INDUSTRIAL HEAT ENERGY

Introduction

Biomass derived energy provides around 51% of the total primary energy need in Sri Lanka as indicated in figure 1. Petroleum fuels provide around 37% and hydro electricity 12%.

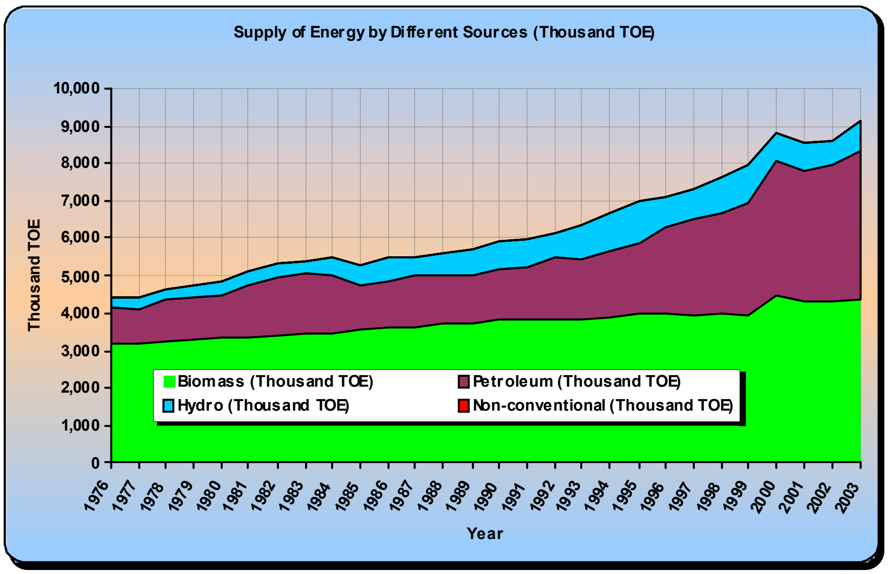


Figure 1. Supply of Energy in Sri Lanka (Source – BEASL)

Virtually all the biomass consumed for energy is for supply of heat. The largest use is by the domestic sector as cooking fuel and this sector is considered elsewhere. Figures showing the pattern of biomass use in various sectors are provided in table 1.

Sector/Industry	**2002**		**2003**	
	tonne	**%**	**tonne**	**%**
Agro industry				
Tea	620	5.6	610	5.4
Rubber	91	0.8	92	0.8
Coconut	82	0.7	120	1.1
Manufacturing				
Brick	890	8.1	950	8.4
Tile	630	5.7	630	5.6
Lime	260	2.4	280	2.5
Commercial				
Bakeries, hotels & eating houses	470	4.3	430	3.8
Household Cooking	8000	72.4	8200	72.5
Total	**11043**		**11312**	

Table 1 Biomass Energy Use in Sectors (Source: Sri Lanka Energy Balance – 2003, ECF)

Table 1 shows that the principal industrial users of biomass energy are in traditional industries such as brick and tile manufacture, and in tea production. Many of these traditional industries remain totally reliant on fuel wood as their main energy resource

Fossil fuel is also widely used to provide heat energy in various industries but this paper will focus on the use of biomass for heat in industrial applications. It will outline design considerations that apply to use of biomass for supply of industrial heat. Emphasis is given to key issues for selection of equipment and characterization of biomass as a fuel.

The use of electricity by industry, including the potential for biomass derived power, through combined heat and power systems is covered elsewhere.

It is useful to examine the pattern of energy consumption by energy type and this is outlined in table 2. It will be seen that 74% of industrial needs were provided from biomass in 2002, i.e. it is by far the main source. However due to the low price of biomass in terms of the value of the different energy requirements biomass is the lowest, with electricity being the predominant energy cost.

	Energy Consumption (Amount in thous. TOE)					**Energy Consumption (Value of in milln. Rs.)**		
	2000	**2001**	**2002**			**2000**	**2001**	**2002**
Biomass	1178	1000	1208		Biomass	1767	1500	1812
Electricity	167	173	157		Electricity	10719	13216	15317
Petroleum	261	235	264		Petroleum	5220	5405	6600
Total	**1606**	**1408**	**1629**		**Total**	**17706**	**20121**	**23729**
	2000	**2001**	**2002**			**2000**	**2001**	**2002**
Biomass	73%	71%	74%		Biomass	10%	7%	8%
Electricity	10%	12%	10%		Electricity	61%	66%	65%
Petroleum	16%	17%	16%		Petroleum	29%	27%	28%

Table 2 Industrial energy needs in Sri Lanka by type (BEASL)

This reversal in order of ranking in the amount used and value of energy is a direct consequence of the low cost of biomass energy in Sri Lanka in comparison to other fuels. This is amplified by the data provided in table 3. This shows that there are considerable cost benefits in using biomass energy wherever this is possible.

