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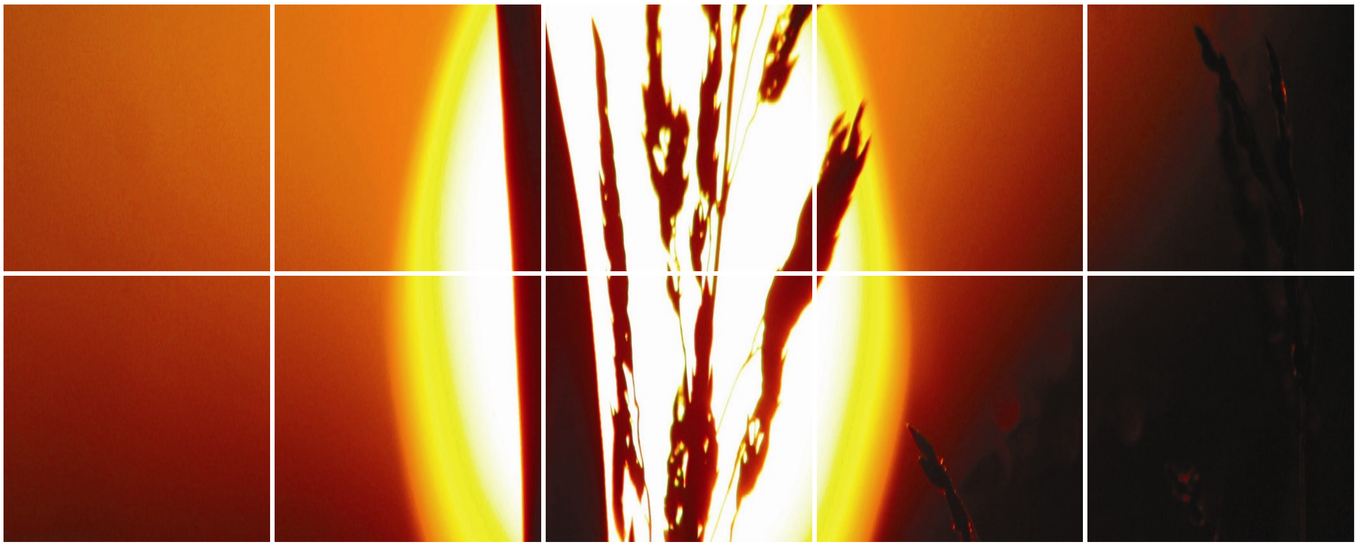

Biomass Environmental Assessment Tool Version 2 User Guide

Issue Number 2
May 2008

AEA Energy & Environment
From the AEA group

NORTH ENERGY

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1 Introduction

This manual provides a guide to use of the BEAT 2 Biomass Environmental Assessment Tool. BEAT was developed by AEA Energy & Environment in association with North Energy Associates for DEFRA and the Environment Agency.

1.1 Aims of the Tool

This tool is intended to provide both DEFRA and Environment Agency staff with a means of assessing biomass schemes by:

1. Providing a comparison of greenhouse gas emissions from the proposed plant and fossil fuel based plant;
2. Providing information on key potential environmental impacts;
3. Identifying potential options for mitigating environmental impacts;
4. Providing an estimate of production costs and of support mechanisms.

The tool considers all stages of the fuel chain i.e. from cultivation through to the production of heat, electricity or liquid biofuels for transport. It is provided with a full set of default data (based on typical values for biomass yields, generating efficiencies), to enable easy examination of typical bioenergy schemes. In addition all of the parameters describing a scheme can be also be changed by the user, allowing specific aspects of individual biomass schemes to be modelled.

1.2 Important notes on the use of the Tool

This Tool is designed to assist staff in the understanding of impacts from biomass and biofuel plant development over the whole life cycle of the technology and fuel chain, and to identify significant impacts that may occur from local proposals. It does not represent a formal view on development proposals and it should not replace or substitute for a formal response to planning or licensing applications or other applicable requirements.

The Tool and summary outputs are prepared purely to enable informed discussion about the possible or likely impacts of proposals, and as such are based on the information and understanding available. We have prepared this report using information and advice provided by consultants in the field, and experience from case studies and research on examples of the technology. Defra or the Environment Agency do not warrant these outputs an authoritative statement of the expected impacts of any specific development.

DEFRA and the Environment Agency cannot ensure that the data (“Data”) in its possession and used in this model is always accurate, complete, up to date or valid. Note that the Data has not been prepared to meet anyone's individual requirements and it is therefore not possible to guarantee that the Data meet your needs or those of any project that may consult the outputs. Outputs should only be copied or shared with that caveat.

2 Quick Start Guide

2.1 Installation

The BEAT tool has been designed to operate using Microsoft Access 2000. It also uses Excel (version 2000 or later) and Word (version 2000 or later). It will operate in Access 2003 but screen displays may be compromised. To avoid this, change the Windows Display settings to ‘Windows Classic’ (click Start button >> Settings >> Control Panel >> Display). Select ‘Windows Classic’ from the Themes dropdown box (on the Themes tab). The macro security settings on Access 2003 or above should be set to low (under Tools, select Macro, then Security and select low) or BEAT will not operate.

The BEAT tool should be installed on the hard drive (c:) in a directory called BEAT and the structure of the directories should be maintained. It is not recommended for BEAT to be installed on a network as this will give very slow performance. It must also be noted that BEAT is not a multi-user application – more than one person simultaneously using the application from a network will cause an application failure.

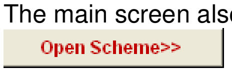
2.2 Getting started

The BEAT tool opens with the Main Menu screen.

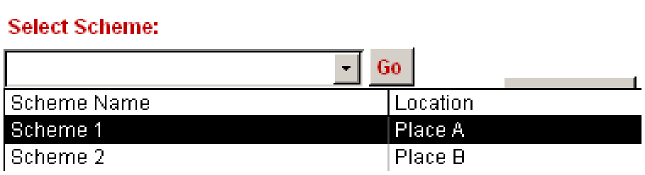
Buttons at the bottom of the screen provide access to **Introduction** text and basic **Instructions on Use**.

To get started with the tool select the Create New Scheme button.

The main screen also includes a button to view schemes previously created in the tool.



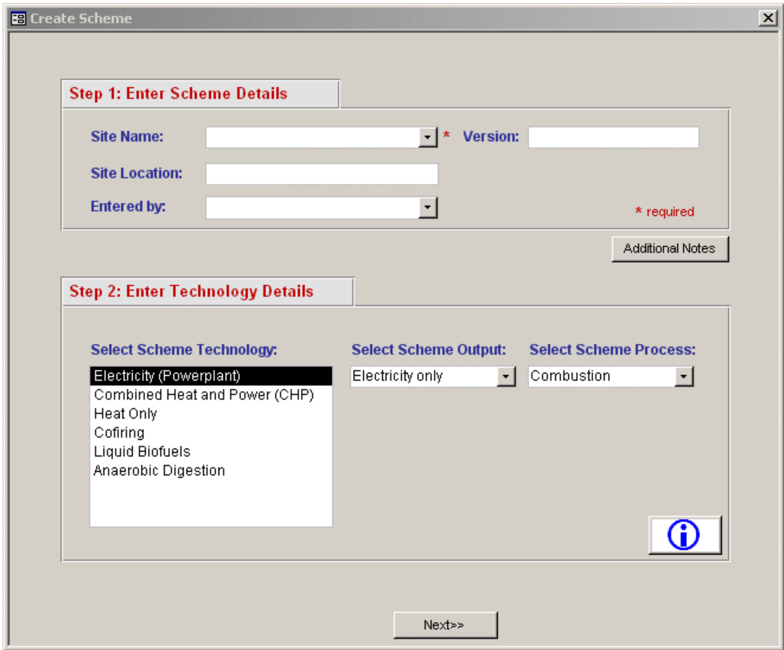
Simply select the relevant scheme from the displayed drop down box.



To exit from the Tool, click File (in the top left hand corner of the screen) then exit.

2.3 Creating a scheme

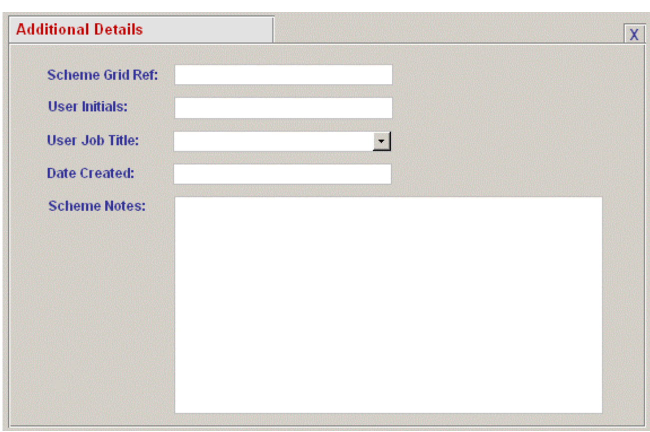
After selecting ‘Create New Scheme‘ you will be guided through a short process to define the technology used in the scheme and feedstocks used.



Step 1: Enter Scheme Details

Details of the scheme you are examining are entered here; e.g. Site Name, Site Location, Version. The only mandatory field is Site Name. The Version field is used to describe copies/variations of a scheme (see section 2.7). When searching for a scheme in the database, you will see site name and version, so it is helpful to make these as descriptive as possible.

Additional information can be entered by clicking the Additional Notes button. For example, this gives the option of entering more descriptive text and date the scheme was entered into the field. This can be useful for entering notes on sources of data for the scheme etc.



To hide the additional notes field click Hide Notes.

Step 2: Enter Technology Details

Select Scheme Technology: Six types of scheme are contained in the tool:

- Electricity (power plant) – dedicated plant built to burn biomass fuels and produce electricity;
- Combined heat and power (CHP) - dedicated plant built to burn biomass fuels and produce electricity and heat;
- Heat only – dedicated boilers burning biomass fuels to produce heat;
- Cofiring – combustion of biomass fuels in existing large power stations;
- Liquid biofuels – production of biodiesel and bioethanol;
- Anaerobic digestion – anaerobic digestion of animal and food waste to produce biogas which is then burnt to produce electricity and/or heat.

After selecting Scheme Technology, additional drop down boxes may be displayed which provide extra definition to the scheme. Some of the drop down boxes will only have one possible selection depending on the choice of Technology.

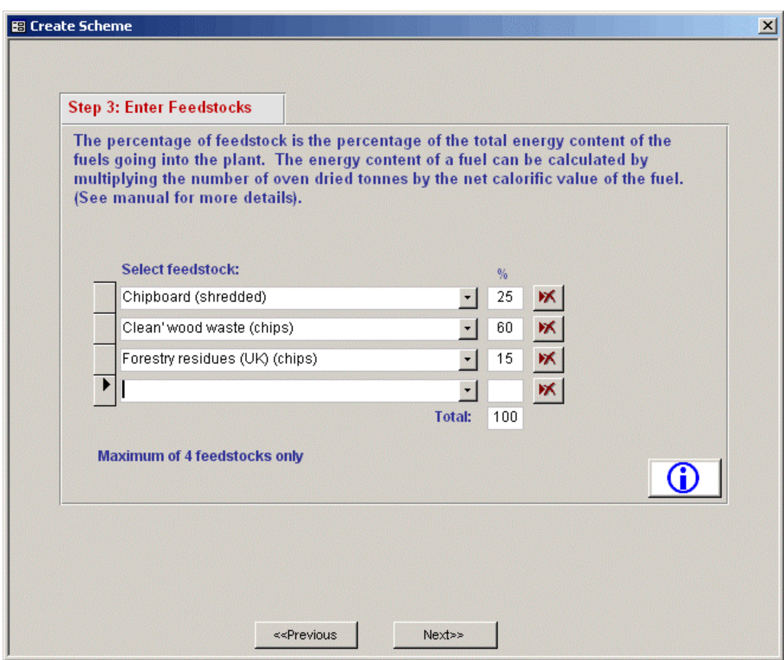
Scheme Output: this defines the product from the technology you have chosen. In the case of **anaerobic digestion**, select whether the biogas produced is burnt to produce electricity, electricity and heat, or heat only. In the case of **liquid biofuels**, select whether biodiesel or bioethanol is produced.

Scheme Process: In the case of **power plant** and **CHP plant** select how the fuel will be burnt: combustion, pyrolysis or gasification.

Scheme Scale: In the case of **Heat Only** plant, select whether the boiler is a size used in industry (typically 100 kW to 1.5 MWh) or a 'domestic' sized boiler (typically 5 to 100 kW). For **Anaerobic Digestion** plant, select whether the plant is a small, on-farm plant, or a large centralised plant.

After defining all Technology Details click 'Next' (at bottom of screen).

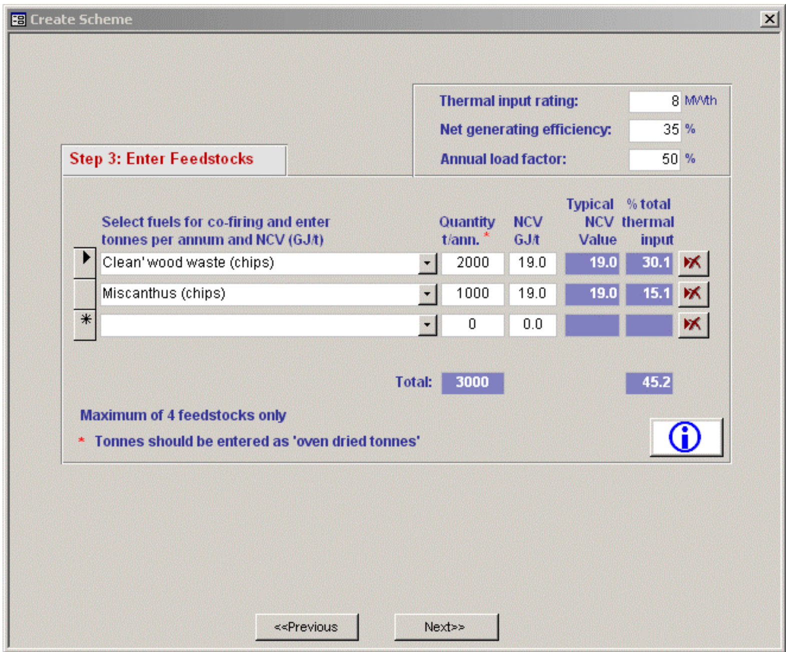
Step 3: Define Feedstocks



The feedstocks used to fuel the scheme are defined here. Up to 4 feedstocks can be entered for all types of Technology except Liquid Biofuels where only one feedstock can be selected, and on–farm anaerobic digestion where only 2 feedstocks can be entered.

Select the feedstocks from the drop down and enter a percentage value indicating how much of the total input comes from each feedstock. Obviously this total must equal 100%. For power, CHP and heat plant, the percentage refers to percentage of total energy input in the fuels. This can be calculated from mass of fuel (in odt) by multiplying by their net calorific value (NCV). For anaerobic digestion plant, the percentage refers to percentage by weight.

In the case of **cofiring**, the number of tonnes (as odt) of the fuel should be entered directly. You will also need to enter the thermal input rating of the power station or power station unit the cofiring takes place in. Default values are provided for the generating efficiency and load factor of the power station (unit) but these may be altered if you wish. The cofiring feedstock form is shown below.



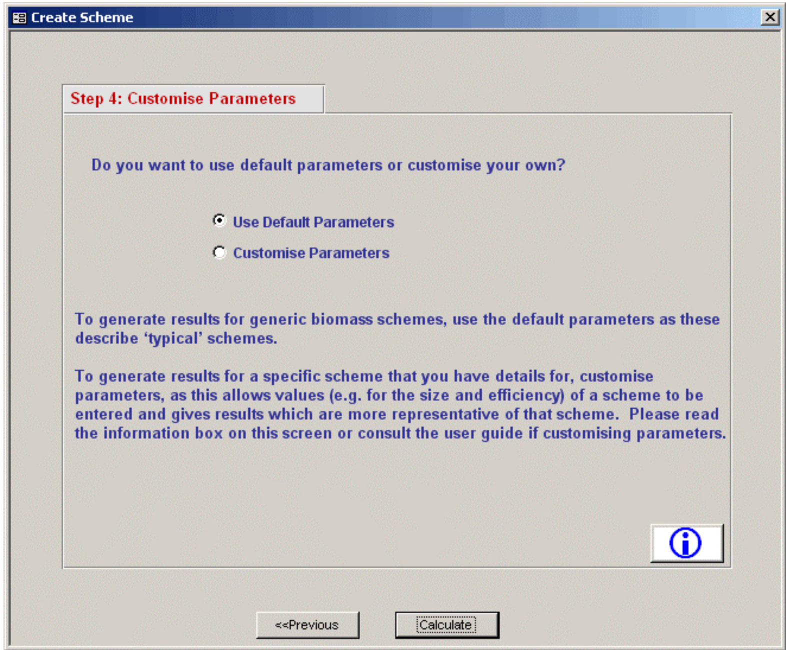
After defining Feedstocks click ‘Next’ (at bottom of screen) for the final step.

Step 4: Define Parameters

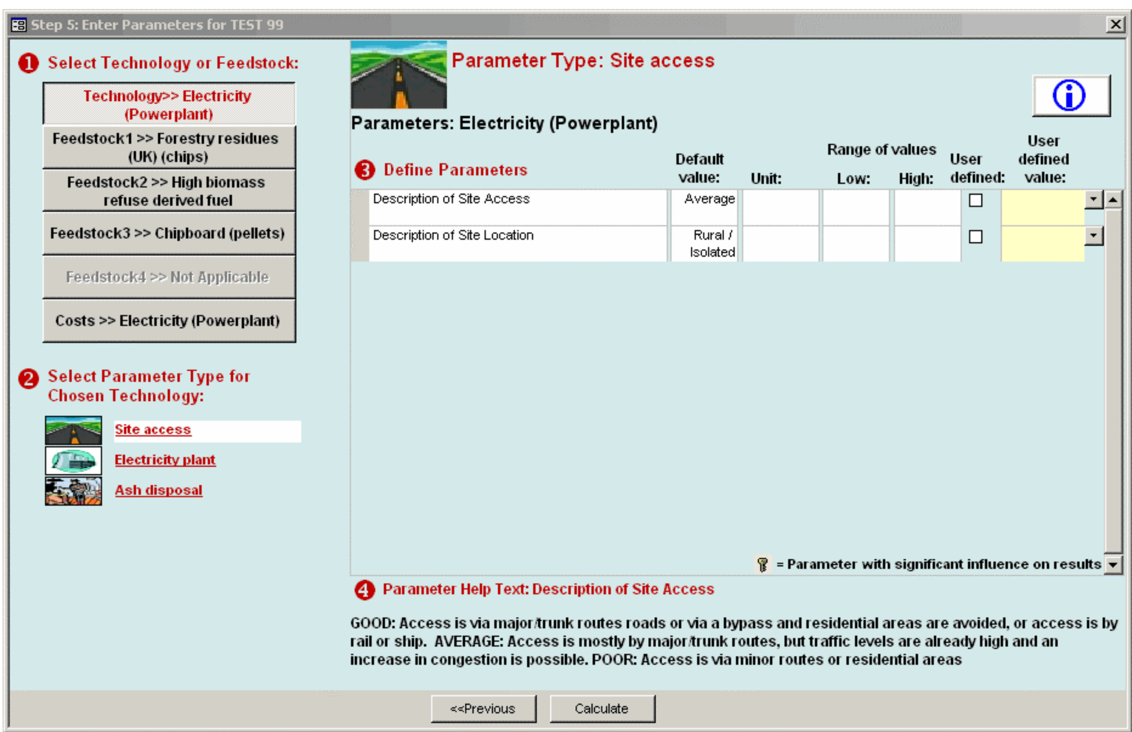
You may now define a number of parameters which describe fuel/feedstock production, processing, transport and the combustion technology or production plant. See Section 2.5 below for details of how to do this. To define your own parameters select ‘Customise Parameters’ and click Next (at the bottom of the screen).

Alternatively, you can select ‘Use Default Parameters’ to accept the default values which are typical values provided for all parameters. To accept these and proceed to results simply click Calculate (at the bottom of the screen).

See Section 2 for a description of the results.



