Co-firing of Biomass with Coal

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OBJECTIVES

Under the ***Renewable Energy (Electricity) Bill 2000,*** the renewables component of co-firing an eligible renewable energy source with fossil fuels will be eligible to receive renewable energy certificates (RECs).

This short report sets out a methodology to calculate electrical output (MWh) from renewable fuels when co-fired with coal. The objective is to develop a formula/formulae/methodology that a Generator can easily apply to biomass co-firing situations to calculate the number of RECs that may accrue to the Generator.

BACKGROUND

Initially, the AGO provided a simple methodology for co-firing with wood. This method was thought to cover all aspects of the issue, but representations from Generators have made it clear that a better method to cover all biomass is needed.

An example of the current method is shown below:

- FUEL 1: Wood 5% by weight 15 GJ/t 33% conversion
- FUEL 2: Coal 95% by weight 25 GJ/t 36% conversion
- Electrical energy output from wood = 0.05 x 15 x 0.33 = 0.2475 GJ/t fuel
- Electrical energy output from coal = 0.95 x 25 x 0.36 = 8.550 GJ/t fuel
- Total electrical output = 0.2475 + 8.550 = 8.7975 GJ/t fuel
- Percentage output from coal = 8.550 / 8.7975 = 97.2%
- Percentage output from wood = 0.2475 / 8.7975 = 2.8%

Therefore, if the output energy were 100 MWh, the Generator would receive 2.8 RECs.

This method is correct for the assumed efficiencies of the two fuels, 33% and 36% for wood and coal respectively. What the method does not take into account is the difference in efficiency with different fuel properties or different fuels.

Generators are asking questions on issues such as:

- How will we be arriving at figures on thermal efficiencies of feedstocks and what are the requirements for determining this?
- How will we determine mass and calorific value for all biomass (including wood)?

NEW METHODOLOGY

BOILER EFFICIENCY

The main thrust of this work is to develop a simple procedure that will allow the calculation of cycle efficiencies for variable fuel properties that will be applicable to different biomass fuels that could be co-fired with fossil fuels. At this stage the study is restricted to co-firing with coal.

The main fuel properties that affect efficiency are specific energy and moisture content. The boiler efficiency for a particular fuel can be calculated by the "loss" method, expressed as:

$$\eta = \frac{Useful\ heat\ out\ in\ steam}{Heat\ in\ from\ fuel}$$

or

$$\eta = 1 - \frac{Boiler\ losses}{Heat\ in\ from\ fuel}$$

It is normal to use the higher heating value (HHV) of the fuel in efficiency calculations. The boiler losses consist of:

- *Flue gas exit losses* are due to the heat in the flue gas, which is discarded to the atmosphere. The temperature at which the gases are discarded is above the temperature of the combustion air being drawn into the boiler at ambient conditions. Typically, the flue gases leave the boiler at about 120°C to 150°C, depending on the boiler design.
- *Latent heat losses* are due to moisture in the coal and to the formation of water from hydrogen in the coal. The heat required to evaporate this water is not recovered in the cycle and is lost to the atmosphere.
- *Heat in the ash,* which is disposed of at an elevated temperature.
- *Unburnt carbon losses* from incomplete combustion of the coal, and which is disposed of from the boiler with the coal ash.
- *Other losses,* including heat loss from the external walls of the boiler.

Biomass

Sets out typical fuel properties for wood (or other biomass) and the assumptions that have been used in the calculations of boiler efficiency.

Table 1: Assumptions used in Boiler Efficiency Calculations

Parameter		Typical Value	Range
Biomass Properties			
Moisture content	% ar[1]	30	20 – 65
Ash content	% ar	10	0 - 40
Heating value	MJ/kg daf[2]	20	18 – 22
Carbon	% daf	50	47 – 51
Hydrogen	% daf	6.5	5.9 – 7.0
Nitrogen	% daf	<0.1	
Sulphur	% daf	0.02	0.01 – 0.02
Oxygen (by difference)	% daf	43.5	47.0 – 42.0
Boiler parameters			
Flue gas exit temperature	°C	130	120 – 180
Excess air	%	20	18 - 30

Calculations of boiler efficiency were carried out for a range of moisture contents and heat values, based on the fuel properties given in Table 1. These calculations are illustrated in Figure 1.