Type of Fuel	**Density kg/lt**	**Calorific Value Kcal/ Kg**	**Current Prices Rs/ Lt inc. VAT**	**Energy Cost Rs / 10mill. cal**
Furnace Oil	0.95	10,200	31.50	30.88
Diesel	0.87	10,500	50.00	47.60
LPG	1.77 kg/m^3 @STP	11,000	890.00 / 12.5 Kg	64.72
Coal		6500	10.20 /kg	15.69
Wood @ 20 % H_2O	0.3	3700	2.50/Kg	6.75

Table 3 Comparative costs of energy for industrial heating in Sri Lanka by fuel type (BEASL)

The availability of different biomass materials that can be used in a sustainable way to provide heat energy in Sri Lanka is given in table 4.

Type	MT / Year	%
Rice Husk available from commercial mills	179,149	6.2
Biomass from Coconut Plantations available for industrial use	1,062,385	37
Sugar bagasse	283,604	8.3
Bio degradable garbage	786,840	27.4
Saw dust	52,298	1.8
Off cuts from timber mills	47,938	1.7
Biomass from home gardens, e.g Gliricidia	505,880	17.6
Total	2,873,880	100

Table 4 Different biomass materials available for industrial heat in Sri Lanka by type (BEASL)

Major Design Factors for Biomass-Fuelled Industrial Heat Systems

Major factors influencing design of equipment are:

- Fuel properties (e.g. bulk density, moisture, proximate and ultimate analysis, calorific value, ash properties, and size characteristics)
- Thermal requirement (e.g. heat load, processing temperature, furnace and heat exchanger design, etc.)
- Economics (e.g. cost of available fuels, labour rates, equipment costs)
- Local factors (e.g. operational and construction/maintenance skills, spares availability, roads and local infrastructure, environmental legislation)

Knowledge of fuel properties is a prerequisite for both design and operation. Key aspects are described later. Once fuel properties are ascertained, the design approach to sizing of a furnace and heat exchanger system involves the theoretical steps outlined below:

1. Estimate process heat requirement and overall thermal efficiency
2. Determine net calorific value of fuel and estimate fuel consumption rate
3. Estimate combustion airflow rate
4. Calculate mass flow rate, temperature and heat flow in exhaust gas stream
5. Design fuel combustion furnace requirement
6. Choice and design of heat exchanger
7. Calculate heat transfer to system, estimate heat losses

In practice, design and specification for any particular duty will be an iterative process that draws extensively upon the experience of equipment suppliers and industrial know-how. The primary choice that has to be made in any specific application is the combustion and heat exchanger system. Other key features are the methods of fuel handling, air supply, ash removal, and flue gas quality control.

Combustion Systems

Grate systems are the most common combustion arrangement. These are used for burning a variety of biomass materials. The grate supports the fuel that is fed from above and allows combustion air to circulate freely. The grate may be flat, conical, stepped or sloping, and it may have mechanical movement to alleviate ash removal. The grate is a cast-iron grid on which the fuel is fired with primary air introduced under the grate and drawn up through the bed of burning fuel. Supplementary secondary combustion air is introduced above the bed. Underfeed stokers are sometimes used for particulate biomass and are similar to grate burners. Various other systems with gas phase combustion are applicable for particulate biomass e.g. suspension, gasification or fluid bed burners.

Flat grate traditional designs, involving hand-firing of fuelwood logs are still commonly used in the agroprocessing industries such as tea and coconut. These may be of modular construction and are used to service smaller heat loads of up to 1MW.

Inclined or sloping grate systems are used for a wide range of heat loads from about 1 MW to 100 MW. At larger capacity, systems with particulate fuels require automatic stoking to introduce fuel to the top of the grate allowing a progressive downward flow of the fuel. In the progression of the fuel, drying, evolution of volatiles and burning of char take place, and ash is removed from the bottom of the grate. A typical system is illustrated in the figure 2. Sometimes spreader-stoker mechanisms are used to spread the fuel laterally across the grate.

