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Ist Progress Report

Contract No. 3000019137 (SAP ID: 120047)

Promoting small biomass power plants in rural Thailand for sustainable renewable energy management and community involvement

Prepared for

The United Nations Industrial Development Organization

Prepared by

The Energy and Resources Institute

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Chapter - 1 Introduction

1.1 Background

The project is for promoting small biomass power plants in rural Thailand for sustainable renewable energy management and community involvement. The capacity of the proposed biomass gasifier based power plant will be 250 kWe. Two biomass gasifier systems each with capacity of 125 kWe will be provided to produce the required power output of 250 kWe.

The project is aimed to use bamboo waste produced from the chopstick industries in Napoon. Bamboo industries produce two types of waste. One is in a fine fiber form which is bulk and in the category of loose biomass. The other one is nodes of bamboo which is not suitable for chopstick production. The nodes of bamboo are suitable for biomass gasification and power generation. The bamboo waste (Nodes) available from the industries is fresh harvested having moisture content above 50%. Shadow drying and sun drying can bring down the moisture content substantially.

Figure 1: Bamboo waste available at site

General observations from the Chopstick manufacturing industries are:

- The chopstick industries produce two types of wastes. One of them is nodes of the bamboo and another one is the bamboo waste in the form of fibers.
- The nodes of the bamboo can be used directly for gasification, with a minimum pre- processing. Fibers are in a loose form and suitable for applications like direct firing.
- There are about 30 units in the cluster (in a radius of 5 km) and twenty units are close by the site, in one village.

- These twenty units are capable of providing sufficient waste (Bamboo nodes) to run the biomass power plant at its full capacity. Primary data was collected for quantifying the waste availability.
- Each machine is capable of handling 4 tonnes of bamboo per day. Every day 2 tonnes of nodes and one tonne of bamboo fiber are produced along with production of one tonne of chopstick, the end product (Figure 2).

Figure 2: Bamboo processing at site

- Currently, a part of the bamboo nodes are used to produce charcoal. The selling rate of the bamboo node is 0.35 Baht per kg. A portion of the bamboo is collected, stored and sold to the brick industries at a cost of 0.5 Baht per kg.
- The charcoal is produced through a crude pyrolyser at a poor efficiency of about 20% with a polluting environment. However a detailed analysis of bamboo nodes as a fuel for gasification shall be conducted in India by TERI.

The chopstick industries produce sufficient amount of waste for sustainable operation of the biomass gasifier based power plant. Potential of Bamboo waste generated from the Chopstick industries are presented in Table 1.

Table 1: Potential of Bamboo waste generated from the Chop-stick industries

S.No.	Component	Details	Unit
1	Processing capacity of each industry	4	Tonnes/day
2	Bamboo waste (Nodes)	2	Tonnes/day
3	Bamboo waste (Fibers)	1	Tonnes/day
4	End product: chop-stick	1	Tonnes/day
5	Total number of units in the cluster	30	Numbers
6	Total number of units close to the site	20	Numbers
7	Total potential of bamboo nodes (Wet) (from one village having 20 units)	40	Tonnes/day

From the above table, it may be noted that there is a sufficient quantity of bamboo node available for operating the biomass gasifier based power plant. A sustainable supply chain needs to be in place for taking care of the biomass procurement and supply to the site.

Biomass gasifier designs are fuel specific. For developing a biomass gasifier for any specific feedstock, it is important to analyze the proximate, ultimate and calorific value of the biomass fuel to check its combustion characteristics.

1.2 Choice of fuel for biomass gasifier

The local authorities asked for designing the gasifier system to use the fuels apart from the bamboo nodes. Option for multiple choices of fuel is asked for removing the dependency on bamboo nodes from chopstick industries. The users are concerned with the cost of the fuel from chopstick industries. Observations during presentation made to the officials at Phrae province and the feedback communicated from UNIDO Thailand, there is a need to design the gasifier system to use additional biomass fuel apart from bamboo nodes. The gasifier system is fuel specific. Few modifications were will be incorporated in the gasifier system to use the following fuels.

i. Bamboo nodes
ii. Bamboo sticks
iii. Corn cob
iv. Fuel wood (thinning and pruning)

When using bamboo nodes or fuel wood, the gasifier system can operate on single fuel with 100% of bamboo nodes or fuel wood chips. Also, bamboo nodes and fuel wood chips can be used together as mixed fuel at any ratio depending on the availability of bamboo and fuel wood. While going for a multiple fuel option, a maximum amount of 30% corn cob can be mixed with bamboo nodes or with fuel wood. In case of using all the three fuels (bamboo nodes, corn cob and fuel wood) together, then it has to be ensured that total contribution of corn cob does not exceed 30 % by weight.

It was observed that the chop stick industry uses the main stem of the bamboo. The bamboo sticks are not used by the industries and having no market value. These sticks (which have the diameter as more than 20 mm) can be effectively used as fuel mix for gasification. Bamboo sticks can be mixed with bamboo nodes and fuel wood to a maximum limit of 40%. By its physical property exceeding the limit of 40% may obstruct the fuel flow in the reactor.

Chapter -2 Biomass characterization

The proposed biomass gasifier system is designed to use three types of biomass fuels. Each type of biomass has specific properties that determine its performance as a fuel in combustion, or gasification devices, or both. The most important properties relating to the gasification of any biomass fuel is the proximate analysis. A fuel can be analyzed based on the volatile matter content, ash, moisture and fixed carbon present in it.

2.1 Proximate analysis

a) **Moisture Content:** The moisture content of biomass is the quantity of water present in the biomass. The moisture content affects the value of biomass as a fuel. This is particularly important because biomass materials exhibit a wide range of moisture content (on a wet basis), ranging from 10-55%. Moisture content of the fuel is responsible for calorific value, gasification efficiency, impurities in the gas and specific fuel consumption for power generation.

b) **Ash Content:** When produced by combustion in air, the solid residue is called 'ash'. The ash content of biomass affects both the handling and processing costs of the overall biomass energy conversion cost. Dependent on the magnitude of the ash content, the available energy of the fuel is reduced proportionately. In a thermo-chemical conversion process, the chemical composition of the ash can present significant operational problems. This is especially true for gasification processes where the ash can melt to form a 'slag', a liquid phase formed at elevated temperatures, which can disturb the operation of the gasifier.

c) **Volatile Matter, and Fixed Carbon content:** The volatile content, or volatile matter (VM) of a solid fuel, is that portion driven-off as a gas (including moisture) by heating, and the Fixed Carbon content (FC), is the mass remaining after the releases of volatiles, excluding the ash, and moisture contents. These two parameters are important to analyze as in solid fuels chemical energy is stored in two forms, fixed carbon and volatiles. The quantity of the volatile mater in biomass is responsible for the impurity level in producer gas.

d) **Calorific Value:** The Calorific Value (CV) of a material is an expression of the energy content, or heat value released when burnt in air. The CV is usually measured in terms of the energy content per unit mass; hence kcal/kg of biomass. The CV of the biomass is responsible for the quality of producer gas and overall efficiency of the biomass gasifier based power plant.

2.2 Ultimate analysis

The elemental or ultimate analysis is the second typical way to present the components in biomass fuels. The ultimate analysis presents directly the main elements present in the organic part of biomass. The main elements of biomass are carbon, hydrogen oxygen and nitrogen. The measurement of the elemental composition for C, H, O and N is typically performed in laboratory equipment called elemental analyzers. The following key points can be made for each element:

a) **Carbon (C)** is the most important constituent of biomass fuels. Carbon represents the major contribution to the overall heating value. The carbon content of the fuel is directly related to its content of lignin, hemicellulose and cellulose. A low lignin content, like with herbaceous biomass, leads to lower carbon content as compared to woody biomass. Carbon content is responsible for heating value of the gas, cold gas efficiency of the system and gas quality.

b) **Hydrogen (H)** is another major constituent of biomass, as can be expected from the chemical structure of the carbohydrate and phenolic polymers. During combustion, hydrogen is converted to H_2O, significantly contributing to the overall heating value. In woody biomass, the total weight content of hydrogen is 6 – 8 % (on a dry basis).

c) **Oxygen (O)** is a major element in all biomass fuels, as is evident from the nature of the photosynthetic process and the chemical composition of the biomass constituents. Fuel oxygen reduces the amount of air needed for combustion and is found in the combustion products chemically bound in the molecules of CO_2 and H_2O. Oxygen content of the biomass determines the additional air required for gasification and combustion.

d) **Nitrogen (N)** is the most important nutrient for plants. It is absorbed via the soil or the applied N-fertilizers by the plant during its growth. Nitrogen's contribution to the overall heating value of the biomass is zero. Hence, the nitrogen content of the producer gas brings down the heating value of the gas as it absorbs part heat generated during the combustion process.

Detailed analysis was carried out for the selected fuels to be used in the proposed 250 kWe power generation system. The results of the proximate analysis of the selected fuels are presented in Table 2.

Table 2: Proximate analysis of selected biomass fuels

Parameters	**Units**	**Fuels**			
		Bamboo (Fresh)	Bamboo (Dried)	Corn cob (Dried)	Fuel wood (Dried)
Moisture	%	49.91	10.0	10	10.00
Ash	%	0.78	1.24	2.81	1.58
Volatile Matter	%	39.39	70.91	70.36	69.08
Fixed Carbon	%	9.92	17.85	16.84	19.34
Bulk density	Kg / Nm3	350-375	300-325	200-280	325-350

From Table 2, it may be noted that the fresh bamboo is having moisture content as high as 50.00%. For obtaining a good quality gas suitable to run the IC engine the moisture content of the biomass fuel has to be less than 10%. Proximate analysis of fresh bamboo and dried bamboo (to 10 % MC) are presented in Table 2 for a better understanding of the value change in proximate analysis. Comparison of the three selected fuels is presented at 10 % Moisture content.

The results of the ultimate analysis of the selected fuels are presented in Table 3. The calorific values of the selected fuels are presented in Table 4. It may be noted that the CV of the fuel wood and bamboo are closer to each other's value whereas the CV of corn cob is much lower than fuel wood and Bamboo. Similarly the bulk density of Bamboo is closer to the value of fuel wood but the bulk density of corn cob is much lower than fuel wood. Low bulk density biomass fuels will create problems related to fuel flow and affect the energy density per unit volume. Hence it is important to limit such fuel mix during operation of the system.

Table 3: Ultimate analysis

Parameters	**Units**	**Fuels**		
		Bamboo	Corn cob	Fuel wood
Carbon Content	%	51.69	48.05	48.00
Hydrogen	%	5.31	5.87	9.23
Oxygen	%	42.38	45.59	41.35
Nitrogen	%	0.62	0.49	1.42

The carbon content in the bamboo is 52%, hydrogen 5% and oxygen is about 42%, while in wood, the carbon ranges about 48% of the total elemental content, hydrogen is about 9% and oxygen is 41%. The fuel properties of corn cob is closer to the value of bamboo and fuel wood. These three fuels are found to be suitable to operate the proposed gasifier with a choice of fuel mix.

Table 4: Calorific Value (Moisture free basis)

Parameters	**Units**	**Fuels**		
		Bamboo	Corn cob	Fuel wood
Calorific Value	MJ/Kg	15-17	14.0-15.0	16-18

The calorific value of the bamboo is 15-17 MJ/kg. Fuel wood has a heating value of 16-18 MJ/ Kg while corn cob has lower heating value in the range of 14-15 MJ/ Kg. The ratio of biomass fuel mix should not exceed with 30% of corn cob to maintain the operating conditions of the reactor and to maintain the quality of the producer gas.