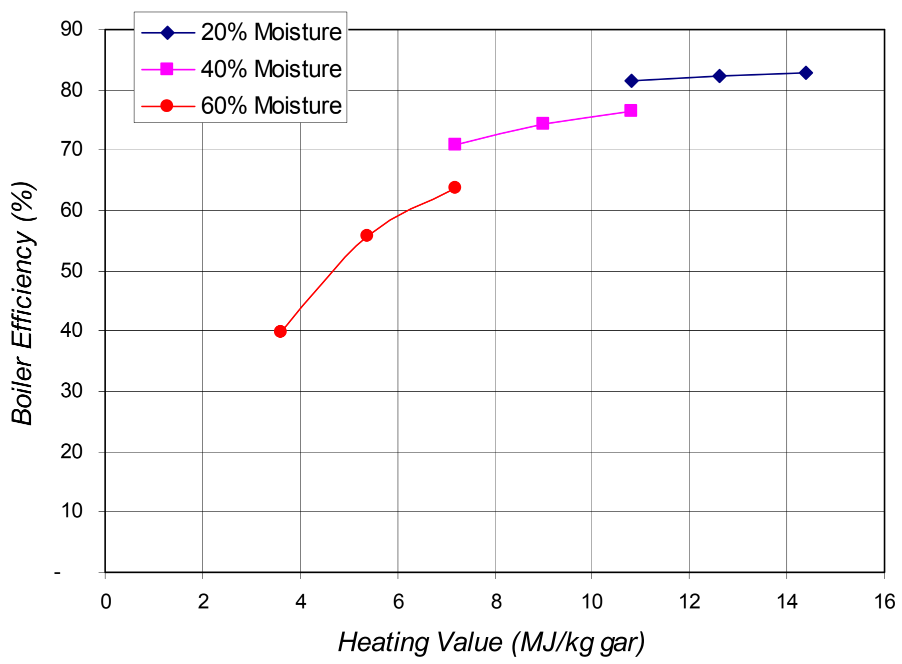

Figure 1: Boiler Efficiency Calculations for Biomass Fuel[3]

The calculations above were carried out using a constant dry ash free specific energy (18 MJ/kg) and varying the heating value by adjusting the moisture content of the fuel from 20% to 60% and the amount of ash in the fuel from zero to 40%. Note that the boiler efficiency is a

1 ar = as received basis
2 daf = dry ash free basis
3 gar = gross as received

strong function of heating value, but is also affected by the moisture content due to additional latent heat losses as moisture content increases. The effect of ash content (apart from varying the as-received heating value) on efficiency is relatively small.

The heating value used in the calculations in Figure 1 was the gross heating, or higher heating value. However, the effect of moisture content can be accounted for by using the net heating value in which the latent heat of the moisture in the coal is subtracted from the higher heating value.

When the coal is burnt, water in the coal will be evaporated, and additional water that is formed from combustion of the hydrogen in the coal will also be evaporated. The heat required for evaporation of this water is the difference between gross and net heating values, and the formula is:

$$\textit{Net heating value} \quad = \quad \textit{Gross heating value} - 2.42x\left(\frac{H_2O}{100} + 9x\frac{H_2}{100}\right)$$

$$\begin{aligned} \textit{where} \quad \textit{Heating value} &= \textit{MJ/kg as received} \\ H_2O &= \textit{Moisture content}\ (\%\ \textit{as received}) \\ H_2 &= \textit{Hydrogen content}\ (\%\ \textit{as received}) \end{aligned}$$

As-received hydrogen content can be calculated from an assumed dry ash free hydrogen content (say 6.5% daf). In addition, the as-received ash content can be calculated from the moisture content and the dry ash free heating value (constant at 18 MJ/kg daf). This will allow calculation of the net heating value as a function of the gross heating value and moisture content alone:

- *Hydrogen content(ar) = Hydrogen content(daf) x {1 – (Moisture(ar)/100+Ash(ar)/100)}*
- *Ash content (ar) = 1 – Moisture(ar) – Gross heating value/18*
- *Hydrogen content (ar) = 0.065 x Gross heating value/18*