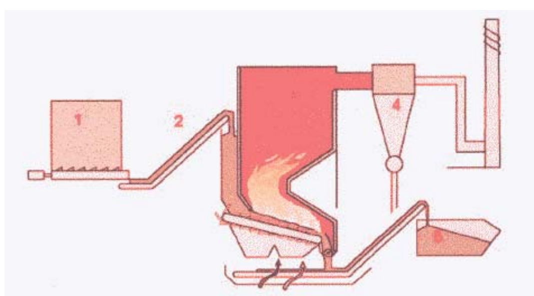


Figure 2 – Inclined or sloping grate biomass firing system: fuel bunker(1), fuel feeder (2), furnace (3), fly ash removal (4), and bottom ash discharge(5). (COGEN3, 2003)

The rate of release of heat in grate systems is a function of the fuel supply and is controlled by adjusting the primary airflow to maintain near stoichiometric levels. Completion of the combustion process then occurs in the gas-phase above the bed, through controlled addition of secondary air into the combustion chamber.

With automated combustion and with combustion of some specialized biomass materials, **moving or vibrating grate** mechanisms are needed. These may involve chain-like conveyors or oscillating bars.

Under-fed stokers are another combustion systems used for biomass and a typical system is illustrated in figure 3.

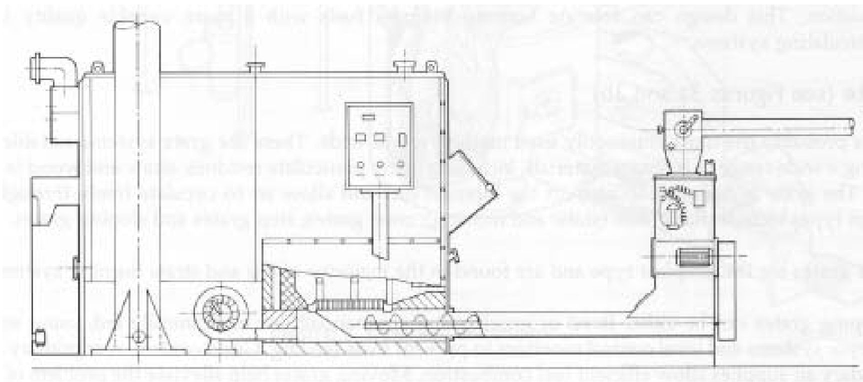


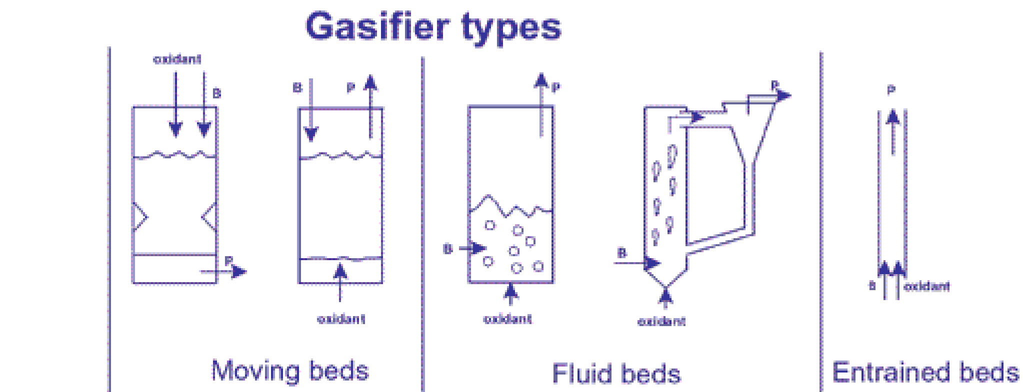
Figure 3 - Underfeed Stoker (Sarwar et al, 1992)

Under-feed stokers are used for combustion of particulate biomass with relatively high moisture content. The fuel is introduced into the middle of the furnace by means of a screw feeder creating a mound of fuel at the base of the combustion chamber. Primary air is blown through this mound of fuel and secondary air is introduced above the fuel mound. These systems are used for thermal duties up to 5 MW.

Suspension and cyclonic burners (also designated **pulverised** fuel burners) are a type of gas phase combustion suited to particulate fuels. Fuel is blown into the combustion zone. They meet duties from around 0.5 MW upwards and are often used for retrofitting or modification of fossil fuel burners to use biomass fuel. The fuel needs to be of regular size, relatively low moisture content, and with high ash fusion temperatures to avoid fouling. With these systems, removal of fly ash from the exhaust gas is necessary through gas cleaning devices such as cyclones or bag filters before venting from the exhaust stack. These can offer high combustion efficiencies at a range of thermal capacities.

