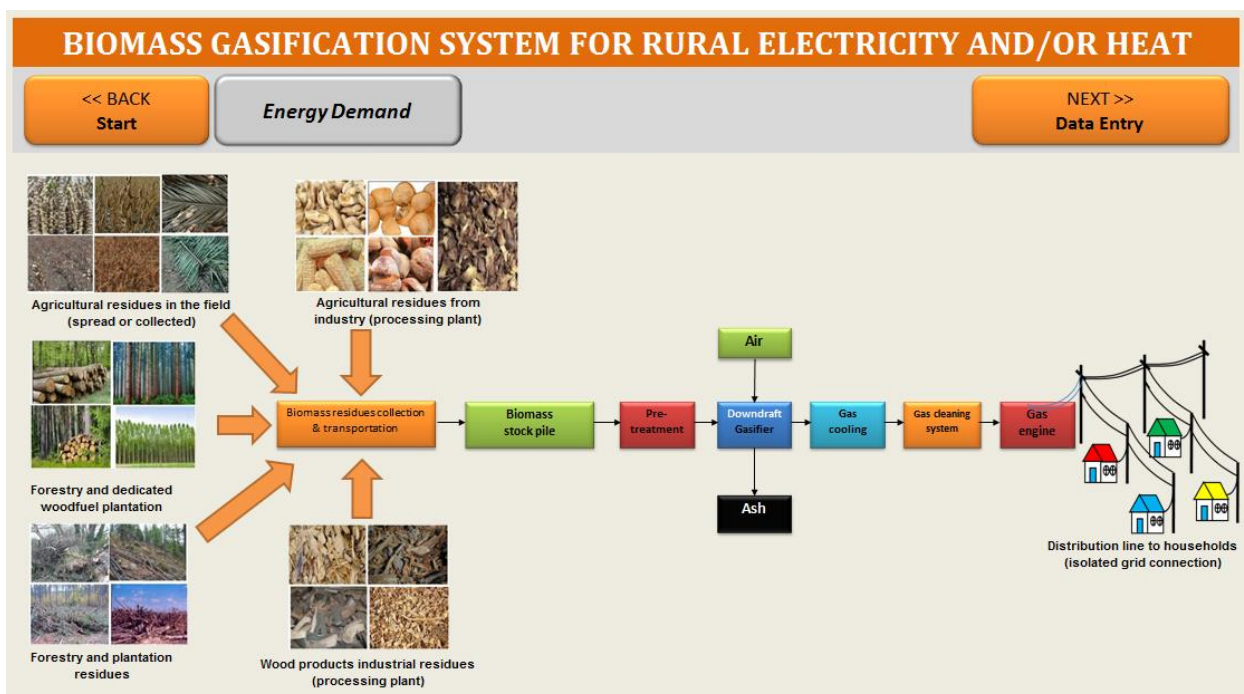


Figure 2: Biomass Gasification System for Rural Electricity and/or Heat Generation

After completing of the analysis, the user will have an indication on: 1) the biomass consumption and area required to set up the various scales of biomass gasification plants; 2) the potential number of biomass gasification plants that can be developed in the country; 3) the investment cost and production cost per kWh for each scale; 4) the number of households that could be electrified; 5) the employment generation potential and financial viability associated to each level of production as shown in Figure 3. The user will also be able to compare across different biomass types (feedstock) and plant capacities to identify the most appropriate biomass sources based on a number of factors including physical availability, economic and social results.

⁵ The Pretreatment Calculator can be used prior to utilising the Energy End Use Tools. The exceptions are the *Biogas Community and Transport Tools*, as these tools already include pretreatment.

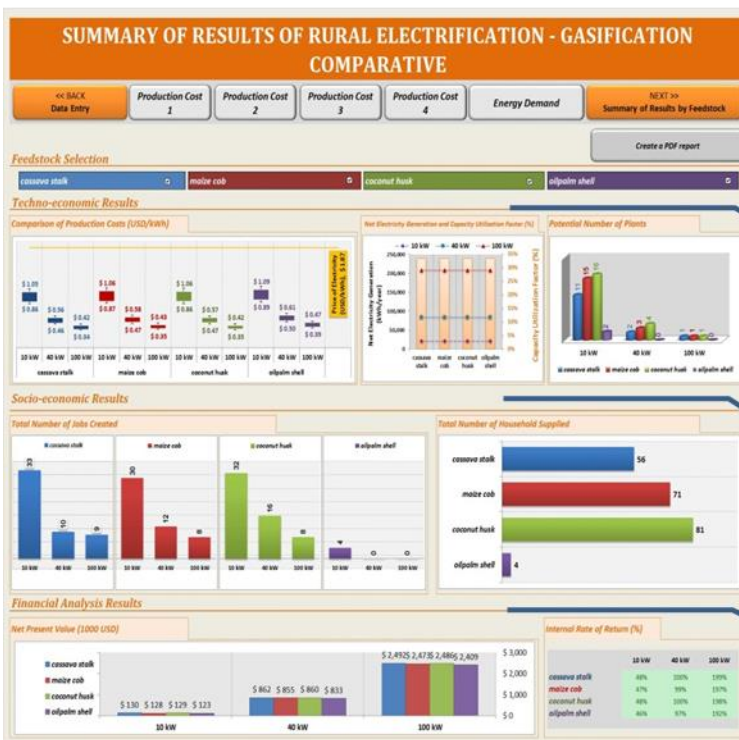


General Outputs by Feedstock

Production Costs and Investment Results: Cost of production of electricity, Share of total production costs and Total investment cost

Operating Results: Biomass consumption, Biomass area required, Potential number of gasification plants, Number of households supplied and Potential job creation

Financial Analysis-Before Taxes: Net Present Value (NPV) and Internal Rate of Return (IRR)



Comparative Outputs by Capacity

Techno-Economic Results: Production cost of electricity, Net electricity generation, Capacity utilization factor and Number of gasification plants

Socio-Economic Results: Total number of jobs created, Total number of households supplied

Financial Analysis-Before Taxes: Net Present Value (NPV) and Internal Rate of Return (IRR)

Figure 3: Layout of the Gasification Results Sheets

3 Terms and Definitions in the *Gasification Component*

This section includes the definitions of specific terms used in the *Gasification Component*. It is important to anticipate these definitions and consider them throughout the analysis, as to be able to interpret the results correctly.

- **Gasification** refers to a process in which combustible materials such as biomass are partially oxidized or partially combusted with a change of the chemical structure at 500–900 °C in the presence of a gasifying agent (for instance air, oxygen, steam, CO₂, or mixtures of these components) (Göransson, Söderlind, He, & Zhang, 2011). The product is a combustible synthesis gas or syngas. The syngas can be used to generate heat and power.
- **The biomass gasification analysis** involves the following steps: collection of the biomass residues, transport and storage at the gasification plant. Before feeding the biomass residues into the gasifier, these undergo pretreatment processes. For example, drying to remove excess moisture or billet size reduction for big sizes of agriculture/wood residues. After the pretreatment processes, the biomass residue is ready to be converted to syngas by feeding it into the gasifier. The syngas goes through the cooling and cleaning system and is then fed into a gas engine for power generation. The output of the gas engine is electricity which is distributed to households in a particular area.
- **Feedstock** is biomass raw material that is used in the gasification process to produce syngas.
- **Downdraft gasifier** is a fixed bed gasifier where gasification reactions take place. The feedstock and air move in the same direction. The syngas leaves the gasifier after passing through the hot zone, enabling the partial cracking of the tars. The syngas composition is typically 40–50% N₂, 15–20% H₂, 10–15% CO, 10–15% CO₂ and 3–5% CH₄, with a net heating value of 4–6 MJ/Nm³.
- **Pretreatment of biomass:** Biomass residues have a great potential in most developing countries, since they are able to replace energy sources such as firewood. However, only a small proportion of biomass residues are being used as fuel because of their high moisture content, high polymorphism and low energy density. These troublesome characteristics increase costs for transport, handling, and storage, making the use of biomass as a fuel impractical (Patel, Gami, & Bhimani, 2011). There are many varieties of biomass (agri-residues) that have different heating values, sizes, moisture content, and chemical composition. Therefore, pretreatment of biomass is required to adequately prepare feedstock that is suitable for each type of gasifier and leads to a high conversion efficiency and high heating value of syngas product. In addition, the proper size and moisture content of feedstock are also required for working conditions of feeding systems to convey feedstock from storage area to gasifier (Cummer & Brown, 2002). Pretreatment processes include drying to remove excess moisture, size reduction for big size of agri-residues, densification process (e.g. pellet and briquette) to increase the size and energy density of fine grain feedstock, and torrefaction process to improve characteristics and storage efficiency of biomass.
- **Gas cooling and cleaning system:** The syngas coming out of gasifier is hot (250-500°C). The major components of syngas produced in gasifier are CO and H₂ and contains contaminants, particulates and volatiles, which need to be cooled and cleaned before feeding into the generators (Jain, 2008). The gas cooling and cleaning system are: (i) cyclone filter separating ash, (ii) syngas water-cooling and scrubbing unit containing ~20 m³ water, (iii) two parallel filter units to remove tar, particulates and moisture. Each of filter unit consists of a coarse filter and

two fine filters. Two parallel filters installation allow constant operations during cleaning of one filter unit (Buchholz, Silva, & Furtado, n.d.).

- **Electricity generation devices by using syngas:** The possible devices that can be used to convert the syngas into electricity and heat application are steam turbine, gas turbine, external fired gas turbine, micro turbine, fuel cell, stirling engine and gas engine (Arena, Di Gregorio, & Santonastasi, 2010a). In the *Gasification Component*, the device that is being considered is the gas engine. Gas engines or Reciprocating IC engines are widespread and well-known technologies. A variety of stationary engine products are available for a range of power generation market applications and duty cycles, including standby and emergency power, peaking service, intermediate and base load power, and CHP. Reciprocating IC engines are available for power generation applications in sizes ranging from a few kilowatts to more than 5 MW. There are two basic types of reciprocating IC engines—spark ignition (SI) and compression ignition (CI). SI engines for power generation use natural gas as the preferred fuel, although they can be configured to run on propane, gasoline, biogas, or LFG. CI engines (often called diesel engines) operate on diesel fuel or heavy oil, or they can be set up to run in a dual-fuel configuration that burns primarily natural gas or biogas with a small amount of diesel pilot fuel (EPA, 2007).

4 Scope and Objective of the *Gasification Component*

The aim of the *Gasification Component* is to assess the feasibility to develop a biomass gasification system to supply electricity in rural areas where extension of the national grid is not economically or physically viable. It provides the user with a technical foundation to perform an analysis of biomass gasification systems for the production of electricity at 10kW, 40kW and 100kW from an assortment of biomass sources. The results of the analysis can be used to identify the viability of electricity production from gasification in terms of feedstock availability, the financial viability of the different production scales, the optimum production capacity and feedstock combination and the socio and economic benefits that can be attained for each production scheme. The information generated by the analysis can also be used as an initial basis to discuss potential strategies to promote the development of electrification through biomass gasification systems in rural areas without current electricity access.

The following section describes the flow of analysis and options within this component. The background methodology for the gasification financial analysis, biomass collection and biomass storage is described in detail in Annex.