The equations above can be substituted and re-arranged to give an equation for net heating value as a function of gross heating value and moisture content:

- *Net heating value = 0.91 x Gross heating value –2.42 x Moisture(ar)*

To calculate the boiler efficiency on a net heating value basis, the following applies:

$$\textit{Net boiler efficiency} \quad = \quad \textit{Gross boiler efficiency } x\ \frac{\textit{Gross heating value}}{\textit{Net heating value}}$$

Replotting the calculations in Figure 1 and plotting the net boiler efficiency against net heating value yields the graph shown in Figure 2.

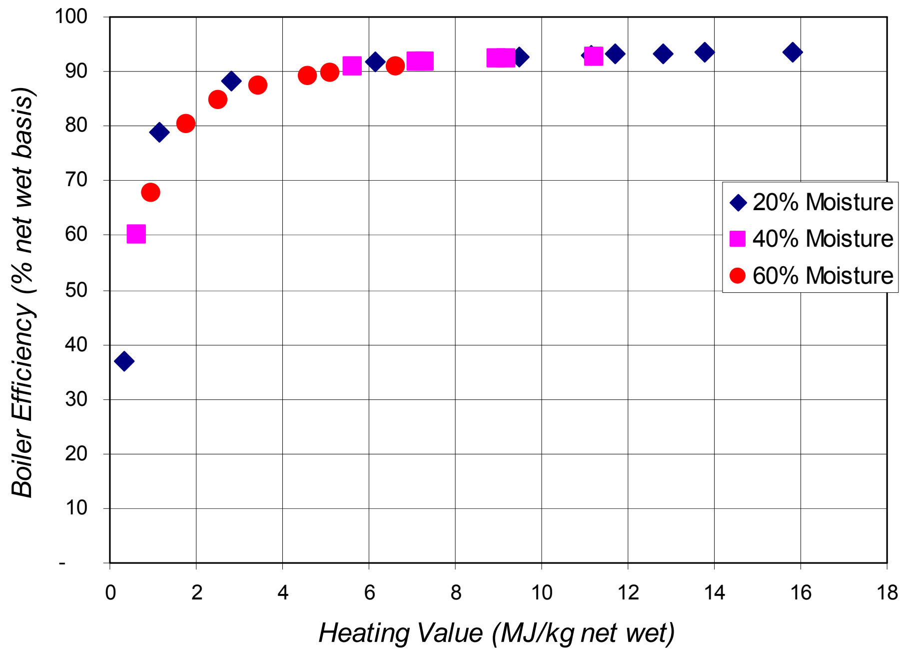

Figure 2: Net Boiler Efficiency plotted against Net Heating Value for Biomass

Since the points generally lie on the same line, apart from some minor deviations due to the effect of ash, this line could be used as a general correlation between fuel properties and boiler efficiency for a range of biomass fuels.

In order to allow a simple calculation, the range of data of interest was linearised for the following heat value ranges:

- *2 MJ/kg net wet - 4 MJ/kg net wet*
- *4 MJ/kg net wet - 8 MJ/kg net wet*
- *8 MJ/kg net wet - 16 MJ/kg net wet*

The linear relationships are illustrated in Figure 3 and the equations follow:

- *For the range 2 MJ/kg net wet - 4 MJ/kg net wet*

  Net efficiency = 3.6 x Heating value + 74.8

- *For the range 4 MJ/kg net wet - 8 MJ/kg net wet*

  Net efficiency = 0.8 x Heating value + 86.0

- *8 MJ/kg net wet - 16 MJ/kg net wet*

  Net efficiency = 0.2 x Heating value + 90.7

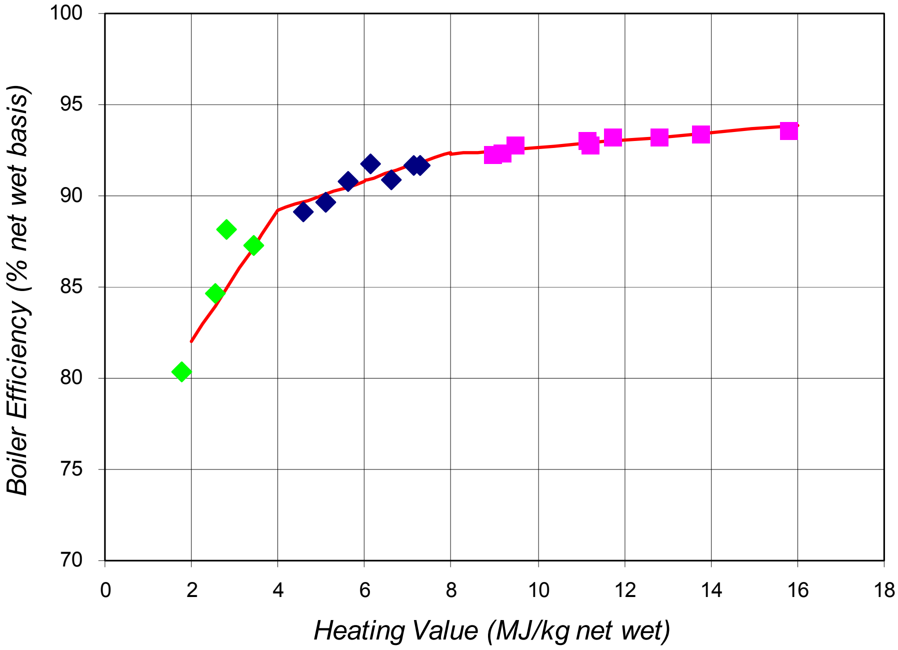

Figure 3: Linear Relationships to Predict Boiler Efficiency

Coal

A similar method can be used for the case of coal. In this case the variables impacting on efficiency, moisture and ash contents, were varied over the range 10 – 20% as received for both variables. The results for the efficiency calculations are illustrated in Figure 4.

In this case the boiler efficiency only varied from 93.63% to 93.99% over the range of heating values from 19.2 MJ/kg to 27.6 MJ/kg. Thus, for all practical purposes, it would be reasonable to assume a constant net boiler efficiency for coal:

- *Net boiler efficiency for coal = 93.8%*

The net heating value for coal can be calculated using a constant dry ash free value for hydrogen (say 5.0% daf) and a constant as-received gross heating value (constant at 34 MJ/kg daf) in a similar manner to the biomass case:

- *Hydrogen content (ar) = Hydrogen content (daf) x (1 – Moisture(ar)/100 – Ash(ar)/100)*
- *Ash content (ar) = 1 – Moisture(ar) – Gross heating value/34*
- *Hydrogen content (ar) = 0.05 x Gross heating value/34*
- *Net heating value = 0.97 x Gross heating value –2.42 x Moisture(ar)*