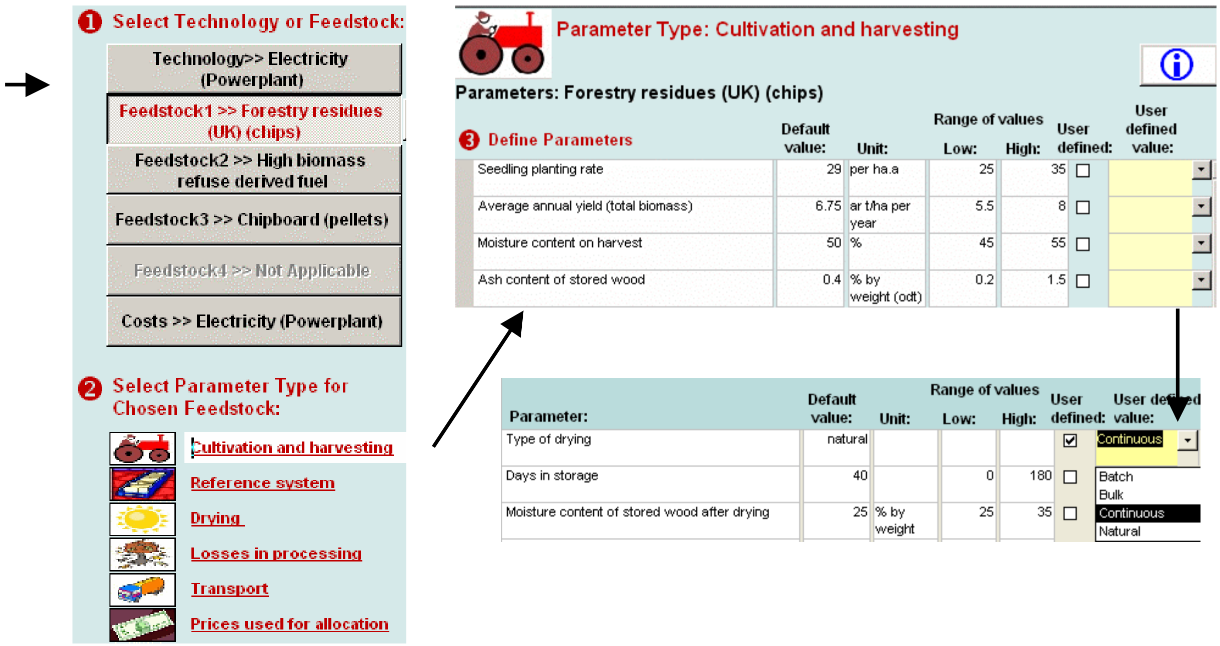
2.4 Changing the characteristics of a scheme



Define scheme parameters: clicking on each of the buttons in the top left of the screen (Technology, Feedstock, Costs) brings up a number of parameter types in the box underneath. Clicking on each of these parameter types (e.g. cultivation and harvesting) will bring up the default values for the scheme.

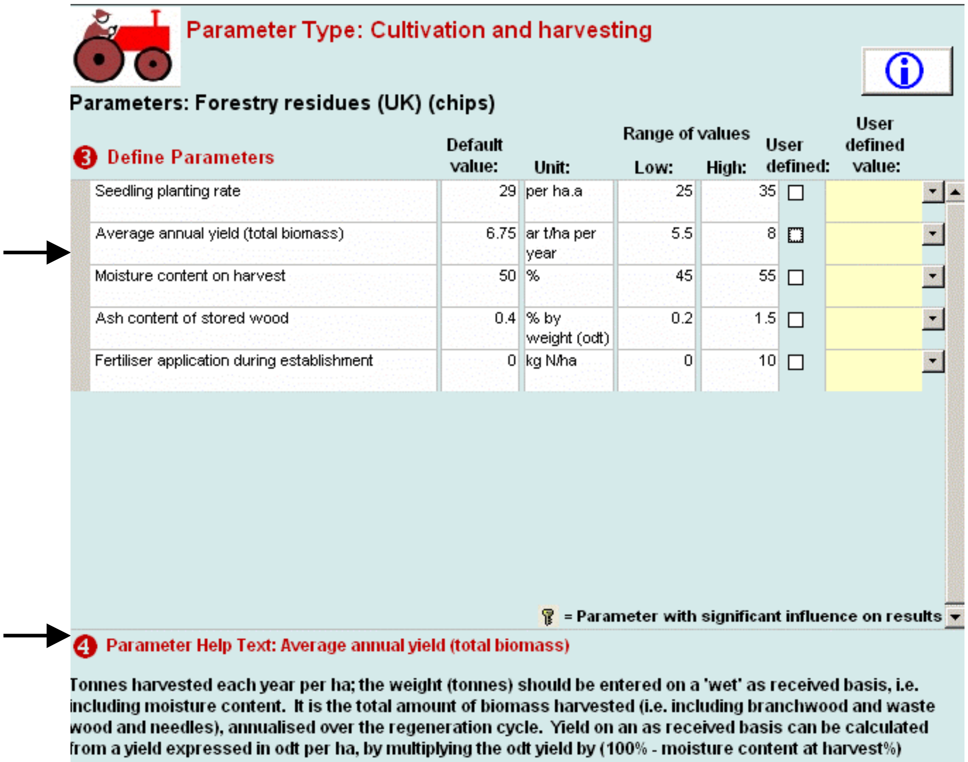
To change parameters enter a value in the 'user defined value' column. When complete, click finish. To accept the default parameters leave the form unchanged and click 'Finish' to generate results.

Clicking on the Feedstock buttons (in the top left of the screen) also displays a flow chart symbol; clicking on the flowchart symbol will open the emissions calculation workbook which contains a flow chart of the bioenergy scheme. This can be useful in visualising the process fuel chain and understanding the different parameters,



Help Text

Help text is displayed for each parameter at the bottom of the screen. When a parameter is clicked on help text will be brought up for guidance.



The key symbol next to some parameters indicates the parameter to be a key influence on the emissions produced by the scheme.

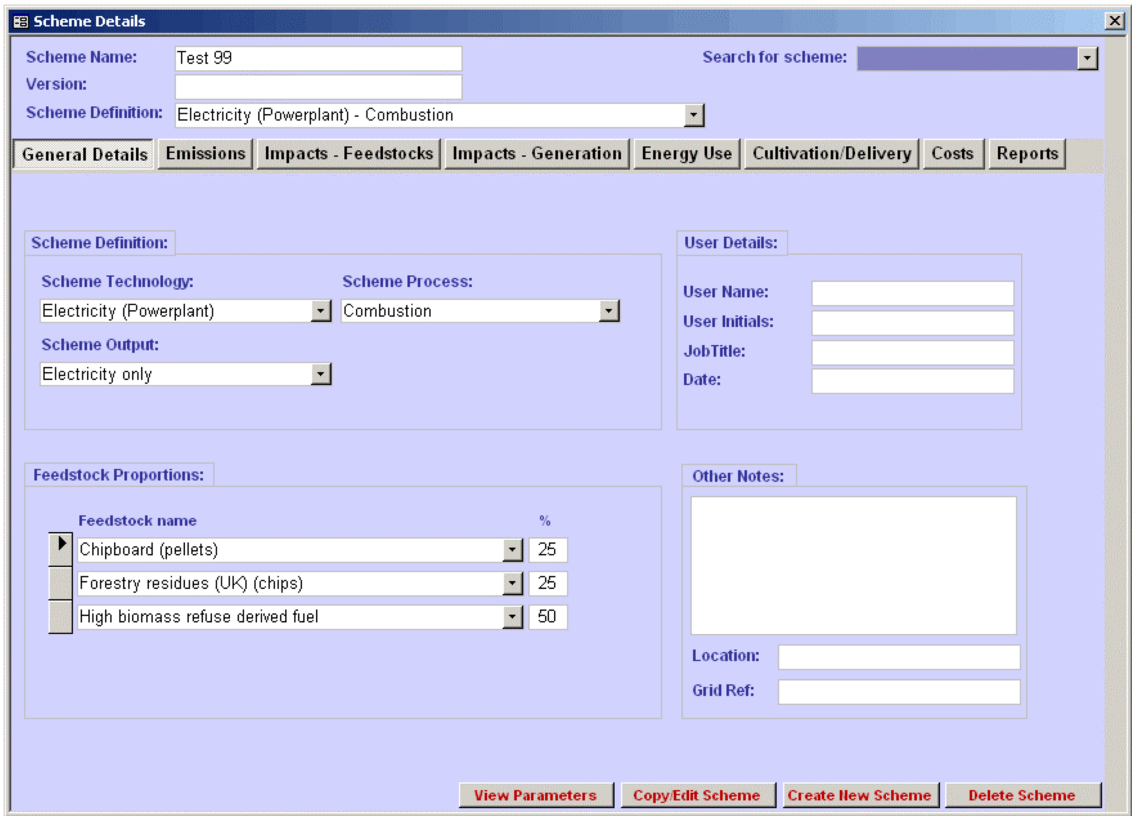
After defining the parameters, click ‘Finish’. After a few seconds the emissions, impacts and cost results will be generated.

2.5 Results

The results and calculations for the scheme are displayed in the form below. It is composed of separate sections (General Details, Impacts, Emissions, Energy Use, Cultivation/Delivery, Costs, Reports) accessed by clicking the buttons at the top of each section.

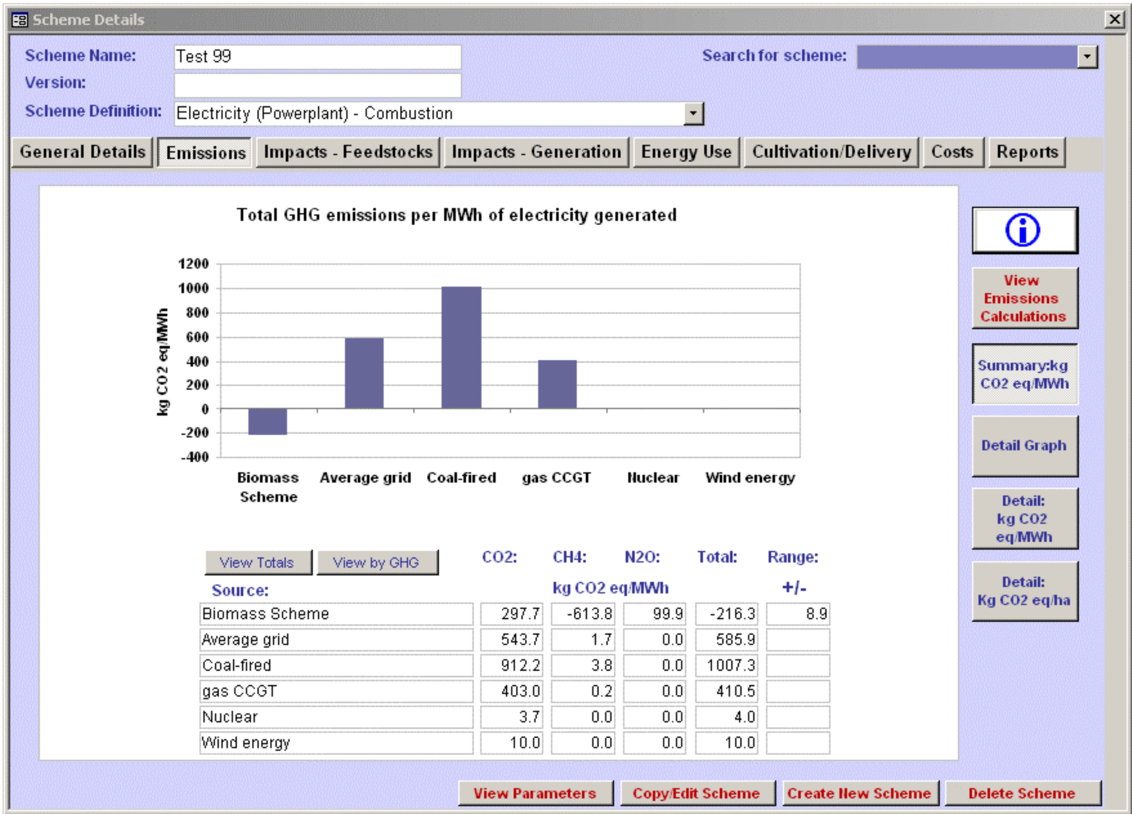
General Details

The General Details screen provides a brief overview of the scheme definition including technology and feedstock properties.



Emissions

The Emissions section provides summary and graphical views of the total greenhouse gas (GHG) emissions produced by the scheme.

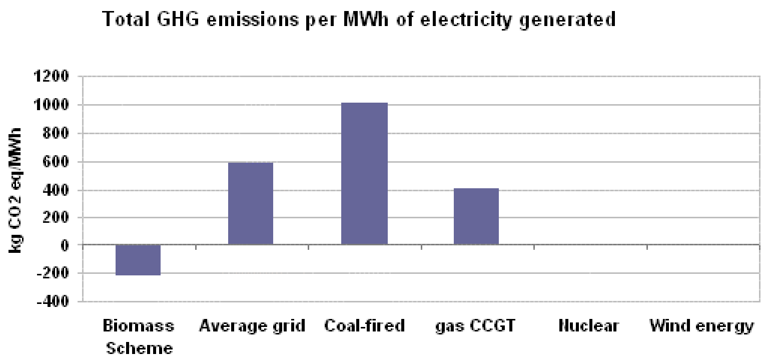


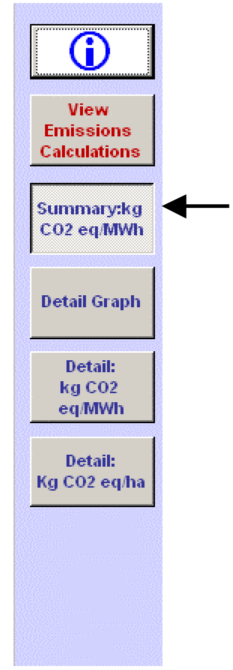
The graph above shows a summary graph of the total GHG emissions produced by the scheme compared against the relevant comparison technologies for the scheme. The table below provides the data view of the graph. The two buttons at the top of the table – 'View Totals' and 'View by GHG' can be clicked to show different views of the graph. 'View Totals' is the default view shown above. 'View by GHG' shows the graph broken down into the 3 GHG (below).

This graph shows the total GHG emissions from the production of the biofuel you have modelled (i.e. over the whole life cycle from cultivation of the feedstock, processing into a biofuel and its transport to a distribution depot). The 'net view' shows total net emissions; the breakdown view shows a breakdown by greenhouse gas. Total life cycle greenhouse gas emissions from other transport fuels are also shown for comparison; (these include emissions from fuel extraction, refining, and transport to a distribution depot as well as the CO_2 which will be released when the fuel is combusted in an engine). Emissions are shown as kg CO_2 equivalent per thousand ('000) litres of biofuel. For other transport fuels, emissions are for the amount of fuel with the same energy content as 1000 l of biofuel.

On the right hand side there are 6 buttons which provide both help text and different graphical and tabular views of the data.

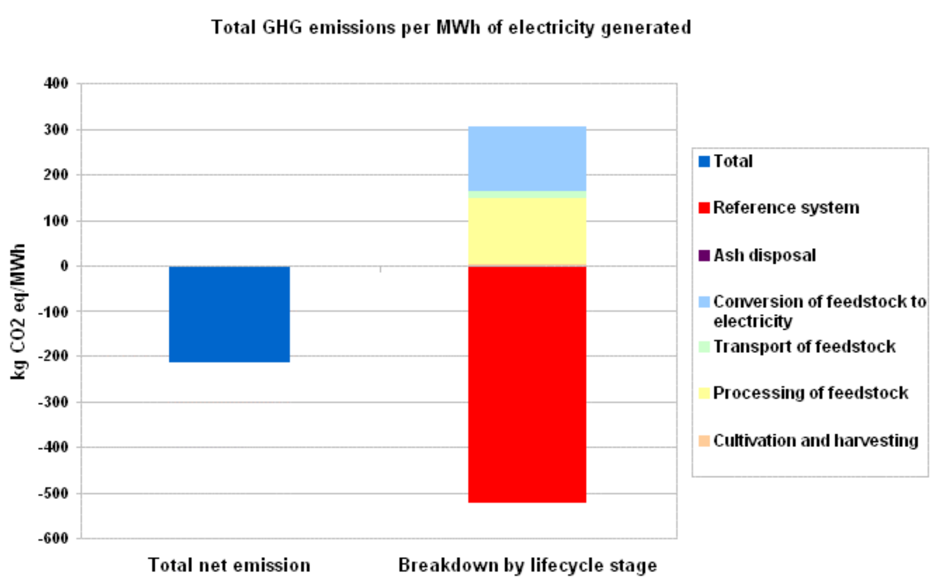
Detail Graph view

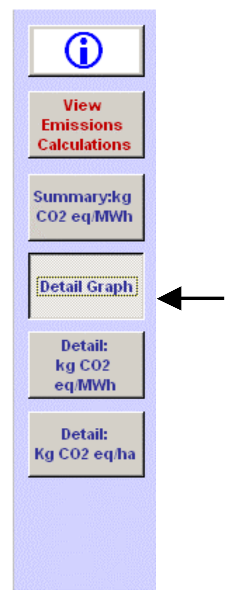




View Totals | View by GHG

Source:	CO2:	CH4:	N2O:	Total:	Range:
	kg CO2 eq/MWh				+/-
Biomass Scheme	297.7	-613.8	99.9	-216.3	8.9
Average grid	543.7	1.7	0.0	585.9	
Coal-fired	912.2	3.8	0.0	1007.3	
gas CCGT	403.0	0.2	0.0	410.5	
Nuclear	3.7	0.0	0.0	4.0	
Wind energy	10.0	0.0	0.0	10.0	

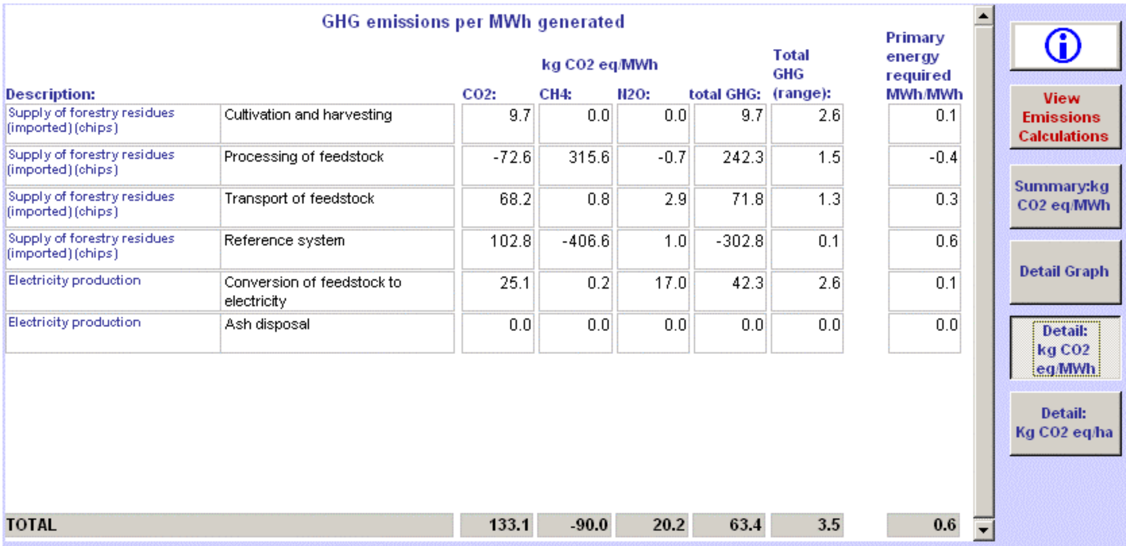




The above screen shows the graphical view of the emissions that are produced by the scheme broken down into lifecycle stages. The blue column on the left is the net total; the coloured column on the right is the breakdown for the lifecycle stages.

This graph shows the GHG emissions for the biofuels scheme you have modelled by process stage. The term 'reference system' is used for what would have happened if the feedstock had not been used to produce biofuels. These emissions are 'avoided' when the biofuel scheme is implemented and so are shown as negative numbers on the graph. For wheat, sugar beet and OSR the reference system is that land would have been in fallow set aside. It is assumed that waste feedstocks would be disposed of to landfill, with energy recovery. The user can choose whether or not to include a reference system in the analysis by selecting the option in the parameters describing the scheme. Emissions are shown as kg CO_2 equivalent per thousand ('000) litres of biofuel (or equivalent amount in terms of energy content for other transport fuels). The emissions which occur during distribution of the fuels (from a distribution depot to forecourt) are not included.

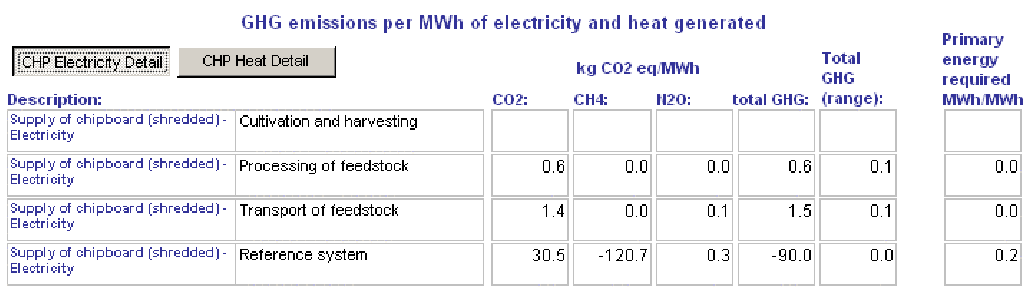
Detail: kg CO_2 eq/MWh view



GHG emissions per MWh generated

Description:		CO2:	CH4:	N2O:	total GHG:	Total GHG (range):	Primary energy required MWh/MWh
Supply of forestry residues (imported) (chips)	Cultivation and harvesting	9.7	0.0	0.0	9.7	2.6	0.1
Supply of forestry residues (imported) (chips)	Processing of feedstock	-72.6	315.6	-0.7	242.3	1.5	-0.4
Supply of forestry residues (imported) (chips)	Transport of feedstock	68.2	0.8	2.9	71.8	1.3	0.3
Supply of forestry residues (imported) (chips)	Reference system	102.8	-406.6	1.0	-302.8	0.1	0.6
Electricity production	Conversion of feedstock to electricity	25.1	0.2	17.0	42.3	2.6	0.1
Electricity production	Ash disposal	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL		133.1	-90.0	20.2	63.4	3.5	0.6

The screen above shows the tabular view of the Detail Graph. If more than one feedstock is associated with the scheme then each lifecycle stage will be displayed for each feedstock.