Figure 4: Rapid Appraisal Tool for Rural Electrification

5 Running the *Gasification Component*

The flow of analysis within the *Gasification Component* and the inter-linkages it has with other components is depicted in Figure 5. The user has the choice to select the components of analysis in a different order or even omit some components. It is, however, strongly recommended that the user follows the order and flow of analysis as described below, given that the *Gasification Component* relies on the information generated in the *Natural Resources* module and information can be cross-referenced with other modules to contextualize the results of the analysis. The results of this component are essential for the comprehensiveness of the analysis. When interpreting the results, the user should take into account all relevant factors, particularly aspects related to food security, agricultural trade and the sustainable use of natural resources.

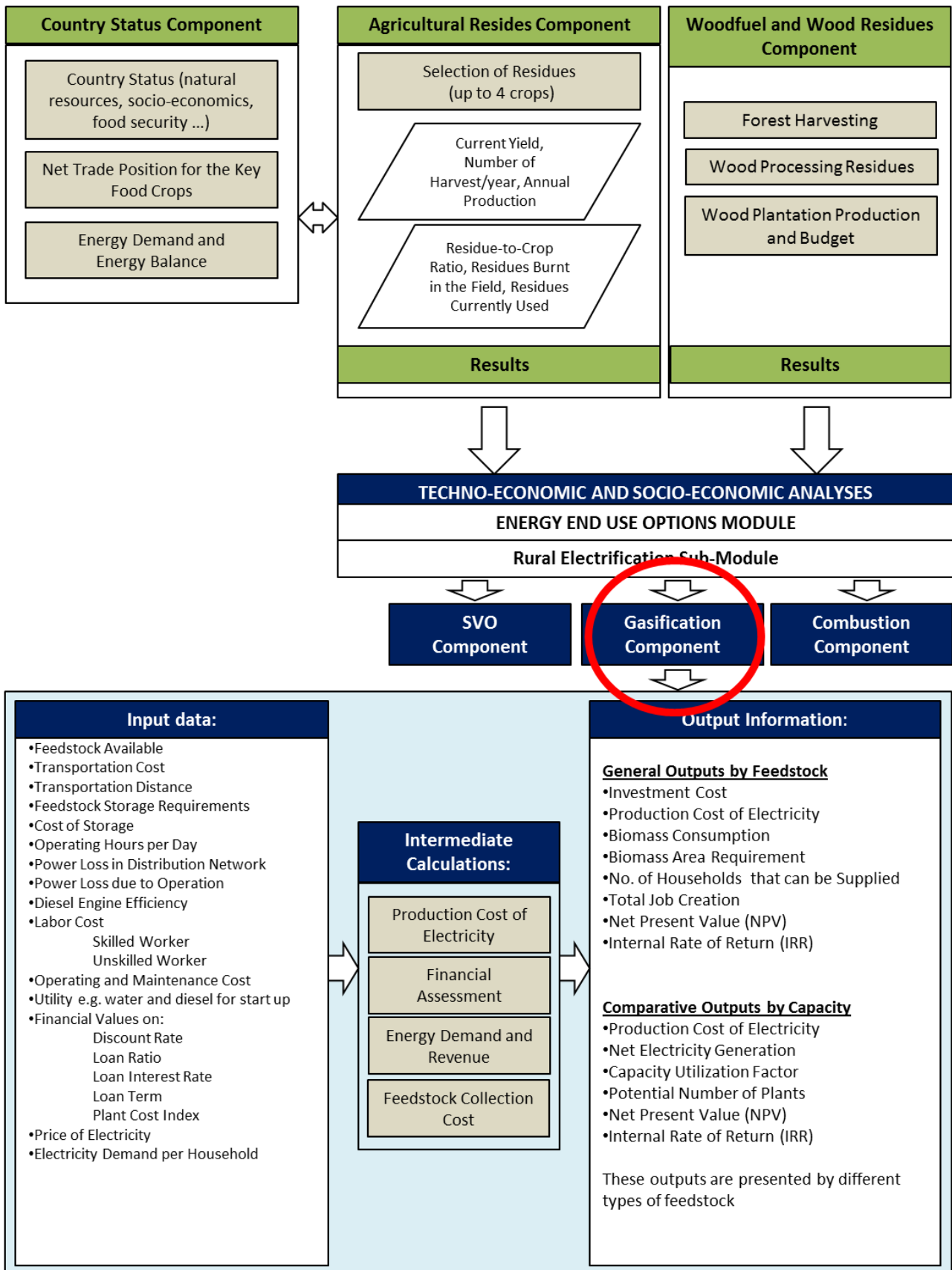


Figure 5: Gasification Component: Flow of Analysis and Inter-linkages with other BEFS RA Modules and Components

The user navigates step by step through the options and is asked to input necessary data to obtain final results. When the required data are limited or unavailable, then the default values provided by the tool can be utilised. The navigation buttons are placed on the top and bottom of each sheet, indicating the next step with the button “NEXT>>” and allowing the user to return to a previous section with the “<<BACK” button.

The following sub-chapters describe each step of the analysis, using an example from the **Agriculture Residues Component** to feed the gasification system to generate power in a rural remote area without current electricity access. All input parameters are based on a generic situation.

At the beginning of the analysis, the user must select the language of preference in order to view the tool in that language (Figure 4, label 1). The language choices are: English (EN), French (FR) and Spanish (ES). Next, the user has three options, with the following navigation buttons: “Gasification Process Description”, “Data Entry Sheet” and “Energy Demand” as shown in Figure 4.

5.1 Step 1: Energy demand

The user needs to enter the electricity consumption per household (kWh/month) as it was defined in the *Country Status* module (Figure 6).

The screenshot displays the 'ENERGY DEMAND FOR ELECTRICITY AND/OR HEAT - GASIFICATION' interface. At the top, there is a title bar. Below it, there are three buttons: '<< BACK Start' on the left, 'Gasification Process Description' in the center, and 'NEXT >> Data Entry' on the right. Underneath these buttons, the section 'Electricity Demand per Household' is highlighted. It contains a text input field with the value '300' and a note that says 'Value calculated in Country Status Module'.

Figure 6: Energy Demand

5.2 Step 2: Defining the feedstock

Before proceeding with the analysis, the user can choose to load the default values for running this component by clicking on the “Load Default Values” button as shown in Figure 7, label A.

Step 2.A Selection of the feedstock

The user will:

1. Select the crop(s) from the dropdown menu and the residue associated with the crop. The list includes 7 key food/cash crops, two types of wood processing residues and briquettes (Figure 7, label 1). Up to four crop residues can be analysed at the same time.

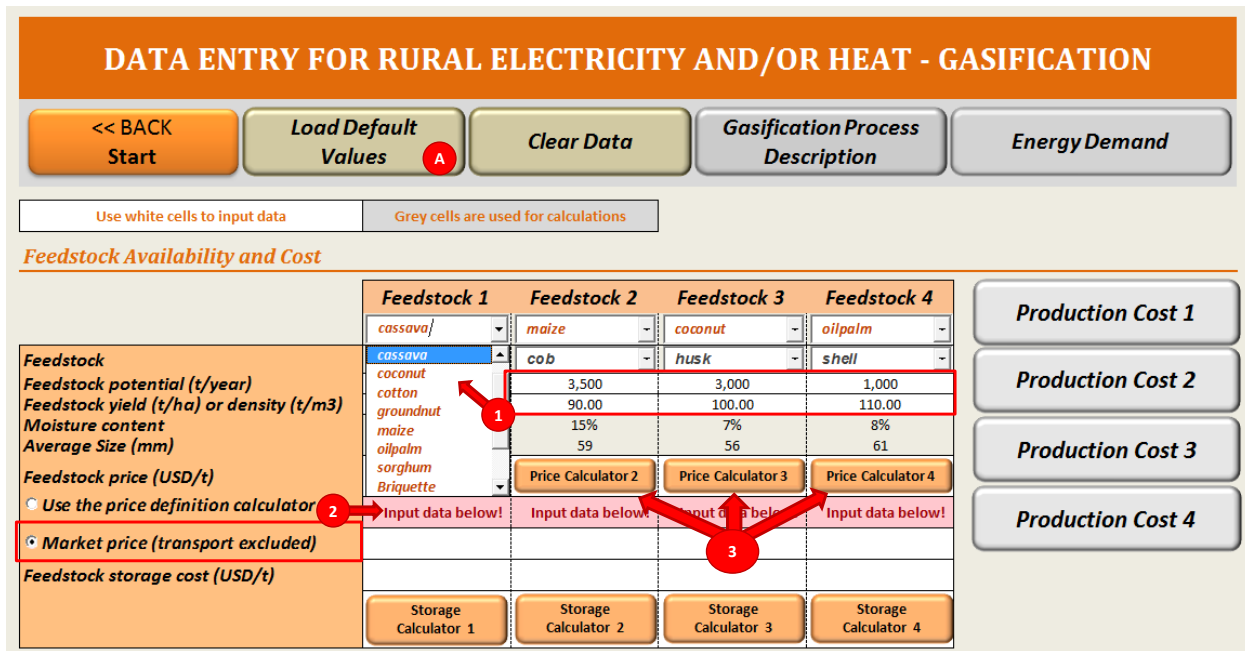


Figure 7: Feedstock Selection

2. Enter data on feedstock available (t/year) and yield (t/ha) of the selected crop residues (Figure 7, red box). *This information is generated in the Natural Resources module.*
3. The moisture content (%) or average percentage of moisture content of the selected crop residues and the size (mm) or average size of feedstock in millimetre are automatically generated from the technical database in the tool.

For this example, the following were selected: Feedstock 1 “Cassava stalk”, Feedstock 2 “Maize cob”, Feedstock 3 “Coconut husk” and Feedstock 4 “Oil palm shell” (Figure 7).

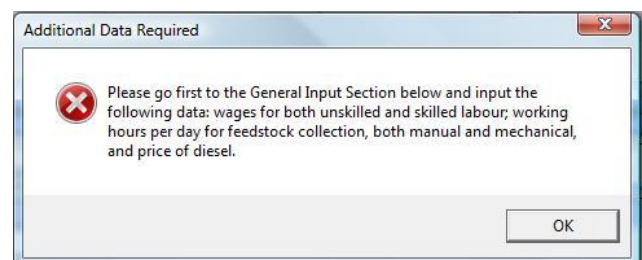
Step 2.B Feedstock price (USD/t)

The user has two options for determining the feedstock price:

- A. If there is a current price in the country for this feedstock, the user clicks on the “Market Price (transport excluded)” (Figure 7, label 2) and directly inputs the price of the selected feedstock (USD/t) in the corresponding cell.
- B. If there is *no* current price for this feedstock, the user can estimate the feedstock price by clicking on the “Use Price Definition Calculator” and selecting the “Price Calculator” (Figure 7, label 3).

The user will get a “warning” before continuing with the use of the calculator, and the user will need to enter:

1. The wage for both unskilled and skilled labour in “Labour” section in unit of USD per person-hour.
2. The working hours and price of diesel in the corresponding lines under “Feedstock collection”.



The “Price Calculator” (Figure 8) assists the user in estimating the potential feedstock price based on the source and collection method of the feedstock.