Chapter -3 Technical specification of the proposed Biomass gasifier based power generation system

3.1 Introduction - The biomass gasifier system

The biomass gasifier based power generation system comprises of a fixed bed down draft reactor and a series of gas cleaning and cooling equipment. The reactor with multi-layer insulation helps to reduce heat loss and to maintain high temperature. Hot air is introduced into the gasification reactor through twelve nozzles distributed equally at two tiers with six nozzles in each layer.

The use of a rotating grate, ash removal system helps towards effective ash removal from the reactor. The design of the grate is such that it removes the ash from the reactor with a minimum charcoal. Thus charcoal from the biomass is retained inside the reactor to ensure complete gasification.

Since, the reactor is a down draft design, the producer gas is drawn from the bottom of the gasifier and is passed through a cyclone filter, where coarse dust particles are separated. The partially cleaned hot gas is passed through a shell and tube (gas to air) heat exchanger. Air passes through the shell whereas the gas is passed through the tubes. In which air is preheated to 250- 300° C using the heat exchanger, which is capable of working at high temperature. A hot gas filter is used to remove the fine dust. Further cooling of the producer gas is done in two heat exchangers connected in series. The reduction in the producer gas temperature allows condensation of the moisture present in the gas. The condensate is collected at a fixed frequency. The producer gas is finally allowed to pass through two filters (a fabric filter and a paper filter), connected in series. These filters remove the fine dust particulates. The clean producer gas is fed into an Internal Combustion (IC) engine for generating electric power. The gasifier is designed to perform with high efficiency and to produce cleaner gas, with less impurity. The components of the biomass gasifier based power generation system are shown in Figure 3.

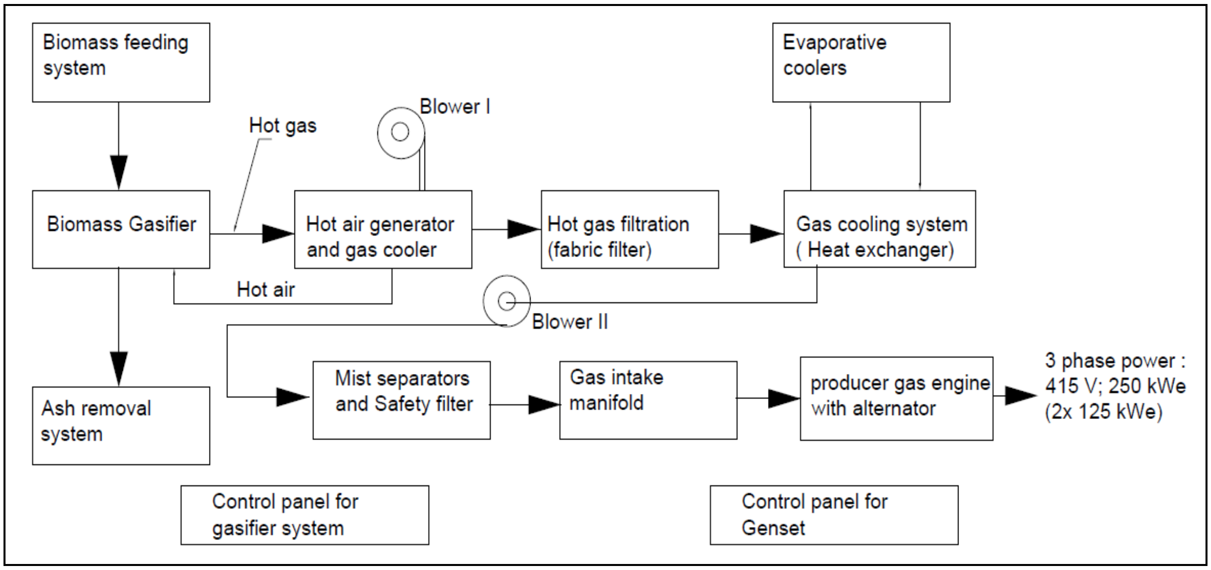

Figure 3: Components of the biomass gasifier based power plant

3.2 Main gasifier unit

The gasifier proposed is a down draft type gasification reactor, designed for conversion of bamboo waste into "producer gas". The gasifier system is fabricated using mild steel of 4 mm sheet thickness. The reactor is designed to ensure free flow of large size fuel into the reactor. Multiple layers of insulation linings are used to minimize the heat losses and maintain a high temperature inside the reactor.

A fuel hopper is attached to the reactor. The fuel hopper is having two parts one in a conical shape and another is in cylindrical shape. The fuel hopper is designed to store and feed fuel to the reactor for five hours of continuous operation. The gasifier is operated in force draft mode with pressure ranging between 30 cm and 40 cm of water column. A lid with appropriate sealing arrangement is provided at the top of the gasifier to facilitate the fuel feeding. Lower portion of the gasifier is attached with the ash removal system to facilitate continuous ash removal from the reactor.

The ash removal system is employed with a timer and a motor connected through a reduction gear box. The frequency of ash removal system operation can be controlled by the timer settings.

The gasifier is designed with a dual fired gasification rector in two stages. Hot air at the order of 250 °C is supplied in both the stages. The reactors are well insulated with high temperature resistant insulation materials.

3.2.1 Reactor stage I

The gas produced at the end of gasification reactor stage I is similar to the gas quality from a single stage down draft type gasifier. Since the gas produced from the single stage gasifiers have more tar content, there is a need to reduce the tar content to further to use it in internal combustion engine (ICE).

Adequate air required for gasification is supplied at stage I by maintaining high temperature above 950 °C. With a partial combustion of the charcoal leaving the stage one of the reactor has very less volatile matters and high carbon content. Eventually the stage II of the reactor was ensured with a free flow of good quality charcoal for gasification. In reactor stage I the biomass is partially burnt and converted into charcoal.

The stage I of the gasifier reactor was designed to reduce the volatile matter present in the biomass. It also plays a key role to ensure the complete conversion of biomass into charcoal before the fuel enters into the stage II of the reactor. Efficient reduction of the volatile matters of the fuel wood and production of high quality charcoal from the stage I of the reactor, contributes to reduction of tar content in the producer gas.

3.2.2 Reactor stage II

In stage II of the reactor about 30% of the air required for gasification of biomass was supplied through multiple nozzles, located at the same level. The nozzles are located at an equal distance to have a uniform temperature across the reactor. In stage II the gas produced in stage one is partially burnt and the tar cracking process is further enhanced at a high temperature charcoal bed (charcoal with high carbon content. In the present system the stage I of the reactor vertically mounted on top of the reactor stage II. The charcoal flow to stage II of the reactor is by gravity itself. The reactor of stage I was designed in such a way that the charcoal leaving the stage I will have high carbon content and less volatile matter. Stage II of the reactor produces the gas with low tar content, since the gas produced in stage one is passed through high quality and a high temperature charcoal bed. The preheated air supplied is increasing the bed temperature, in comparison to the reactors with supply of non- pre heated air. Maintaining the charcoal bed temperature of the reactor reduces the tar content and facilitates the production of the combustible gas with low impurities.

3.2.3 Heat Exchanger I

Heat exchanger I is used for cooling the producer gas which exit the high temperature reactor and the heat recovered from the hot gas is used to raise the temperature of the air supplied for gasification. The sensible heat of the hot gas is used to pre-heat the air; otherwise, this energy is wasted in the cooling process. A heat exchanger will be used to pre heat the air used for gasification of the bamboo waste. The producer gas generated from the reactor is drawn from the high temperature zone of the reactor, maintained around 1000 °C. At the entry of the heat exchanger, the gas flows upward at a low velocity, which enables the separation of particulates due to gravity. The producer gas from the gasifier exits at 500 °C to 600 °C. The gas is cooled down to the order of 250 °C by passing it through a shell and tube heat exchanger. In this process, it exchanges the waste heat with the ambient air; as a result, the temperature of the ambient air is increased to the order of 250-300 °C. Supply of preheated air in to the reactor helps facilitates cracking the tar produced inside the reactor. Cracking of tar improves the quality of the producer gas thereby increasing the overall efficiency of the gasifier system and reduces the load on gas cleaning equipment.

3.2.4 Cyclone filter

A cyclone filter is provided next to the heat exchanger I. The cyclone filter will reduce the dust loading rate to the hot gas filter by separation of coarse dust present in the hot gas. The cyclone filter is introduced before the hot gas filter will reduce the maintenance cycle of the bag filters used in hot gas filter. Cyclone filter is provided with a dust collection chamber and the dust can be removed periodically by dismantling the end cap provides at the base of the cyclone filter.

3.2.5 Hot gas filter

The proposed gasifier system is designed with hot gas cleaning (Dry gas cleaning). To reduce the temperature of the hot gas, indirect gas cooling method is adopted by using heat exchangers. Generally spray tower and venturi scrubbers are used to cool and clean the gas. Spray towers and venturi scrubbers are completely eliminated. These systems needs a large quantity of water and have an additional task of water treatment and disposal. Also using water spray increases the moisture content of the gas and reduces its heating value. To have an environment friendly and efficient system, the proposed dual fired, two-stage gasifier system will be equipped with a hot gas cleaning equipment, which will not have any water spray.

The hot gas filter will be operated in the temperature range of 120 °C to 150 °C, to avoid any condensation. Elimination of condensation in the filter zone will enable to reduce the pressure drop. Reduction of pressure drop across the bag house filter also reduces the maintenance cycle. Reduction in maintenance cycle increases the ease of operation.

3.2.6 Heat exchangers II and III

Two heat exchangers (Exchanger II and III) are used to bring down the gas temperature closer to ambient temperature. These heat exchangers are shell and tube type. Both the heat exchangers are connected in series. The gas flows through the pipes the water flow through the shell. An evaporative cooler is used to reject the heat gained by the water, in the process of cooling the gas. As the gas exits from the gasification reactor is saturated, it losses the moisture when bringing the gas temperature close to ambient. The moisture present in the gas is condensed in the inner wall of the tubes and collected below the heat exchangers. The condensate is removed periodically. The frequency of condensate removal depends on ambient condition and moisture content of the biomass fuel. A blower is connected at the gas outlet of Heat exchanger III, to compensate the pressure drop created by the equipment used for gas cleaning and cooling equipment.

3.2.7 Mist separator

A mist separator is designed to remove the fine droplets carried away by the producer gas when exiting from heat exchangers II and III. The mist separator will eliminate the fine droplets and will protect the gas cleaning equipment to maintain the pressure drop minimum. Droplet is collected at the base of the mist separator and can be removed periodically.

3.2.8 Safety filter

A safety filter is used to ensure the quality gas supplied to the engine is clean enough for smooth operation. Commonly used paper filter cartridge is used in the safety filter for supply of clean gas to engine. The cartridge filters are fitted with easily removable and replaceable arrangements. Two reduce the pressure drop across the safety filter, two cartridges are used. They are placed one on top of another with a common bolt-net arrangement. The details of the equipment used in the proposed biomass power plant are shown in Figure 4 and Figure 5. The sectional view of the gasification plant can be seen in Figure 4. The arrangement of the individual components (on plan and its locations can be seen in Figure 5.) The detail of the components referred in Figure 4 and Figure 5 are given in Table 5. All the dimensions referred in the figures are in mm.