GHG emissions per MWh of electricity and heat generated

Description:		CO2:	CH4:	N2O:	total GHG:	Total GHG (range):	Primary energy required MWh/MWh
Supply of chipboard (shredded) - Electricity	Cultivation and harvesting						
Supply of chipboard (shredded) - Electricity	Processing of feedstock	0.6	0.0	0.0	0.6	0.1	0.0
Supply of chipboard (shredded) - Electricity	Transport of feedstock	1.4	0.0	0.1	1.5	0.1	0.0
Supply of chipboard (shredded) - Electricity	Reference system	30.5	-120.7	0.3	-90.0	0.0	0.2

For CHP scheme 2 extra buttons are displayed to display the table in electricity and heat form.

This table shows the GHG emissions and primary energy requirement for the biomass scheme you have modelled by process stage.

Primary energy required is the amount of fossil fuels used both directly e.g. as diesel in tractors and indirectly e.g. to manufacture materials in the power plant in the biomass scheme. Emissions and primary energy required are shown per MWh of electricity generated at the power plant. The losses that occur during transmission and distribution of the electricity are not included.

The term ‘reference system’ is used for what would have happened if the feedstock had not been used for electricity generation. These emissions are 'avoided' when the biomass scheme is implemented so are negative numbers. For energy crops the reference system is fallow set aside; for waste feedstocks it is disposal to landfill with energy recovery.

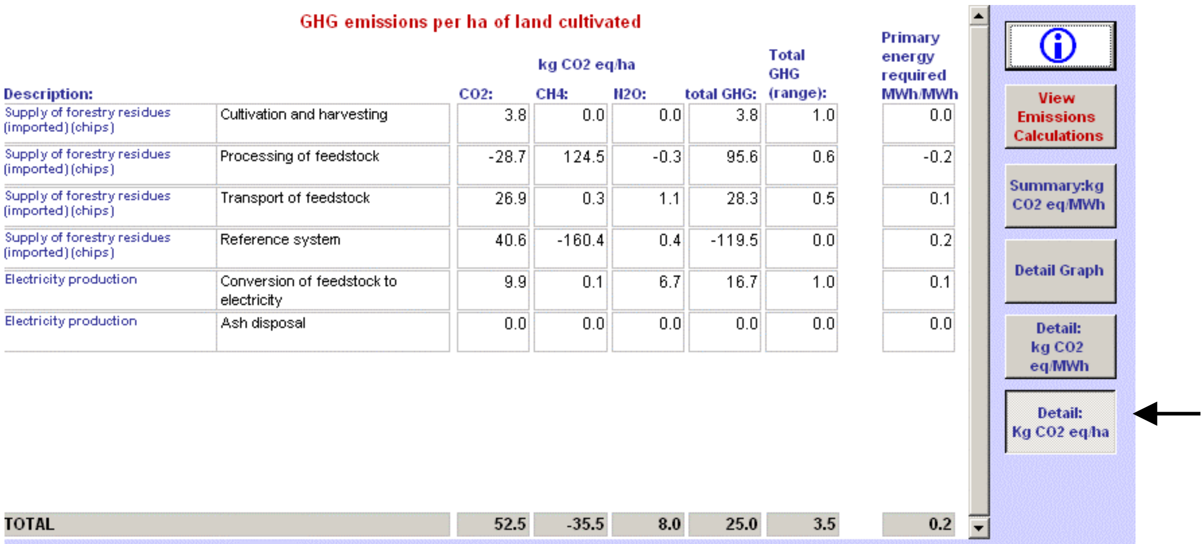
Detail: kg CO_2 eq/ha view

For schemes where all feedstocks associated with the biomass plant are naturally grown an additional view of the table is possible. This displays the emissions per hectare of land cultivated.

For energy crops, this table shows the GHG emissions and primary energy requirement for the biomass scheme on the basis of land used (i.e. per ha of land).

The primary energy required is the amount of fossil fuels used both directly e.g. as diesel in tractors, and indirectly e.g. to manufacture materials in the power plant in the biomass scheme. The losses which occur during transmission and distribution of the electricity are not included.

The term ‘reference system’ is used for what would have happened if the feedstock had not been used for electricity generation. These emissions are 'avoided' when the biomass scheme is implemented so are negative numbers. For energy crops the reference system is fallow set aside.

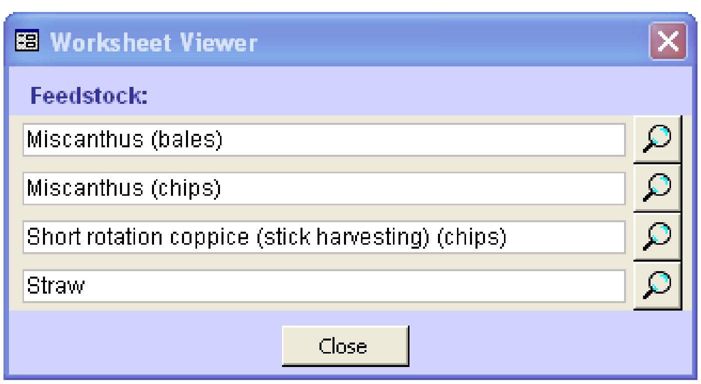


GHG emissions per ha of land cultivated

Description:		CO2:	CH4:	N2O:	total GHG:	Total GHG (range):	Primary energy required MWh/MWh
		kg CO2 eq/ha					
Supply of forestry residues (imported) (chips)	Cultivation and harvesting	3.8	0.0	0.0	3.8	1.0	0.0
Supply of forestry residues (imported) (chips)	Processing of feedstock	-28.7	124.5	-0.3	95.6	0.6	-0.2
Supply of forestry residues (imported) (chips)	Transport of feedstock	26.9	0.3	1.1	28.3	0.5	0.1
Supply of forestry residues (imported) (chips)	Reference system	40.6	-160.4	0.4	-119.5	0.0	0.2
Electricity production	Conversion of feedstock to electricity	9.9	0.1	6.7	16.7	1.0	0.1
Electricity production	Ash disposal	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL		52.5	-35.5	8.0	25.0	3.5	0.2

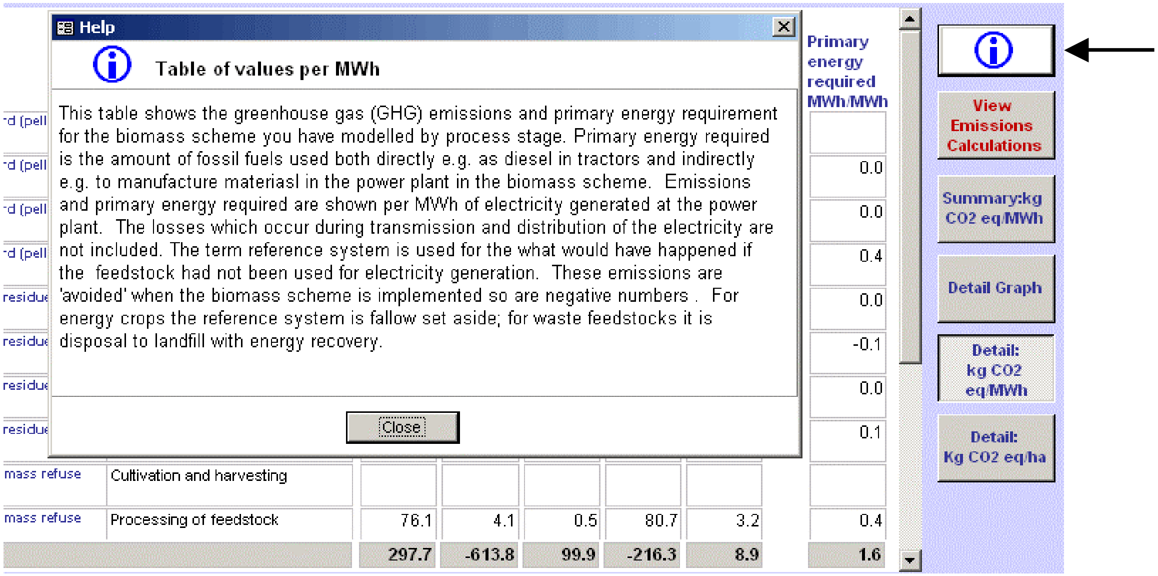
Excel Workbook Viewer

Clicking the ‘Excel Workbook Viewer’ opens the screen below. It provides access to the Excel workbooks which drive the calculations of the emission figures. There is a workbook associated with each feedstock chosen for the scheme. To view the workbooks click the magnifying glass icon.



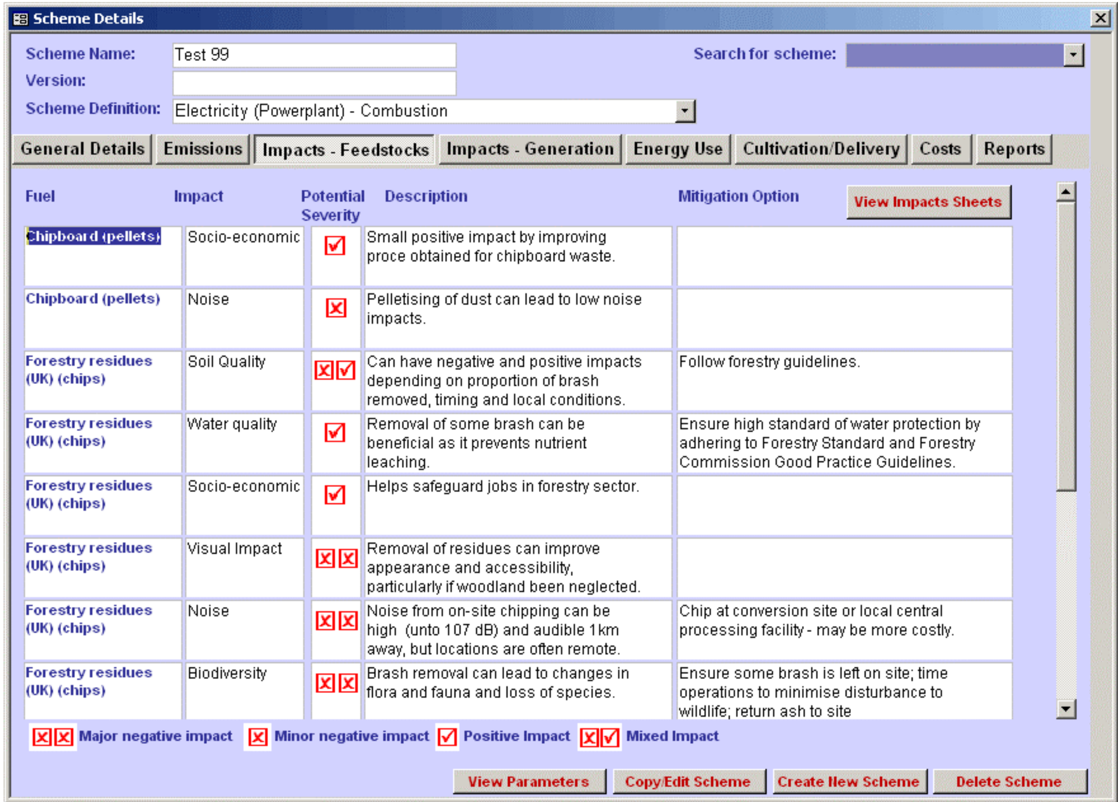
Help Text

For all the views described above help text is available – simply click the blue and white information icon.



Impacts – Feedstocks

The Impacts–Feedstocks screen summarises impacts from cultivating and processing feedstocks. Click the ‘View More Details’ button to see more detailed descriptions of impacts.



The impacts screen is displayed in columns – Fuel indicates the type of feedstock used to power the scheme. Impact describes the impacts from various stages of the biomass-energy chain.

This page summarises the potential environmental impacts associated with establishment, cultivation and harvesting of the biomass fuel.

Use the scroll bars at the side of the screen to scroll down through the list of impacts.

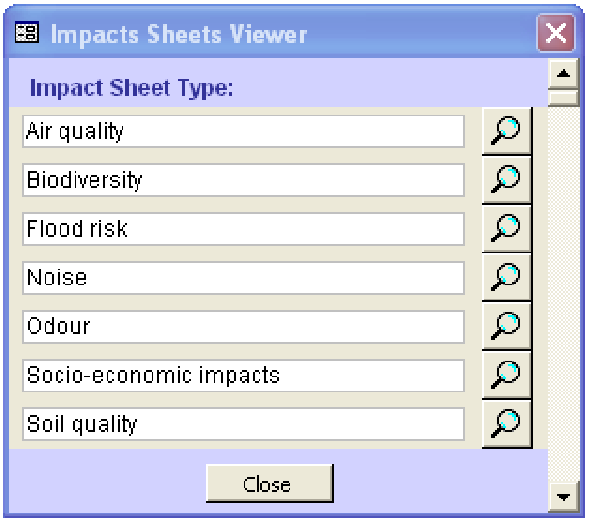
Where several fuels are used at a plant, the impacts of establishment, cultivation etc of each of the fuels is dealt with separately.

The potential severity of impacts is rated in a star format (=major, = minor) to indicate major or minor. This is a relative ranking only.

The impact categories are:

- Biodiversity
- Flood risk
- Noise
- Odour
- Socio-economic
- Soil quality
- Visual impact
- Water quality
- Water resources

More details of the impacts can be seen by pressing the 'View Impact Sheets' button to display the screen below.

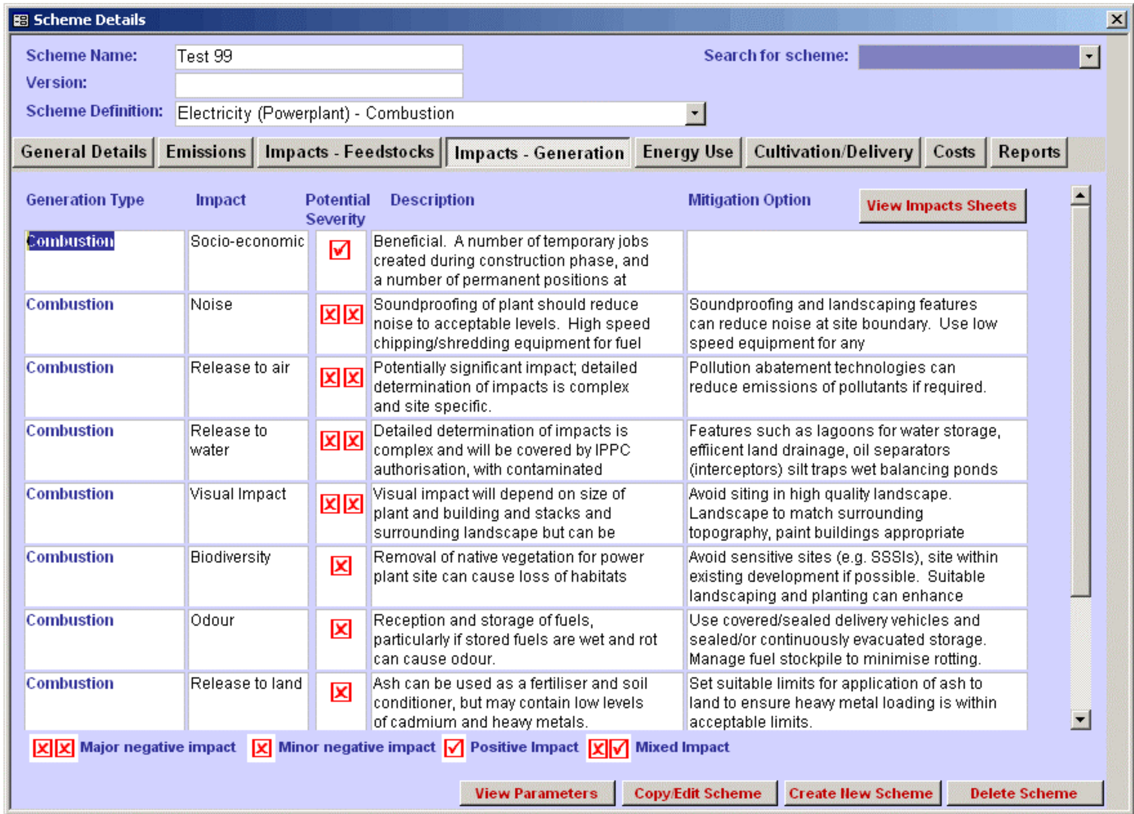


Clicking on the magnifying glass icon will display detailed impact sheet Word documents for each impact type. These more detailed descriptions can be printed from the Adobe Acrobat window using the print button.

The exact potential impacts from any particular plant can only be assessed through a detailed environmental impact assessment (EIA). The tool indicates potential impacts from typical plant, based on information supplied in the input page. It provides a guide to issues that should be addressed by a detailed EIA, and suggests generic options for reducing environmental impacts. Not all options may be applicable for all plant.

Impacts – Generation

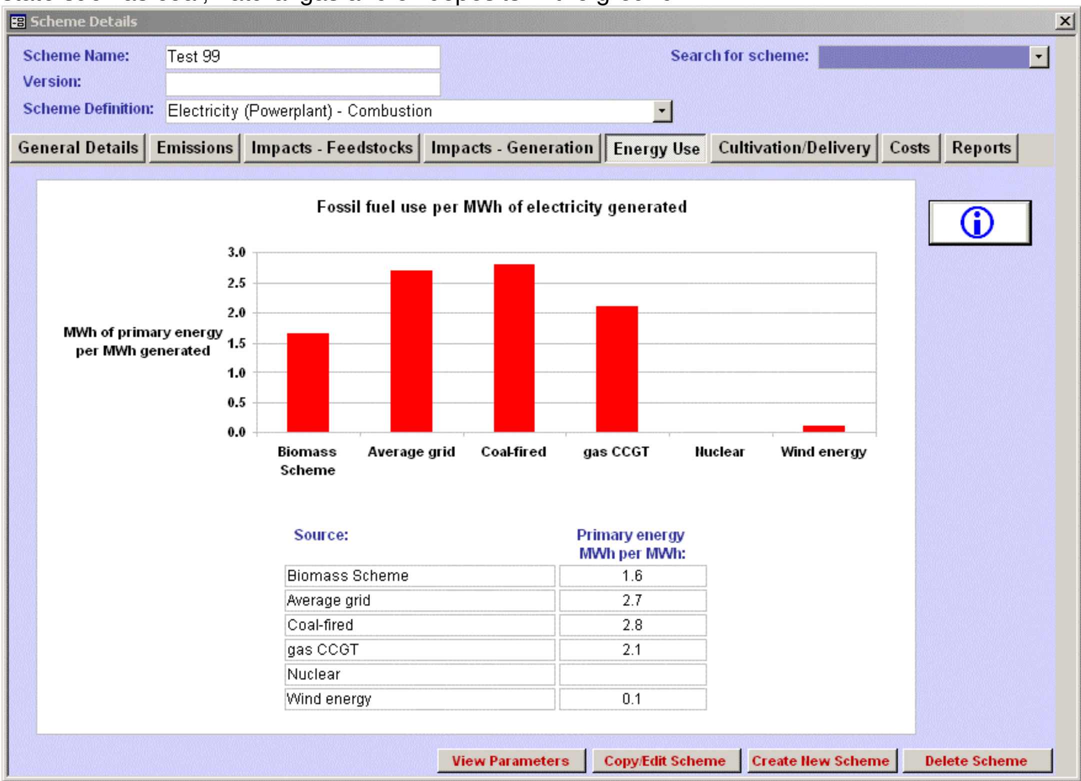
The page summarises the potential impacts associated with transporting biofuels to the plant and from the plant itself.



To see more detailed descriptions of impacts, click on the 'View Impact Sheets' button.