COLLECTION COSTS CALCULATOR FOR CASSAVA STALK

<< BACK
Data Entry

<< BACK
Production Cost 1

Hide this sheet

Use white cells to input data
Grey cells are used for calculations

Biomass Collection Definition

Sources of biomass

Collecting method

Agricultural residues spread in the field 1

Mechanized 2

Biomass Collection Definition

Biomass price definition

Labour cost		Quantity	Unit	Quantity	Unit	Total	Unit
Number of skilled workers		4	person-hour/ha	Skilled labour wage	\$ 2.00	USD/person-hour	USD/year
						Subtotal	USD/year
						\$ 132	USD/year
Machinery and operating cost		Quantity	Unit	Quantity	Unit	Total	Unit
Average fuel economy		0.8	l/h	Fuel price	\$ 1.00	USD/l	USD/year
						Subtotal	USD/year
						\$ 100	USD/year
						Total	USD/year
						\$ 232	USD/year

Collection price of cassava stalk
\$ 0.09 USD/t

Figure 8: Feedstock Price Calculation based on the Collection Method and Source

To run the calculator, the user will need to:

1. Identify the *biomass source* from one of the following options (Figure 8, label 1):
 - Agriculture residues spread in the field
 - Agriculture residues collected from the field
 - Agriculture residues from food processing plant
 - Forestry
 - Forestry and plantation residues
 - Residues from wood industry
 - Dedicated wood energy plantation

As a reference, Table 1 summarizes the biomass sources that can be used for gasification.

2. Select the *biomass collection method* (Figure 8, label 2) from the following options:
 - manual
 - semi-mechanized
 - mechanized

Guidance: The collection method can be identified based on similar practices currently applied in the country.

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3. Enter the labour requirements (person-hour per hectare) and the fuel needs (litres per hour) associated with the selected biomass collection method (Figure 8, label 3). To return to the previous section, the user must click on the “<<BACK Data Entry” button.

Note: The type of labour and diesel required will depend on the collection method: manual, semi-mechanized and mechanized.

The calculator will automatically generate a feedstock price (Figure 8, red box), and this value is transferred to the “Data Entry Needs” worksheet for further calculation.

4. The user will need to carry out similar steps for each feedstock chosen.

Table 1: Specific Feedstock that can be used in the Gasification System

Source	Specific feedstock that can be used
Agricultural field residues	cassava stalk, coconut frond, cotton stalk, and sorghum straw/stalk
Agriculture residues from industrial processing	coconut husk & shell, groundnut shell, maize cob, oil palm shell, and briquettes
Forestry	N/A
Forestry and plantation residues	limbs, stump, roots, etc.
Residues of wood industry	wood chips and barks, etc.
Dedicated energy plantations	<i>Acacia spp.</i> , <i>Cunninghamia lanceolata</i> , <i>Eucalyptus spp.</i> , <i>Pinus spp.</i> , <i>Populus spp.</i> (poplars) and <i>Salix spp.</i> (willows)

For this example, the selected Feedstock 1 “Cassava Stalk” is assumed to be sourced from “agricultural residues spread in the field” and the collection method is “mechanized”. The number of person-hours for skilled workers (machine operators) is 4, and the diesel consumption of the machine is 0.8 litres per hour. Using the information that manual labour works 8 hours per day and machinery works 16 hours and diesel price of 1 USD per litre, a proxy price of the feedstock is calculated at 0.09 USD/t (Figure 8, red box).

Step 2.C Feedstock storage cost (USD/t)

Step 2.C.1 The user can enter *the existing prices* of storage of agricultural products in the country as a proxy. The price should be entered in the respective cell for each feedstock (USD/tonne). If this information is not available, then the user should go to the next step.

Step 2.C.2 The user can determine *a proxy* for this value. The user will need to do the following:

1. Identify a type of feedstock storage likely associated with conditions in their country from the options presented in Table 1.
2. For the selected storage option, look up the global building cost provided in Table 2.
3. Enter the proxy value (USD/tonne) in the respective cell for each feedstock.

Table 2: Estimated Cost of Storage

Estimated Cost of Storage	Unit	Min	Average	Max
Enclosed structure with crushed rock floor	USD/tonne	10	12.5	15
Open structure with crushed rock floor	USD/tonne	6	7	8
Reusable tarp on crushed rock	USD/tonne	n/a	3	n/a
Outside unprotected on crushed rock	USD/tonne	n/a	1	n/a
Outside unprotected on ground	USD/tonne	n/a	0	n/a

Source: (EPA, 2007)

For this example, all feedstock are stored on crushed rock and covered by a reusable tarp. Therefore, the cost of storage is 3 USD/tonne. (User inputs the cost in the corresponding cells as shown in Figure 9, label 1).

DATA ENTRY FOR RURAL ELECTRICITY AND/OR HEAT - GASIFICATION

<< BACK Start
Load Default Values
Clear Data
Gasification Process Description
Energy Demand

Use white cells to input data Grey cells are used for calculations

Feedstock Availability and Cost

	Feedstock 1	Feedstock 2	Feedstock 3	Feedstock 4
Feedstock	cassava	maize	coconut	oilpalm
	stalk	cob	husk	shell
Feedstock potential (t/year)	2,500	3,500	3,000	1,000
Feedstock yield (t/ha) or density (t/m3)	80.00	90.00	100.00	110.00
Moisture content	12%	15%	7%	8%
Average Size (mm)	77	59	56	61
Feedstock price (USD/t)	Price Calculator 1	Price Calculator 2	Price Calculator 3	Price Calculator 4
<input checked="" type="radio"/> Use the price definition calculator	\$ 0.09	\$ -	\$ -	\$ -
<input type="radio"/> Market price (transport excluded) 1				
Feedstock storage cost (USD/t)	\$ 3.0	\$ 3.0	\$ 3.0	\$ 3.0
	Storage Calculator 1 2	Storage Calculator 2	Storage Calculator 3	Storage Calculator 4

Figure 9: Feedstock Storage Cost

Step 2.C.3 In order to calculate the storage capacity needs, the user needs to click on the “Storage Calculator” (Figure 9, label 2). This will take the user to the Biomass Storage Calculator (Figure 10). In this worksheet, the user will need to:

1. Selects the harvesting month(s) of the crop (Figure 10, label 2).
2. Enter the biomass safety stock rate (%). This is the percentage of biomass needed to secure continuous supply of feedstock to deal with uncertainty in production due to seasonal availability, flood, drought, and other factors. This stock rate % is used to estimate the storage capacity (Figure 10, label 1).
3. Click on “Calculate” (Figure 10, label 3) to automatically compute the amount of maximum storage capacity required (tonnes) and the minimum safety storage (tonnes per month) for each of the pre-defined capacities (Figure 10, label 4).
4. Clicks “OK” to return to the Data Entry Needs sheet (Figure 10, label 5).
5. Repeat the same steps for all feedstock.

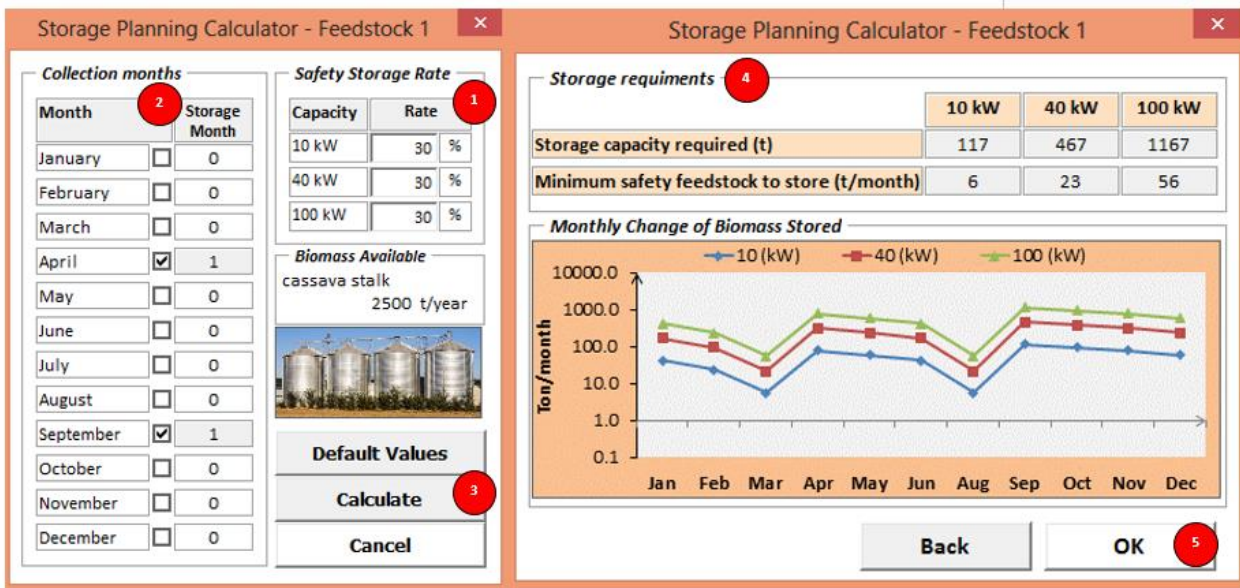


Figure 10: Storage Calculator of Feedstock

For this example, Feedstock 1 is harvested in 2 months: April and September. As a result, the storage capacity required is 117 tonnes for 10kW production capacity. The minimum safety feedstock to store is 6 tonnes per month. For other pre-defined capacities please see Figure 10.

5.3 Step 3: Defining the price of electricity

The electricity price is used to analyse the total revenue of power generation by the gasification plant. The user selects a method to define the price of electricity from the following options:

A. Method 1: Use a calculator to define the price of electricity based on a diesel generator system.

To run this option the user must:

1. Select “Method 1” to define the price of electricity (Figure 11, label 1).
2. Click on “Electricity Price Calculator” (Figure 11, label 2).
3. Enter the following data in the “Electricity price calculator” (Figure 11, red box). However, if specific data are unavailable, then default values are provided in the tool (Figure 11, label 3).
 - Current electricity generation technology:
 - Diesel generator capacity (kW)
 - Operating hours per day
 - Operating day per year
 - Typical efficiency (%)
 - Cost parameters:
 - Diesel cost (USD/litre),
 - Transportation cost of diesel (USD/t/km)
 - Transportation distance (km),
 - Operating and maintenance cost (USD/kWh)
 - Equipment cost (USD)
4. Once all data is entered, click on “Calculate” (Figure 11, label 4)

- The comparative production cost of electricity will be generated (Figure 11, label 5). This is linked to the “Data Entry Needs” worksheet and will be used for further calculation.

Electricity Price Definition

Select a method to define the price of electricity

Method 1 Units: \$ 1.87 USD/kWh

Method 1: Use a calculator to define the price of electricity generator using a diesel generator based system.

Electricity price calculator

Current electricity generation technology

- Typical diesel generator capacity: 100 kW
- Operating hours per day: 8 h/day
- Operating days per year: 330 day/year
- Typical efficiency: 30 %

Costing parameters

- Diesel cost: 1 USD/L
- Transportation cost of diesel: .55 USD/t/km
- Transportation distance: 100 km
- Operating and Maintenance Cost: 1.5 USD/kWh
- Equipment Cost: 21000 USD

Buttons: Default Values, Calculate, Cancel

Comparative Production Cost of Electricity

Concept	Units
Diesel Cost	\$ 7,959 USD/year
Transportation Cost	\$ 367.71 USD/year
Labor and Maintenance Costs	\$ 118,800 USD/year
Investment Costs	\$ 21,000 USD/year
Total production cost of electricity	\$ 148,127 USD/year

Comparative Production Cost of Electricity: \$ 1.87 USD/kWh

Buttons: Back, OK

Figure 11: Electricity Price Definition - Method 1

B. Method 2: Use an electricity price identified by the user. The user identifies a price of electricity in unit of USD/kWh. This price can be the current price from the national grid or the price of electricity that is generated decentralized energy options e.g. solar energy, mini-small hydro power, etc. To run this analysis, the user has to:

- Select “Method 2” to define the price of electricity (Figure 12, label 1).
- Enter the price of electricity paid by the customer (Figure 12, label 2).