Table 5: The details of the components of the biomass gasifier system shown in Fig 4 and Fig 5

S. No.	Component details
1	Main gasifier unit with ash removal system
2	Heat exchanger I (Gas cooler and Hot air generator)
3	Cyclone filter (to remove coarse dust)
4	Hot gas filter (Fabric filter I, to remove fine dust)
5	Heat exchanger II and III (indirect gas cooling system)
6	Mist separator (separates the fine droplets from the gas)
7	Fabric filter ii (dust and droplet remover)
8	Cartridge filter (safety filter)
9	Air blower (to supply air for gasification)
10	Gas blower (to compensate the pressure drop)
11	Pipe lines used to connect the equipment

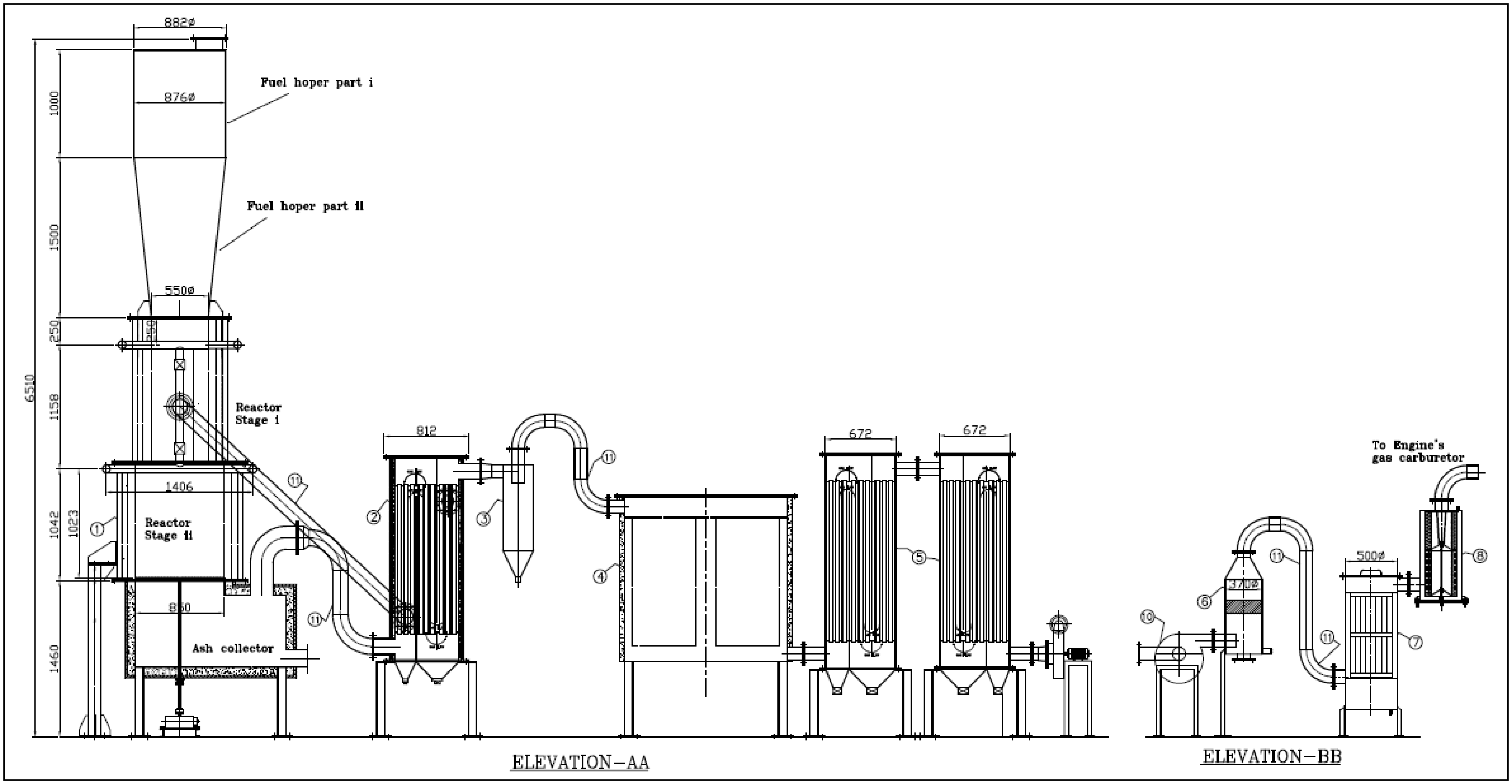

Figure 4: Sectional view of the individual components of the gasifier system

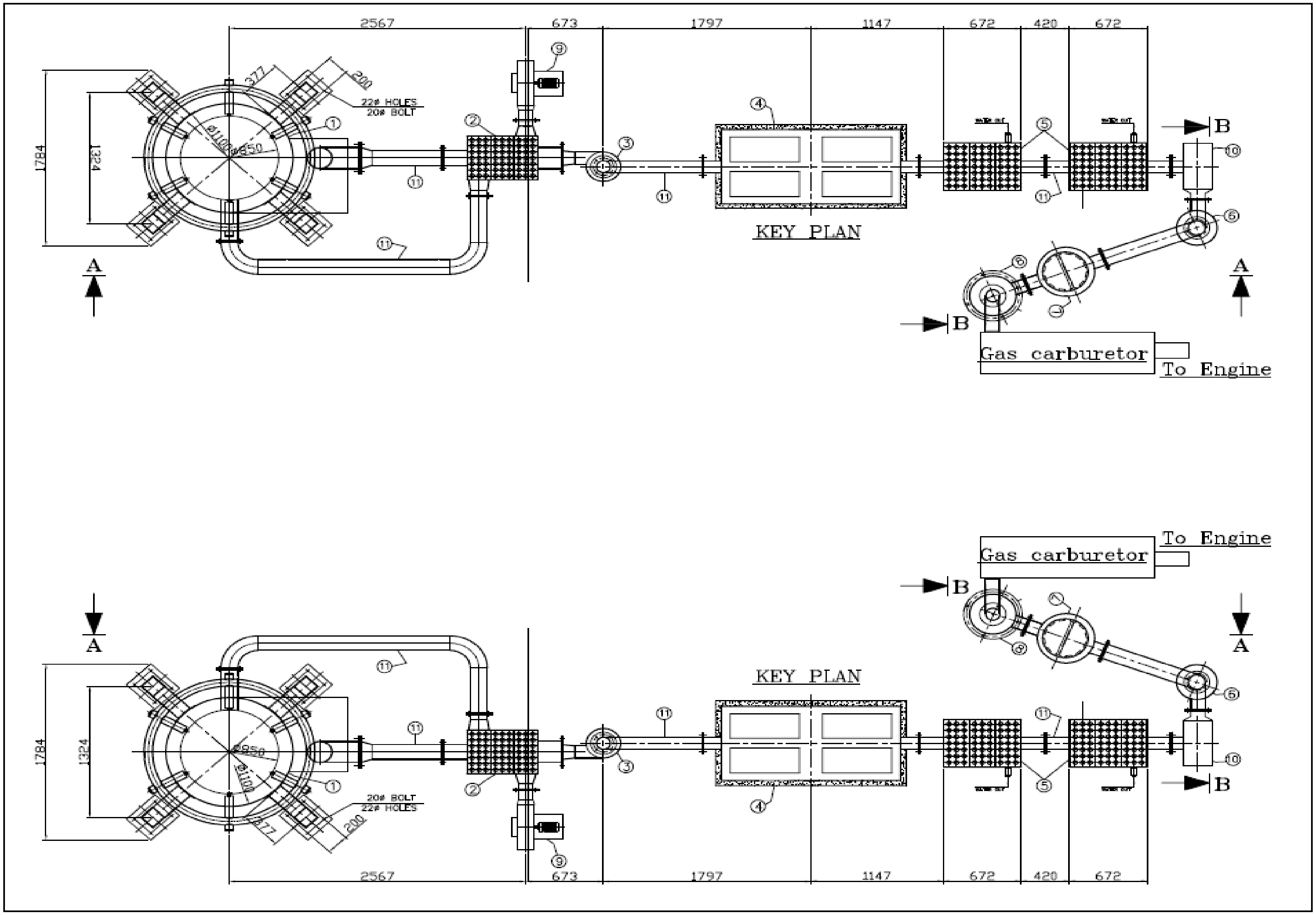

Figure 5: Assembly diagram of the individual components of the gasifier systems (1 and 2)

3.3 Producer gas engine.

A natural gas engine coupled with alternator will be used for power generation using the producer gas generated from the biomass gasifier system. Necessary modifications will be carried out to run the natural gas engine on producer gas. Two numbers of 125 kWe system will be installed to produce 250 kWe power output. The Technical specifications of the producer gas engine and power generator are given in Table 6 below:

Table 6: Technical specifications of the configuration of the prime mover and the genset

S.No.	Component	Unit	Details
1	Rated capacity of the engine	hp	310-330
2	Rated engine speed	RPM	1500
3	Overall Genset Dimensions (Length x Width x Height)	mm	3825 x 1501 x 1816
4	Power output (on producer gas)	kW_e	125
5	Bore x Stroke	mm	159 x 159
6	Number of cylinders	No.	6
7	Compression Ratio	Proportion	10:1
8	Number of strokes per cycle	No.	4
9	Type of cooling	------	Water cooling
10	Ignition system	------	Electronic ignition system,
11	Ignition timing	Degree	28° BTDC
12	Output Voltage and Frequency	V and Hz	415 Volts, 50 Hz
13	No. of Phases	No.	Three phase
14	Specific fuel consumption at peak load (Fuel wood @ 10% MC)	$kg\ kWh^{-1}$	1.2-1.6*

* At and above 80% load and controlled by fuel type and its moisture content

3.3.1 Control panel:

The control panel to be provided with the engine will have the following components:

- MCCB of suitable rating with overload and short circuit
- Indicators
  - Voltmeter and Ammeter with selector switch
  - Frequency meter
  - KW meters
  - Indicating lamps for "Load On" and "Set Running"
- Aluminum bus-bars of suitable capacity with incoming and outgoing termination

3.3.2 Engine Manifold

The producer gas composition and stoichiometric air requirement of the producer gas is entirely different from that of natural gas. Generally, natural gas is supplied to the engine from a high pressure cylinder using pressure regulators. The inlet pressure is positive in case of natural gas engines. In most of the cases, the producer gas pressure at the inlet of the engine is below atmospheric pressure. Gas to air ratio of producer gas is 1:1.2 whereas gas to air ratio for natural gas is 1:13.5. Due to variations in inlet pressure, heating value of the fuel and stoichiometric air requirement a fuel intake manifold was designed to operate the engine on 100% producer gas. The fuel mixture intake manifold was designed to supply the appropriate fuel mixture of air and gas required to the engine according to the variation in the operating load conditions. A diagram of the fuel intake manifold designed to operate the engine on 100% producer gas is shown in Figure 6. From the figure, it may be noted that the manifold comprises of two separate chambers for entry of gas and air into the engine. The intake manifold is provided with a mixing chamber to produce a homogeneous mixture of producer gas and air. Individual valves were installed at the inlet of the manifold to maintain the required gas to air ratio. The outlet of the designed fuel intake manifold has a venturi arrangement for achieving a homogeneous fuel mixture. The outlet of the manifold is connected to the engine inlet through a throttle valve. The governor (hydraulic /electronic) connected to the throttle valve, controls the flow of fuel mixture into the engine according to the operating load of the engine.