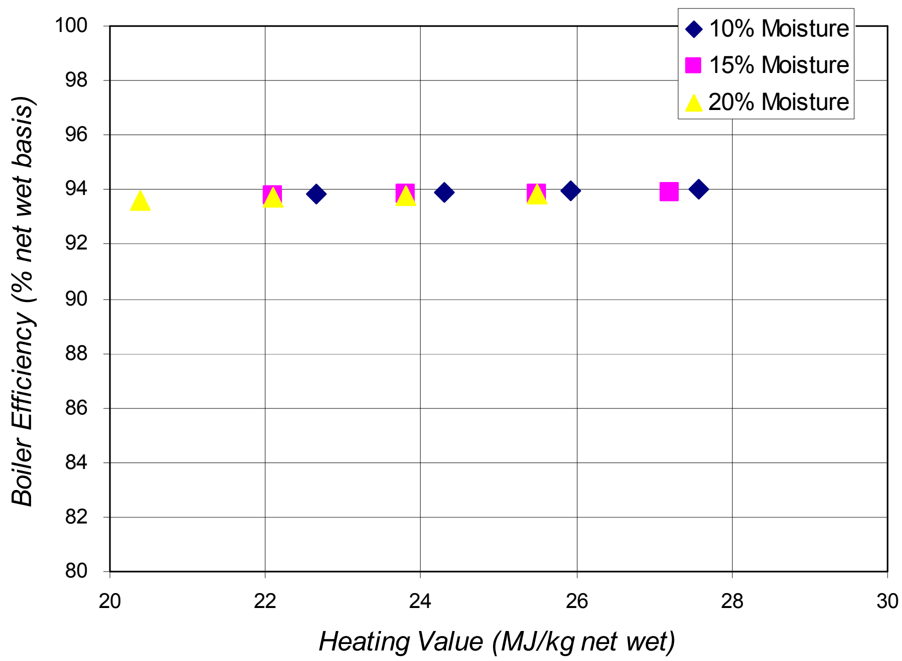

Figure 4: Net Boiler Efficiency plotted against Net Heating Value for Coal

RENEWABLE ENERGY CERTIFICATES

The previous methodology to calculate the RECs can now be used with the efficiencies calculated from the previous Sections. The overall power plant efficiency will be the boiler efficiency, multiplied by the turbine efficiency, say 40% as a typical value for a sub-critical unit.

SUMMARY OF METHODOLOGY

An example of the current method is shown below:

- FUEL 1: Wood — 5% by weight
  - … Gross heating value — 15 GJ/t
  - … Moisture content — 20% as received
  - … Net heating value = 0.91 x 15 - 2.42 x 0.2 = 13.2 MJ/kg
  - … Net boiler efficiency = 0.2x13.2 + 90.7 = 93.3 %
  - … Energy conversion = 93.3 x 0.4 = 37.3 %
- FUEL 2: Coal — 95% by weight
  - … Gross heating value — 25 GJ/t
  - … Moisture content — 10% as received
  - … Net heating value = 0.97 x 25 - 2.42 x 0.1 = 24.0 MJ/kg
  - … Net boiler efficiency = 93.8 = 93.8 %
  - … Energy conversion = 93.8 x 0.4 = 37.5 %
- Electrical energy output from wood = 0.05 x 13.2 x 0.373 = 0.2462 GJ/t fuel
- Electrical energy output from coal = 0.95 x 24.0 x 0.375 = 8.550 GJ/t fuel
- Total electrical output = 0.2462 + 8.550 = 8.7962 GJ/t fuel
- Percentage output from coal = 8.550 / 8.7962 = 97.2%
- Percentage output from wood = 0.2462 / 8.7962 = 2.8%

Therefore, if the energy output were 100 MWh, the Generator would receive 2.8 RECs.

Another example using a different form of biomass:

- FUEL 1: Sewage sludge — 5% by weight
  - … Gross heating value — 4.0 GJ/t
  - … Moisture content — 60% as received
  - … Net heating value = 0.91 x 4.0 - 2.42 x 0.6 = 2.19 MJ/kg
  - … Net boiler efficiency = 3.6x2.19 + 74.8 = 82.7 %
  - … Energy conversion = 82.7 x 0.4 = 33.1 %
- FUEL 2: Coal — 95% by weight
  - … Gross heating value — 25 GJ/t
  - … Moisture content — 10% as received
  - … Net heating value = 24.0 MJ/kg
  - … Energy conversion = 37.5 %

- Electrical energy output from sludge = 0.05 x 2.19 x 0.331 = 0.0362 GJ/t fuel
- Electrical energy output from coal = 0.95 x 24.0 x 0.375 = 8.550 GJ/t fuel
- Total electrical output = 0.0362 + 8.550 = 8.5862 GJ/t fuel
- Percentage output from coal = 8.550 / 8.5862 = 99.6%
- Percentage output from sludge = 0.0384 / 8.5862 = 0.4%

Therefore, if the energy output were 100 MWh, the Generator would receive 0.4 RECs.

MEASUREMENT OF FUEL PROPERTIES

To enable the calculations developed in the previous Sections to be made, the gross heating value and the moisture content of the fuel must be measured on a regular basis.

Taking regular routine samples of the biomass and coal and subjecting them to the appropriate analyses could achieve this end. Power stations normally take daily coal samples and have them analysed on a routine basis, so that extending this sampling to the biomass should not be too onerous.