Note: This price might include subsidies. It is advised to take this into consideration and carefully assess the likelihood that this price reflects the price paid by rural consumers.

Electricity Price Definition

Select a method to define the price of electricity

Method 2 Units: \$ 0.13 USD/kWh

Method 2: Use a electricity price defined by the user. This price might include subsidies, and it is advised to consider this during the assessment stage.

Figure 12: Electricity Price Definition - Method 2

For this example, the user can use the minimum price of electricity paid by customers, which is 1.87 USD/kWh (result of Method 1 as shown in Figure 11) or 0.13 USD/kWh (Method 2 for defining the price paid by customer as shown in Figure 12) for further analysis.

5.4 Step 4: Production cost and financial parameters

General inputs required to run the operations are shown in Figure 13. The user will need to provide data on:

Production Cost and Financial Parameters			
Labour		Unit	Unit
Unskilled worker	<input type="text" value="\$ 1.25"/>	USD/person-h	Skilled worker
			<input type="text" value="\$ 2.00"/>
			USD/person-h
Utilities		Unit	Unit
Water	<input type="text" value="\$ 0.47"/>	USD/m ³	Diesel
			<input type="text" value="\$ 1.00"/>
			USD/litre
			==>Required to start up the engine
Feedstock collection		Unit	Unit
Working hours per day (manual)	<input type="text" value="8"/>	h/day	Working hours per day (mechanized)
			<input type="text" value="16"/>
			h/day
Transportation cost		Unit	
Feedstock (collection point to plant)	<input type="text" value="\$ 0.09"/>	USD/t/km	
Other costs		Unit	Unit
General and administrative (%)	<input type="text" value="10%"/>		Maintenance cost (%)
			<input type="text" value="25%"/>
Plant overhead (%)	<input type="text" value="20%"/>		Miscellaneous cost (%)
			<input type="text" value="20%"/>
Financial parameters		Unit	Investment cost update
Discount rate	<input type="text" value="10%"/>		Plant Cost Index during 4/2014
Loan ratio	<input type="text" value="50%"/>		<input type="text" value="157.30"/>
Loan interest rate	<input type="text" value="12%"/>		http://base.intratec.us/home/ic-index
Loan term	<input type="text" value="5"/>	year	

NEXT >>
Summary of Results Comparative
NEXT >>
Summary of Results by Feedstock

Figure 13: General Inputs

1. **Labour cost (USD/person-hour):** the labour rate for unskilled and skilled workers (USD per person per hour). These parameters are required to calculate the feedstock price (as explained in Step 2.B) and the labour cost of the gasification process.
2. **Utilities cost:** the price of water (USD/m³) and diesel (USD/litre) required to start-up the engine.
3. **Feedstock collection:** these parameters are required to calculate the feedstock price as explained in Step 2.B. The user enters the hours of labour required for manual labour and the hours of labour required for running the machinery.
4. **Transportation cost of feedstock (USD/t/km):** cost of transportation of feedstock from the collection point to the gasification plant. The user will need to:
 - Identify the current methods of transportation to move agriculture commodities within the country.
 - Define the current transportation prices associated to the transportation method identified above in unit of USD per tonne per km.

Guidance: This can be based on unprocessed agricultural goods.

Guidance: If the method of transportation is by person or bike, then it is recommended that the user estimates the cost by using the cost of labour per hour, working time, the amount of material that can be transported and the approximate kilometres that can be travelled under the selected method as given in the following equation:

$$\begin{aligned} \text{Transportation cost (USD/tonne/km)} \\ = \frac{\text{Hourly wages (USD/hour/person)} \times \text{Working time (hours)}}{\text{Transportation distance (km)} \times \text{Feedstock transport (tonne/person)}} \end{aligned}$$

Alternatively, the user can include this cost in the collection cost of feedstock by adding this to the number of workers in **Step 2.B** (estimate price of feedstock) and then inputting zero costs for the transportation of feedstock from the collection point to plant.

5. Other costs (%): The user enters the percentage of:

- General and administrative cost,
- Plant overhead,
- Maintenance cost and
- Miscellaneous cost.

These parameters are used to estimate the production cost of electricity.

6. Financial parameters: The user identifies the values for the following financial parameters:

- Discount rate (%),
- Loan ratio (%),
- Loan interest rate (%),
- Loan term (years) and
- Plant Cost Index.

The plant cost index data for equipment cost is obtained from technical literature and based on past technical and economic conditions. Therefore, the Intratec Chemical Plant Construction Index (IC), a dimensionless index used as a proxy to update the capital cost of a chemical plant, which accounts for price changes due to inflation/deflation and economic conditions, is applied to the BEFS RA tool. This index is freely updated and available on (<http://base.intratec.us/home/ic-index>).

For this example, the values shown in Figure 13 were used to carry out the analysis.

5.5 Step 5: Calculation of the production cost of electricity

After entering the data in Steps 1 to 4, the user can click on any of the “Production Cost” buttons (Figure 14, label 1).

Note: This section also shows the budgets for calculating the processing cost. These calculations are done automatically using the information entered by the user in the previous steps and can be reviewed if needed (see section 7.1 for more details).

DATA ENTRY FOR RURAL ELECTRICITY AND/OR HEAT - GASIFICATION

<< BACK Start
Load Default Values
Clear Data
Gasification Process Description
Energy Demand

Use white cells to input data Grey cells are used for calculations

Feedstock Availability and Cost

	Feedstock 1	Feedstock 2	Feedstock 3	Feedstock 4
<i>Feedstock</i>	<i>cassava</i>	<i>maize</i>	<i>coconut</i>	<i>oilpalm</i>
<i>Feedstock potential (t/year)</i>	2,500	3,500	3,000	1,000
<i>Feedstock yield (t/ha) or density (t/m3)</i>	80.00	90.00	100.00	110.00
<i>Moisture content</i>	12%	15%	7%	8%
<i>Average Size (mm)</i>	77	59	56	61
<i>Feedstock price (USD/t)</i>	Price Calculator 1	Price Calculator 2	Price Calculator 3	Price Calculator 4
<input checked="" type="radio"/> Use the price definition calculator	\$ 0.09	\$ -	\$ -	\$ -
<input type="radio"/> Market price (transport excluded)				
<i>Feedstock storage cost (USD/t)</i>	\$ 3.0	\$ 3.0	\$ 3.0	\$ 3.0
	Storage Calculator 1	Storage Calculator 2	Storage Calculator 3	Storage Calculator 4

Production Cost 1

Production Cost 2

Production Cost 3

Production Cost 4

Figure 14: Production Cost Calculation

This will take the user to the budget processing section for the selected feedstock (Figure 15).

PROCESSING COSTS FOR POWER GENERATION FROM CASSAVA STALK

<< BACK Data Entry
Gasification Process Description
Energy Demand
NEXT >> Summary of Results Comparative
NEXT >> Summary of Results by Feedstock

Use white cells to input data Grey cells are used for calculations

Summary of Feedstock and Storage

Feedstock available (t/year)	2500
Feedstock yield (t/ha)	80
Moisture (%)	12%
Size (mm)	77
Feedstock storage cost (USD/t)	3

Price Calculator 1
Storage Calculator 1

Summary of Operational Parameters

Gasifier type	Downdraft
Gas engine type	100% Syngas
Capacity utilization factor	33%
Power conversion (kWh/kg feedstock)	0.91
CO (%Vol)	20%
CO ₂ (%Vol)	15%
H ₂ (%Vol)	18%
CH ₄ (%Vol)	7%
Power loss due to operation (%)	15%
Operating hours per day	8
Power loss in distribution network (%)	6%
Gas engine efficiency (%)	17%

Financial Parameters

Annual price change (%)	0%
Loan interest rate (%)	12%
Loan ratio (%)	50%
Loan term (years)	5
Discount rate (%)	10%
Plant Cost Index during 3/2015	157
Price of electricity (USD/kWh) - Calculated	\$ 1.87
Project lifetime	20

Transport Distance of Feedstock		Transport Quantity		Transport Distance of Feedstock		Transport Quantity	
Distance small scale production (km)	1	Small scale (t/year)	222	Distance large scale production (km)	10	Large scale (t/year)	2,222
Distance medium scale production (km)	5	Medium scale (t/year)	889	Transportation cost (USD/t/km)			\$ 0.09

Figure 15: Processing Costs for Power Generation

In this worksheet, the user will need to enter additional data in the white cells, specifically on:

- Power losses due to operation (%):** losses due to inappropriate operation of the gasification-engine system. These losses are assumed to be 15%. However, a parameter can be entered directly by the user (Figure 15, label 1).

Note: These could be due to a lack of control and monitoring of units measuring gas pressure, gas composition, air leakage, or temperatures, etc. These lead to lower power outputs than the installation capacity.

- 2. Operating hours per day:** The user enters the operating hours per day to run the gasification system⁶. The daily operating hours are used to compute the total annual operating hours and the capacity factor, assuming the gasification system runs 365 days per year (Figure 15, label 1).

Guidance: The operating hours should be related to electricity demand in a given rural location. For example, operate six hours per day in the evening to meet the lighting demand in rural area A.

- 3. Power losses in distribution network (%):** The user identifies the power loss (%) in the distribution network. If this information is not readily available the following database can be used: <http://data.worldbank.org/indicator/EG.ELC.LOSS.ZS> (The World Bank, n.d.) (Figure 15, label 1).

Guidance: The power loss in distribution from the current electric grid could be used as proxy.

- 4. Gas engine efficiency (%):** The typical gas engine efficiency by using syngas as fuel is 13-28% (Arena, Di Gregorio, & Santonastasi, 2010). The assumed value is 17% (Figure 15, label 1).

- 5. The transportation distance of feedstock to gasification plant:**

The user identifies an estimated distance, in kilometres, that will be required to transport the feedstock. The transportation distance depends on the availability of biomass in a particular area and the amount of biomass required for each production capacity (Figure 15, labels 2 and 3).

Guidance: The small-scale plants use less biomass compared to the medium and large-scale ones. Therefore, the distance of transportation could be shorter. If the availability of biomass in that area is high and sufficient enough to supply for all production scales of the plants, then the users can input the same transportation distance of feedstock for all production scales.

Once all data is entered, the user must click on “<<BACK Data Entry” to return to the Data Entry Needs sheet. The user can repeat the same steps for all feedstock.

⁶ Nouni, Mullick, & Kandpal, 2007

For this example, the “Production Cost 1” is “Cassava stalk”. The values that were used to carry out the analysis are:

Power losses due to operation (%):	15%
Operating hours per day:	8
Power losses in distribution network (%):	6%
Gas engine efficiency (%):	17%
The transportation distance of feedstock to gasification plant:	
Distance for small scale plant:	1 km
Distance for medium scale plant:	5 km
Distance for large scale plant:	10 km
The transportation quantities are automatically generated:	
Small scale plant:	222 t per year
Medium scale plant:	889 t per year
Large scale plant:	2,222 t per year

These parameters are used for further analysis.

6 Assumptions and Limitations of the *Gasification Component*

Before starting the analysis, the user should become familiar with the assumptions and limitations of the tool and take them into consideration during the analysis and most especially when interpreting the results.