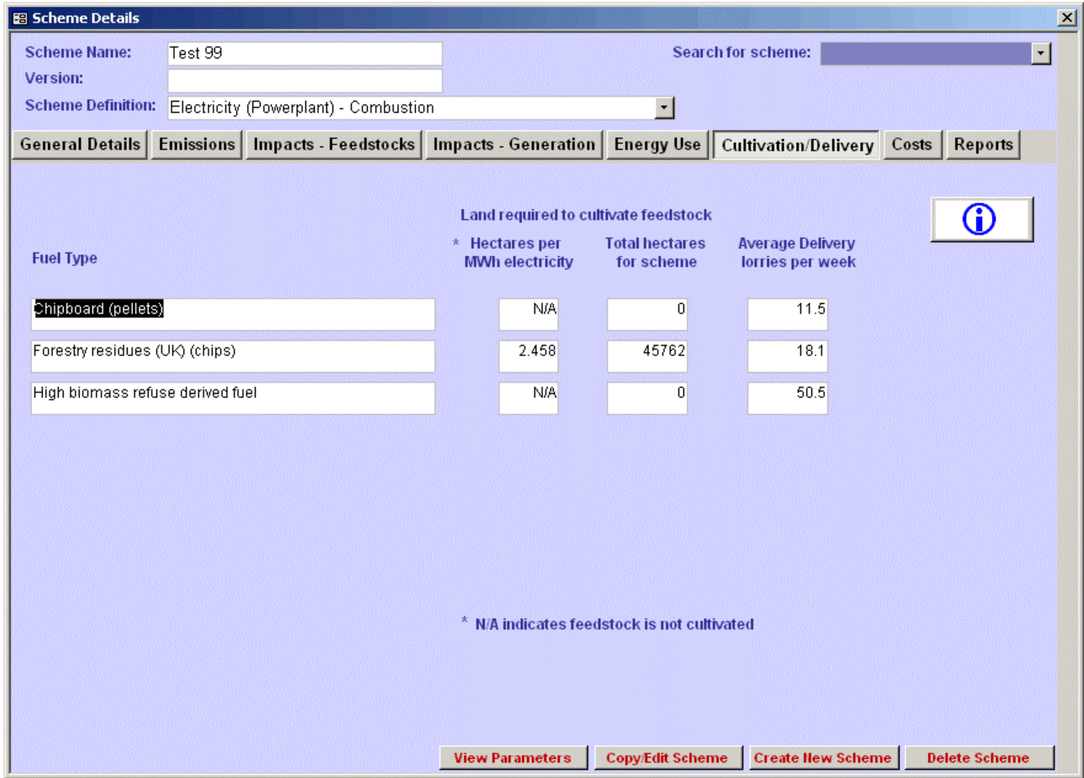
Primary Energy

This graph shows the amount of fossil fuels used to generate 1 MWh of electricity for the biomass scheme you have modelled and a range of other generation technologies. Fossil fuel use is the sum of the direct energy due to the use of fuels (e.g. diesel for tractors) and electricity; the indirect energy associated with the production of materials, equipment, etc.; and the energy contained in any feedstocks, such as chemicals and materials derived from fossil fuels. Fossil fuel use is expressed in terms of primary energy i.e. the amount of energy available in fossil fuel resources in their natural state such as coal, natural gas and oil deposits in the ground.



Cultivation/Delivery

This screen shows the number of weekly lorry deliveries to the scheme and the land area needed to grow feedstocks supplying the scheme.



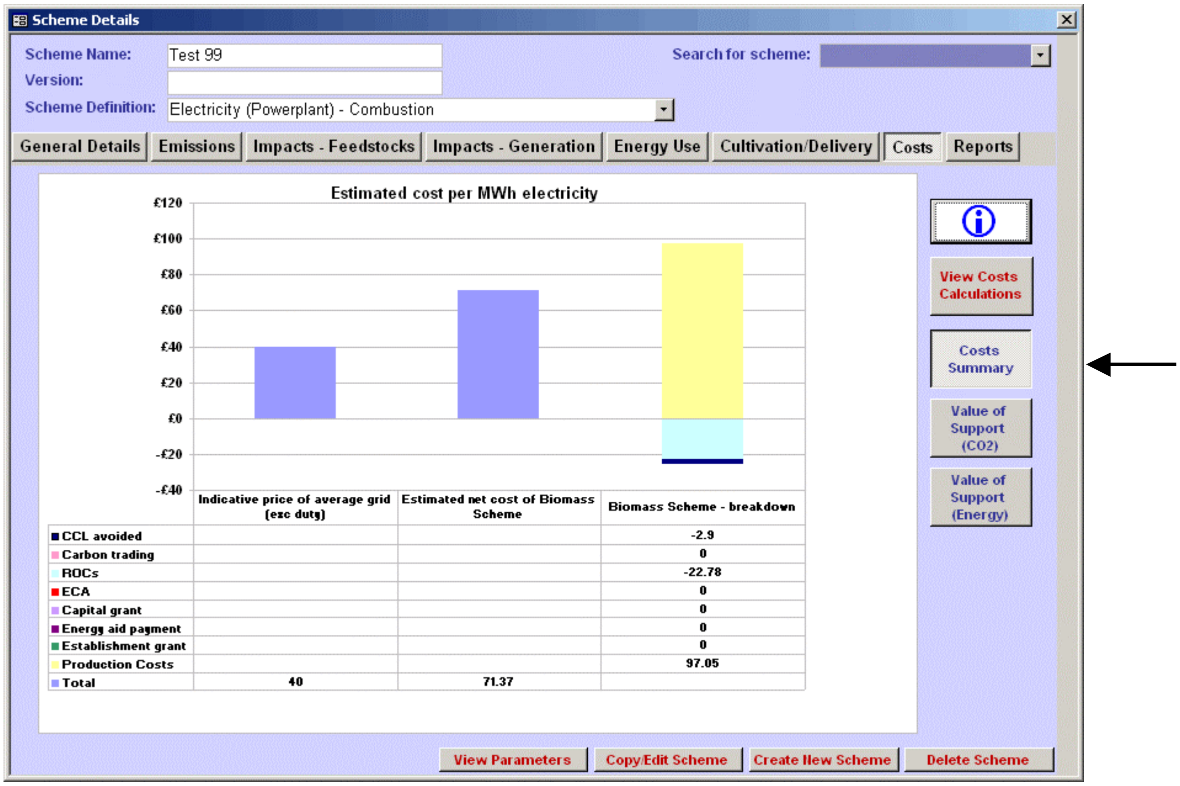
This screen shows the area of land required to cultivate biomass for the plant, and the number of deliveries which can be expected each week. The figures are based on typical yields, fuel properties and lorry sizes/loads. Yields can vary, so these figures should be used as a guide only. Note that for liquid biofuel plant, if fuel produced at the plant is distributed onwards by road tanker then there will be additional traffic movements.

Costs

Buttons along the right hand side show different costs related graphs.

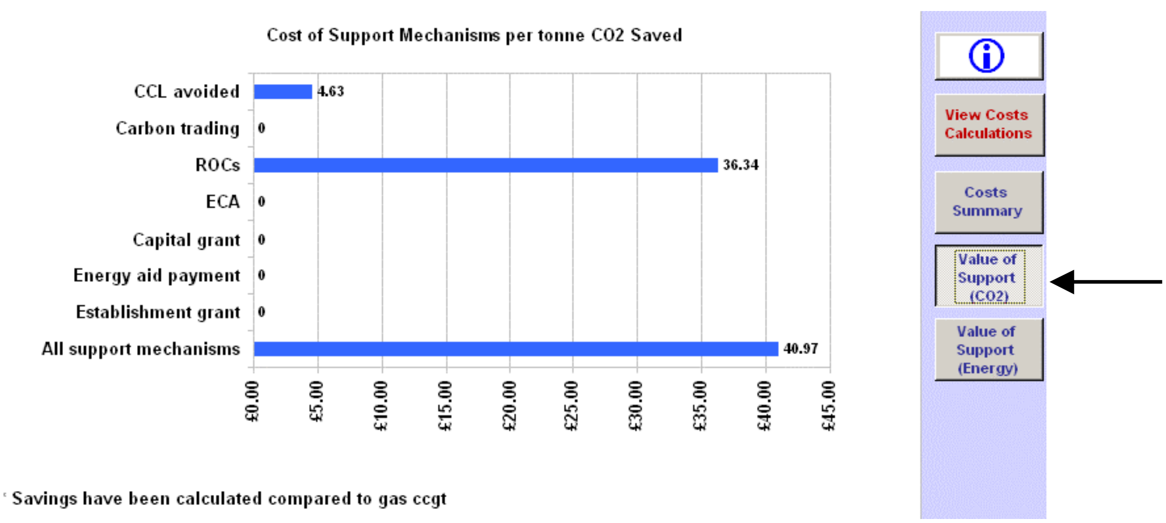
Costs Summary

This graph shows the costs associated with producing electricity from the biomass scheme modelled. Production costs reflect capital and operating costs of the scheme, including feedstock costs. The amount of support that the scheme receives, either directly e.g. as capital grants or Renewable Obligation Certificates (ROCs), or indirectly through mechanisms to support feedstock production are also shown. The estimated cost of producing electricity from the scheme is the sum of these costs and support mechanisms. This estimated cost does not include a profit element. A heat, electricity or fuel from a conventional fossil fuel source is shown for comparison.



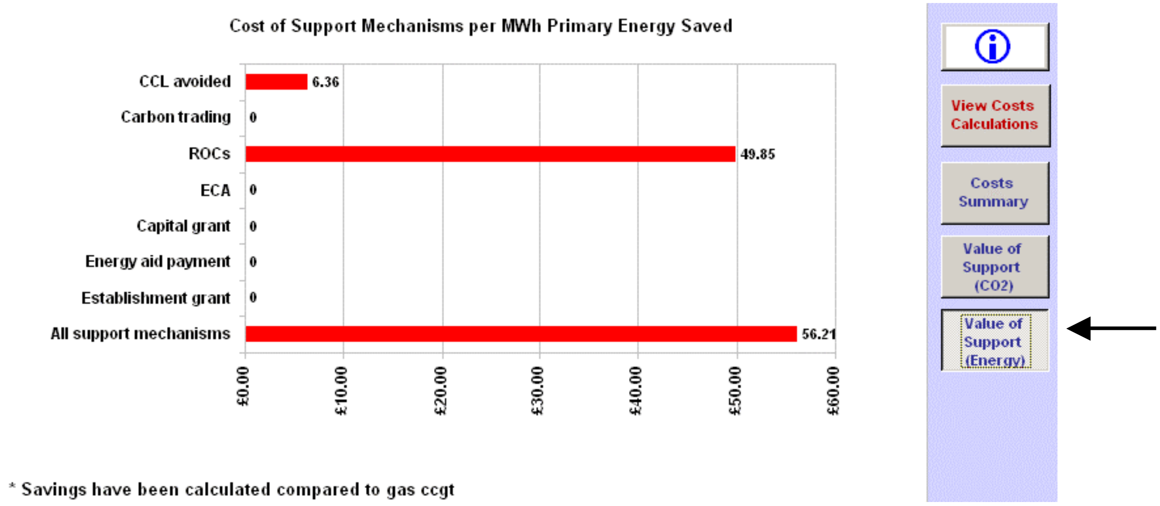
Support Mechanisms

This graph expresses the cost of the support the scheme recovers through various mechanisms in terms of per tonne of CO_2 saved. In order to calculate the CO_2 savings the scheme is compared against a default fossil fuel technology. The user has the option to change this in the costs parameters part of the tool, where the support mechanisms are defined.



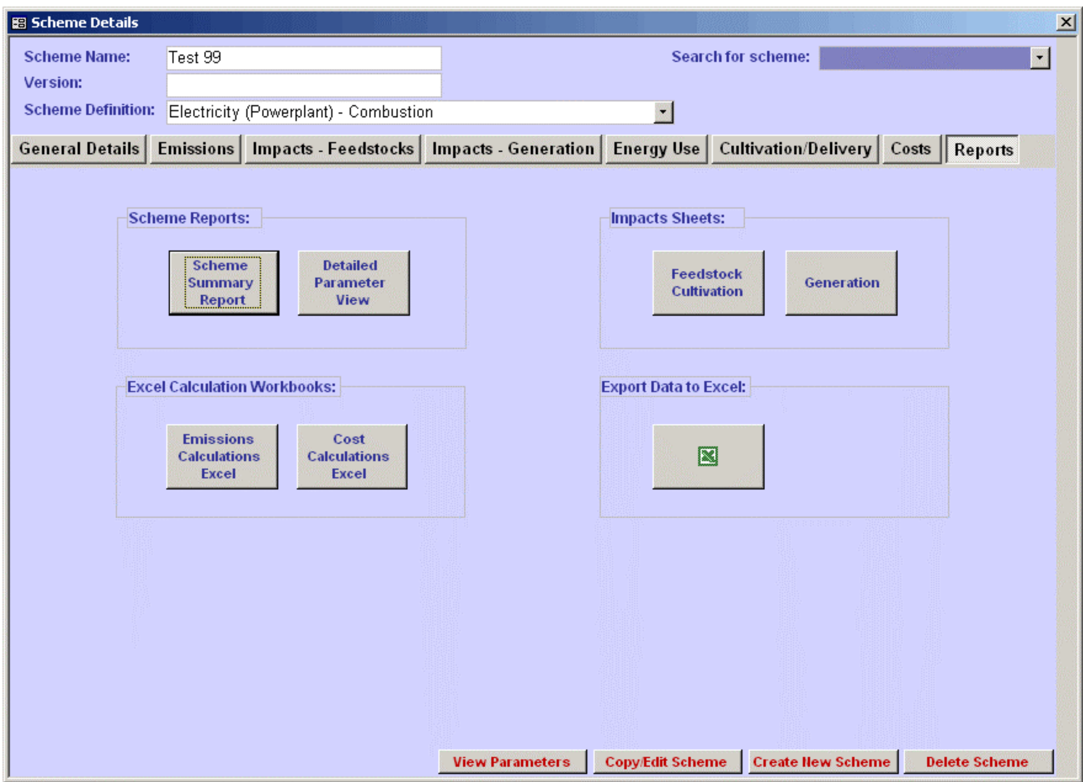
Energy Savings

This graph expresses the cost the support the scheme recovers through various mechanisms in terms of per tonne of primary fossil fuel energy saved. In order to calculate the primary fossil fuel energy saved, the scheme is compared to a default fossil fuel technology. This can be altered using the 'costs parameters' part of the tool, where the support mechanisms are defined.



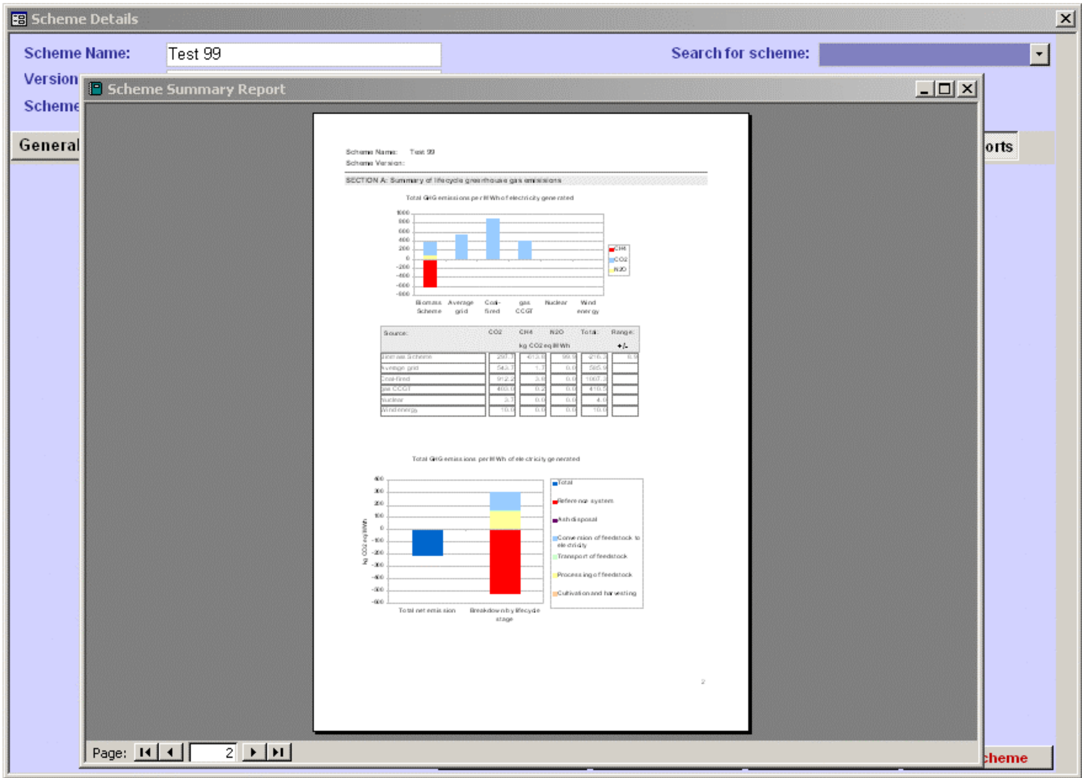
Reports

The reports section is used to produce printable summaries of the calculated outputs. It also contains various ways to access and export worksheets, impact sheets and data.



Scheme Reports

Clicking the ‘Scheme Summary Report’ button will produce a printable colour document, summarizing the results discussed in the sections above.



Clicking the ‘Detailed Parameter View’ produces a table of all the parameters used in the scheme, with the values associated with them.

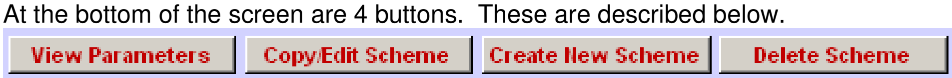
The report section also provides another route to viewing the detailed impact sheets – by selecting either ‘Feedstock Cultivation’ or ‘Generation buttons’.

The Excel workbooks used to produce the emissions and costs can also be accessed here.

The calculated figures for all the sections can be exported into Excel by clicking the Excel icon. This enables the user to save the results in a separate spreadsheet, which could be used to compare the results of different scheme options.

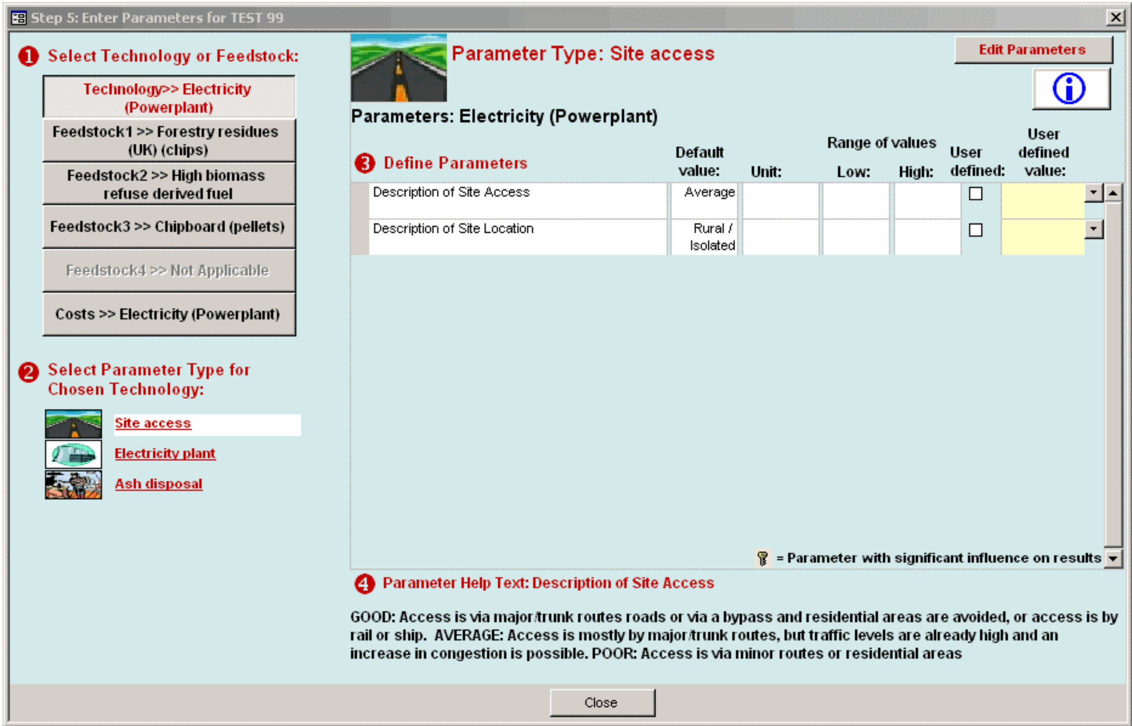
2.6 Other facilities

At the bottom of the screen are 4 buttons. These are described below.

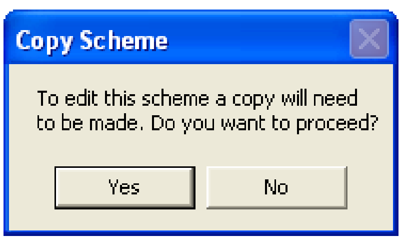


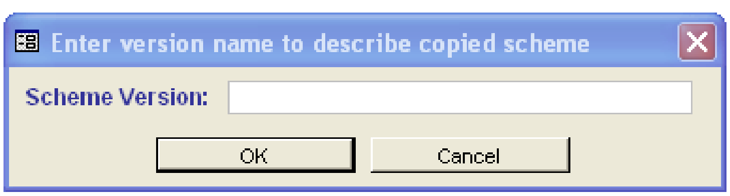
View Parameters

The parameters associated with a scheme can be viewed by clicking the ‘view parameters’ button. This will open up the familiar parameter form in read only mode. Parameters can be viewed by clicking the various selections along the left side.



To edit the parameters of an existing scheme click the Edit Parameters button in the top right corner of the screen. The user will be asked if a copy is to be made – click 'Yes' and enter a Version name to describe this new variant of the existing scheme.





After clicking OK you are free to modify the parameters of this scheme. Click Finish and wait a few seconds for the new results based on these new parameter values to be generated.

Copy/Edit Scheme

An alternative way to copy/edit the scheme is to click Copy/Edit Scheme button. This will ask for the Scheme Version as described above. The parameter form will open to allow modification of the scheme's parameters.