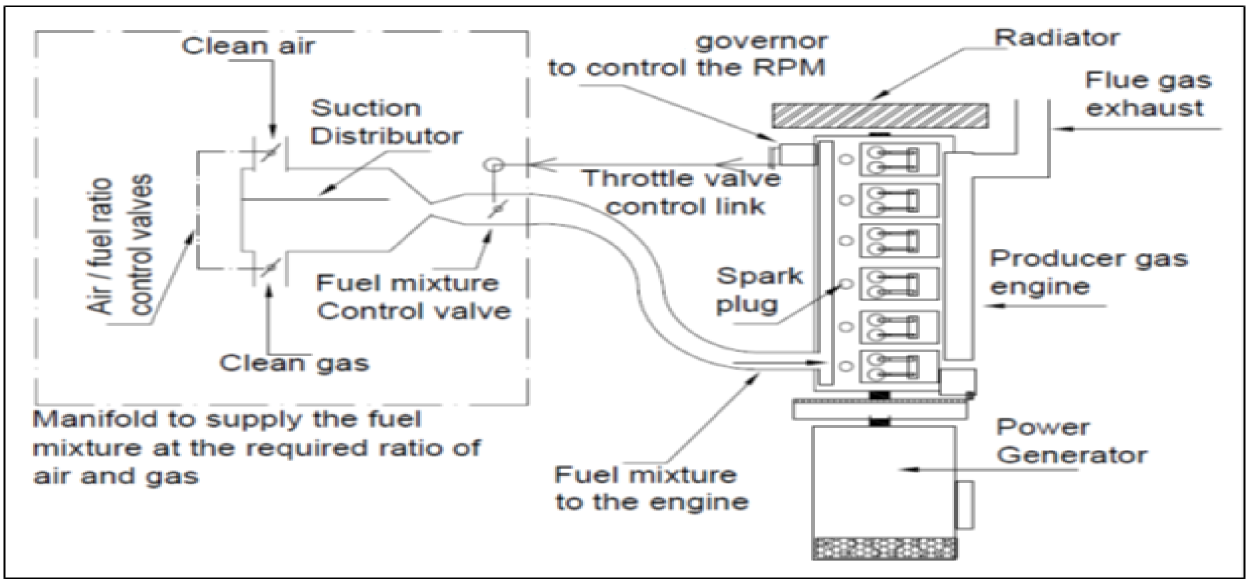

Figure 6: A Schematic diagram of the fuel intake manifold for the producer gas engine

3.3.3 Gasification efficiency and gas quality:

Producer gas generated from dual fired gasifier using fuel wood is comparatively much cleaner than the conventional single stage gasifiers. Cold gas efficiency of the system is 80-85%. The residue (ash and char) removal rate is less than 5%, when the ash content in the fuel is less than 2 %. The cold gas efficiency varies based on type of the fuel and its ash content. The calorific value of the producer gas is 1000-1100 kcal/Nm^3. The calorific value varies based on the type of fuel and moisture content. The impurities in the clean gas are less than 100 mg / Nm^3. The impurity level in the gas can vary according to the moisture content and CV of the gas. To obtain a good quality gas it is essential to maintain the moisture content of the fuel at less than 10 %. The specific fuel consumption is 1.2-1.6 kg/kWh at and above 80% load. The specific fuel consumption varies according to the calorific value, ash and moisture content of the feed stalk.

3.3.4 Noise reduction:

Based on the discussion at the Phrae office TERI will explore the possibility of noise reduction by incorporating an acoustic cladding through the engine suppliers.

3.3.5 Initial start-up

The self-power consumption of the power plant will be about 7 %, which will be 8-9 kWe. This is the energy required to run the blowers, pumps and ash removal system. The power consumption for fuel loading is occasional for few minutes, which is once in 4-5 hrs of operation. During the cold start of the biomass power plant, the equipment mentioned above have to be operated by the power from the grid for 1 to 1.5 hrs. Intermediate start of the system during regular operation will take about 15-30 minutes only.

Chapter 4 Civil structure for the biomass power plant

The system needs an appropriate civil structure for installation of the gasifier system, power generation system and control panels.

4.1 Building for Gasifier system, generator and control panel

A schematic diagram of the building required for installation of the gasifier system with the power generator and control panel is given in Figure 7 and 8. The earthing pits along with earthing strips for the proposed power plant to be made adjacent to the control panels. Plan view of the proposed building is given in Figure 7 and Sectional view of the building is given in Figure 8. All the measurements in Fig. 7 and 8 are referred in mm. Staircases need to be provided to access the First floor and Second floor. The civil diagram provided in fig 5 and 6 need to be further modified to incorporate the structural components based on the local soil conditions. The access areas are clearly marked for installation, operation and regular maintenance of the system.

4.1.1 Foundation for gasifier

The biomass gasifier has to be placed on a foundation made by RCC. The foundation details are shown in Figure 9.

4.1.2 Fuel storage shed

A simple fuel storage shed for an area of 96 m^2 is required to store the biomass fuel required for 2 weeks. The net volume of the storage space needs to be 8 meter width and 12 meter long for a storage height of 5 meter. The net storage volume needs to be about 385 - 400 m^3.

4.1.3 Site details

In addition to the building for the gasifier based power plant, there is a need for a shed to store the fuel. Open areas are needed for installation of equipment like fuel feeder, evaporative water coolers and water tank etc. Sufficient space is needed for free access of all equipment and work areas in the site. A comprehensive diagram depicting the area requirement is presented in Figure 10. In figure 10, the open area front of the fuel storage shed can be used for sun drying of the biomass fuel.