Large coal fired power stations burning pulverised coal in multiple fuel injectors (with possibly 10+ GW thermal rating) are an important example of this combustion technology. In the past decade it has been established that particulate biomass fuel can be added to coal in such systems up to around 10%. This is a major development since these power plants with their high-pressure boilers are extremely efficient and offer the highest available conversion efficiency for biomass to power of up to 40%. (N.B. Whist this is not a topic appropriate for detailed cover in this context, it is important to note that where any such coal power plant exists it may generate high demand and thereby distort the supply and availability of biomass fuel for thermal applications.)

Pre-combustion or gasification of biomass is a another commonly used technique for industrial thermal application, especially for retrofitting or modification of oil or gas fossil fuel burners to use biomass fuel.



	Co-current	Counter current	dense	circulating	
T°C	700-1200	700-900	< 900	< 900	[illegible]1500
tars	low	very high	intermediate	intermediate	absent
control	easy	very easy	intermediate	intermediate	very complex
scale	$< 5\ MW_t$	$< 20\ M_t$	$10 < MW_t < 100$	$20 < MW_t < ?$	$> 100\ MW_t$
feedstock	very critical	critical	less critical	less critical	very fine particles

Figure 4 - Gasification types

A variety of designs of gasifier types are available as is shown in figure 4 where some key considerations are summarized. For thermal application as opposed to power, the level of tars from any type of gasifier is less critical - so selection will predominantly be decided from operational scale and feedstock characteristic.

Heat supply through biomass gasification has a long history. Counter-current or updraft gasifiers were important in early industrialization and downdraft or co-current gasifiers had extensive use in WW2 as means of powering vehicles in the absence of fossil fuel. Commercial systems for both types continue to be available from suppliers in Europe, as well as from India and Sri Lanka. Various successful examples of the latter are described in the Conference Proceedings of this project.

Since the mid 1980's commercial fluid bed biomass gasifiers (see section below on fluid bed technology) have been introduced in Europe and elsewhere for heat supply. These only have application for large industrial thermal duties.

Fluidized bed combustion is suited to particulate and chipped fuels. It provides good combustion control and heat transfer characteristics. It is a relatively more complex and expensive technology than conventional grate systems, so it is more applicable for higher duty applications when cost benefits in operation and fuel efficiency balance additional installation costs. It is not usually applied for heat loads below 10 MW, but it is now the preferred technology for biomass-fuelled steam boiler in power and CHP applications.

Fluid bed combustion systems have a combustion chamber containing a sand bed that acts as the heat transfer medium. The sand bed is fluidized by combustion air that enters through a perforated base plate. The system requires preheat but then operates by sustained combustion of particulate biomass fuel fed into the bed. Bed temperature is maintained typically in the range 850-900 C through removal of heat by heat exchanger elements within the sand bed.

In bubbling fluidized beds combustion products separate from the sand at the top of the fluid bed and travel through to a boiler or other heat generating system. Some secondary air is added to the freeboard space above the fluidized bed.

Circulating fluidized bed systems use air at greater velocity compared to bubbling beds, and achieve higher efficiency with increased heat transfer rates. They require cyclones for gas/solid separation and are applicable at higher thermal capacities.

Overall Heat Exchange System

For any given installation, the combustion system will normally be an integrated part of the overall heat exchange system. In general, any of the combustion systems described above can be combined within one of the overall heat exchange system below:

- Low pressure hot water boiler
- Low pressure super-heated water boiler
- Low pressure steam boiler
- High pressure saturated steam boiler
- High pressure super-heated water boiler
- High pressure super-heated steam boiler
- Thermal fluid heat exchanger
- Combustion gas-to-air heat exchanger

Different manufacturers supply equipment across this range and will offer overlapping choices. Economic and local factors also influence selection of such equipment and features that apply in relation to the Sri Lanka situation are described later.

Fuel Handling

Selection of suitable handling equipment for biomass fuels is important. Biomass fuel quality is very variable in terms of moisture content, shape and size, and contamination. Flow properties are strongly influenced by such quality variations.

Use of hoppers for particulate biomass storage is greatly dependent upon having effective discharge equipment. Common devices are stirring screws, rotary screw conveyors, travelling screw conveyors and en-mass bottom grid conveyors. Such systems are expensive, so storage in piles is common.

Moving biomass fuel mechanically, as in automatic feeding into furnaces, will usually require either pneumatic, screw or trough type conveyors – with choice depending on the particular properties of the fuel.