The limitations of the *Gasification Component* are:

1. Three gasification capacities are considered: 10kW, 40kW and 100kW.
2. The gasifier type is the Downdraft gasifier using air as a gasifier agent.
3. There is no chemical catalyst used in the biomass gasification system.
4. The gas engine is run by using 100% syngas.
5. A suitable size of feedstock is 20-80 mm with a moisture content of less than 15%.
6. The business lifetime is considered to be 20 years for the financial analysis.

The details of key assumptions and calculation equations are presented in the Annex.

7 The Results of the *Gasification Component*

7.1 Overview of the production cost calculation (optional)

After the user inputs all required data (Steps 1 to 5), then the user has the option to review the detailed production cost as shown in Figure 16. There are five main sections in this worksheet as explained below.

- **PART 1** (Figure 16, label 1) shows the distribution of production cost along the following categories: inputs, labour, transportation of feedstock, storage, investment, plant overhead, general and administrative cost, loan interest, and income tax. The total production costs (USD/year) of three power generation capacities (such as 10kW, 40kW and 100kW) are presented for comparative analysis.
- **PART 2** (Figure 16, label 2) shows the total power generation, which is the electricity in unit of kWh per year (note that the self-consumption, used to run the operation and

power loss in transmission and distribution network, has been subtracted). These values are used to calculate the revenue of biomass gasification for the power generation system. The results are presented for all three power generation capacities.

- **PART 3** (Figure 16, label 3) shows the unit cost of electricity (USD/kWh) for all three power generation capacities.
- **PART 4** (Figure 16, label 4) summarizes the loan details, e.g. loan amount, loan interest, annual loan payment, etc., for financial analysis.
- **PART 5** (Figure 16, label 5) the “Financial Analysis” buttons will open the worksheet with the details on the financial analysis for each power generation system.

				Capacities (kW of power generation)							
				10		40		100			
				Operating hours per year	2,920	Operating hours per year	2,920	Operating hours per year	2,920		
				Financial Analysis 10 kW		Financial Analysis 40 kW		Financial Analysis 100 kW			
Inputs				Unit	Unit Price (USD/Unit)	Quantity (Unit/year)	Total (USD/year)	Quantity (Unit/year)	Total (USD/year)	Quantity (Unit/year)	Total (USD/year)
Feedstock				t	\$ 0.1	222	\$ 21	889	\$ 82	2,222	\$ 206
Water				m ³	\$ 0.5	3	\$ 1	11	\$ 5	27	\$ 13
Diesel for start up				litre	\$ 1.0	55	\$ 55	219	\$ 219	548	\$ 548
Subtotal							\$ 77		\$ 306		\$ 766
Labour and miscellaneous cost				Unit	Unit Price (USD/person-hour)	Quantity (Unit)	Total (USD/year)	Quantity (Unit)	Total (USD/year)	Quantity (Unit)	Total (USD/year)
Unskilled worker				# employee	\$ 1.3	1	\$ 3,650	3	\$ 10,950	6	\$ 21,900
Skilled worker				# employee	\$ 2.0	1	\$ 5,840	1	\$ 5,840	2	\$ 11,680
Miscellaneous cost						20%	\$ 1,898	20%	\$ 3,358	20%	\$ 6,716
Subtotal							\$ 11,388		\$ 20,148		\$ 40,296
Transport of feedstock				Unit	Unit Price (USD/t/km)	Quantity (Unit)	Total (USD/year)	Quantity (Unit)	Total (USD/year)	Quantity (Unit)	Total (USD/year)
Feedstock (farm to plant)				km	\$ 0.1	1	\$ 20	5	\$ 400	10	\$ 1,999
Subtotal							\$ 20		\$ 400		\$ 1,999
Storage				Unit	Unit Price (USD/t)	Quantity (Unit)	Total (USD/year)	Quantity (Unit)	Total (USD/year)	Quantity (Unit)	Total (USD/year)
Feedstock				t	\$ 3.00	117	\$ 351	467	\$ 1,401	1,167	\$ 3,501
Subtotal							\$ 351		\$ 1,401		\$ 3,501
Investment				Unit	Years	Total (USD)	Depreciation (USD/year)	Total (USD)	Depreciation (USD/year)	Total (USD)	Depreciation (USD/year)
Equipments				USD	20	\$ 58,937	\$ 2,947	\$ 183,260	\$ 9,163	\$ 208,186	\$ 10,409
Building				USD	20	\$ 3,044	\$ 152	\$ 9,349	\$ 467	\$ 23,640	\$ 1,182
Installation				USD	20	\$ 1,739	\$ 87	\$ 2,174	\$ 109	\$ 50,432	\$ 2,522
Distribution network				USD	20	\$ 787	\$ 39	\$ 3,148	\$ 157	\$ 7,869	\$ 393
Total investments						\$ 64,507	\$ 3,225	\$ 197,931	\$ 9,897	\$ 290,126	\$ 14,506
						Total Depreciation	\$ 3,225	Total Depreciation	\$ 9,897	Total Depreciation	\$ 14,506
Maintenance cost					25%		\$ 806		\$ 2,474		\$ 3,627
Subtotal							\$ 4,031.67		\$ 12,370.68		\$ 18,132.89
Other costs				Unit	Rate (%)	Total (USD/year)		Total (USD/year)		Total (USD/year)	
Plant overhead				USD	20%	\$ 2,059		\$ 3,853		\$ 7,441	
General and administrative cost				USD	10%	\$ 1,433		\$ 2,678		\$ 5,213	
Loan interest				USD	12%	\$ 540		\$ 1,656		\$ 2,427	
Income tax				USD	0%	\$ -		\$ -		\$ -	
Subtotal						\$ 4,032		\$ 8,187		\$ 15,082	
						Total (USD/year)	Share (%)	Total (USD/year)	Share (%)	Total (USD/year)	Share (%)
Total operating costs						\$ 11,836	59%	\$ 22,255	52%	\$ 46,562	58%
Total fixed costs						\$ 4,032	20%	\$ 12,371	29%	\$ 18,133	23%
Total other costs						\$ 4,032	20%	\$ 8,187	19%	\$ 15,082	19%
Total production costs						\$ 19,899		\$ 42,813		\$ 79,777	

Power Generation				Quantity (Unit)	Quantity (Unit)	Quantity (Unit)
Power generation				24,820	99,280	248,200
Electricity - self use				-2,482	-9,928	-24,820
Power loss in distribution network				-1,489	-5,957	-14,892
Subtotal				20,849	83,395	208,488

Total Production Cost+Distribution				Capacities (kW of power generation)							
Unit cost of electricity (USD/kWh)				10		40		100			
				Total investment (USD)	Loan amount (USD)	Total investment (USD)	Loan amount (USD)	Total investment (USD)	Loan amount (USD)		
				\$ 0.95		\$ 0.51		\$ 0.38			
Average loan interest				Unit	Loan ratio (%)	Total investment (USD)	Loan amount (USD)	Total investment (USD)	Loan amount (USD)		
Loan amount				USD	50%	\$ 64,507	\$ 32,253	\$ 197,931	\$ 98,965	\$ 290,126	\$ 145,063
Loan interest rate				%		12%		12%		12%	
Loan payment				USD/month		\$ -717	\$ -2,201	\$ -3,227	\$ -3,227		
Annual loan payment				USD/year		\$ -8,610	\$ -26,417	\$ -38,722	\$ -38,722		
Loan terms				years		5		5		5	
Total loan payment				USD		\$ -43,048	\$ -132,086	\$ -193,611	\$ -193,611		
Loan interest				USD		\$ -10,794	\$ -33,120	\$ -48,548	\$ -48,548		
Average loan interest				USD/year		\$ -540	\$ -1,656	\$ -2,427	\$ -2,427		

Figure 16: Detail of Production Costs of Electricity by Power Generation Capacity

For this example, the total production cost of electricity when using cassava stalk to run a 10kW capacity is 19,899 USD/year and the unit cost of electricity is estimated at 0.95 USD/kWh. Moreover, the total power generation is 20,849 kWh/year (Figure 16).

7.2 The summary results by feedstock

The information presented in this section aims to help the user in the decision making process to support the development of biomass gasification for power generation in his/her country. The results aim to answer the following questions:

- What are the investment and production costs per kWh for the various production capacities and feedstock selections?
- How much biomass and area are required to secure the supply of biomass for the development of combustion systems?
- How many potential gasification plants can be developed based on the availability of biomass?
- How many households can gain access to electricity through biomass gasification?
- How many jobs can be created through biomass gasification?
- Which type of feedstock is more suitable and could be promoted for the gasification system?
- What is the financial viability of the gasification system?

Results for the *Gasification Component* are divided along three main categories: Production Cost and Investments; Plant Operating; and Financial Analysis.

1. The user first selects the feedstock from the dropdown menu that he/she wants to review (Figure 17, label 1). The results for that specific feedstock will be generated.
2. The production cost and investments results are presented as follows:
 - Cost of production and distribution of electricity (USD per kWh) (Figure 17, label 2). The user can compare the production cost to the price of electricity (according to the method selected in Step 3).
 - Share of production cost (%) (Figure 17, label 3).
 - Total investment cost (USD) of the gasification system according to power generation capacity (Figure 17, label 4).

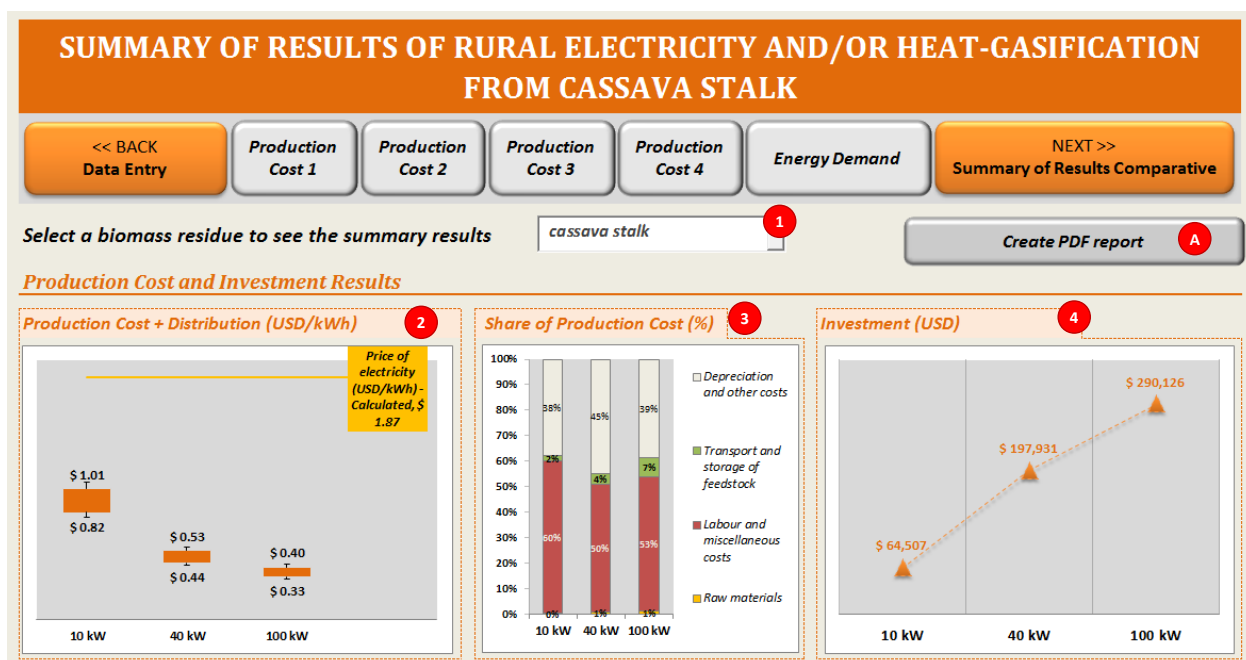


Figure 17: Production Cost and Investment Results

For the example of Cassava stalk, the production cost included distribution costs of 10kW ranging between 0.82-1.01 USD per kWh. These unit costs are lower than the electricity price 1.87 USD/kWh (Method 1 in Step 2 was selected). Therefore, this plant is feasible and attractive investment. The total investment cost of 10kW is 64,507 USD. For other pre-defined capacities refer to Figure 17.