Create New Scheme

Creates a new scheme

Delete Scheme

Deletes the selected scheme

3 Assumptions and Background Data

3.1 Bioenergy Routes Modelled in BEAT

The tool covers six main conversion routes for Bioenergy:

- Biomass-fuelled power plant producing electricity using grate combustion, gasification or pyrolysis;
- Biomass-fuelled industrial scale combined heat and power plant producing electricity and heat using grate combustion, gasification or pyrolysis;
- Biomass-fuelled heating boilers ranging in size from industrial/commercial scale to domestic scale;
- Co-firing of biomass in existing large power plant;
- Anaerobic digestion and combustion of biogas to produce electricity and/or heat in small scale, on-farm plant and in centralised anaerobic digestion;
- Production of liquid biofuels.

BEAT 2 contains the feedstocks and technologies which are considered to be the most likely to be deployed in the next five to ten years within the UK. The combinations of feedstocks and technologies that can be modelled in the tool are shown in Figure 3.1. The emphasis of the tool is on production and processing of biomass in the UK. It therefore does not include imported fuel stocks for liquid biofuels such as palm oil. These routes will be covered in the methodology for accreditation of liquid biofuels being developed under the Renewable Transport Fuel Obligation by E4Tech.

3.2 Fuels

A description of the biomass fuels included in BEAT 2 is given in Table 3.1. Where plants are burning fuel not included in the table, then you should choose the closest equivalent, but be aware that there may be additional environmental impacts. Furniture waste is typically made up of off-cuts of ‘clean’ wood (e.g. as used for furniture legs) and mdf and chipboard waste. You can model it in BEAT 2 by including the correct proportions of these three fuels; if you do not know the composition of the furniture waste then a composition of 70% clean wood waste, and 15% mdf and 15% chipboard waste is recommended. The impacts on greenhouse gas emissions and primary energy requirements of changes in the source of imported wood chips can be examined by changing the transport distances.

BEAT allows for four different types of fuels to be considered for any one combustion plant. This limit was placed from experience with current and proposed biomass plants. However, some developers may propose the use of more than four types of fuel. To overcome this it is suggested that one of the following approaches is taken:

- Most biomass plants are constrained on the types of fuels that can be used by their operating conditions. Thus, although a number of different types of fuels may be proposed it is likely that they will fall into a typical type of fuel – i.e. they may be predominantly wood-based fuels or predominantly crop residues (e.g. straw). In this case it should be possible to group the fuels together and examine them as one predominant type, thus decreasing the fuels examined to four general groups.
- If the above is not possible, or it is suspected that it leads to incorrect assumptions about impacts (e.g. transport or cultivation), it may be necessary to examine the fuels in two separate records – that is, set up two versions of the same plant. The impacts of these two separate records will then need to be considered together.

One of the types of plant where more than four fuels may be considered is co-firing. The major driver for co-firing over the next few years will be the Renewables Obligation (RO). Under the RO power stations are only permitted to fire two different fuels at once. Thus, they can co-fire coal and biomass or coal and waste at the same time, but not coal, biomass and waste. This decreases the number of types of fuels that can be co-fired at any one time and may help to allocate fuels to two separate input forms.

Figure 3.1 Fuel and Technology Combinations included in BEAT 2

Dedicated Biomass Fuelled Plant

	Technology							
	Electricity generation (3-85 MWth)			Combined heat and power (CHP) generation (0.3 - 10 MWth)			Heat only boilers	
Feedstock	Combustion	Gasification	Pyrolysis	Combustion	Gasification	Pyrolysis	industrial scale scale 0.1 to 1.5 MWth	Domestic scale 5 to 100 kWth
Short rotation coppice (stick harvest) - chips	x	x	x	x	x	x	x	
Short rotation coppice (cut and chip) - chips	x	x	x	x	x	x	x	
Short rotation coppice (stick harvest) - pellets							x	x
Short rotation coppice (cut and chip) - pellets							x	x
Forestry residues - chips	x	x	x	x	x	x	x	
Forestry residues - pellets							x	x
Long' logs								x
"Clean" waste from wood processing - chips	x	x	x	x	x	x	x	
"Clean" waste from wood processing - pellets							x	x
Imported woodchips - chips	x	x	x	x	x	x	x	
Wood pellets from imported wood chips							x	x
Miscanthus (elephant grass) - chips	x	x	x					
Miscanthus (elephant grass) - pellets	x							
Miscanthus (elephant grass) - bales	x							
Straw	x	x	x	x	x	x	x	
Chipboard waste - shredded	x			x			x	
Chipboard waste - pellets	x			x			x	
MDF waste - shredded	x			x			x	
MDF waste - pellets	x			x			x	
High biomass rdf	x	x		x			x	
Glycerine (from waste oils)							x	
Glycerine (from rapeseed oil)							x	

Cofiring in power stations

	Form of Feedstock		
Feedstock	Chips	Pellets	Liquid
Olive cake		x	
Palm Kernel Expeller		x	
Cereal milling residues		x	
Glycerine (from waste oils)			x
Glycerine (from rapeseed oil)			x
Short rotation coppice* (e.g. willow)	x	x	
Miscanthus (elephant grass)	x	x	
Forestry residues	x	x	
"Clean" waste from wood processing	x	x	
Imported forestry residues	x	x	

Anaerobic Digestion Plant

	Technology				
	On farm (0.2 to 2 MWth)			Centralised (4 to 40 MWth)	
Feedstock	Electricity generation	CHP	Heat only	Electricity generation	CHP
Animal manures - pig	x	x	x	x	x
Animal manure - dairy	x	x	x	x	x
Wet' poultry waste				x	x
Typical food waste (currently being defined)				x	x

Liquid Biofuels

Biodiesel from UK oilseed rape	x
Biodiesel from waste oils	x
Bioethanol from sugar beet	x
Bioethanol from wheat	x

Table 3.1 Description of fuels contained in BEAT 2

Cereal milling residues	Cereal milling residue is a by-product of flour manufacture and is also known by other names such as wheat feed, cereal co-product or milling co-products. It is obtained from screened husked grains of wheat and comprises fragments of the outer skins and of particles of grain. This product is variable because of the variable nature of wheat and also because varying quantities of skin, grain and endosperm are present, depending on the precise milling and blending processes used. Cereal milling residue is available as a dust or may be offered pelleted for use as a fuel. In this tool, only a pelleted version is considered.
Forestry residues (chips and pellets)	The branches and tops of the trees (brash) removed from the logs when a forest plantation is clear-cut at the end of its rotation, or small trees removed in thinning operations. The wood fuel is likely to be stored in the forest either whole or in chips prior to transport to the conversion plant
Glycerine	Glycerine is a viscous hydrocarbon liquid at room temperature, also known as glycerol, 1,2,3 propanetriol or trihydroxy-propane. It is used in a multitude of cosmetic and medical preparations and material of such high quality commands a high price. However, low-grade glycerine is produced as a by-product of the manufacture of biodiesel. Glycerine from this source is available in excess of current market needs and is not of sufficiently high grade to command the same price as medical grade material. It has a reasonable CV and is being considered as a fuel.
High biomass RDF	There are a number of high biomass content refuse derived fuels currently being proposed. These include fuels also known as cellulosic fibres and refined renewable biomass fuel. Within BEAT2 the term high biomass refuse derived fuel is used to refer to any potential fuel resulting from the processing of mixed waste streams to a fraction with a biomass content >90% and a low fossil derived content. This fuel may be available as a floc or as a pellet. In this tool, only the pelletised version is considered.
MDF and Chipboard wastes	Medium density fibreboard (MDF) and chipboard are produced from wood fibres glued together under heat and pressure. The waste material is produced as both off cuts and dust as part of the furniture making process. MDF and chipboard are generally less suitable for higher value waste recycling options such as animal bedding and so are readily available for combustion. The material has low moisture content and is suitable as a combustion fuel. The dust can be pelletised or briquetted for combustion. Care must be taken to ensure the PVC (e.g. from edge banding) is excluded from the waste fuel. This tool includes shredded chipboard and MDF waste that would typically be used on site, and pelleted waste that could be transported offsite.
Miscanthus (chips, pellets and bales)	Miscanthus is a rhizomatous perennial grass that produces multiple shoots from the rhizomes in April/May. These grow rapidly during May, June and July to produce 3-4 m stems. By February March these have dried and are harvested, left on the field to dry down naturally and then baled and transported to the plant.
Olive cake	Olive cake residue is the by-product of olive oil manufacture that remains after the olives have been pressed and the olive oil extracted. It generally comprises olive kernel shell, the skin and crushed pulp that remains after oil extraction, but can vary in composition, depending on the extraction process. There is a lot of interest in using olive cake as a fuel, because of its relatively high CV (compared to other wetter biomass fuels). It is used as a secondary fuel for co-firing in power stations and for co-firing in district heating plant across Europe.

Palm Kernel Expeller	Palm kernel expeller is a residue from the processing of palm oil using an expeller or solvent. The palm oil industry sells palm kernel cake (expeller) (PKE) and palm kernel pellets, which are rich in nutrients. These products are used as a component of animal feed manufacture, blended with other, more palatable, materials. However, PKE is also a potential fuel and has been used by coal power stations in the UK as a fuel for co-firing since 2001.
Sawmill waste	Clean wood waste from saw milling: this can comprise sawdust, shavings and off cuts.
SRC (stick harvest) (chips and pellets)	Short rotation coppice (SRC) fast growing tree species – typically willow or poplar - that are grown intensively and harvested in winter every 2 to 5 years. In this option, harvested sticks are typically stored on edge of field to dry, before transport to the conversion plant where they are chipped.
SRC cut and chip) (chips and pellets)	Short rotation coppice (SRC) fast growing tree species – typically willow or poplar - that are grown intensively and harvested in winter every 2 to 5 years. In this option, the coppice is harvested and chipped in one pass. The chips are easy to transport and handle, but can be difficult to store safely unless they are dried first.
Straw	The residue from the production of cereal and seed crops harvested and immediately baled between July and October. It is stored on field with a specially designed 'roof' to reduce moisture ingress before transport as needed to the conversion plant.

3.3 Technologies

The 'default' or reference vales for the key characteristics of the power CHP and heating boilers modelled in the tool are shown in Table 3.2. As described in Section 2.4, these values can be changed by the user to reflect the particular characteristics of the plant being modelled

Table 3.2 Typical plant characteristics used as default values

Process	Output	Thermal Input	Plant Efficiency	Heat to power ratio
		MWth		
Combustion	Electricity	40	25%	
Combustion	Electricity and heat	10	75%	4
Combustion	Heat only (industrial)	0.8	80%	
Combustion	Heat only (industrial)	0.03	89%	
Gasification	Electricity	40	35%	
Gasification	Electricity and heat	10	75%	1.5
Pyrolysis	Electricity	40	35%	
Pyrolysis	Electricity and heat	10	70%	1.5
Co-firing	Existing plant	Not specified	35%	

3.4 Access and Delivery

The three choices of access to the plant site are used to determine the potential magnitude of transport impacts. Guidelines for choosing the access ranking are shown in Table 3.3.

Table 3.3 Guidelines for access ranking

Ranking	Criteria
Good	Access is via major/trunk routes roads or via a bypass; residential areas are avoided. Access is by rail or ship thus avoiding increases in road transport.
Average	Access is mostly by major/trunk routes, but traffic levels are already high and an increase in congestion is possible.
Poor	Access is via minor routes or is through residential areas.

In estimating the number of delivery lorries which are required, it has been assumed that for power plant it will be by the largest lorry size available as this will generally be the most economic. For industrial boilers a smaller lorry size is assumed, and for domestic boilers a smaller lorry size again. The amount of fuel in oven dried tonnes (odt) a lorry delivering to each of these types of plant is assumed to carry is shown in Table 3.4. Feedstocks for liquid biofuels (vegetable oil, oil seed rape, wheat or sugar beet) are assumed to be delivered in 25t loads. For centralised anaerobic digestion plant, tankers are assumed to carry 20 t of manure or food waste.

Table 3.4 Typical mass of biomass fuel in a lorry load (in odt)

	Power and CHP plant	Industrial heat plant	domestic heat plant
Chipboard (pellets)	25	15	1
Chipboard (shredded)	18	10.8	0.72
Clean' wood waste (chips)	15	9	0.6
Clean' wood waste (pellets)	25	15	1
Forestry residues (imported) (chips)	15	9	0.6
Forestry residues (imported) (pellets)	25	15	1
Forestry residues (UK) (chips)	15	9	0.6
Forestry residues (UK) (pellets)	25	15	1
Glycerine (from oil seed rape)	25	15	1
Glycerine (from used oil)	25	15	1
High biomass refuse derived fuel	15	9	0.6
Logs	25	15	1
Medium density fibreboard waste (pellets)	25	15	1
Medium density fibreboard waste (shredded)	18	10.8	0.72
Miscanthus (bales)	15	9	0.6
Miscanthus (chips)	17	10.2	0.68
Miscanthus (pellets)	25	15	1
Short rotation coppice (cut and chip) (chips)	15	9	0.6
Short rotation coppice (cut and chip) (pellets)	25	15	1
Short rotation coppice (stick harvesting) (chips)	15	9	0.6
Short rotation coppice (stick harvesting) (pellets)	25	15	1
Straw	15	9	0.6

The factors that determine the amount of fuel that can be transported is the density of the fuel, the available volume in the vehicle and its maximum axle load. Where the material has a low bulk density, such as chipped material, the load is volume limited - it will not be possible to reach the maximum weight carrying capacity of the vehicle before the available volume has been filled.

Heavier materials such as pellets that have been artificially compressed have a much higher bulk density are weight limited - the maximum load carrying capacity can be reached within the available volume. Often chipped materials are transported in high box back units that maximise the available volume. Higher bulk density materials use standard tipper units.

Increasing the moisture content in a dense material will reduce the useful energy that can be transported by a unit load because water is being carried instead of fuel. The water will also need to be evaporated at the plant. This will therefore increase the number of trips necessary to supply a power plant.

If on the other hand the load is volume limited then the moisture content can increase until the maximum weight is reached. The same amount of dry matter will be carried - the water is effectively taking up spare volume. This moisture will of course have to be evaporated at the plant.

Table 3.5 extracted from the EU Bioheat project website shows the potential variation in energy density for a range of wood products.

Table 3.5 Potential variation in energy density for wood products

	Wood Residue Chips	Saw residue chips	Saw-dust	Cutter chips	Grinding dust	Plywood residue	Uncoated wood
Moisture content, w-%	10-50	45-60	45-60	5-15	5-15	5-15	15-30
Net calorific value in dry matter, MJ/kg	18.5-20	18.5-20	19-19.2	19-19.2	19-19.2	19-19.2	18-19
Net calorific value as received, MJ/kg	6-15	6-10	6-10	13-16	15-17	15-17	12-15
Bulk density as received, kg/loose m^3	150-300	250-350	250-350	80-120	100-150	200-300	150-250
Energy density, MWh/ m^3 of bulk volume	0.7-0.9	0.5-0.8	0.45-0.7	0.45-0.55	0.5-0.65	0.9-1.1	0.65-0.8

3.5 Support Mechanisms

BEAT contains a simple model of the cost of producing heat, electricity or transport fuels from biomass feedstocks. The main aim of this part of the tool is to allow the estimation of the value of support mechanisms (e.g. grants) on a per MWh or per litre basis, and to combine this with the relevant GHG saving to obtain an estimate of the effectiveness of these support mechanisms in reducing GHG emissions. The tool is not intended to provide accurate estimates of the cost of biomass based heat, electricity or fuels, but to give an indicative cost based on typical prices for feedstocks and capital and operating costs.

The model takes a price for feedstock (on an as delivered basis) and combines this with capital and operating costs in a simple net present value model to calculate a p/MWh or p/l production cost; the value of any support mechanisms is calculated using the same model. Parameters such as output of the plant are taken from the emissions part of the tool. As in the rest of BEAT, all parameters can be altered from their default values.

4 Life cycle assessment principles

This Section introduces the basic principles of life cycle assessment and how they have been applied in relation to specific aspects of BEAT2. These principles and their application are illustrated by means of examples relevant to the particular biomass energy technologies covered by BEAT2.

4.1 Basic Principles

Life cycle assessment is an established technique for quantifying the total environmental impacts of the provision of a product or service from original resources to final disposal, or so-called "cradle-to-grave". Amongst the many reasons for performing life cycle assessment studies is the possibility of comparing the total environmental impacts of alternative products or services. As such, life cycle assessment is a potential tool for assisting decision-making for a range of interested parties including policy-makers, regulators and developers. Its practical application is underpinned by an official framework for life cycle assessment in the form of the International Standard ISO 14040 series (Refs. 4.1 to 4.6). This framework establishes the definitions and conventions of life cycle assessment, and provides practical advice on methods of calculation. As a complete method of environmental evaluation, life cycle assessment is composed of six major stages, consisting of goal and scope definition, life cycle inventory analysis, life cycle impact assessment, life cycle interpretation, reporting and critical reviewing. It is only the first two major stages that are covered in the current version of BEAT 2.

The goal of a life cycle assessment establishes the intended application of subsequent results, the reasons for generating these results and the expected audience for these results. The scope of a life cycle assessment provides full specification of the study and the product or service that is being examined. In particular, the scope indicates the "functional unit" which is being investigated by providing a clear, full and definitive description of the product or service that enables subsequent results to be interpreted correctly and compared with other results in a meaningful manner. In terms of BEAT 2, the functional unit is either 1 MWh of electricity and/or heat available at the production plant or 1,000 litres of liquid biofuel available at the filling station. Life cycle inventory analysis involves quantifying relevant inputs and outputs of the life cycle of a product or service. This is a significant activity in life cycle assessment since it usually requires considerable data collection and analysis. Various life cycle inputs and outputs must be quantified, including energy resources, such as fossil fuels, and emissions to atmosphere, such as CO_2 and other greenhouse gases.

4.2 Inputs and Outputs

Since energy, and CO_2 and other greenhouse gas emissions are the principal inputs and outputs, respectively, addressed by BEAT 2, it is necessary to provide related definitions to ensure clarity with subsequent results. The appropriate measure of fossil fuel resource depletion is primary energy, which consists of the amount of energy available in resources in their natural state, such as coal, natural gas and oil deposits in the ground. As such, it is an indicator of energy resource availability which is greater than the energy provided by fuels, electricity and heat used by consumers, known as delivered energy, and the energy services required by these consumers, referred to as useful energy. Using the terminology of energy analysis, a fore-runner of life cycle assessment (Refs. 4.7 and 4.8), the energy requirement is equal to the total amount of primary energy involved in the provision of a given product or service. The total amount of primary energy consists of the sum of the direct energy due to the use of fuels and electricity, the indirect energy associated with the production of materials, equipment, etc., and the energy contained in any feedstocks, such as chemicals and materials derived from fossil fuels. Only by including direct, indirect and feedstock energy inputs in the evaluation will the energy requirement reflect fully the depletion of primary energy resources. In BEAT 2, the energy requirements include all these inputs although they are aggregated together in the workbooks for simplicity of presentation.

The calculation of greenhouse gas emissions from the provision of a product or service is based, principally, on the evaluation of emissions from the use of fuels and electricity. This is achieved by means of suitable carbon coefficients, or combustion emission factors, which indicate the CO_2 emissions produced per unit of energy available when a fuel is burnt or electricity is generated. Similar coefficients are available for assessing other greenhouse gas emissions, which include CH_4 and N_2O emissions. Although such coefficients include relevant greenhouse gas emissions from fuel combustion and electricity generation, they usually exclude greenhouse gas emissions from other fuel cycle activities, such as the construction, operation and maintenance of infrastructure for processing fuels. However, it is necessary to account for all the greenhouse gas emissions in subsequent coefficients for fuels and electricity to ensure that they adequately reflect the impact on global climate change. Elsewhere, coefficients that include all relevant emissions are referred to as total upstream and combustion emission factors (Ref. 4.9).

Using these coefficients and factors in life cycle assessment, it is possible to derive the carbon, methane or nitrous oxide requirement of a product or service which consists of the total CO_2, CH_4 or N_2O emissions, respectively, associated with the provision of a physical unit of the product or service. The total emissions of any given greenhouse gas equal the direct emissions from the combustion of fuels and the indirect emissions due to the generation of electricity and the manufacture of materials, equipment, etc. In particular, as well as CO_2 emissions from the direct or indirect combustion of fossil fuels, other sources of CO_2 emissions, such as the manufacture of cement and nitrogen fertiliser, must be taken into account. The matter of feedstocks in such CO_2 calculations is more complicated than in primary energy calculations. Whether any CO_2 emissions arise from feedstocks that store carbon originally derived from fossil fuels depends on the ultimate fate of this carbon. If the carbon always remains stored in the feedstock, then it is excluded from calculations. However, if the feedstock is eventually burnt or decomposes naturally, the CO_2 released must be included. Additionally, the carbon in fossil fuels used as feedstocks in chemical processes may be released as CO_2 emissions as a result of chemical reactions. As might be expected, actual calculation procedures depend on specific circumstances.