Air Supply

Air supply for combustion in simple systems may be through natural draught induced by a chimney. The major air requirement is for primary air, which with grate systems is introduced below the burning bed of fuel on the grate and is drawn up through the combustion zone. Secondary air is fed in above the grate to complete combustion.

For larger systems fans or blowers are commonly required to induce the air flow. A common method will be to have an exhaust stack blower, thereby holding the pressure down within the furnace itself. Air fans and blowers are an integral part of suspension and fluid bed combustors, since the fuel has to be transported pneumatically to enable gas phase combustion.

Ash Removal

Ash content in fuelwoods or waste wood is generally less than 5%, unless there is contamination. Ash handling systems with these materials can therefore normally be of smaller capacity than used in coal furnaces and are often manual. Some gate systems rely on an ash coating to maintain a low grate temperature.

In contrast, ash content with certain agricultural residues may be over 20%. Rice husk is one notable example and as rice husk ash has high silica content, it can be very abrasive with mechanical handling equipment.

Ash from uncontaminated biomass fuel is often used as fertiliser since it normally is high in potassium and phosphorus. The high-silica content ash from rice husk combustion systems can be a saleable by-product.

Flue Gas Quality

Control of quality of flue gas discharge may be a requirement to meet emission standards for pollution abatement.

Removal of fine ash particles can be achieved through use of cyclones, bag filters and electrostatic filters, or a combination of these.

Maintenance of good combustion conditions will normally avoid unacceptable gaseous emissions of volatile organic compounds (VOC), carbon monoxide (CO), nitrogen oxides (NO_X) and sulphur dioxides (SO_2). (Tariq et al, 1996)

Most biomass fuels are low in chlorine thereby avoiding any risk of emission of chlorinated organic compounds or dioxins in the flue gas. However it is important to check the elemental analysis of all biomass fuels, particularly for chlorine and heavy metals content, since if these arise then special combustion systems and/or ash disposal methods may be needed to maintain acceptable emission levels.

Local Factors

In Europe, much commercial activity in biomass energy technology is focussed on equipment for heating buildings. Whilst such duties do not apply for Sri Lanka and neighbouring countries, these systems may be of relevant thermal capacity for other kinds of applications. However, as this equipment will be designed to meet levels of automation and environmental legislation that are not currently applicable to this region, it is not easy to match such types of equipment for local use. European suppliers of traditional equipment to the plantation industries have now largely vanished and equipment needs are increasingly met more competitively from within the region.

Many traditional biomass-fuelled systems for heat applications are still operated in the plantation industries of SE Asia. Typical of these are the wood-burning furnaces for supply of hot air for tea and desiccated coconut drying. These furnaces are generally made up from cast iron elements that are assembled on site with appropriate furnace brickwork. This modular style of design was adopted due to the transport difficulties to remote locations and for ease of repair and maintenance of equipment on site. These constraints can often still apply.

It is difficult to sustain good fuel efficiency on such equipment since they are very sensitive to operation and management. In many cases these systems have been adapted to burn fuel oil, often with poor efficiency. Any review of biomass energy technology for the region needs to address the potential for energy efficient use of biomass in existing applications within the plantation industries. It is important to acknowledge the continuing traditional skills that exist to maintain these industries but also it is necessary to make provision for appropriate up-dated technical training to managers and operators.

There is a large potential for well-engineered modification or re-design of equipment. The NERD Centre paper at the recent Conference in this project described a notable example of initiative in this area. This paper described a design of retrofit to burn *Gliricidia sepium* wood chips as a substitute to woodfuel logs on traditional furnaces in the tea industry. Tests of this design have shown greatly improved fuel efficiency on the furnaces at around 77% and this represents a 47% saving of fuelwood compared to previous practice.

Properties of Biomass Fuels

Three key properties that determine the overall applicability of different types of biomass as fuel are:

- Moisture content, i.e. the % water content per unit weight of wet material
- Bulk density, i.e. mass of loosely packed material per unit volume
- Gross calorific value - a measure of energy content, technically defined as the heat released on combustion in an oxygen-filled bomb calorimeter at constant volume.

Standard analytical techniques are used to determine these properties and other fuel related properties. More information will be given below about fuel analysis and detailed procedures are well documented elsewhere. (Hollingdale et al, 1999), (Tariq et al, 1994)

Energy Density

Table 5 shows how different values of key properties can greatly influence energy density of biomass fuels. Energy density is calculated in terms of the volume of different forms of biomass that provide the same energy content as is available from 1 m^3 of oil. Thus biomass can have up to100 times less energy density compared oil, although more commonly materials used for biomass energy have figures in the range 3 to 30 times less energy density. This low energy density has particular implications for cost of transportation and storage. In particular this shows how the logistics of fuel supply and location of the fuel consuming installation is of far greater significance when compared to fossil fuels. It also has implication for design of furnaces and ancillary equipment for fuel handling.