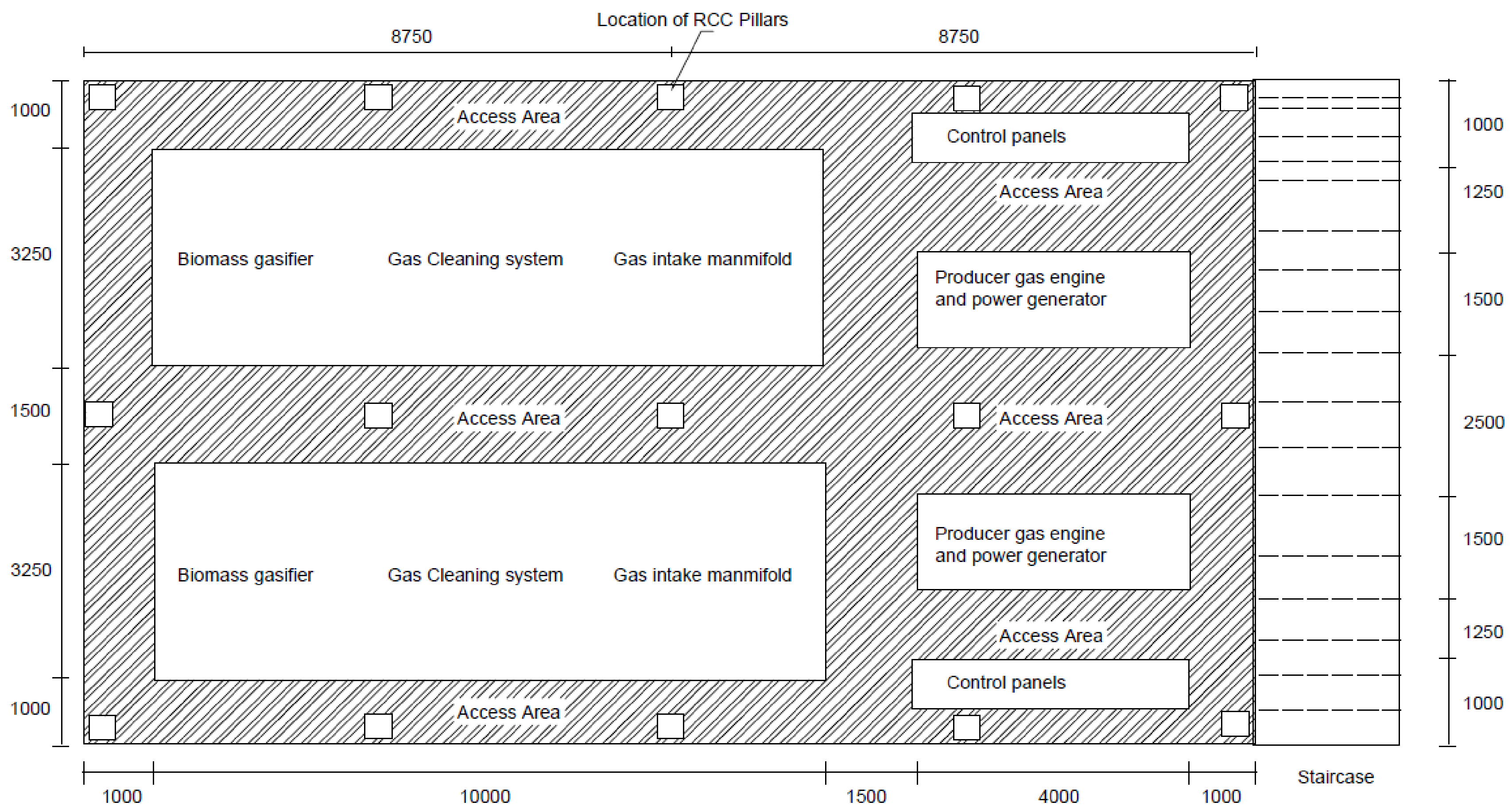

Figure 7: Civil structure required for the proposed biomass power plant: Plan

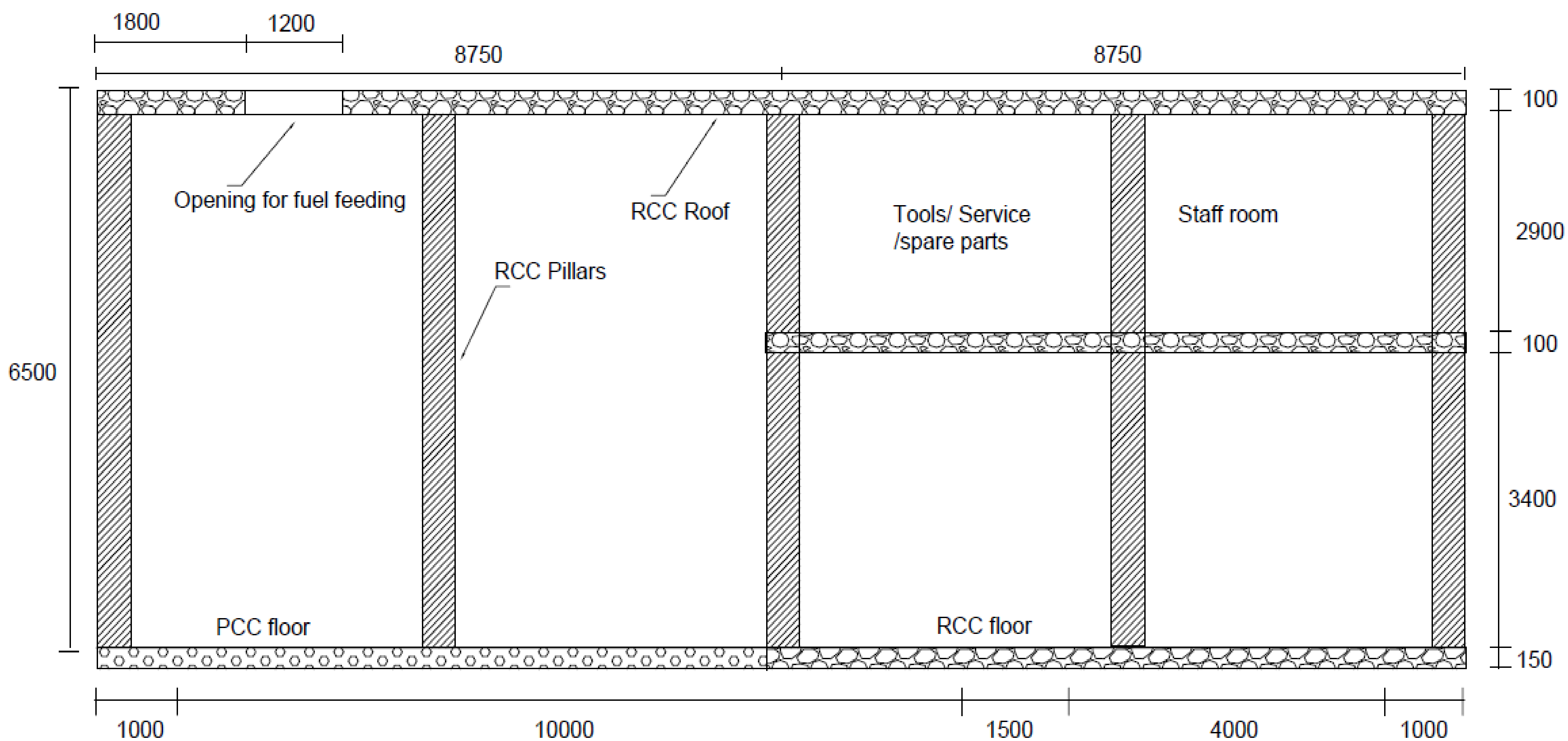

Figure 8: Civil structure required for the proposed biomass power plant: Section

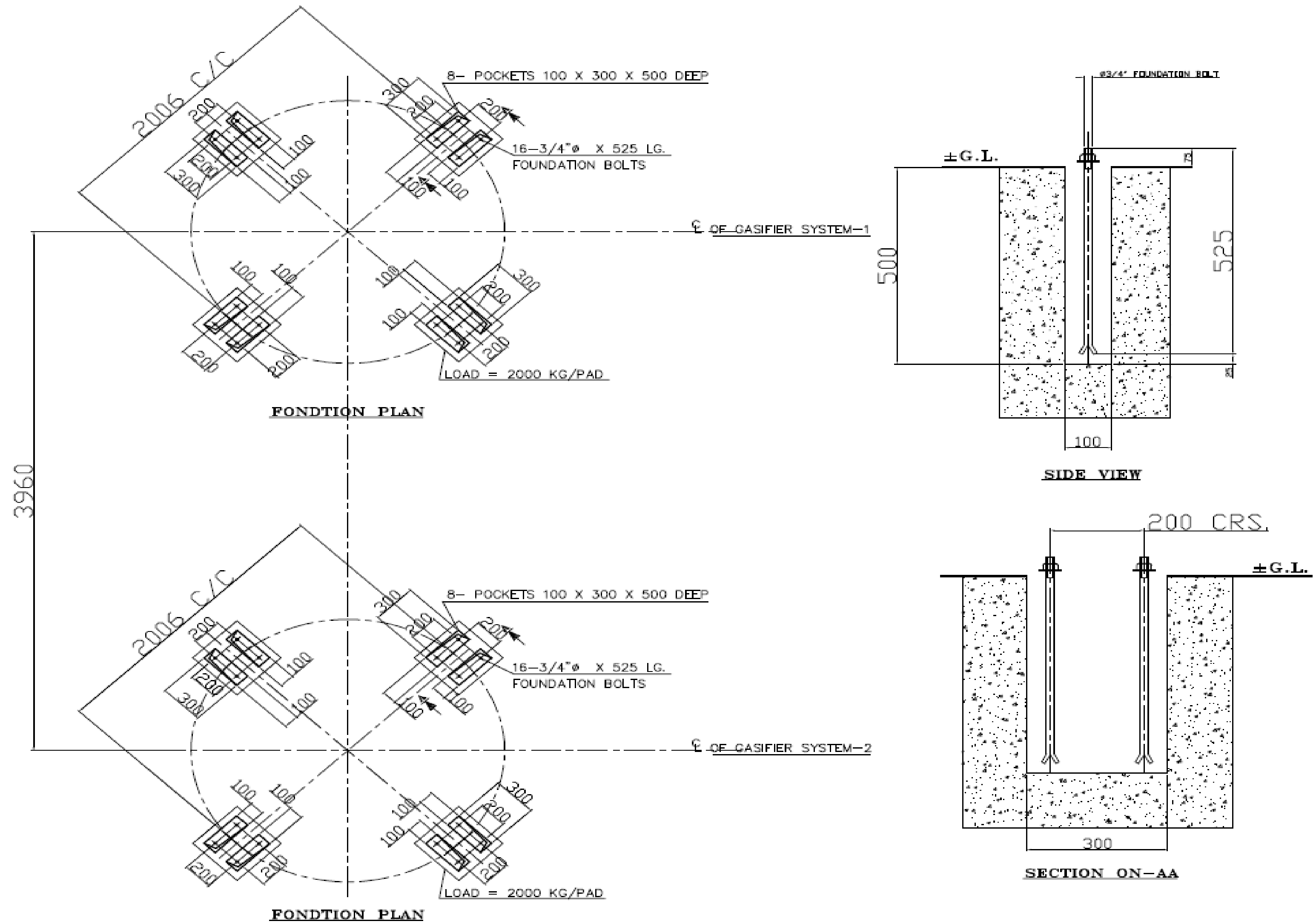

Figure 9 Foundation details of the gasifier

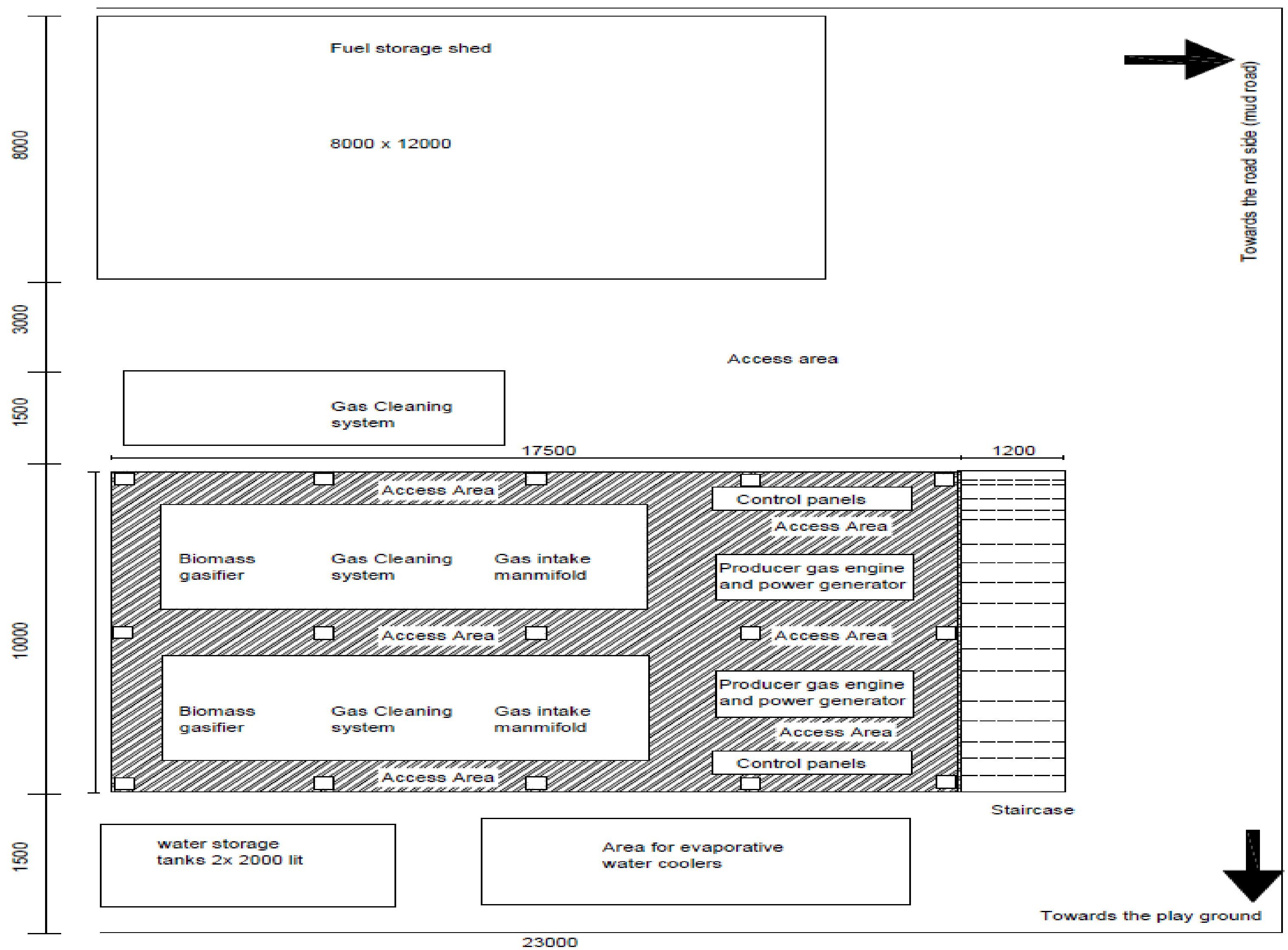

Figure 10 Details of the site along with area allocation for different activities

Chapter 5 Environment Factors

The biomass gasifier system is an advanced technology to produce much cleaner gas in comparison with the conventional gasifiers.

In the proposed gasifier system dry gas filtration and indirect gas cooling concepts were adopted. Thus, The gas cleaning and cooling system completely climates the water scrubbers, in which water comes in direct contact with gas and demands the need for a treatment plant.

The gasifier is designed to control the ash removal rate to the order of 4-5% of biomass fed in to the gasifier. Thus reduces the ash disposal problem. The ash from the gasifier consists of minerals and charcoal which can be used to enrich the soil nutrient. Biochar and soil nutrient enhancement is a well-known factor.

The producer gas is flared during the initial starting of the system for duration of one hour. Once the reactor reaches the required temperature it will be used to run the internal combustion engine. To ensure the air quality in the gasification area CO alarm will be installed to ensure the safety in the work place.

Operating IC engines on producer gas generated from biomass is one of the new and upcoming technologies. Hence, there are no IC engines made specifically to run on producer gas. Generally, natural gas engines are procured from the engine manufactures and used to run on producer gas with necessary modifications. The engines will be procured with acoustics cladding to reduce the noise level at work place. Acoustic cladding will be done as per the standard parameters available from the engine manufacturers.

Any additional requirement of the local regulations, which need to be followed, has to be adopted by the system operators, as a part of the operating practice.

Chapter 6 Conclusions

A feasibility study was conducted to estimate the biomass potential availability for a 250 kWe (2 x 125 kWe) biomass power plant at Napoon, Phare province, Thailand. It was observed that sufficient biomass is available in the form of bamboo waste (bamboo nodes), which is more suitable for gasification and to run an IC engine for power generation. The details of observations made during the field visits along with the biomass potential availability for the proposed system is provided in Annexure 1. However, due to its cost and request from the beneficiaries, the biomass gasifier was designed to have a fuel choice. Different fuels which can be used in the proposed system are reported along with their fuel characteristics.

Several benchmarks and standards exist in Thailand for ensuring clean environment. According to the studies, a set of standards prescribed for the systems above 10 MWe and below 5 MWe. The prescribed standards and the remarks in the context of the proposed system are given in Annexure 2. It has to be noted that the proposed gasifier system is designed with advanced technological configurations. The proposed gasifier system does not generate waste water. The engine will be incorporated with an acoustic cladding to reduce the noise level. Acoustic cladding norms are as per specifications provided by the engine manufacturers.