In terms of BEAT 2, the most significant consideration arises from the use of natural gas as a feedstock in the production of ammonium nitrate fertiliser. Details of how such associated CO_2 emissions and related N_2O emissions are incorporated are explained and presented elsewhere (Ref. 4.10). In order to use estimates of total CO_2, CH_4 and N_2O emissions in relation to impact on global climate change, it is necessary to convert contributions from separate greenhouse gases into terms of equivalent CO_2. This conversion is achieved using appropriate quoted values of global warming potential that relate CH_4 and N_2O emissions to an equivalent amount of CO_2. Due to the differing periods over which individual greenhouse gases reside in the atmosphere and effectively contribute to the greenhouse effect, values of global warming potential vary depending on the timescale under consideration. Using standard procedure adopted by the Inter-governmental Panel on Climate

Change, the values of global warming potential used in the Biomass Environmental Assessment Tool are 23 kg equivalent CO_2 per kg of CH_4 and 296 kg equivalent CO_2 per kg of N_2O (Ref. 4.11).

4.3 Processes and Systems

The central feature of a life cycle assessment is the process chain, which summarises the main activities in the provision of a product or service. The process chain reflects the life cycle of the product or service from the original natural resources, or "cradle", through actual use, and on to eventual disposal, or "grave". In the case of the delivered energy, such as heat, electricity or liquid fuel, provided by a biomass energy technology, the issue of eventual disposal is irrelevant, apart from any ash disposal. Some other disposal activities may be considered as a result of incidental and accidental spillages of liquid fuels. Even so, under normal circumstances, the majority of the delivered energy should be consumed in combustion processes. However, this does not mean that “disposal” does not, effectively, occur since any combustion products, which are exhaust gases, are released into the environment. Fortunately, life cycle assessment recognises these as outputs, which are accounted along with other outputs and inputs to the process chain.

The process chain represents the main sequence of process stages, which are directly involved in the production of the final product from its principal natural resource. For example, the process chain for the generation of electricity from wood chips derived from short rotation coppice would begin with the cultivation of poplar or willow setts or cuttings and end with the provision of electricity at a defined point such as the power plant (and the disposal of wood ash) . The process chain includes all the stages in between these start and end points. In this instance, harvesting, transportation, electricity generation and ash disposal would be included in the process chain. Apart from specifying the individual stages of processing, the process chain should record the actual amounts of products or service exchanged between each stage. For example, given amounts of setts and cutting are planted on a specified area of land to produce, subsequently, particular quantities of wood chips, electricity and wood ash. This information is a fundamental part of life cycle assessment and it is summarised with the details of the process chain in a flow chart. Such graphical presentation is extremely helpful to understanding the complete process under consideration. In the Biomass Environmental Assessment Tool, all the relevant information on the process chain is listed in the Unit Flow Chart worksheet.

It is possible to restrict life cycle assessment to the inputs and outputs directly associated with the main stages represented by the process chain. However, it is possible that prominent inputs, outputs and their related environmental impacts could be overlooked if attention only focuses on the activities involved with the process chain. For example, considerable amounts of primary energy and CO_2 and N_2O emissions are associated with the production of ammonium nitrate fertiliser. Although such fertiliser can be an input to cultivation, its production lies outside this stage in the process chain. In order to ensure that the primary energy inputs and CO_2 and N_2O emissions for fertiliser production are incorporated, it is necessary to make links between related processes or, in the terminology of life cycle assessment, expand the systems boundary of the processes under investigation. Obviously, this approach can apply to any input to any process stage and it can, in theory, be continued indefinitely. In order to include all the inputs and outputs from all possible sources, it would be necessary to expand the systems boundaries so that the start point for everything used, directly or indirectly, by the process chain is, in fact, a natural resource. At first, this may seem to be a very demanding, if not impossible, task. However, there are practical solutions to ensure that appropriate estimates of inputs and outputs can be generated realistically within life cycle assessment. One solution is to continue expanding the systems boundary until the actual contributions to total inputs and outputs become insignificant. Another solution is to use estimates from databases that actually do take into account all the interconnections of the industrial economy.

4.4 Reference Systems

One particular aspect of life cycle assessment that needs to be considered for biomass energy systems is the matter of reference systems, which are used to determine effects of alternative activities that are avoided or displaced by the main process under investigation. In the case of many biomass energy systems, reference systems are needed to account for the fact that the land used to grow the biomass could have been used for growing another crop. The reference system represents this other land use. The inputs and outputs for this reference system form credits, which are subtracted from the relevant inputs and outputs of the main process chain under consideration. For example, land is used to grow oilseed rape for the production of biodiesel. At one extreme, such land could be left fallow, under current set-aside regulations, so that only relatively small amounts of primary energy inputs and associated greenhouse gas emissions would arise due to occasional mowing. At the other extreme, the land could be used for growing an energy-intensive crop that would result in relatively large quantities of primary energy inputs and associated greenhouse gas emissions. In the former case, the primary energy, greenhouse gas credits would be fairly small and, in the latter, they might be quite significant.

Hence, having accepted the need to apply reference systems and subsequent credits, it is necessary to determine which should be chosen. Although there is no absolute rule, it is important to take into account the broader implications and policy considerations of any choice of reference system. If oilseed rape for biodiesel production is, in current circumstances, most likely to be grown on set-aside land that will be left fallow, then this is clearly the appropriate reference system. If the economic conditions exist for expanding biodiesel production dramatically so that oilseed rape is grown on land normally used for cultivating energy-intensive crops, then this might seem to indicate the correct choice of reference system. However, this raises the question of whether such energy-intensive crops are still in demand and, therefore, where they will be produced. This concern applies particularly to food crops, which are essential over the long term, even if temporary surpluses exist in certain areas. As such, this would require the introduction of broader and more complex considerations into policies towards biodiesel production. Above all, the eventual choice of reference systems and subsequent credits should reflect economic reality.

The application of these reference systems also applies, crucially, to biomass energy systems that use feedstocks that would normally be considered as wastes. The primary energy inputs and greenhouse gas emissions associated with the conventional disposal of these wastes have to be taken into account during assessment. As with alternative land use, there can be a variety of options for the disposal of these wastes. The actual choice of these options can have a significant effect on the subsequent primary energy input and greenhouse gas emissions credits that must be applied to the biomass energy system. In many instances, the main future disposal option is for the wastes to go to landfill with energy recovery. This involves the collection of landfill gas from the disposal site and the generation of heat and/or electricity. In terms of the current version of BEAT 2, it is assumed that electricity only generation is the main energy recovery option. In order to perform the relevant calculations, it is necessary to calculate the avoided primary energy inputs and greenhouse gas emissions which occur because the waste has been used in a biomass energy system rather than sent to landfill for disposal. The energy recovery element of landfill disposal adds complexity to such calculations since the electricity generated displaces, in turn, fossil fuels used in conventional electricity generation. Hence, potentially confusing but entirely consistent situations can arise in which the benefits of displacing fossil fuels are “avoided”. This can cause primary energy input and greenhouse gas emissions deficits, instead of credits, to occur in the assessment.

Reference systems must also be applied to the generation of heat and/or electricity from animal and food wastes by means of anaerobic digestion. It is necessary to consider the fate of these wastes during current conventional disposal. In the case of animal wastes, it has been assumed that their disposal would, in effect, be achieved by spreading them on farm land. The greenhouse gas emissions, especially direct methane emissions, and direct and indirect nitrous oxide emissions, arising from such disposal have to be taken into account. Such emissions occur during the storage of the waste and its decomposition on the land. Whilst these emissions have negative consequences for such disposal, it could be argued that they have beneficial effects as organic fertilisers. Their use as such reduces the application of artificial fertilisers. Hence, they avoid some primary energy inputs and greenhouse gas emissions in the manufacture and use of artificial fertilisers. However, in order to incorporate this fully, it would be necessary to take into account the effect on the subsequent crop or crops. This expands the systems boundaries considerably and could not be accommodated within the current version of the BEAT 2. It should, of course, be noted that the avoided impact of animal waste disposal must be evaluated relative to anaerobic digestion which includes the disposal of digestate, as a co-product of this process, on farm land. The actual emissions from digestate during storage and after spreading on the land have not been studied in as much detail as those from the storage and decomposition of the original animal manure. Hence, it has been necessary to assume that the main effect of anaerobic digestion is to remove most of the methane and make it available for subsequent use whilst overall nitrous oxide emissions are unchanged to any significant degree. This results in a substantial credit in avoided methane emissions. The situation regarding the anaerobic digestion of food wastes is somewhat less complex since it has been assumed that the reference system for this is disposal to landfill with energy recovery.

Other reference systems occur with specific biomass energy technologies represented in the current version of BEAT 2. In particular, it is assumed that the appropriate reference system for any type of waste wood is disposal to landfill with energy recovery. Certain assumptions have had to be made to account for the composition of various types of waste wood and the manner of decomposition of different components in relation of carbon dioxide, methane and nitrous oxide emissions. Coverage of waste wood sources in the current version of BEAT 2 chipboard, medium density fibreboard (MDF) and any substantial amounts of waste wood generated during the recovery and processing stages of the biomass energy technology. This can include losses during chipping of any form of wood. Whilst it could be argued that there are more common forms of alternative use for wood waste, it should be appreciated that these mainly consist of waste wood products (such as animal bedding, horticultural mulch, etc.) which would subsequently expand the systems boundary to include the products that these alternative uses would displace. For simplicity, this is excluded from the current version of BEAT 2. In case this causes difficulties, the option of disregarding the reference system is provided for all relevant biomass energy technologies.

4.5 Allocation Procedures

Another consideration that is particularly relevant to the life cycle assessment of many biomass energy technologies is the issue of how inputs and outputs are divided between more than one product or service from a single process chain. The ways in which this might be achieved are referred to as allocation procedures and considerable attention is devoted to the nature of these procedures in the literature, especially ISO 14041 (Ref. 4.2). It is important to recognise at the very beginning that there is no single allocation procedure that is appropriate for all circumstances. In economics, the problem is resolved, mainly, by using prevailing market prices determined by relevant demand to allocate costs between different products and services from a single process chain. In relation to products specifically, economic distinctions are drawn, effectively, between the main product that attracts the greatest revenue, co-products that receive equal revenues, by-products which result in smaller revenues and waste products which provide little or no revenue (or, even, may attract an expenditure for disposal). Although this approach, referred to as allocation by price, can be adopted in life cycle assessment, it is not necessarily the obvious or acceptable choice. The reasons for this are, chiefly, due to concerns about the fundamental effects of relative price fluctuations on the results of life cycle assessment and an inclination to base allocation procedures on relatively fixed physical characteristics rather than varying economic relationships between multiple products or services.

Consequently, various allocation procedures are available in life cycle assessment. Most are based on a common feature which is shared by the multiple products or services. For example, the mass, volume or calorific value of products can be used, although reliance on such simple features for allocation needs to be justified satisfactorily. In cases where all the products are fuels, such as petroleum products produced by an oil refinery, allocation by relative output and calorific value is often regarded as appropriate. However, allocation by this means for products that might have calorific values but are not, in fact, used as fuels is quite tenuous and not wholly justifiable. Of course, most allocation procedures are applied in instances where multiple products or service share no common feature. Hence, it would appear that the most preferred allocation procedure is the one that uses a substitution approach. This involves identifying the usual process for producing a co-product or by-product. The inputs and outputs of this process are then treated as effective credits that are subtracted from the life cycle inventory of the process chain under investigation. This allocation procedure recognises that the co-products or by-products are, in practice and in economic terms, substituting for the equivalent product derived from its main source. Although this allocation procedure increases the amount of work required to undertake a life cycle assessment study, it is fundamentally sound and widely adopted. Indeed, it is the allocation procedure which is most favoured by many life cycle assessment practitioners. Unfortunately, the main drawback with the substitution approach is that it cannot be used easily when co-products or by-products are not produced as a main product by another process. In other words, such products are always regarded as co-products or by-products. To address this, it is usually necessary to extend the analysis quite considerably (which is another example of expanding the systems boundaries). Even so, the explanation and interpretation of subsequent results can become extremely complex. In such difficult cases, it is sometimes more practical to revert to simpler allocation procedures, of which allocation by market price and subsequent revenue may be the most appropriate.

One feature of allocation by price is that the results change as the relative prices of main products, co-products and by-products vary over time. Although this runs counter to the idea that results for a given process chain should be fixed and absolute, it can be argued that varying results are a more realistic reflection of the actual economic world in which process chains function. This can be demonstrated by taking the extreme example of a co-product or by-product that is produced in such large quantities that its economic value falls to such an extent that it becomes a waste product. In such circumstances, it would be inappropriate to allocate any inputs and outputs to this waste product. Instead, these should be allocated correctly to the main product and any remaining co-products and by-products that still have economic value. Using the substitution approach or adopting an allocation procedure based on physical attributes does not necessarily reflect this situation, which can be adequately addressed by allocation by price. It might be argued that this extreme example is unlikely to arise in practice. However, it is very possible outcome for liquid biofuels, which, if produced in significant quantities, would generate considerably large amounts of co-products and by-products. Faced with a possible glut of these products, their prices are most likely to fall dramatically so that they would become re-classified as waste products. Interestingly, this might encourage their use as sources of energy in the same process chain that generates them. This is because almost all of the co-products and by-products produced alongside liquid biofuels, such as biodiesel and bioethanol, have inherent potential as heating fuels. Their use in this way can result in a significant reduction in the total primary energy input and total greenhouse emission per unit of delivered energy output from the relevant process chains (see, for example, Refs. 4.12 to 4.15). Whilst allocation by price is adopted for the co-products and by-products of liquid biofuels and some other biomass energy technologies accommodated by the current version of BEAT 2, a mixture of allocation by price and substitution is applied in relation to the other biomass energy technologies. In particular, allocation by substitution is adopted in cases where the displaced product can be identified easily and unambiguously. Additionally, it must also be possible to establish its associated primary energy inputs and greenhouse gas emissions so that subsequent credits can be determine clearly and applied with confidence. It should be noted that, for some biomass energy technologies, the choice of allocation procedure can be very important because it can alter subsequent results fundamentally especially in relation to those of comparative energy technologies.

4.6 Weighting of Electricity and Heat

One specific aspect of allocation that features prominently in BEAT2 is the approach adopted for dividing inputs and outputs between the electricity and heat generated by various types of combined heat and power plants. In theory, these co-products can be treated in the same manner as any co-products produced by a process chain. However, allocation between electricity and heat in combined heat and power plants is also an issue outside life cycle assessment. In particular, concern over allocation in such cases features in the approaches adopted for compiling energy statistics in the United Kingdom (Ref. 4.16), in the guidelines for company reporting on greenhouse gas emissions prepared by the Department for the Environment, Food and Rural Affairs (Ref. 4.17), and the negotiated agreements on energy efficiency established between government and selected industries as part of the Climate Change Levy (Ref. 4.18). The effective allocation procedures adopted in these instances form established rules based, generally, on the relative efficiency of electricity and heat produced by non-combined heat and power plants. For consistency with these rules, a weighting procedure is required for dividing primary energy inputs and greenhouse gas emissions between electricity and heat generated by combined heat and power plants accommodated within the Biomass Environmental Assessment Tool. The weighting procedure is simply expressed as a ratio between the inherent "value" of electricity relative to the "value" of the heat. In the sources cited above, a ratio of 2:1 is assumed and this is adopted as a default value in BEAT 2 for biomass energy technologies involving combined heat and power plants. However, it is recognised that this ratio may change over time and the facility for varying this weighting is incorporated into the relevant spreadsheets.

5 Life Cycle Assessment Workbooks

5.1 Workbooks

There is an Excel workbook for each biomass energy technology covered by BEAT 2. Summarised descriptions of these biomass energy technologies and the individual file names of their respective spreadsheets are given in Tables 5.1. to 5.4, together with the main features of the technologies, the reference systems, the allocation procedures, the key assumptions and any data gaps. It should be noted that some of these biomass energy technologies consist of different combinations of means of providing the same type of biomass material from different sources and converting this into various forms of delivered energy. This applies, in particular, to biomass energy technologies that are based on wood chips. This specific biomass material can be produced from a number of different sources including wood processing wastes, forest residues and short rotation coppice. Additionally, forest residues can be obtained from sources located either in the United Kingdom or overseas. Furthermore, there are 2 different options for producing wood chips from short rotation coppice; one in which coppiced wood is chipped during harvesting and then dried prior to processing in the plant, and the other in which coppiced wood is harvested as sticks that are transported to the plant for drying and chipping. Once the wood chips are available from any source at the plant, they can be processed by different means to produce different forms of delivered energy. In BEAT 2, the technological options considered are combustion to provide heat, electricity or combined heat and power, gasification or pyrolysis to generate electricity or combined heat and power, and co-firing in an existing power plant. Hence, 5 different sources of wood chips combine with 8 different wood chip processing technologies to represent 40 different biomass energy technologies in BEAT 2. To a lesser extent, similar considerations apply to the use of miscanthus and straw, and the production of biodiesel from oilseed rape and recycled vegetable oil. Only single biomass source options are represented in BAET2 for the production of bioethanol from sugar beet and wheat grain. As an improvement on the earlier version of the Tool, different options for the provision of heat and electricity (heat from a natural gas-fired boiler and imported grid electricity, or natural gas-fired combined heat and power generation) are provided for the production of liquid biofuels.

Table 5.1 Specific Aspects of Spreadsheets for Biomass Energy Technologies (New/Dedicated Biomass Plant)

File Name	Biomass Source	Harvesting	Intermediate Product	Processing Technology	End Product(s)	Reference System	Allocation Procedures	Key Assumptions	Data Gaps
srca_c_cb_e.xls	Short rotation coppice	Cut and chip harvesting	Wood chips	Combustion	Electricity	Mown fallow set aside land, wood ash used to replace agricultural lime	None	Chipping at source	None
srca_c_g_e.xls	Short rotation coppice	Cut and chip harvesting	Wood chips	Gasification	Electricity	Mown fallow set aside land, wood ash used to replace agricultural lime	None	Chipping at source	None but direct emissions based on combustion
srca_c_py_e.xls	Short rotation coppice	Cut and chip harvesting	Wood chips	Pyrolysis	Electricity	Mown fallow set aside land, wood ash used to replace agricultural lime	None	Chipping at source	None but direct emissions based on combustion
srca_c_cb_chp.xls	Short rotation coppice	Cut and chip harvesting	Wood chips	Combustion	Combined heat and power	Mown fallow set aside land, wood ash used to replace agricultural lime	None	Chipping at source	None
srca_c_g_chp.xls	Short rotation coppice	Cut and chip harvesting	Wood chips	Gasification	Combined heat and power	Mown fallow set aside land, wood ash used to replace agricultural lime	None	Chipping at source	None but direct emissions based on combustion
srca_c_py_chp.xls	Short rotation coppice	Cut and chip harvesting	Wood chips	Pyrolysis	Combined heat and power	Mown fallow set aside land, wood ash used to replace agricultural lime	None	Chipping at source	None but direct emissions based on combustion
srca_c_cb_h.xls	Short rotation coppice	Cut and chip harvesting	Wood chips	Combustion	Heat (industrial)	Mown fallow set aside land, wood ash used to replace agricultural lime	None	Chipping at source	None

File Name	Biomass Source	Harvesting	Intermediate Product	Processing Technology	End Product(s)	Reference System	Allocation Procedures	Key Assumptions	Data Gaps
srcb_c_cb_e.xls	Short rotation coppice	Stick harvesting	Wood chips	Combustion	Electricity	Mown fallow set aside land, wood ash used to replace agricultural lime	None	Stick baling at source	None
srcb_c_g_e.xls	Short rotation coppice	Stick harvesting	Wood chips	Gasification	Electricity	Mown fallow set aside land, wood ash used to replace agricultural lime	None	Stick baling at source	None but direct emissions based on combustion
srcb_c_py_e.xls	Short rotation coppice	Stick harvesting	Wood chips	Pyrolysis	Electricity	Mown fallow set aside land, wood ash used to replace agricultural lime	None	Stick baling at source	None but direct emissions based on combustion
srcb_c_cb_chp.xls	Short rotation coppice	Stick harvesting	Wood chips	Combustion	Combined heat and power	Mown fallow set aside land, wood ash used to replace agricultural lime	None	Stick baling at source	None
srcb_c_g_chp.xls	Short rotation coppice	Stick harvesting	Wood chips	Gasification	Combined heat and power	Mown fallow set aside land, wood ash used to replace agricultural lime	None	Stick baling at source	None but direct emissions based on combustion
srcb_c_py_chp.xls	Short rotation coppice	Stick harvesting	Wood chips	Pyrolysis	Combined heat and power	Mown fallow set aside land, wood ash used to replace agricultural lime	None	Stick baling at source	None but direct emissions based on combustion
srcb_c_cb_h.xls	Short rotation coppice	Stick harvesting	Wood chips	Combustion	Heat	Mown fallow set aside land, wood ash used to replace agricultural lime	None	Stick baling at source	None

File Name	Biomass Source	Harvesting	Intermediate Product	Processing Technology	End Product(s)	Reference System	Allocation Procedures	Key Assumptions	Data Gaps
srca_p_cb_h_i.xls	Short rotation coppice	Cut and chip harvesting	Wood pellets	Combustion	Heat (industrial)	Mown fallow set aside land, wood ash used to replace agricultural lime	None	Chipping at source	None
srca_p_cb_h_d.xls	Short rotation coppice	Cut and chip harvesting	Wood pellets	Combustion	Heat (domestic)	Mown fallow set aside land, wood ash used to replace agricultural lime	None	Chipping at source	None
srcb_p_cb_h_i.xls	Short rotation coppice	Stick harvesting	Wood pellets	Combustion	Heat (industrial)	Mown fallow set aside land, wood ash used to replace agricultural lime	None	Stick baling at source	None
srcb_p_cb_h_d.xls	Short rotation coppice	Stick harvesting	Wood pellets	Combustion	Heat (domestic)	Mown fallow set aside land, wood ash used to replace agricultural lime	None	Stick baling at source	None