3. The technical and operating results are presented as follows:

- Feedstock required to operate each of the production capacities (t per year) (Figure 18, label 1).
- Feedstock area required to produce enough biomass to run the gasifier (hectare) (Figure 18, label 2).
- Number of gasification plants that can be developed based on the availability of feedstock (Figure 18, label 3).
- Number of households which can be supplied by the different gasification systems (Figure 18, label 4).
- Total number of jobs that can be created through the implementation of each of the pre-defined gasification systems (Figure 18, label 5).

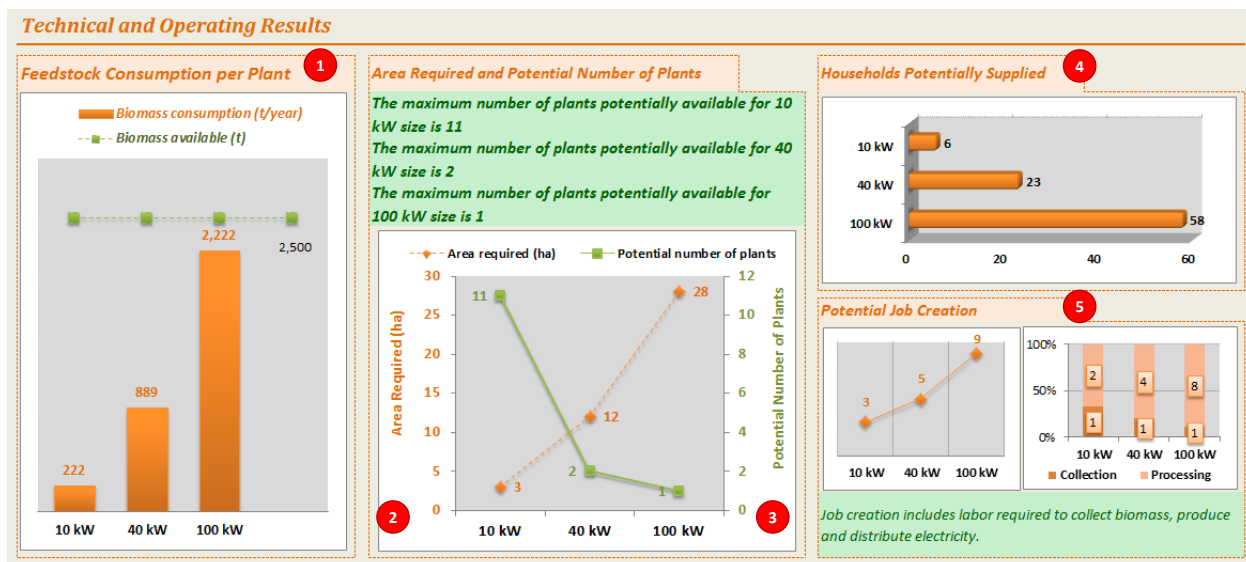


Figure 18: Operating Results

In the example of cassava stalk, the feedstock available is 2,500 t per year, which is sufficient to supply the feedstock needed for the three production capacities. Considering the feedstock availability, 11 potential plants of 10kW capacity, which require 3 hectares of area of feedstock, can be developed. Up to 25 households could be supplied electricity from the 10kW plant. In addition, the potential job creation from the gasification plant with a 10kW capacity is a total of 3 jobs for the collection of feedstock and plant processing. For other pre-defined capacities refer to Figure 18.

4. The financial analysis (before tax return) results are presented as follows:

- Net Present Value (NPV) (Figure 19, label 1)
- Internal Rate of Return (IRR) (Figure 19, label 2)

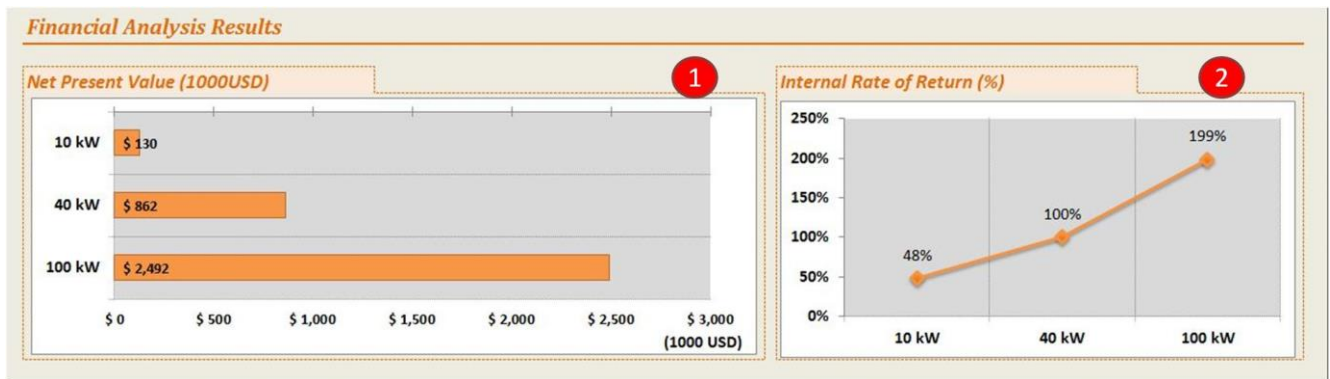


Figure 19: Financial Analysis Results

For the cassava stalk example, the Net Present Value (NPV) and Internal Rate of Return (IRR) for all plant capacities are positive as shown in Figure 19.

It can be concluded that cassava stalk is feasible for power generation at all plant capacities.

The user can save and print the results in PDF format by using “Create a PDF report” and following the instructions (Figure 17, label A).

7.3 The summary of comparative results

The information presented in this section helps the user in the decision making process to develop biomass gasification for power generation in rural areas. The user can compare the results across the different feedstock selected in the analysis.

1. The user first selects the feedstock, by clicking on it, that he/she wants to review. The results for that feedstock will be generated.
2. Comparison results are presented on:
 - Production costs according to feedstock (USD/kWh) (Figure 20, label 1)
 - Net electricity generation and the utilization capacity factor of the plant by feedstock (Figure 20, label 2)
 - Number of gasification plants that can be potentially developed according to feedstock (Figure 20, label 3)
 - Total number of jobs that can be created (Figure 20, label 4)
 - Total number of households that can be supplied (Figure 20, label 5)
 - Comparison of NPV (before taxes) across the selected feedstock options (Figure 20, label 5)
 - Comparison IRR (before taxes) across the selected feedstock options (Figure 20, label 6)

The user can save and print the results in PDF format by using “Create a PDF report” and following the instructions (Figure 20, label A).

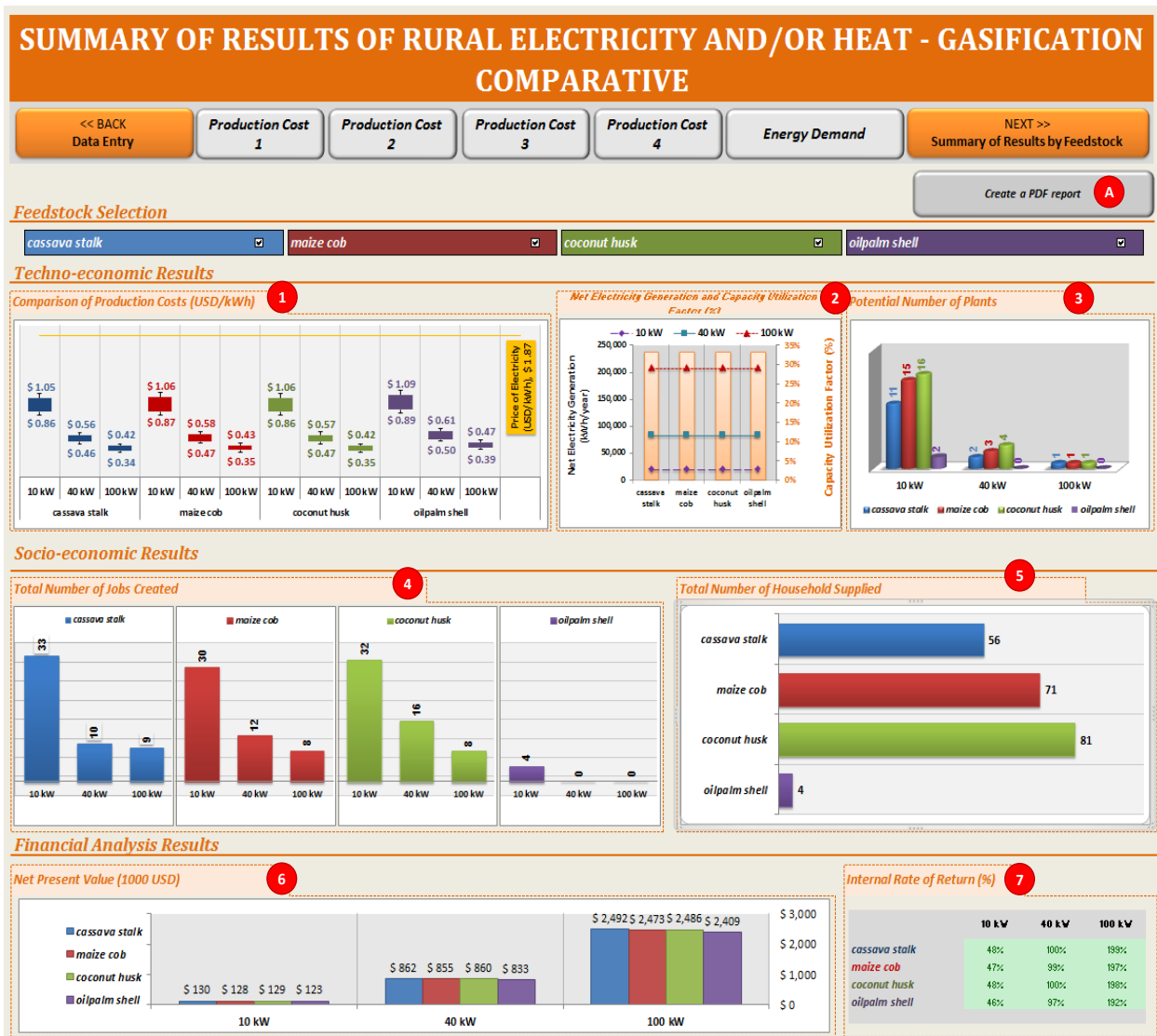


Figure 20: Layout of Comparative Results

For this example, the production cost of electricity when using oil palm shell as feedstock is the highest compared to other feedstock for all plant capacities. Cassava stalk, maize cob and coconut husk all have the lowest production cost. Notably, all of the feedstock provide positive NPV and IRR as shown in Figure 20. From this analysis, the user can conclude that:

1. Cassava stalk, maize cob and coconut husk are feasible options and are available for power generation at all capacities.
2. Oil palm shell is feasible and available for power generation at 10kW or 40kW, but not sufficient for 100kW capacity.