The proposed biomass power plant will be having a gasifier system, biomass power plant, gas cleaning system and producer gas engines to deliver 250 kWe power output. The generator set will have a three phase A/C power output with 415 V and 50 Hz. The required capacity of 250 kWe power will be produced by two identical systems of 125 kWe each (i.e 125 x 2= 250 kWe).

TERI will supply the 250 kWe (3 phase; 415 V) biomass power plant. The beneficiary has to procure any equipment which is required to use the power produced from the proposed biomass power plant. In case of using the power through the grid, the beneficiary has to procure the interface components, which are required to link the power plant and the grid. In such a case, the procurement of the component, installation, commissioning and obtaining relevant permission from the local electricity authority is in the scope of the beneficiary’s responsibility. The component and other requirements to be organized for the grid connection by the beneficiary are provided in Annexure 3.

The requirement of a building and an open space are earmarked and the details are provided in the report as part of the site preparation. The civil constructions, water and electrical line to the site are to be arranged by the beneficiary.

Manpower arrangement for installation commissioning and regular operation and maintenance of the system, have to be arranged by the beneficiary. TERI’s professional will be providing all the technical support during installation and commissioning of the biomass power plant. A detailed operation and maintenance manual will be provided along with the system during installation. The O&M manual will be provided instructions related to Dos and Don’ts.

During the field visit, based on the request of the beneficiary, a feasibility study was conducted for 1 MW biomass power plant using corn stover as a feedstock. The details of the technology and the investment required for 1 MW biomass power plant are provided in the Annexure 4.

Annexure 1- Field visit and biomass potential assessment

To kick start the project activities and to engage in a dialogue with the concerned stakeholders the project team has conducted a field visit to the project sites in Thailand. This included visit to actual project site to mobilize and assist the local partners. Further the project established contact and initiated a dialogue with the stakeholders that include briefing about the proposed technology, highlighting its salient feature. Beyond this TERI team also planned to assess the availability of the fuel at the project site. A team consisting of representatives from the different organization was engaged in the field visit. The details are as given below.

Table A: Details of the Project Team visited the site

Name of the Organization/Institutes	**Place**	**Representatives**
UNIDO	Vienna	Mr Thomas Jossy
UNIDO	Bangkok-Thailand	Ms Suttirut Pimpasut
TERI	New Delhi-India	Dr P Raman
		Mr N K Ram
Chiang Mai University	Chiang Mai-Thailand	Dr Chatchawan Chaichana
		Mr Nitthinan Borirak

Visit to Napoon, Phrae Province

On 29th January 2014 the team visited the sub-district administrative organization office, which is located very close to the proposed project site of biomass gasifier based power plant to the capacity of 250 kWe. The project team had a meeting with the officials at the sub-district administrative organization office. A detailed list of officials present in this meeting is as given in the table:

Table B: List of officials present in this meeting

S. No.	Name Place	Position
1	Mr Plang Wongla	Minister of Na Pun
2	Mr Wichean Sunpong	Managing crafts man
3	Mr Sunphet Suksakij	Civil engineer
4	Badin Nqam Prasong	Chairman of Craftsman
5	Prateep Kadaosod	Municipal Cleark

The officials at the sub district office were briefed about the UNIDO initiative. Subsequently the project team visited the proposed project site. The project site was about 200 meters away from the main road and it was well connected by a forest road (mud road). The site indeed was easily accessible and the connecting road conditions are good enough hence this facilitates transport of machineries and equipment's by heavy vehicles (for receiving and unloading the components at the site). Close to the project site there are two water ponds which is indeed a good source for water which is essential for basic needs of the plants. Though the system will be using minimum water (makeup water for evaporation loss) arrangements need to be made for water supply at the plant site.

Subsequently the project team visited Chop-stick manufacturing industries to estimate/assess the quantity, type, quality of the bamboo waste and it's potential. Summary of observations at the Chop-stick manufacturing industries are:

- The chop-stick industries produce two types of wastes. One of them is nodes of the bamboo and another one is the bamboo waste in the form of fibers.
- The nodes of the bamboo can be used directly for gasification, with a minimum pre- processing. Fibers are in a loose form and suitable for applications like direct firing.
- There are about 30 units in the cluster (in a radius of 5 km) and twenty units are close by the site, in one village.
- These twenty units are capable of providing sufficient waste (Bamboo nodes) to run the biomass power plant at its full capacity. Primary data was collected for quantifying the waste availability.

- Each machine is capable of handling 4 tonne of bamboo per day. Every day 2 tonne of nodes and one tonne of bamboo fiber are produced along with production of one tonne of chopstick, the end product.
- Currently, a part of the bamboo nodes are used to produce charcoal. The selling rate of the bamboo node is 0.35 Baht per kg. A portion of the bamboo is collected, stored and sold to the brick industries at a cost of 0.5 Baht per kg.
- The charcoal is produced through a crude pyrolyser at a poor efficiency of about 20% with a polluting environment. However a detailed analysis of bamboo nodes as a fuel for gasification shall be conducted in India by TERI.

The key findings of the field visits are provided in the following table:

Table C: Potential of Bamboo waste generated from the Chop-stick industries

S.No.	Component	Details	Unit
1	Processing capacity of each industry	4	Tonnes/day
2	Bamboo waste (Nodes)	2	Tonnes/day
3	Bamboo waste (Fibers)	1	Tonnes/day
4	End product: chop-stick	1	Tonnes/day
5	Total number of units in the cluster	30	Numbers
6	Total number of units close to the site	20	Numbers
7	Total potential of bamboo nodes (Wet) (from one village having 20 units)	40	Tonnes/day

From the above table it may be noted that there is a sufficient quantity of bamboo node available for operating the biomass gasifier based power plant. A suitable system need to be in place for taking care of the biomass procurement and supply to the site.

Project inception meeting at Napoon, Phrae Province

Visit to chop-stick production industries cluster

Bamboo waste from chopstick industries

Annexure 2- Regulations related to biomass power plants in Thailand

Table A: Regulations: Noise level

Announcement of National Environmental Committees

a) on value of noise disturbance, Volume 29, B. E. 2550 (2007), Book no. 124, Special Chapter 98 (d), Page 23

b) on assessment of General Noise standard, Volume 15, B. E. 2540 (1997)

Code of practice/ standard/ Clause	Remarks
a) Noise disturbance level is hereby identified at 10 Decibels A b) The max. Noise level not exceeding 115 dB (A). The average noise level in 24 hours not exceeding 70 dB (A)	• The engine will be provided with an acoustic cladding, as per the engine manufacturer's specifications. • The system will be provided with the prescribed norms and standards by the engine manufacture. • Testing and measurements are in the scope of the beneficiary. • TERI will supply the 250 kWe biomass gasifier based power plant along with the equipment which is related to only energy monitoring.

Table B: Regulations: Air quality-

Announcement of Ministry of Natural Resources and Environment

a) on determination of emissions control standards for air pollutants of new electric power plants, Book no. 127, Special Chapter 7 (d), Page 18, January 15, 2010

b) on value evaluation of contaminants in the air emitted from plants which generate, transmit or distribute electricity, B. E. 2547 (2004)

Particulars	Code of practice/ standard/ Clause	Remarks
Electric power stations using biomass fuels (**Referring clause 2)**	**Dust Particles-** Not exceed 120 mg/ m^3 **Sulfur dioxide** – Not exceed 60 ppm **Oxide gases of nitrogen** calculated in the form of Nitrogen Dioxide – Not exceed 200 ppm	• Producer gas engine emits much lower than the dust content compared to the engines work on conventional fuels. • As sulfur is not a component of producer gas. Hence, SO_2 should be within the limit. • Nitrogen is one of the major components of the producer gas. Hence, NOx in the exhaust is usually in the range of 150 to 400 ppm depending on the engine capacity, load and fuel quality • Testing and measurements are at the scope of the beneficiary. TERI will supply equipment which is related to only energy monitoring.
(Referring Clause 3)	The excess air volume for burning shall be at 50 percent, or the excess oxygen volume for burning shall be at 7 percent.	• Generally for internal combustion engines, about 20% of excess air is supplied to optimize the performance of the engine.

Table C- Regulations: Ambient air quality

Announcement of National Environmental Committee

a) on determination of national ambient air quality standards, volume 28, B.E. 2550 (2010)
b) on determination of national ambient air quality standard, volume 24, B.E. 2547 (2004)

Remarks
• There is no reported value available on ambient air quality with respect to 100% producer gas engine operation. Actual ambient air quality in regular operation of 100% producer gas has to be studied. • Oxygen gas is not the component of producer gas. Producer gas is product of partial combustion and reduction. • As sulfur is not a component of producer gas. Hence, SO_2 should be within the limit.

Table D: Regulations: Wastewater discharge

a) Announcement of Ministry of Science and Technology on standard control of wastewater discharge from sources under the types of industrial plants and industrial estates, volume 3, B. E. 2539 (1996)
b) Announcement of Ministry of Industry on determination of wastewater quality discharging from factories, volume 2, B. E. 2539 (1996)
c) Announcement of National Environmental Committees on standard control of wastewater discharge from sources under the types of industrial plants and industrial estates, volume 3, B. E. 2539 (1996)

Remarks
• There is no water scrubbing cleaning system in the proposed design of the gasifier plant. Thus, the proposed system will no generate waste water. • The proposed biomass gasifier system is designed with advance technology and environment - friendly. Hence, it does not produce polluted water and eliminates the need for any effluent treatment plant.

Annexure 3- Grid inter- face

As per the contract signed with UNIDO, TERI will supply a biomass (bamboo waste) gasifier based power plant to a capacity of 250 kWe (2 X 125 kWe). Based on different factors and parameters, it was proposed to supply two biomass gasifier systems of 125 kWe each. The proposed system to be supplied will be capable of producing 250 kWe power output at 415 V, 3 Phases and 50 Hz. The beneficiary can use the system directly with 3 phase dedicated grid of 415 V. If in case the beneficiaries wish to connect the plant to the grid, in that scenario then the beneficiary need to procure and install a grid interface system. The grid interface system will be converting the power produced from the gasifier system suitable to feed into the H.T grid. The details of the grid interface components are shown in Figure A. The details of the equipment's that need to procure for grid interface are as given below:

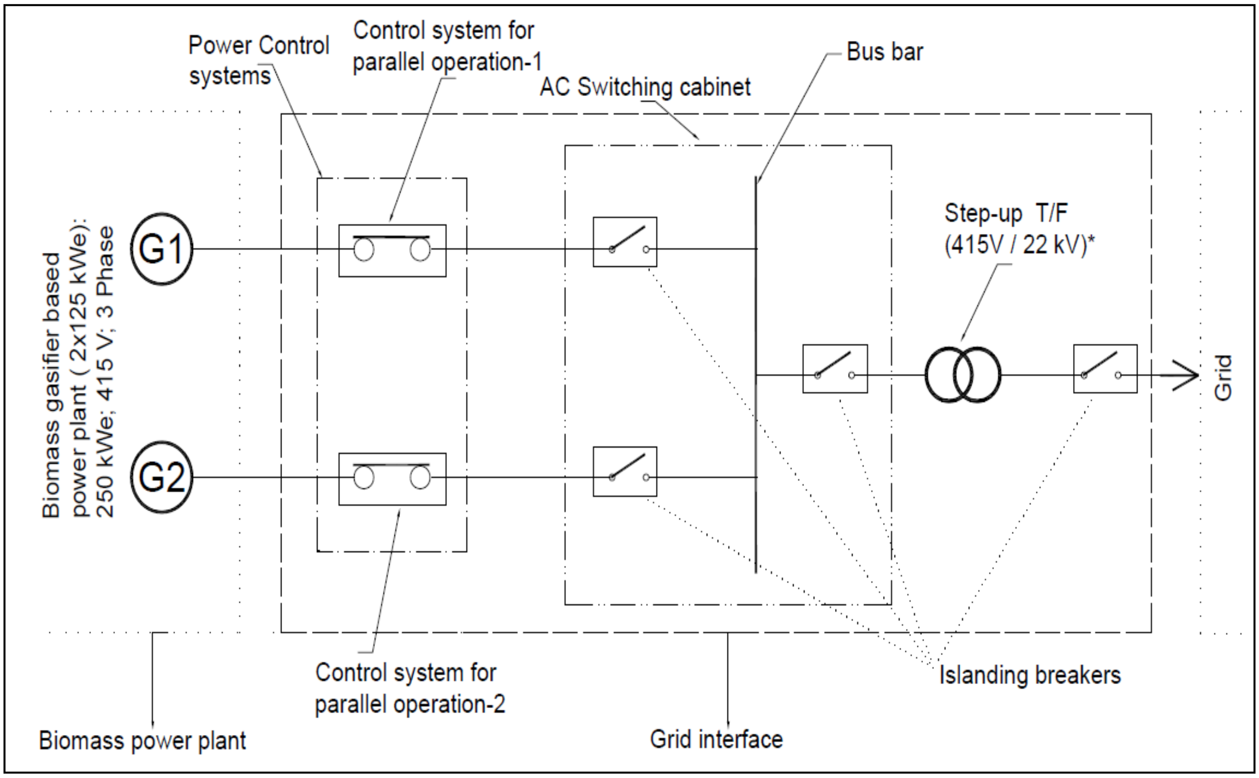

Figure A: Details of the grid interface along with components

Control system of the grid interface system should be capable of controlling the output power and supply quality to the grid. The power controller specifications should be as per the guidelines specified by the electricity authority of Thailand.

Generally, the guidelines specified by “Electricity Authority” include the following points:

1. Harmonic current injections shall not exceed the specified limits
2. The power from the grid interface system shall not inject Direct Current greater than specified percentage of the full rated output at the interconnection point.
3. The power from the grid interface system shall not introduce flicker beyond the limits specified.
4. The grid interface system shall be equipped with automatic synchronization device.
5. The circuit breakers of thee grid interface system shall be equipped with 3-phase devices with electronic or electromechanical controls.
6. The grid interface system shall be equipped with the following protective functions to sense abnormal conditions on electricity system and cause the distributed generation resource to be automatically disconnected from electricity system or to prevent the distributed generation resource from being connected to electricity system inappropriately.
    a. Over and under voltage trip functions if voltage reaches beyond the specified range, respectively with a specified clearing time.
    b. Over and under frequency trip functions, if frequency reaches beyond the specified range
    c. The grid interface system shall cease to energize the circuit to which it is connected in case of any fault in this circuit.
    d. A voltage and frequency sensing and time-delay function of the grid interface system shall prevent the distributed generation resource from energizing a de-energized circuit and to prevent the distributed generation resource from reconnecting with electricity system unless voltage and frequency is corrected within the prescribed limits and are stable, and
    e. Adequate earthing system need to be provided for the design capacity of the proposed power plant.
7. The equipment of the grid interface system shall meet the requirement of circuit breakers or other interrupting equipment. The circuit breakers or interrupting equipment shall be suitable for their intended application with the capability of interrupting the maximum available fault current expected at their location.

Annexure - 4

Feasibility study for setting up 1 MW biomass based power system in Phrae Province, Thailand

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Chapter - 1 Introduction

1.1 Background

During the field visit it has been requested to conduct a feasibility study for a 1MW biomass power plant using corn stover as feedstock.

The National Renewable Energy Master Plan (2008-2022) of Thailand aims at increasing the share of renewable energy production in the country's overall energy supply to 20.3% by 2022. To achieve the above target, the plan aims at increasing biomass based electricity from 1,610 MWe to 3,700 MWe by 2022, mainly from agricultural residues. In 2010, it was estimated that the biomass residue availability in Thailand was around 72 million tons. Based on that estimation, there is a potential for at least 6,000 MWe of electricity generation from biomass.

In the last 15 years, the Government of Thailand has taken significant steps to promote biomass power generation. There are many small agro and wood processing industries in Thailand, where the biomass residues are either unutilized or underutilized. In such situations, the biomass based power generation will be the most suitable for electricity generation.

1.2 Key Objective

The key objective of this study is to assess the availability of biomass for 1MW biomass based power system in Phrae Province, Thailand.

1.3 Specific Objectives

The specific objectives of the study are

- Agricultural biomass assessment in the Phrae province
- Study of fluidized bed systems
- Feasibility study for setting up 1 MW biomass system

This report provides the information on agricultural biomass assessment in the Phrae province. The technical details about the available fluidized bed systems that can be used for power generation and also indicative cost details for 1 MW power plant is given in the report.

Chapter 2 Phrae Province

2.1 Background- Phrae Province

Phrae Province is one of the most ancient cities of Northern Thailand. Phrae was established in 1371 B.E. by Phaya Pol. The former name wad "Pol Nakorn", then changed to "Wiang Ko Sai" which means "Silk Cloth". With one of the largest reserves of teak forests in Thailand.

2.2 Geography

Phrae covers an area about 6538.6 square kilometers and surrounded on all sides by mountains with level plains in the middle. Phrae lies on the Yom River, at an elevation of 159 meters (522 ft.). The town is mostly built on the east side of the river, but some outlying parts are built on the west side of the river and are connected to the main part by bridges. There are hills both to the east and west of the town; the Phlueng Range to the east is higher, reaching about 800 meters (2,600 ft.) above sea level, whereas the Phi Pan Nam Range to the west is about 500 meters (1,600 ft.) above sea level. The location of Phrae province in Thailand is shown in Figure A.

Figure A: Map of Thailand

2.3 Administrative structure

The Phrae province is subdivided in 8 districts. These are further subdivided into 78 communes and 708 villages. The districts are Muang Phrae, Rong Kwang, Long, Sung Men, Den Chai, Song, Wang Chin and Nong Muang Kai.

2.4 Agro- ecological zones

Thailand is recognized for distinct agro- ecological zones, the southern, central plains, northern and northeast regions. These zones are influence of different weather conditions. The Equatorial zone (Southern Region), which receives 1900-4700 mm per annum with 8.0-11.0 humid months, while three Monsoon zones (Central Plains, Northern and Northeast Regions) which receive 940-2150 mm per annum with humid months ranging from 4.5-8.0 depending on region (Eelaart 1973). Due to varied ecological conditions, the crop pattern is also differs in different regions of the country.

- The Southern Region is dominated by plantation agriculture principally rubber, oil palm, fruit trees and coconuts etc.

- The Central Plains Region lies in the lower watershed of the Chao Phraya River and comprises fertile alluvial soils which are seasonally flooded. The region receives an average annual rainfall of 1260 mm and over 90% of farm holdings are cropped principally to rice. Hence the region is known as the rice bowl of Thailand.
- The Northern Region comprises 3 physiographic zones
- The lowlands (15% of the area), which are relatively flat with fertile alluvial basins, and which produce paddy rice.
- The uplands (45% of the area) which are undulating to hilly in terrain to 500 m above sea level. Principal land use is upland rice, maize, grain legumes and other field crops.
- The highlands (40% of the area) which range in altitude from 500 - 2500 m, and comprise rugged steep sided mountains which are dissected by high valleys. Crops such as rice, maize are cultivated.
- The Northeast Region is a slightly elevated plateau. Principal land use in the region is rain fed paddy rice, upland field crops, forest lands and grazing lands.

The study is focused on biomass potential assessment in the Phrae province to set up a biomass based power plant of 1 MW capacity.

Chapter 3 Biomass Potential in Phrae Province

Thailand is an agricultural country, after harvesting there will be a large amount of agricultural waste left which could be used as biomass energy. In order to promote the biomass based energy generation in that particular area, it is important to assess the biomass energy potential.

Phrae Province comes in the northern region of Thailand. Province has a tropical savanna climate. Winters are dry and warm. Temperatures rise until April, which is very hot with the average daily maximum at 37.3 °C. The monsoon season runs from May through October, with heavy rain and somewhat cooler temperatures during the day, although nights remain warm.

3.1 Agricultural production in Phrae

The agricultural biomass assessment for the Phrae province is done using the agricultural statistics for 3 years[1] (2010, 2011 and 2012) for rice and Maize and 2 years data (2012 and 2013) for Cassava and Sugarcane. The data was further analyzed and evaluated to assess the quantity of biomass which can be used to produce energy. The major crops focused under the study are rice, maize, cassava and sugarcane. In the Table A below, area, production and yield of major crops of Phrae province is provided.

Table A: Plantation area, Production and Yield of major crops in Phrae Province

	Planted area (rai)			**Production (Tons)**			**Yield per rai (Kgs)**		
Crop	2010	2011	2012	2010	2011	2012	2010	2011	2012
Rice	621,300	613,519	645,883	365,570	399,624	408,318	588	651	632
Maize	219,913	253,934	255,742	136,446	161,109	162,779	620	634	636
Cassava		10,243 (2012)	11,175 (2013)		31,550 (2012)	36,039 (2013)		3,080 (2012)	3,225 (2013)
Sugarcane		2190 (2012)	2242 (2013)		24,410 (2012)	25,412 (2013)		11,146 (2012)	11,335 (2013)

3.2 Biomass residue production in Phrae

For calculating the residue potential, the crop production data is averaged out and Residue to Product Ratio (RPR) values are taken from reference[2]. The residue production from the major crops in Phrae is provided in Table B.

1 Agricultural Statistics of Thailand. Bangkok, Thailand: Office of Agricultural Economics; 2012199

2 W. Soontornrangson et al., Potential Crops Residues and Industrial Wastewater as Renewable Energy Resources for Thailand, Institute of Scientific and Technological Research

Table B: Total residue production from Major Crops in Phrae Province

Crop	Total Crop Production (tons)	Residues	Residue to Product ratio (RPR)	Total Residue Production (tons)
Rice	391,171	Husk	0.266	104051
		Straw	1.19	465493
Maize	153,445	Cobs	0.189	29001
		Leaves and stalks	0.892	136873
Cassava	33,795	Stalk, top and leave	0.121	4089
		Rootstock	0.091	3075
Sugarcane	24,911	Tops and leaves	0.201	5007
		Bagasse	0.303	7548
			Total agricultural residue available	**755,138**

However, there is large amount of biomass is available in Thailand but in last 10 years since the petroleum price has increase, industrial sectors, instead of using petroleum fuel, used biomass fuel to replace petroleum fuels to reduce cost of production and to eliminate waste in the plant. At the present time, industrial plants and power plants have increased their demand for biomass, therefore it cannot be assumed that all the available agro residue can be used for biomass power generation while it is utmost important to estimate the consumption of agro residue for different application.

The data for residue consumption used for this study is taken from the report prepared by Department of Alternative Energy Development and Efficiency, Ministry of Energy, Thailand. In this report, for each crop residue, the consumption data at country level is provided. Using that consumption data, available biomass resource in Phrae province is calculated and presented in Table C.