File Name	Biomass Source	Harvesting	Intermediate Product	Processing Technology	End Product(s)	Reference System	Allocation Procedures	Key Assumptions	Data Gaps
fruk_c_bc_e.xls	Forest residues (UK)	Collection	Wood chips	Combustion	Electricity	None for residues but disposal of waste wood chunks to landfill with energy recovery, wood ash used to replace agricultural lime	Price	Initial drying (roadside) and chipping at source	None
fruk_c_cb_chp.xls	Forest residues (UK)	Collection	Wood chips	Combustion	Combined heat and power	None for residues but disposal of waste wood chunks to landfill with energy recovery, wood ash used to replace agricultural lime	Price	Initial drying (roadside) and chipping at source	None
fruk_c_cb_h.xls	Forest residues (UK)	Collection	Wood chips	Combustion	Heat	None for residues but disposal of waste wood chunks to landfill with energy recovery, wood ash used to replace agricultural lime	Price	Initial drying (roadside) and chipping at source	None

File Name	Biomass Source	Harvesting	Intermediate Product	Processing Technology	End Product(s)	Reference System	Allocation Procedures	Key Assumptions	Data Gaps
fruk_c_g_e.xls	Forest residues (UK)	Collection	Wood chips	Gasification	Electricity	None for residues but disposal of waste wood chunks to landfill with energy recovery, wood ash used to replace agricultural lime	Price	Initial drying (roadside) and chipping at source	None but direct emissions based on combustion
fruk_c_g_chp.xls	Forest residues (UK)	Collection	Wood chips	Gasification	Combined heat and power	None for residues but disposal of waste wood chunks to landfill with energy recovery, wood ash used to replace agricultural lime	Price	Initial drying (roadside) and chipping at source	None but direct emissions based on combustion
fruk_c_p_e.xls	Forest residues (UK)	Collection	Wood chips	Pyrolysis	Electricity	None for residues but disposal of waste wood chunks to landfill with energy recovery, wood ash used to replace agricultural lime	Price	Initial drying (roadside) and chipping at source	None but direct emissions based on combustion
fruk_c_p_chp.xls	Forest residues (UK)	Collection	Wood chips	Pyrolysis	Combined heat and power	None for residues but disposal of waste wood chunks to landfill with energy recovery, wood ash used to replace agricultural lime	Price	Initial drying (roadside) and chipping at source	None but direct emissions based on combustion
fruk_p_cb_h_i.xls	Forest residues	Collection	Wood pellets	Combustion	Heat (industrial)	None for residues but disposal of waste wood chunks to landfill with energy recovery, wood ash used to replace agricultural lime	Price	Initial drying (roadside) and chipping at source	None but direct emissions based on combustion
fruk_p_cb_h_d.xls	Forest residues	Collection	Wood pellets	Combustion	Heat (domestic)	None for residues but disposal of waste wood chunks to landfill with energy recovery, wood ash used to replace agricultural lime	Price	Initial drying (roadside) and chipping at source	None but direct emissions based on combustion

File Name	Biomass Source	Harvesting	Intermediate Product	Processing Technology	End Product(s)	Reference System	Allocation Procedures	Key Assumptions	Data Gaps
frim_c_cb_e.xls	Forest residues (overseas)	Collection	Wood chips	Combustion	Electricity	None for residues but disposal of waste wood chunks to landfill with energy recovery, wood ash used to replace agricultural lime	Price	Initial drying (roadside) and chipping at source	None
frim_c_cb_chp.xls	Forest residues (overseas)	Collection	Wood chips	Combustion	Combined heat and power	None for residues but disposal of waste wood chunks to landfill with energy recovery, wood ash used to replace agricultural lime	Price	Initial drying (roadside) and chipping at source	None
frim_c_cb_h.xls	Forest residues (overseas)	Collection	Wood chips	Combustion	Heat	None for residues but disposal of waste wood chunks to landfill with energy recovery, wood ash used to replace agricultural lime	Price	Initial drying (roadside) and chipping at source	None
frim_c_g_e.xls	Forest residues (overseas)	Collection	Wood chips	Gasification	Electricity	None for residues but disposal of waste wood chunks to landfill with energy recovery, wood ash used to replace agricultural lime	Price	Initial drying (roadside) and chipping at source	None but direct emissions based on combustion
frim_c_g_chp.xls	Forest residues (overseas)	Collection	Wood chips	Gasification	Combined heat and power	None for residues but disposal of waste wood chunks to landfill with energy recovery, wood ash used to replace agricultural lime	Price	Initial drying (roadside) and chipping at source	None but direct emissions based on combustion

File Name	Biomass Source	Harvesting	Intermediate Product	Processing Technology	End Product(s)	Reference System	Allocation Procedures	Key Assumptions	Data Gaps
frim_c_p_e.xls	Forest residues (overseas)	Collection	Wood chips	Pyrolysis	Electricity	None for residues but disposal of waste wood chunks to landfill with energy recovery, wood ash used to replace agricultural lime	Price	Initial drying (roadside) and chipping at source	None but direct emissions based on combustion
frim_c_p_chp.xls	Forest residues (overseas)	Collection	Wood chips	Pyrolysis	Combined heat and power	None for residues but disposal of waste wood chunks to landfill with energy recovery, wood ash used to replace agricultural lime	Price	Initial drying (roadside) and chipping at source	None but direct emissions based on combustion
frim_p_cb_h_i.xls	Forest residues (overseas)	Collection	Wood pellets	Combustion	Heat (industrial)	None for residues but disposal of waste wood chunks to landfill with energy recovery, wood ash used to replace agricultural lime	Price	Initial drying (roadside) and chipping at source	None
frim_p_cb_h_d.xls	Forest residues (overseas)	Collection	Wood pellets	Combustion	Heat (domestic)	None for residues but disposal of waste wood chunks to landfill with energy recovery, wood ash used to replace agricultural lime	Price	Initial drying (roadside) and chipping at source	None

File Name	Biomass Source	Harvesting	Intermediate Product	Processing Technology	End Product(s)	Reference System	Allocation Procedures	Key Assumptions	Data Gaps
log_cb_h_d.xls	Forestry products	Felling and sawing	Long logs	Combustion	Heat (domestic)	Wood ash used to replace agricultural lime	Price	Initial drying (roadside) at source and final natural drying	None

File Name	Biomass Source	Harvesting	Intermediate Product	Processing Technology	End Product(s)	Reference System	Allocation Procedures	Key Assumptions	Data Gaps
wpw_c_cb_e.xls	Wood processing wastes	Collection	Wood chips	Combustion	Electricity	Disposal of waste wood chunks to landfill with energy recovery, wood ash used to replace agricultural lime	None	Waste wood chipped and stored on same site	None
wpw_c_cb_chp.xls	Wood processing wastes	Collection	Wood chips	Combustion	Combined heat and power	Disposal of waste wood chunks to landfill with energy recovery, wood ash used to replace agricultural lime	None	Waste wood chipped and stored on same site	None
wpw_c_cb_h.xls	Wood processing wastes	Collection	Wood chips	Combustion	Heat	Disposal of waste wood chunks to landfill with energy recovery, wood ash used to replace agricultural lime	None	Waste wood chipped and stored on same site	None
wpw_c_g_e.xls	Wood processing wastes	Collection	Wood chips	Gasification	Electricity	Disposal of waste wood chunks to landfill with energy recovery, wood ash used to replace agricultural lime	None	Waste wood chipped and stored on same site	None but direct emissions based on combustion
wpw_c_g_chp.xls	Wood processing wastes	Collection	Wood chips	Gasification	Combined heat and power	Disposal of waste wood chunks to landfill with energy recovery, wood ash used to replace agricultural lime	None	Waste wood chipped and stored on same site	None but direct emissions based on combustion

File Name	Biomass Source	Harvesting	Intermediate Product	Processing Technology	End Product(s)	Reference System	Allocation Procedures	Key Assumptions	Data Gaps
wpw_c_py_e.xls	Wood processing wastes	Collection	Wood chips	Pyrolysis	Electricity	Disposal of waste wood chunks to landfill with energy recovery, wood ash used to replace agricultural lime	None	Waste wood chipped and stored on same site	None but direct emissions based on combustion
wpw_c_py_chp.xls	Wood processing wastes	Collection	Wood chips	Pyrolysis	Combined heat and power	Disposal of waste wood chunks to landfill with energy recovery, wood ash used to replace agricultural lime	None	Waste wood chipped and stored on same site	None but direct emissions based on combustion
wpw_p_cb_h_i.xls	Wood processing wastes	Collection	Wood pellets	Combustion	Heat (industrial)	Disposal of waste wood chunks to landfill with energy recovery, wood ash used to replace agricultural lime	None	Waste wood chipped and stored on same site	None
wpw_p_cb_h_d.xls	Wood processing wastes	Collection	Wood pellets	Combustion	Heat (domestic)	Disposal of waste wood chunks to landfill with energy recovery, wood ash used to replace agricultural lime	None	Waste wood chipped and stored on same site	None

File Name	Biomass Source	Harvesting	Intermediate Product	Processing Technology	End Product(s)	Reference System	Allocation Procedures	Key Assumptions	Data Gaps
misc_c_cb_e.xls	Miscanthus	Cutting and chipping	Miscanthus chips	Combustion	Electricity	Mown fallow set-aside land, ash used to replace agricultural lime	None	Chipping at source	None
misc_c_g_e.xls	Miscanthus	Cutting and chipping	Miscanthus chips	Gasification	Electricity	Mown fallow set-aside land, ash used to replace agricultural lime	None	Chipping at source	None but direct emissions based on combustion
misc_c_py_e.xls	Miscanthus	Cutting and chipping	Miscanthus chips	Pyrolysis	Electricity	Mown fallow set-aside land, ash used to replace agricultural lime	None	Chipping at source	None but direct emissions based on combustion
misc_p_cb_e.xls	Miscanthus	Cutting and chipping	Miscanthus pellets	Combustion	Electricity	Mown fallow set-aside land, ash used to replace agricultural lime	None	Chipping at source	None
misc_b_cb_e.xls	Miscanthus	Cutting and baling	Miscanthus bales	Combustion	Electricity	Mown fallow set-aside land, ash used to replace agricultural lime	None	Storage and drying at source	None

File Name	Biomass Source	Harvesting	Intermediate Product	Processing Technology	End Product(s)	Reference System	Allocation Procedures	Key Assumptions	Data Gaps
str_cb_e.xls	Straw	Collection and baling	Straw bales	Combustion	Electricity	Mown fallow set-aside land, ash used to replace agricultural lime	Price	Initial drying at source	None
str_g_e.xls	Straw	Collection and baling	Straw bales	Gasification	Electricity	Mown fallow set-aside land, ash used to replace agricultural lime	Price	Initial drying at source	None but direct emissions based on combustion
str_py_e.xls	Straw	Collection and baling	Straw bales	Pyrolysis	Electricity	Mown fallow set-aside land, ash used to replace agricultural lime	Price	Initial drying at source	None but direct emissions based on combustion
str_cb_chp.xls	Straw	Collection and baling	Straw	Combustion	Combined heat and power	Mown fallow set-aside land, ash used to replace agricultural lime	Price	Initial drying at source	None
str_g_chp.xls	Straw	Collection and baling	Straw	Gasification	Combined heat and power	Mown fallow set-aside land, ash used to replace agricultural lime	Price	Initial drying at source	None but direct emissions based on combustion
str_py_chp.xls	Straw	Collection and baling	Straw	Pyrolysis	Combined heat and power	Mown fallow set-aside land, ash used to replace agricultural lime	Price	Initial drying at source	None but direct emissions based on combustion
str_cb_h.xls	Straw	Collection and baling	Straw	Combustion	Heat	Mown fallow set-aside land, ash used to replace agricultural lime	Price	Initial drying at source	None

File Name	Biomass Source	Harvesting	Intermediate Product	Processing Technology	End Product(s)	Reference System	Allocation Procedures	Key Assumptions	Data Gaps
chb_s_cb_e.xls	Chipboard off cuts and sawdust	Collection	Shredded chipboard	Combustion	Electricity	Disposal of waste chipboard to landfill with energy recovery, wood ash used to replace agricultural lime	None	Biomass source treated as a waste, laminate and glue treated as fossil fuel, and option for WID compliance	None but theoretical assumption about direct emissions for laminate and glue
chb_s_cb_chp.xls	Chipboard off cuts and sawdust	Collection	Shredded chipboard	Combustion	Combined heat and power	Disposal of waste chipboard to landfill with energy recovery, wood ash used to replace agricultural lime	None	Biomass source treated as a waste, laminate and glue treated as fossil fuel, and option for WID compliance	None but theoretical assumption about direct emissions for laminate and glue
chb_s_cb_h.xls	Chipboard off cuts and sawdust	Collection	Shredded chipboard	Combustion	Heat (industrial)	Disposal of waste chipboard to landfill with energy recovery, wood ash used to replace agricultural lime	None	Biomass source treated as a waste, laminate and glue treated as fossil fuel, and option for WID compliance	None but theoretical assumption about direct emissions for laminate and glue

File Name	Biomass Source	Harvesting	Intermediate Product	Processing Technology	End Product(s)	Reference System	Allocation Procedures	Key Assumptions	Data Gaps
chb_p_cb_e.xls	Chipboard off cuts and sawdust	Collection	Pellets	Combustion	Electricity	Disposal of waste chipboard to landfill with energy recovery, wood ash used to replace agricultural lime	None	Biomass source treated as a waste, laminate and glue treated as fossil fuel, and option for Waste Incineration Directive compliance	None but theoretical assumption about direct emissions for laminate and glue
chb_p_cb_chp.xls	Chipboard off cuts and sawdust	Collection	Pellets	Combustion	Combined heat and power	Disposal of waste chipboard to landfill with energy recovery, wood ash used to replace agricultural lime	None	Biomass source treated as a waste, laminate and glue treated as fossil fuel, and option for Waste Incineration Directive compliance	None but theoretical assumption about direct emissions for laminate and glue
chb_p_cb_h.xls	Chipboard off cuts and sawdust	Collection	Pellets	Combustion	Heat (industrial)	Disposal of waste chipboard to landfill with energy recovery, wood ash used to replace agricultural lime	None	Biomass source treated as a waste, laminate and glue treated as fossil fuel, and option for Waste Incineration Directive compliance	None but theoretical assumption about direct emissions for laminate and glue

File Name	Biomass Source	Harvesting	Intermediate Product	Processing Technology	End Product(s)	Reference System	Allocation Procedures	Key Assumptions	Data Gaps
mdf_s_cb_e.xls	Medium Density Fibreboard off cuts and sawdust	Collection	Shredded Medium Density Fibreboard	Combustion	Electricity	Disposal of waste medium density fibreboard to landfill with energy recovery, wood ash used to replace agricultural lime	None	Biomass source treated as a waste, laminate and glue treated as fossil fuel, and option for Waste Incineration Directive compliance	None but theoretical assumption about direct emissions for glue
mdf_s_cb_chp.xls	Medium Density Fibreboard off cuts and sawdust	Collection	Shredded Medium Density Fibreboard	Combustion	Combined heat and power	Disposal of waste medium density fibreboard to landfill with energy recovery, wood ash used to replace agricultural lime	None	Biomass source treated as a waste, laminate and glue treated as fossil fuel, and option for Waste Incineration Directive compliance	None but theoretical assumption about direct emissions for glue
mdf_s_cb_h.xls	Medium Density Fibreboard off cuts and sawdust	Collection	Shredded Medium Density Fibreboard	Combustion	Heat (industrial)	Disposal of waste medium density fibreboard to landfill with energy recovery, wood ash used to replace agricultural lime	None	Biomass source treated as a waste, laminate and glue treated as fossil fuel, and option for Waste Incineration Directive compliance	None but theoretical assumption about direct emissions for glue

File Name	Biomass Source	Harvesting	Intermediate Product	Processing Technology	End Product(s)	Reference System	Allocation Procedures	Key Assumptions	Data Gaps
mdf_p_cb_e.xls	Medium Density Fibreboard off cuts and sawdust	Collection	Pelletised Medium Density Fibreboard	Combustion	Electricity	Disposal of waste medium density fibreboard to landfill with energy recovery, wood ash used to replace agricultural lime	None	Biomass source treated as a waste, laminate and glue treated as fossil fuel, and option for Waste Incineration Directive compliance	None but theoretical assumption about direct emissions for glue
mdf_p_cb_chp.xls	Medium Density Fibreboard off cuts and sawdust	Collection	Pelletised Medium Density Fibreboard	Combustion	Combined heat and power	Disposal of waste medium density fibreboard to landfill with energy recovery, wood ash used to replace agricultural lime	None	Biomass source treated as a waste, laminate and glue treated as fossil fuel, and option for Waste Incineration Directive compliance	None but theoretical assumption about direct emissions for glue
mdf_p_cb_h.xls	Medium Density Fibreboard off cuts and sawdust	Collection	Pelletised Medium Density Fibreboard	Combustion	Heat (industrial)	Disposal of waste medium density fibreboard to landfill with energy recovery, wood ash used to replace agricultural lime	None	Biomass source treated as a waste, laminate and glue treated as fossil fuel, and option for Waste Incineration Directive compliance	None but theoretical assumption about direct emissions for glue

File Name	Biomass Source	Harvesting	Intermediate Product	Processing Technology	End Product(s)	Reference System	Allocation Procedures	Key Assumptions	Data Gaps
rdf_p_cb_e.xls	Municipal solid waste	Collection	RRBF pellets	Combustion	Electricity	Disposal of municipal solid waste to landfill with energy recovery	Price	Use of Fairport process, and option for Waste Incineration Directive compliance	None but direct emissions based on combustion of old paper
rdf_p_g_e.xls	Municipal solid waste	Collection	RRBF pellets	Gasification	Electricity	Disposal of municipal solid waste to landfill with energy recovery	Price	Use of Fairport process, and option for Waste Incineration Directive compliance	None but direct emissions based on combustion of old paper
rdf_p_cb_chp.xls	Municipal solid waste	Collection	RRBF pellets	Combustion	Combined Heat and Power	Disposal of municipal solid waste to landfill with energy recovery	Price	Use of Fairport process, and option for Waste Incineration Directive compliance	None but direct emissions based on combustion of old paper
rdf_p_cb_h.xls	Municipal solid waste	Collection	RRBF pellets	Combustion	Heat (industrial)	Disposal of municipal solid waste to landfill with energy recovery	Price	Use of Fairport process, and option for Waste Incineration Directive compliance	None but direct emissions based on combustion of old paper

File Name	Biomass Source	Harvesting	Intermediate Product	Processing Technology	End Product(s)	Reference System	Allocation Procedures	Key Assumptions	Data Gaps
gly_rvo_cb_h.xls	Recycled vegetable	Collection	Glycerine	Cleaning, esterification and combustion	Heat (industrial)	Disposal of waste vegetable oil to landfill with energy recovery, ash used to replace agricultural lime	Price	Option for Waste Incineration Directive compliance	None but direct emissions based on combustion of gas oil
gly_osr_cb_h.xls	Oilseed rape	Combine harvesting	Glycerine	Solvent extraction, refining, esterification and combustion	Heat (industrial)	Mown fallow set-aside land, ash used to replace agricultural lime	Price	Option for Waste Incineration Directive compliance	None but direct emissions based on combustion of gas oil

Table 5.2 Specific Aspects of Spreadsheets for Biomass Energy Technologies (Co-firing in Existing Biomass Plant)

File Name	Biomass Source	Harvesting	Intermediate Product	Processing Technology	End Product(s)	Reference System	Allocation Procedures	Key Assumptions	Data Gaps
fruk_c_co_e.xls	Forest residues (UK)	Collection	Wood chips	Co-firing	Electricity	None for residues but disposal of waste wood chunks to landfill with energy recovery	Price	Initial drying at source	None but grinding based on theoretical equation
fruk_p_co_e.xls	Forest residues (UK)	Collection	Wood pellets	Co-firing	Electricity	None for residues but disposal of waste wood chunks to landfill with energy recovery	Price	Initial drying at source	None but milling and grinding based on theoretical equations
frim_p_co_e.xls	Forest residues (overseas)	Collection	Wood chips	Co-firing	Electricity	None for residues but disposal of waste wood chunks to landfill with energy recovery	Price	Initial drying at source	None but grinding based on theoretical equation
frim_p_co_e.xls	Forest residues (overseas)	Collection	Wood pellets	Co-firing	Electricity	None for residues but disposal of waste wood chunks to landfill with energy recovery	Price	Initial drying at source	None but milling and grinding based on theoretical equations