8 Annex

8.1 Methodology and outputs

This section describes the methodologies integrated in the *Gasification Component*. It also includes a description of the equations which support the analysis. The equations are not visible to the user, but their structure and content might be important for those who will update them and/or work on the improvement of the tool.

8.1.1 Cost calculation of required inputs

The required inputs consist of the cost of feedstock (biomass), cost of water, and cost of diesel consumption. The equations used to calculate the cost of these items are presented in Table 3.

Table 3: Inputs Cost Equations

Item	Equation and Assumption	Remark
Quantity of feedstock	$QF = PG / [PC \times \text{gas engine efficiency} \times (1 - \text{Power losses due to operation})]$ <p>Where: QF is Quantity of feedstock (tonne per year) PG is Power generation (kWh per year) PC is Power conversion potential (kWh per kg of feedstock)</p>	PC is varied depending on the type of feedstock A power loss due to operation is assumed at 15%.
Water consumption	$WC = PG / WS$ <p>Where: WC is Water consumption (m³ per year) PG is Power generation (kWh per year) WS is Specific water consumption (kWh per m³)</p>	Default value of WS is 10,872.73 kWh per m ³ (Arena et al., 2010a)
Diesel consumption for start up (100% Syngas system)	$DC = 10\% \times PC \times OP / DS$ <p>Where: DC is Diesel consumption (litres per year) PC is Power generation capacity (kW) OP is Operating hours of startup period (hours per year) DS is Specific diesel consumption (kWh per litre)</p>	PC are 10kW, 40kW and 100kW capacity Default value of OP is 365 hours per year (1 hour per day) Default value of DS is assumed to be 3.33.
Total Inputs cost	$TIC = (QF \times Cf) + (WC \times Cw) + (DC \times Cd)$ <p>Where: TIC is Total Inputs cost (USD per year) QF is Quantity of feedstock (tonne per year) WC is Water consumption (m³ per year) DC is Diesel consumption (litres per year) Cf is unit cost of feedstock (USD per tonne) Cw is unit cost of water (USD per m³) Cd is unit cost of diesel (USD per litre)</p>	Cost of oxygen as gasifier agent and steam is not considered in this tool.
Power generation (PG) (kWh per year)	$\text{Power capacity (kW)} \times \text{Operating hours per year}$ <p>Where, Operating hours per year = Operating hours per day \times 365 days per year</p>	Operating hours per year entered by the user.

To calculate the biomass consumption as feedstock

The quantity of feedstock is calculated based on the power generation in kWh per year and the power conversion of biomass to electricity through gasification system.

$$\begin{aligned} \text{Gas engine efficiency (\%)} &= \frac{\text{Power Output}}{\text{Power input}} \\ &= \frac{\text{Power capacity (kW)} \times \text{Operating hours } \left(\frac{\text{h}}{\text{year}}\right)}{\text{Power Conversion Potential } \left(\frac{\text{kWh}}{\text{kg biomass}}\right) \times \text{Biomass consumption } \left(\frac{\text{kg}}{\text{year}}\right)} \end{aligned}$$

Where:

$$\text{Power Conversion Potential} = \text{Calorific Value Syngas } \left(\frac{\text{MJ}}{\text{m}^3_{\text{syngas}}}\right) \times \text{Syngas to biomass yield } \left(\frac{\text{m}^3_{\text{syngas}}}{\text{kg}_{\text{biomass}}}\right) \times \frac{1\text{kWh}}{3.6 \text{ MJ}}$$

Therefore, biomass consumption (kg/year) is calculated by

$$= \frac{\text{Power capacity (kW)} \times \text{Operating hours } \left(\frac{\text{h}}{\text{year}}\right)}{\text{Power Conversion Potential } \left(\frac{\text{kWh}}{\text{kg biomass}}\right) \times \text{gas engine efficiency (\%)}}$$

However, to calculate the biomass consumption (kg/year) based on the actual power generation has to take “the power losses due to operation” into consideration. These losses are due to inappropriate operation of the gasification-engine system. These include lack of control and monitoring of units measuring gas pressure, gas composition, air leakage, or temperatures etc. Therefore, these causes lead to lower power output than the installation capacity. These losses are assumed to be 15%.

Therefore, biomass consumption (kg/year) is calculated by

$$\begin{aligned} &= \frac{\text{Power capacity (kW)} \times \text{Operating hours } \left(\frac{\text{h}}{\text{year}}\right)}{\text{Power Conversion Potential } \left(\frac{\text{kWh}}{\text{kg biomass}}\right) \times \text{gas engine efficiency (\%)} \times (1 - \text{Power losses due to operation (\%)})} \\ &= \frac{\text{Power capacity (kW)} \times \text{Operating hours } \left(\frac{\text{h}}{\text{year}}\right)}{\text{Power Conversion Potential } \left(\frac{\text{kWh}}{\text{kg biomass}}\right) \times \text{gas engine efficiency (\%)} \times (85\%)} \end{aligned}$$

To calculate the diesel consumption for start up

Figure 21 presents an operation scheme of the gasification system using 100% Syngas for power generation.

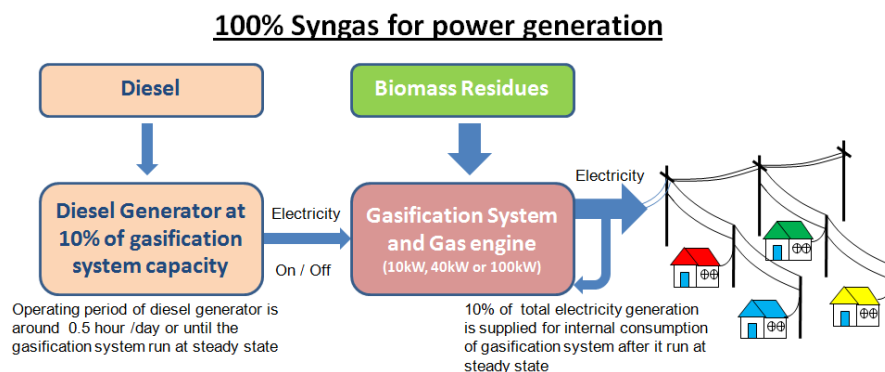


Figure 21: Gasification System of 100% Syngas for Power Generation

It is assumed that the electricity generation that is used to supply households by this gasification system is produced by using 100% syngas. The diesel generator, at 10% of the total power generation capacity of gasification system, is used to supply the internal demand of electricity during the start-up of the gasification system. After the gasification system is operating at the steady state, then the internal electricity consumption will be shifted to gas engine mode and the diesel engine will be stopped. The operating hours of diesel engine is assumed to be only a half hour per day to supply all power requirements to start up the gasification system.

8.1.2 Cost calculation of required labour

This step presents the equations and assumptions for calculating the labour and miscellaneous cost based on the power generation capacity as shown in Table 4.

Table 4: Labour and Miscellaneous Cost Equations

Item	Equation and Assumption	Remark
Number of unskilled labour	10kWcapacity is 1 person 40kWcapacity is 3 person 100kWcapacity is 6 person	(Nouni et al., 2007) (Dasappa, Subbukrishna, Suresh, Paul, & Prabhu, 2011)
Number of skilled labour	10kWcapacity is 1 person 40kWcapacity is 1 person 100kWcapacity is 2 person	(Dasappa et al., 2011)
Total unskilled labour cost (USD per year)	Unit cost of unskilled labour x number of unskilled labour x operating hours per year	Unit cost of unskilled labour (USD/person/hour) Input entered by user in “Data Entry Needs” Operating hours per year same as Table 3.
Total skilled labour cost (USD per year)	Unit cost of skilled labour x number of skilled labour x operating hours per year	Unit cost of skilled labour (USD/person/hour) Input entered by user in “Data Entry Needs” Operating hours per year same as Table 3.
Miscellaneous cost (USD per year)	Percentage of miscellaneous cost (%) x (Total unskilled labour cost + Total skilled labour cost)	Percentage of miscellaneous cost input by user. Default value is 10%
Total labour cost (USD per year)	Total Unskilled labour cost + Total skilled labour cost + Miscellaneous cost	

Note that miscellaneous costs consist of labour benefits, health & life insurance, operating supplies and/or laboratory charges (if any).

8.1.3 Cost calculation of required transportation

This step presents the calculation equations of transportation cost as shown in Table 5.

Table 5: Transportation of Feedstock Cost Equations

Item	Equation and Assumption	Remark
Transportation of feedstock (field to plant) (USD per year)	Unit transportation cost x Transportation distance x QF Where: QF is Quantity of feedstock (tonne per year)	Unit transportation cost (USD/tonne/km) and Transportation distance (km) entered by the user QF is calculated in Table 3.

8.1.4 Cost calculation of storage

Table 6 presents the calculating equations for estimating the storage cost.

Table 6: Storage Cost Equations

Item	Equation and Assumption	Remark
Storage Capacity (tonne/year)	The estimate storage capacity in “Storage Calculator#” worksheet by pressing on the “Storage Calculator”	
Storage cost (USD per year)	Unit storage cost x Storage Capacity	Unit storage cost (USD/tonne) entered by user based on guidance provided in the manual.

8.1.5 Fixed cost calculation

Fixed cost consists of the cost associated with equipment, building, installation and distribution network. Table 7 presents the equations and assumptions applied to calculate the fixed cost and the depreciation cost.

Table 7: Fixed Cost Equations

Item	Equation and Assumption	Remark
Equipment cost (EC) (USD)	The database of cost details is provided and adjusted by considering the replacement equipment that has the lifetime less than the project lifetime. The cost consists of Biomass pretreatment processes, Gasification system, Gas cleaning system, Gas engines system. EC at current period = EC (base year) x [Plant Cost Index (current period) / Plant Cost Index (base year)]	(Nouni et al., 2007)(Buchholz et al., n.d.) Plant cost index (current period) input by the user
Building cost (BC) (USD)	The database of cost is provided including: building of gasification system, gas engine, water pool, and civil work. BC at current period = BC (base year) x [Plant Cost Index (current period) / Plant Cost Index (base year)]	(Nouni et al., 2007)(Buchholz et al., n.d.) Plant cost index (current period) input by the user

Installation cost (IC) (USD)	The database of cost is provided including: Feasibility study, Development and Engineering, Installation, Erection, commissioning, Training, Shipping, Duty, Insurance, Clearance, etc. IC at current period = IC (base year) x [Plant Cost Index (current period) / Plant Cost Index (base year)]	(Nouni et al., 2007)(Buchholz et al., n.d.) Plant cost index (current period) input by the user
Distribution network cost (USD)	$(27.1 \times \text{Power capacity (kW)}) + (7.5 \times 10 \times \text{Number of households access electricity})$ Where: Connection and earthing: 27.1 USD/kW. Primary electricity cable: 7.5 USD/m Average electricity cable length : 10 m/household	(Bouffaron, Castagno, & Herold, 2012)(Wiskerke, Dornburg, Rubanza, Malimbwi, & Faaij, 2010)
Total investment (USD)	Equipment cost + Building cost + Installation cost + Distribution network cost	
Equipment Depreciation (USD per year)	Equipment cost divided by project life time	Straight line method of depreciation calculation
Building Depreciation (USD per year)	Building cost divided by project life time	Straight line method of depreciation calculation
Installation Depreciation (USD per year)	Installation cost divided by project life time	Straight line method of depreciation calculation
Distribution network Depreciation (USD per year)	Distribution network cost divided by project life time	Straight line method of depreciation calculation
Total depreciation (USD per year)	Equipment Depreciation + Building Depreciation + Installation Depreciation + Distribution network Depreciation	Straight line method of depreciation calculation
Maintenance cost (USD per year)	Percentage of maintenance cost (%) x Total depreciation	Percentage of maintenance cost input by the user Default value is 10%.
Total of Fixed cost (USD per year)	Total depreciation + Maintenance cost	

Note: The plant cost index is used to update equipment, building and installation cost to the current period.