	Moisture	**Bulk**	**GCV**	**Energy**	**Vol of fuel**
	(Wet basis)	**Density**		**Content**	**≡1 m^3 oil**
unit	(%)	(tonne/m^3)	(GJ/tonne)	(GJ/m^3)	(m^3)
Straw					
Loose(unchopped)	15	0.03	13.5	0.4	102
Loose(chopped)	15	0.06	13.5	0.8	50
Large bales	15	0.15	13.5	2.0	21
Pellets	12	0.50	14.0	7.0	6
Wood					
Forest waste	50	0.3	8.4	1.7	24
Unseasoned timber (logs)	50	0.8	9.3	7.4	6
Seasoned timber (chips)	25	0.23	15.0	3.5	12
Process waste (shavings/etc)	12	0.12	16.5	2.0	21
Pellets	12	0.7	16.5	11.5	4
Wood Charcoal	5	0.4	34	12.5	3
Rice Husk	10	0.1	18.7	1.9	21
Sugar Cane Bagasse -loose	50	0.13	9	1.2	34
Coal	9	0.85	28	24	1.7
Oil	0	0.9	46	41	1

Table 5 - Energy density of some types of biomass fuel compared to fossil fuels

Chipping and size reduction of large size biomass, like logs, may be required to enable automated feed systems at the point of use as fuel. In contrast, densification of disperse or loose packed materials can greatly improve their energy density and reduce the cost of transportation and storage, though this will also make certain conditions on the design of combustion plant.

Fuel Preparation

Some solid biomass is difficult to handle and doesn't burn efficiently. Various fuel preparation processes are used to improve these situations such as:

- size reduction by chopping and grinding
- screening to provide a more uniform particle size
- mechanical and thermal drying to reduce moisture content
- classification/cleaning for removal of unwanted contaminants such as soil, rocks and scrap metal

These processes provide a fuel with improved flow properties, higher combustion efficiency and greater uniformity for better combustion control.

Another process for improving solid fuels is densification. In this process, the solid biomass is first dried, ground to a small size and then forced through a metal die. The metal die compresses and heats the biomass to produce solid fuels such as:

- logs that are sold for use in residential stoves and fireplaces
- briquettes for commercial combustors
- pellets for a wide range of automated combustion systems ranging from household stoves to large central co-generation boilers

Proximate Analysis

Proximate analysis is a standardized method to provide the essential basic fuel properties of moisture, volatiles, fixed carbon and ash content. This is done by weighing sampled fuel material before and after stages of controlled heating in a laboratory oven (for moisture) and a muffle furnace. These relatively simple techniques will provide all the normal fuel information needed for day-to day use of any biomass fuel.

Calorific Value

Calorific values of biomass fuels are derived from controlled combustion of samples in oxygen using a laboratory equipment item known as a bomb calorimeter. The standarised methods applied are those developed for coal.

Under the conditions of the test, water formed during the reaction remains in liquid form. This provides a value for Gross Calorific Value (GCV). In most operational conditions such water is vapourised so the latent heat of vapourisation of this water is not recovered. In such conditions the relevant calorific value is Net Calorific Value (NCF). There are routine calculations to derive values of NCV from GCV.

It is worth noting that for woody biomass an average value of 19.9 GJ/tonne on a dry, ash-free basis can be used for most routine calculations.

Ultimate Analysis

Ultimate analysis determines chemical composition of fuels in terms of carbon, hydrogen, oxygen, nitrogen and sulphur as mass percentages of biomass material. Generally nitrogen and sulphur are present only in small quantities in woody biomass. Ultimate analysis and GCV are usually reported on a dry and ash-free basis, to avoid the effects of contamination of sample with soil and the variability of the moisture content.

More detailed elemental analysis may be required in evaluation and control for operation with certain biomass fuel materials. For example, high chlorine and heavy metal content can create problems in emission quality waste ash disposal.

Ash Characteristics

When dealing with any potential fuel application of a biomass energy resource another important characteristics are its ash properties. Ash composition obtained analytically can have implications in the design, operation and control. In addition, ash fusion information is needed to anticipate the likely behavior of ash in combustion, and in the potential such ash has for fouling, clinker formation and erosion.

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