Table C: Total residue available after consumption in Phrae Province

Crop residue	Residue production (tons)	Consumption (%)	Residue consumed (tons)	Residue left (tons)
Rice Husk	104051	80	83241	20810
Rice Straw	465493	10	47015	418478
Maize Cobs	29001	82	23897	5104
Maize Leaves and stalks	136873	5	6844	130029

Cassava Stalk, top and leave	4089	80	3271	818
Cassava Rootstock	3075	100	3075	0
Sugarcane Tops and leaves	5007	10	521	4486
Bagasse	7548	100	7540	8
Total residue available for power generation				175404

3.3 Biomass potential from Corn Stover and Rice husk for power generation

In Phrae, corn and rice are the major crops and from the study done on consumption of agro –residue in Thailand, it is envisaged that there is huge potential of power production in Phrae province from corn stover as more than 90% residue is unutilized. Further, rice husk can be an additional resource for the biomass based plant having potential of more than 4 MW in Phrae province.

Based on the biomass assessment, about 0.13 million tons of corn stover is available in the Phrae. For a 1 MW biomass based power plant, assuming 300 days and 24 hours operations, about 13000 tons of corn stover is required. Therefore, a huge amount of stover is available that can be used for power generation.

3.4 Potential site in Phrae Province

3.4.1 Huaymai Sub-district, Song District, Phrae Province

There are 17 villages in Huaymai sub-district of Song District, Phrae Province. The area of the sub-district is 173 square kilometers. The potential fuels for the biomass power plant from the location are corn cobs, rice husks and wood chips. At Huaymai sub-district, there are 5-6 rice milling plants and large corn plantation area. The corn cobs and corn husks are potential feedstock for power generation.

3.4.2 Tao Poon Sub-district, Song District, Phrae Province

The Tao Poon Sub-district of Song District is another potential site. The area of the sub-district is 339.01 square kilometer or 211,878.75 rai (33,900.6 hectares). There are 12 villages in the sub-district. The main water resource is Song River which can be used for agriculture. The potential raw materials for biomass power plant are corn cobs, corn husk, bamboo wastes from chopstick factories and wood chips. Agriculture is the major source of income for the villagers; corn plantation accounts for around 87 per cent of total area of plantation. The area of corn production in the sub-district is 13,531 rai or 2,164.96 hectares. There are 4-6 corn milling yards and 3 chopstick factories in the area. The quantity of bamboo nodes from the sub-district is around 30-45 tonnes per month.

Chapter 4 Biomass based technologies for power generation

Biomass gasification is the process of partial combustion of biomass under controlled air supply, thus producing a mixture of gases called "Producer gas". It is a thermo-chemical (chemical, and heat) process in which solid biomass is converted into a gaseous fuel by a series of chemical reactions. The producer gas will consist mainly of carbon monoxide (CO), hydrogen (H_2), methane (CH_4), nitrogen (N_2), and carbon dioxide (CO_2). The first three of these are combustible gases.

4.1 Types of gasifiers

Generally, two types two types of gasifier design are popularly used for biomass based power generation system. They are fixed bed and fluidized bed gasifiers. Fixed bed gasifiers are used for solid biomass having high bulk density and fluidized bed gasifiers are used for low- density and loose biomass.

- **Fixed Bed Gasifiers**

Fixed bed gasifiers typically have a fixed grate inside a refractory-lined shaft. The fresh biomass fuel is typically placed on top of the pile of fuel, char, and ash inside the gasifier. These gasifiers are fuel specific and always suitable for solid biomass, which has bulk density of the order of 300 to 350kg/m^3. The size of the fuel needs to be at least 50mm x 50mm x 50mm (l x b x h) and moisture content less than 5-10%. Fixed bed gasifiers are used for small scale, less than 1 MW, power and thermal applications.

- **Fluidized bed reactor**

Fluidized bed gasifiers utilize the same gasification processes and offer higher performance than fixed bed systems. Similar to fluidized bed boilers, the primary gasification process takes place in a bed of hot inert materials suspended by an upward motion of oxygen-deprived gas. As the amount of gas is augmented to achieve greater throughput, the bed will begin to levitate and become "fluidized." Sand or alumina is often used to further improve the heat transfer. Notable benefits of fluidized bed devices are their high productivity (per area of bed) and flexibility. Fluidized bed gasifiers can also handle a wider range of biomass feedstock with moisture contents up to 30 percent on average.

For the light- weight, loose ligno- cellulosic biomass (like rice husk, corn stover etc.) fluidized bed gasification is the most appropriate technology. The fluidized bed gasifiers are generally of two types, Bubbling Fluidized Bed (BFB) and Circulating Fluidized Bed (CFB). A schematic of fluidized bed gasifier system is depicted in Figure B.

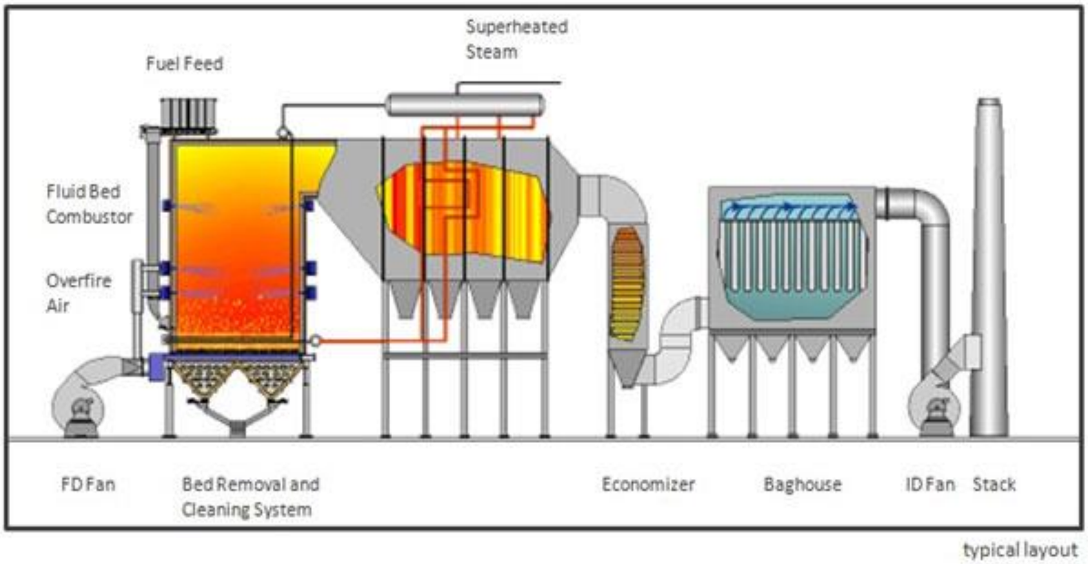

Figure B: Schematic diagram of fluidized bed fired furnace with steam generator

The typical characteristic of fluidized bed gasifiers is presented in Table D.

Table D: Specific characteristics of a fluidized bed gasifier

Characteristics	Specifications
Fuel Size (mm)	1-20
Operating temperature (◦C)	750-950
Turndown ratio	3
Capacity (MW)	1-50

4.2 Fluidized bed technology based combustor/gasifier suppliers

Fluidized bed is a well- known technology around the World. The information of selected technology providers is presented in the Table E.

Table E: Technology providers for Fluidized bed gasification systems

Supplier	Details of Technology
ANDRITZ Carbona, Austria	• Originally licensed from the Gas Technology Institute, United States (U-gas and Renu-gas processes). • Both, bubbling and circulating fluidized bed gasifiers are provided by the Carbona. • Gasifier is used in numerous applications for heat, power, or synthesis gas generation.
Babcock & Wilcox (B & W) Volund, USA	• B&W's offers both BFB and CFB plant. • B&W uses the original, 100 percent open-bottom BFB design, which is ideal for burning fuels containing large pieces of non-combustible material. • The B&W's IR-CFB boiler design employs a patented two-stage particle separation system to provide high-solids loading and a uniform furnace temperature profile.
	• Foster Wheeler offers circulating fluidized bed combustion technology consists of a boiler and a high-temperature cyclone. • A coarse fluidizing medium and char in the flue gas are collected by the high-temperature cyclone and recycled to the boiler. • The intra-furnace gas velocity is as high as 4 to 8 m/s. • To increase the thermal efficiency, a pre-heater for the fluidizing air and combustion air, and a boiler feed water heater, are installed.
Outotec, Finland	• 'Outotec Energy Products' is formerly known as 'Energy Products of Idaho' – EPI. • The technology use a heated bed of sand like material suspended within a rising column of air to burn many types and classes of fuel. • The scrubbing action of the bed material on the fuel particle enhances the combustion process by stripping away the carbon dioxide and char layers that normally form around the fuel particle. This allows oxygen to reach the combustible material much more readily to increases the rate and efficiency of the combustion process.
Repotec, Vienna	• The first gasification plant demonstrated at the Güssing power plant is based on the steam gasification of biomass in the internally circulating fluidized bed. • The plant has two interconnected fluidized bed systems. In the gasification unit the dried biomass is being gasified at approximately 850°C under injection of steam (instead of air) as gasification which creates a nitrogen-free, low-tar producer gas with high calorific value. • The flue gas produced in the oxidation zone is cooled down, dust is removed and finally it is purged by the stack. The heat is used to operate an ORC module in order to improve the electrical efficiency.

Chapter 5 Investment requirements for 1 MW fluidized bed gasification system

This section provides the information about the investment requirements of 1MW biomass gasifier based power plant.

Plant Capacity: 1 MW

Biomass: Agricultural residues (Corn stover and Rice husk)

Technology: Fluidized bed biomass fired furnace – steam turbine – power generator

The cost details for an implementation project can be divided into two parts: fixed cost and variable cost.

Fixed cost: The fixed cost is the capital cost of the plant and other important units. The fixed cost for 1 MW BFB and CFB biomass gasification plant is in the range of 2 to 2.5 million €[3] that includes the cost of following components[4]:

- Building, infrastructure, outside facilities
- Gasifier
- Producer gas cleaning
- Ash container and conveyor
- Heat recovery
- Fuel conveyor
- Crane
- Electrical and hydraulic installations
- Fuel storage unit
- Project planning and implementation
- Vehicles

[3] Prefeasibility study for biomass power plant, Namibia, 2012. WSP, Environment & Energy South Africa

[4] Obernberger I and Thek G., 2008. Cost assessmernt of selected decentralised CHP applications based on biomass combustion and biomass gasification. To be published in: Proceedings of the 16th Europeon biomass conference & Exhibition, June 208, Valencia, ETA- Renewable Energies (Ed.), Itlay

Variable cost: The variable cost (which is the cost for operation and maintenance) of a 1 MW fluidized bed based power plant is about 1.2-1.3 million €. The variable cost includes the cost of the following components:

- Fuel
- Electricity (Auxiliary energy)
- Ash disposal
- Manpower
- Consumables
- Maintenance cost etc.

For a 1 MW gasification plant, about 10- 12 persons are required. The consumables- required are chemicals, water, electricity, auxiliary fuel etc. Maintenance cost comprises the routine maintenance and lifecycle maintenance (replacement of major plant items). The annual maintenance cost as a rule of thumb is about 2.5% of plant capital cost. Besides, the cost of land is significant for implementation of such big projects.

Chapter 6 Conclusions

In Phrae province, agricultural residue particularly corn stover and rice husk are available which is substantial to set up 1 MW biomass based power plant. Further, for the conversion of agricultural residues into energy, fluidized bed based technologies are most appropriate. Fluidized bed technologies are commercially available around the World and there are several technology providers who are well recognized. A list of technology providers were identified. A brief detailing on cost estimate for such plant is provided in the report. Since, the biomass waste like corn stover and rice husk are abundant and involves only transportation cost, it is feasible to set- up a 1 MW biomass based power plant using fluidized bed combustion/ gasification technologies. The fluidized bed combustors can be coupled with steam generation system to run steam turbines.