Please visit this website for further information: http://en.wikipedia.org/wiki/Chemical_plant_cost_indexes.

The assumption in this tool is that plant cost index can be applied to any type and size of plant. It provides an acceptable proxy to update the investment costs.

8.1.6 Calculation of other costs

The plant overhead is defined as a charge to the production for services, facilities, and payroll overhead. The general and administrative cost comprises rents, insurances, managerial, administrative and executive salaries. Table 8 shows the equations for calculating the cost associated with plant overhead, general and administrative cost, average loan interest payment and corporate tax.

Table 8: Other Costs Equations

Item	Equation and Assumption	Remark
Plant Overhead (USD per year)	Percentage of plant overhead (%) x (Total labour cost + Maintenance cost)	Percentage of plant overhead input by the user. Default value is 30%.

General and Administrative Cost (USD per year)	Percentage of general & administrative cost (%) x (Total inputs cost + Total labour cost + Maintenance cost + Plant overhead)	Percentage of general & administrative cost input by the user. Default value is 5%.
Average loan interest payment (USD per year)	<p>Loan amount = Loan ratio (%) x Total investment cost</p> <p>Loan payment (USD/month) = PMT([Loan interest rate/12],[12x Loan term], Loan amount)</p> <p>Annual Loan payment = Loan payment (USD/month) x 12 months</p> <p>Total Loan payment = Annual Loan payment x Loan terms</p> <p>Loan interest payment = Total Loan payment - Loan amount</p> <p>Average Loan interest payment = Loan interest payment divided by project lifetime</p>	PMT is a financial function in Microsoft Excel for calculating the payment for a loan based on constant payments and a constant interest rate.

8.1.7 Total production cost and unit cost of electricity calculation

Table 9 presents the calculation equations of the total operating costs, total fixed costs, and total other costs. The final results of these costs are used to compute the total production cost of electricity and unit production cost per kWh.

Table 9: Total Production Cost Equations

Item	Equation and Assumption	Remark
Total Operating Costs (USD per year)	annual inputs cost + annual labour cost + annual transportation cost + annual storage cost	
Total Fixed Costs (USD per year)	depreciation fixed cost + annual maintenance cost	
Total Other Costs (USD per year)	annual plant overhead + annual general & administration cost + annual Loan payment + annual income tax	
Total Production Cost (USD per year)	Total Operating Costs + Total Fixed Costs + Total Other Costs	
Production cost per kWh	Total Production Cost divided by Power generation	The equation of power generation (kWh per year) is presented in Table 3

8.1.8 Project revenue calculation

Table 10 presents the equations for calculating the potential revenue of gasification system.

Table 10: Potential Revenue Equations

Item	Equation and Assumption	Remark
Potential revenue (USD per year)	$[\text{Power generation} - \text{Electricity self-use} - \text{Power loss in distribution network}] \times \text{Price of electricity}$ <p>Where,</p> $\text{Power loss in distribution network (\%)} \times \text{Power generation}$	<p>Power generation same as in Table 3.</p> <p>Electricity self-use (kWh per year) assumed 10% of power generation.</p> <p>Power loss distribution entered by the user in Step 4.</p>
Price of electricity (USD/kWh)	User selects option: Method 1 or Method 2 to define the price of electricity paid by customer	Input data by the user in "Data Entry Needs".

8.2 Data requirements for running the tool

Table 11 includes data requirements for running the *Gasification Component*.

Table 11: Data Requirements for Running the Tool

Data	Definition and Sources
Biomass and its residue	The user selects the biomass/crops and its residue for detailed analysis.
Price of feedstock	If the price of feedstock is not available, the user will need information on hourly wages for skilled and unskilled workers (USD per employee per hour) and fuel consumption of machinery typically used in agricultural or forestry operations to calculate a proxy for this value.
Price of water	The user enters the current price of water (USD/m ³).
Price of Diesel	The user enters the current price of diesel (USD/litre).
Feedstock storage cost (USD per tonne).	<p>The user identifies the cost for storing the feedstock. The user can enter the current prices on storage for agricultural products in the country.</p> <p>If this information is not available in the country, the user can estimate this based on the selection on the type of storage available in the country and use the estimated global cost for building this type of storage that is provided in the tool. Moreover, the size of the storage site or container is estimated using the biomass storage calculator.</p>
Feedstock safety stock rate (%)	The user defines this value by entering it in each biomass storage calculator. This value defines the percentage of biomass that should be reserved to operate the plant during shortage periods.

The user selects the option to identify the price of electricity paid by customer (USD/kWh)	The price of electricity can be the price for the national grid or the price of electricity that is generated by other energy resources, e.g. diesel generator, solar energy, hydro power, natural gas, etc. To estimate the price of electricity by using a diesel generator, the user inputs the capacity of the diesel generator (kW), operating hour per day, operating day per year, transportation cost and transportation distance of diesel including labour and maintenance cost in the “Electricity price calculator”.
Labour cost	Unskilled and skilled workers in the unit of USD per employee per hour.
Working hours of feedstock collection	Working hours of feedstock collection for manual and mechanized method.
The cost of transportation of feedstock (field/collecting point to plant) in unit of USD per tonne per km	<p>Cost of transportation of feedstock from the collection point (or field) to gasification plant, the user enters the cost of transportation in unit of USD per tonne per km.</p> <p>If transportation is done on foot or by bike, the user can include this cost in the collection cost of feedstock. Alternatively, the user estimate the cost by using the cost of labour per hour, working time, the amount of material that can be transported and the approximate kilometres that can be travelled under the selected method.</p>
The transportation distance of feedstock to gasification plant in kilometres by power generation capacity	Transportation distance is determined based on the availability of biomass in a particular area in relation to the amount required to operate each of the power generation capacities.
Operating hours per day for gasification system	The user will provide an estimated number of hours per day that the system is expected to operate. Most literature indicates that gasification systems are operated only for a few hours during the day. For example, in cases where the gasification system supplies only household electricity, these operate 4 hours, usually during the night time. The user may want to determine this value based on potential energy demands.
Power loss in distribution network (%)	<p>This information can be the current loss in the national electric grid. Alternatively, a link is provided to a World Bank global database compiling national distribution losses. Please visit:</p> <p>http://data.worldbank.org/indicator/EG.ELC.LOSS.ZS</p>
Power loss due to operation (%)	The user estimates the losses due to operation. These losses are due to inappropriate operation of the gasification-engine system. These include lack of control and monitoring of units measuring gas pressure, gas composition, air leakage, or temperatures, etc.
Gas engine efficiency (%)	This parameter is provided by gas engine manufacturer.

Costing parameters	Percentage of plant overhead cost, general and administrative cost, maintenance cost and miscellaneous cost.
Financial parameters	Inflation rate (%) Discount rate (%) Loan ratio (%) Loan interest rate (%) Loan term (years) Plant cost index http://base.intratec.us/home/ic-index
Electricity Demand per household.	The user inputs data from the <i>Country Status</i> module. The electricity consumption will be estimated based on the type of appliances typically used in a rural household, the quantity of these appliances per rural household and the average hours of operation of the appliances. Note that this value will be used as a proxy to identify the number of potential households that can be supplied with electricity. A more detailed and localized analysis according to energy demand profiles and time framework will need to be carried out for adequate planning and implementation of a gasification system.

9 References

- Arena, U., Di Gregorio, F., & Santonastasi, M. (2010a). A techno-economic comparison between two design configurations for a small scale, biomass-to-energy gasification based system. *Chemical Engineering Journal*, 162(2), 580–590. doi:10.1016/j.cej.2010.05.067
- Arena, U., Di Gregorio, F., & Santonastasi, M. (2010b). A techno-economic comparison between two design configurations for a small scale, biomass-to-energy gasification based system. *Chemical Engineering Journal*, 162(2), 580–590. doi:10.1016/j.cej.2010.05.067
- Bouffaron, P., Castagno, F., & Herold, S. (2012). Straight vegetable oil from *Jatropha curcas* L. for rural electrification in Mali – A techno-economic assessment. *Biomass and Bioenergy*, 37, 298–308. Retrieved from <http://www.sciencedirect.com/science/article/pii/S0961953411005964>
- Buchholz, T., Silva, I. Da, & Furtado, J. (n.d.). Electricity from wood-fired gasification in Uganda – a 250 and 10kW case study. Retrieved from <http://www.strathmore.edu/pdf/duel0&250-kW-gasifier-Buchholz-DaSilva-Furtado.pdf>
- Cummer, K. R., & Brown, R. C. (2002). Ancillary equipment for biomass gasification, 23, 113–128.
- Dasappa, S., Subbukrishna, D. N., Suresh, K. C., Paul, P. J., & Prabhu, G. S. (2011). Operational experience on a grid connected 100kWe biomass gasification power plant in Karnataka, India. *Energy for Sustainable Development*, 15(3), 231–239. doi:10.1016/j.esd.2011.03.004
- EPA. (2007). Biomass Combined Heat and Power Catalog of Technologies. *U. S. Environmental Protection Agency*, (September). Retrieved from www.epa.gov/chp/documents/biomass_chp_catalog.pdf
- Göransson, K., Söderlind, U., He, J., & Zhang, W. (2011). Review of syngas production via biomass DFBGs. *Renewable and Sustainable Energy Reviews*, 15(1), 482–492. doi:10.1016/j.rser.2010.09.032
- Jain, B. (2008). PROJECT DESIGN DOCUMENT (PDD): GCL biomass gasification based power generation. *CDM-Executive Board, UNFCCC*, (March).
- Nouni, M. R., Mullick, S. C., & Kandpal, T. C. (2007). Biomass gasifier projects for decentralized power supply in India: A financial evaluation. *Energy Policy*, 35(2), 1373–1385. doi:10.1016/j.enpol.2006.03.016
- Patel, B., Gami, B., & Bhimani, H. (2011). Improved fuel characteristics of cotton stalk, prosopis and sugarcane bagasse through torrefaction. *Energy for Sustainable Development*, 15(4), 372–375. doi:10.1016/j.esd.2011.05.002
- The World Bank. (n.d.). Electric power transmission and distribution losses (% of output). Retrieved from <http://data.worldbank.org/indicator/EG.ELC.LOSS.ZS>
- Wiskerke, W. T., Dornburg, V., Rubanza, C. D. K., Malimbwi, R. E., & Faaij, a. P. C. (2010). Cost/benefit analysis of biomass energy supply options for rural smallholders in the semi-arid eastern part of Shinyanga Region in Tanzania. *Renewable and Sustainable Energy Reviews*, 14(1), 148–165. doi:10.1016/j.rser.2009.06.001