File Name	Biomass Source	Harvesting	Intermediate Product	Processing Technology	End Product(s)	Reference System	Allocation Procedures	Key Assumptions	Data Gaps
scra_c_co_e.xls	Short rotation coppice	Cut and chip harvesting	Wood chips	Co-firing	Electricity	Mown fallow set aside land	None	Chipping at source	None but grinding based on theoretical equation
srca_p_co_e.xls	Short rotation coppice	Cut and chip harvesting	Wood pellets	Co-firing	Electricity	Mown fallow set aside land	None	Chipping at source	None but milling and grinding based on theoretical equations
srcb_c_co_e.xls	Short rotation coppice	Stick harvesting	Wood chips	Co-firing	Electricity	Mown fallow set aside land	None	Stick baling at source	None but grinding based on theoretical equation
srcb_p_co_e.xls	Short rotation coppice	Stick harvesting	Wood pellets	Co-firing	Electricity	Mown fallow set aside land	None	Stick baling at source	None but milling and grinding based on theoretical equations
wpw_c_co_e.xls	Wood processing wastes	Collection	Wood chips	Co-firing	Electricity	Disposal of waste wood chunks to landfill with energy recovery	None	Waste wood chipped and stored on same site	None but grinding based on theoretical equation
wpw_p_co_e.xls	Wood processing wastes	Collection	Wood pellets	Co-firing	Electricity	Disposal of waste wood chunks to landfill with energy recovery	None	Waste wood chipped and stored on same site	None but milling and grinding based on theoretical equations

File Name	Biomass Source	Harvesting	Intermediate Product	Processing Technology	End Product(s)	Reference System	Allocation Procedures	Key Assumptions	Data Gaps
misc_c_co_e.xls	Miscanthus	Cutting and baling	Miscanthus chips	Co-firing	Electricity	Mown fallow set-aside land	None	Chipping at source	None but grinding based on theoretical equation
misc_p_co_e.xls	Miscanthus	Cutting and baling	Miscanthus pellets	Co-firing	Electricity	Mown fallow set-aside land	None	Chipping at source	None but milling and grinding based on theoretical equations
Gly_rvo_co_e.xls	Recycled vegetable oil	Collection	Glycerine	Cleaning, esterification and co-firing	Electricity	Disposal of waste vegetable oil to landfill with energy recovery	Price	Option for Waste Incineration Directive compliance	None but direct emissions based on combustion of gas oil
gly_osr_co_e.xls	Oilseed rape	Combine harvesting	Glycerine	Solvent extraction, refining, esterification and co-firing	Electricity	Mown fallow set-aside land	Price	Option for Waste Incineration Directive compliance	None but direct emissions based on combustion of gas oil
pke_co_e.xls	Palm kernel nut	Collection	Palm kernel expeller	Co-firing	Electricity	Disposal of palm kernel expeller to land as mulch	None	Biomass source treated as waste	None but grinding based on theoretical equation and direct emissions based on combustion of wood chips
ocim_co_e.xls	Olive	Collection	Olive cake	Co-firing	Electricity	Disposal of olive cake to land as mulch	None	Biomass source treated as waste	None but grinding based on theoretical equation and direct emissions based on combustion of wood chips

File Name	Biomass Source	Harvesting	Intermediate Product	Processing Technology	End Product(s)	Reference System	Allocation Procedures	Key Assumptions	Data Gaps
cmres_p_co_e.xls	Cereals	Collection	Cereal milling residues	Co-firing	Electricity	Disposal of cereal milling residues to landfill with energy recovery	None	Biomass source treated as waste	None but grinding based on theoretical equation and direct emissions based on combustion of straw

Table 5.3 Specific Aspects of Spreadsheets for Liquid Biofuels

File Name	Biomass Source	Harvesting	Intermediate Product	Processing Technology	End Product(s)	Reference System	Allocation Procedures	Key Assumptions	Data Gaps
bd_osr.xls	Oilseed rape	Combine harvesting	Oilseed rape	Solvent extraction, refining and esterification	Biodiesel	Mown fallow set-aside land	Price	Drying, cooling and storage on-farm	None
bd_rvo.xls	Recycled vegetable oil	Collection	Recycled vegetable oil	Cleaning and esterification	Biodiesel	Disposal of waste vegetable oil to landfill with energy recovery	Price	Steam treatment of 50% of oil input and natural gas-fired process heating	None
be_sb.xls	Sugar beet	Lifting and loading	Sugar beet	Shredding, diffusion, purification, concentration, fermentation, distillation and dehydration	Bioethanol	Mown fallow set-aside land	Price and substitution	Choice of natural gas fired-boiler and imported grid electricity or natural gas-fired combined heat and power	None
be_wg.xls	Wheat grain	Combine harvesting	Wheat grain	Milling, hydrolysis, fermentation, distillation and dehydration	Bioethanol	Mown fallow set-aside land	Price and substitution	Choice of natural gas fired-boiler and imported grid electricity or natural gas-fired combined heat and power	None

Table 5.4 Specific Aspects of Spreadsheets for Anaerobic Digestion

File Name	Biomass Source	Scale of Plant	Processing Technology	End Product(s)	Reference System	Allocation Procedures	Key Assumptions	Data Gaps
dm_of_e.xls	Dairy manure	On-farm	Mixing, continuously stirred tank reactor, biogas cleaning, modular power plant	Electricity	Storage and spreading dairy manure on land	Price	Manure at farm	Hydrogen carbonate in digester, air pump price
dm_of_chp.xls	Dairy manure	On-farm	Mixing, continuously stirred tank reactor, biogas cleaning, modular combined heat and power plant	Combined heat and power	Storage and spreading dairy manure on land	Price	Manure at farm	Hydrogen carbonate in digester, air pump price
dm_of_h.xls	Dairy manure	On-farm	Mixing, continuously stirred tank reactor, biogas cleaning, small scale heat plant	Heat	Storage and spreading dairy manure on land	Price	Manure at farm	Hydrogen carbonate in digester, air pump price
dm_cntr_e.xls	Dairy manure	Centralised	Mixing, heating, pasteurisation, continuously stirred tank reactor, biogas desulpurisation, modular power plant	Electricity	Storage and spreading dairy manure on land	Price	Manure at farm	Plastic carrier price, air pump price, rating of heat exchange unit and pasteurisation unit
dm_cntr_chp.xls	Dairy manure	Centralised	Mixing, heating, pasteurisation, continuously stirred tank reactor, biogas desulpurisation, combined heat and power plant	Combined heat and power	Storage and spreading dairy manure on land	Price	Manure at farm	Plastic carrier price, air pump price, rating of heat exchange unit and pasteurisation unit

5.2 Individual Worksheets

Each spreadsheet consists of a sequence of linked worksheets consisting of the Summary worksheet, the Parameters worksheet, the Data worksheet, the individual Process Stage worksheets and the Reference worksheet. Each of these types of worksheet has their own specific purposes and characteristics. However, in general, most of the worksheets share a common feature that is used to indicate nature of certain types of cells. In particular, the user can enter values into those cells that have a pale blue background. Those cells with a pale red background contain formulae that must only be over-written by very experienced users who are willing to take full responsibility for the consequences. Those cells with a pale gold indicate that relevant data are missing from the current version of BEAT 2.

5.2.1 Unit Flow Chart

The Unit Flow Chart worksheet provides a graphic representation of the main and related features of the process chain for the biomass energy technology under consideration. It shows that relevant process stages and the relationships between them. Additionally, the Unit Flow Chart worksheet contains estimates of the quantities of main products or services exchanged between related process stages. In many instances, these estimates form a mass balance for the flow of biomass materials on which a biomass energy technology is based. Losses within process stages and the generation of co- and by-products are taken into account. For simplicity, default values in the Unit Flow Chart worksheet are normalised to a given single unit of output (MWh of electricity or heat, 1,000 litres of liquid biofuel, etc.). Values linked by formulae to other values in the Unit Flow Chart worksheet are distinguished by cells with a pale red background. In contrast to the earlier version of BEAT2, the option of changing the magnitude of the final unit of output of the process chain in the current Unit Flow Chart worksheet. This is indicated by green background to the appropriate cell. In additional to fundamental physical and technical data, the Unit Flow Chart worksheet includes entries for the prices of main, co- and by-products in instances where allocation is undertaken by these means. Hyperlinked notes are provided in the Unit Flow Chart worksheet to explain specific details and to provide sources for adopted values through references which are documented elsewhere (see Section 5.2.6). It should be noted that the Unit Flow Chart worksheet replaces the Parameters and Data worksheet, which provided the same fundamental information in tabular form, in the original version of BEAT 2.

5.2.2 Summary Worksheet

The Summary worksheet presents the main results of the calculations of the chosen biomass energy technology. This worksheet has 4 distinct parts. At the top of the Summary worksheet, the main characteristics of the biomass energy technology and its assessment conditions are recorded. This includes a brief description of the biomass energy technology, the functional unit which it provides (heat and/or electricity, or liquid biofuel), the unit of measurement (MWth for heat, MWhe for electricity and 1,000 litres for liquid biofuel), the relevant location of the complete process chain (United Kingdom and overseas), and the relevant period (year) for which the initial data and subsequent results are appropriate. The second distinct part of the Summary worksheet is the summary table of main results. This presents the primary energy inputs and total greenhouse gas emissions, in terms of equivalent CO_2, per unit of the final functional unit for each major stage as well as totals for the complete process chain. The conversion of CH_4 emissions and N_2O emissions into equivalent amounts of CO_2 is performed using the specified values of global warming potentials (see Sections 4.2 and 5.2.3). The third distinct part of the Summary worksheet is the chart which illustrates the percentage contribution of each process stage to total primary energy inputs and total greenhouse gas emissions. The fourth and final distinct part of the Summary worksheet is the detailed table of results. This records individual contributions within each process stage to primary energy and CO_2, CH_4, N_2O and total greenhouse gas emissions. Both average estimates and ranges of results are presented as well as their percentage contribution to total values for the complete process chain. The information required to derive these results in this part of the Summary worksheet are obtained from the Unit Flow Chart, Global Warming Potential, Allocation and individual Process Stage worksheets. As a result of this, the Unit Flow Chart worksheet is the most highly linked part of each workbook and the formula contained in the relevant cells can be extremely lengthy and complex.

5.2.3 Global Warming Potentials Worksheet

Values of global warming potential, which enable CH_4 and N_2O emissions to be converted to equivalent CO_2 emissions, are recorded in the Global Warming Potential worksheet. These values can be altered to accommodate the effect on the total greenhouse gas emissions reported in the Summary worksheet from any future changes in global warming potentials, usually specified by the Inter-governmental Panel on Climate Change.

5.2.4 Allocation Worksheet

The Allocation worksheet uses information on the quantities and prices of main, co- and by-products, as specified in the Unit Flow Chart worksheet, to evaluate allocation by price in instances where this is relevant. Information from the Unit Flow Chart worksheet is summarised as linked data and included in cells with a pale green background towards the top left corner of the Allocation worksheet. This information is used to derive the allocated percentages of primary energy inputs and CO_2, CH_4, N_2O emissions associated with preceding process stages for given main, co- and by-products. Derived values of the individual and cumulative allocation percentages, which are required for the calculations in the Summary worksheet, are presented in the Allocation worksheet.

5.2.5 Process Stage Worksheets

The Process Stage worksheets consist of a series of individual worksheets that represent each stage in the process chain. The nature, details and names of these worksheets depend on the particular biomass energy technology under investigation. The essential feature is that each one relates to a process chain module in the Unit Flow Chart worksheet and to respective stages in the Summary worksheet. Although the details of the Process Stage worksheets reflect the biomass energy in question, they all share common characteristics. At the top of each worksheet is a summary of information relevant to the process stage that is being represented, its functional unit, the unit of measurement, the relevant location and the relevant period. Any linked data from other worksheets in the workbook are recorded towards the top left corner in cells with a pale green background. Each worksheet then lists, in Column A, contributions to this process chain stage. The cells in Column B contain the units in which these contributions are measured. Cells in Columns C and D show the average values and ranges (+/-) of inputs from each of these contributions. Most of these cells have a pale blue background which means that the user can enter new values provided that they are realistic and in the correct units of measurement. It should be noted that the entire collection of worksheets incorporates a propagation of errors routine which enables error bars to be evaluated for the final results based on the combination of ranges for the values of individual contributions to the process chain. It has been assumed that all ranges reflect a symmetrical distribution of values around each average. Column E in the worksheet provides notes on the default average values and ranges for each contribution to the relevant process stage. These notes record the basic details and original sources of the defaults. Column F summarises the units of measurement for primary energy multipliers. Columns G and H contain the average values and ranges (+/-) of the primary energy multipliers for appropriate contributions. These cells have pale green backgrounds, which indicate that the user can change the entries provided that suitable and consistent data are available. It is the responsibility of the user to ensure that this is the case in order to avoid inappropriate results. Column I records the notes on the default average values and ranges for the primary energy multipliers. Calculated average values and ranges (+/-) for primary energy inputs are presented in Columns J and K. The cells in these entries have pale red backgrounds. This sequence of entries is repeated for CO_2 multipliers and estimated emissions (Columns L to Q), for CH_4 multipliers and estimated emission (Columns R to W), for N_2O multipliers and estimated emissions (Columns X to AC). Unlike the earlier version of the Biomass Environmental Assessment Tool, the conversion of CH_4 and N_2O emissions to equivalent CO_2 emissions, by means of specified global warming potentials, is not undertaken in the individual Process Stage worksheets. Instead, this is performed in the Summary worksheet. For convenience, sub-totals are provided, where appropriate, as well as totals in all the relevant results columns of the Process Stage worksheets.

5.2.6 Reference Worksheet

The Reference worksheet lists all the sources cited in the notes in the Unit Flow Chart and Process Stage worksheets. A numbered referencing system is used. The majority of the references are publications that are available in the public domain. Occasionally, it has been necessary to rely on private communications for essential information. This has been referenced accordingly.

5.3 Limitations and Uncertainties

Underlying the model that forms the *Biomass Environmental Assessment Tool* (BEAT 2) is data in a set of workbooks. The workbooks incorporated into BEAT 2 represent the most comprehensive and complete evaluation currently possible of the whole chain of primary energy inputs and greenhouse gas emissions for the biomass energy technologies under consideration. This is reflected in the level of detail they contain and by the transparency they demonstrate. However, users of BEAT 2 and their audiences need to be aware of the limitations of these workbooks. These limitations can be grouped into four specific aspects:

- constraints on life cycle assessment as a practical technique,
- uncertainties in the data,
- changes in the data due to technology, and
- variations in data over time.

5.3.1 Constraints on LCA as a practical technique

Life cycle assessment is a developing technique, some features of which are well established whilst others are still evolving. The most developed feature of life cycle assessment is the preparation of inventories of natural resource inputs and environmental outputs. However, these inputs and outputs are so numerous and diverse that it is rarely possible, under most commercial circumstances, to assemble and quantify a complete inventory. As is common, attention in BEAT2 is focussed on the most prominent natural resource inputs, that is primary energy as measure of energy resource depletion, and the most prominent environmental outputs, which is often the main greenhouse gas emissions associated with global climate change. It is also possible to expand detailed and transparent inventory analysis to other inputs and outputs but this can be extremely time-consuming and costly.

For similar reasons, life cycle assessment is typically truncated at the inventory analysis stage where the natural resource inputs and environmental outputs are identified and quantified. Categorisation and classification is sometimes attempted, as in the current workbooks where the three prominent greenhouse gas emissions (CO_2, CH_4 and N_2O) are grouped together and converted into common units of equivalent CO_2 emissions by means of appropriate global warming potentials. However, the ultimate life cycle assessment stage of interpretation is regularly avoided, mainly for reasons of practicality but also for fundamental concerns over the validity of the procedures involved. Interpretation is sometimes presented, incorrectly, as an attempt to aggregate all the individual values of the natural resource inputs and environmental outputs into a single number that can be readily understood and applied by decision-makers. Whilst most life cycle assessment practitioners would argue that this is not the purpose of the technique, there is often pressure to derive such single values. Academically, there have been numerous studies on such aggregation that normally depend on a weighting procedure which effectively allocates relative values to diverse inputs and outputs so that they can be expressed in a single type of unit and, subsequently, added together. Leaving aside practical problems with this approach, weighting is usually based, directly or indirectly, on subjective judgements that betray the intentionally scientific and objective basis of life cycle assessment. Hence, interpretation tends to be a controversial topic for which there is, currently, no agreed resolution. Most pragmatic practitioners avoid the controversy by recognising that life cycle assessment produces a series of totally objective results that can be used by informed decision-makers to assist their deliberations without expecting a single result that makes the decision for them.

5.3.2 Uncertainties in the data

Turning to the limitations of life cycle assessment due to the uncertainty of data, it will be appreciated that the calculations undertaken in the workbooks have been qualified by the use of data with error bars. These error bars reflect the likely range of values for data which arise due to normal differences in measured and calculated results for any given product or service. In most instances, these error bars are based on typical ranges for values. If necessary, these ranges can be altered to reflect new information. However, it is a fundamental assumption of the propagation of errors routine embedded within the workbooks that the frequency distributions for all the data are, in fact, symmetrical. This is a very important simplifying assumption. In practice, it is often found that life cycle assessment data are more appropriately represented by asymmetrical or "skewed" frequency distributions. Suitable propagation of errors routines can be modified to accommodate such distributions, mainly by adjusting standard formulae for logarithmic rather than normal values of data. However, this adds the complication of specifying the type of frequency distribution relevant to each data entry. The current version of the workbooks avoids this complication but could, in future, be modified to accordingly.

Probably more important than this issue, is the nature and effect of possible changes and variations in data. In general, the data reflect information on primary energy inputs or greenhouse gas emissions associated with the provision of a particular product or service by a specific means at a given point in time. For example, the CO_2 multiplier for electricity can reflect the overall mix of generation capacity in a specified country (say, the UK) during a specified year (say, 1996). Such multipliers can, of course, change with location and time. In particular, the CO_2 multiplier for electricity in the UK has varied considerably up to the current date. This has happened because the mix of fuels used to generate electricity has altered over time. This is the reason why, to avoid unnecessary confusion, the relevant location (country) and time (year) is quoted in each workbook. However, it is often very difficult to ensure the use of a complete dataset that is relevant, exclusively, to one single location at one point in time. Hence, a degree of licence is unavoidable for the practical formulation of suitable workbooks. Whilst it may be possible, for example, to specify that electricity is provided from a dedicated power plant within a given process, it might be necessary to assume that ammonium nitrate fertiliser is obtained from "typical" or "average" supplies available in Western Europe. This is because either the specific source of supply cannot be identified, or only general rather than specific data on a given product or service are accessible, or a combination of both considerations. In general, subsequent problems can be prevented in life cycle assessment by ensuring that, first, sound and relevant data are available for the most prominent inputs and outputs, and, second, that quoted error bars encompass the typical variations in data for a mix of sources of supply.

5.3.3 Changes in the data due to technology

The structure of the workbooks is designed to accommodate changes and variations in data with time and circumstances. However, it should be appreciated that the workbooks provided are "technologically fixed". This means that they are only intended to represent the biomass energy technologies that are specified. Although they can be modified with care and knowledge, this is not a trivial exercise that should be attempted by the inexperienced user. Of course, a degree of variation is possible within the specified technologies by changing assumed values of key parameters, such as thermal efficiencies, heat-to-power ratios, etc., within reasonable limits through the relevant entries in the Unit Flow Chart worksheet. Despite this, basic changes in technology really require the development of properly representative workbooks to provide reliable results. Whilst this may seem to be an obvious point, it should be noted that, occasionally, certain alterations such as the source of heat and electricity within a process can require fundamental changes to workbooks. For example, such changes are necessary if the use of fossil fuels by a combined heat and power plant within a “bioethanol from wheat grain” production unit is replaced by a straw-fired combined heat and power plant.

5.3.4 Variations in data over time

A significant general point that needs to be made about changes and variations in data is that the quality and quantity of data are evolving continuously in life cycle assessment. As time goes by, the number of more detailed life cycle assessment studies increases and this provides more reliable data that can be used in subsequent life cycle assessment studies. In particular, systems boundaries are expanded so that more representative data on the total natural resource inputs and environmental outputs are derived as more subsidiary process chains are traced back to their original natural resources and traced forward to their final means of disposal. Hence, the database from which life cycle assessment studies draw their information improves gradually over time. However, this does not necessarily mean that the values of data diverge significantly from the original values derived during the early stages of life cycle assessment, development. Often, successive iterations bring about increasingly minor changes. Once again, to avoid major unreliability in results, the prudent approach to life cycle assessment is to ensure that most effort and attention is paid to the most prominent inputs and outputs, in terms of their relative magnitude. This is the reason why many life cycle assessment studies focus initially on scoping work that use approximate data to identify the likely prominent inputs and outputs.

This does not prevent the occurrence of genuine gaps in the data. In the workbooks incorporated in the original version of BEAT 2, the most important missing data relate to start-up fuel consumption and direct CH_4 and N_2O emissions from biomass energy plants. For certain biomass energy technologies, such data were simply not available. However, it was expected that data should become available over time as relevant information and monitored measurements are derived from actual operating experience and provided to users either through confidential channels or by release into the public domain. In either case, the workbooks were designed to accommodate such data. In the current version of BEAT2, approximate estimates for values of previously missing data have been include to avoid the consequences of misleading zero values. Whilst not widespread, unresolved uncertainty is another consideration that must be taken into account for some data in the workbooks. Most significantly, this affects the emissions of N_2O from soils that are used to grow biomass. The estimation and prediction of N_2O emissions from cultivated soils is a complex topic and one that has generated a degree of controversy. The amount of N_2O released by soil depends on a range of factors and significant variations can be observed over relatively short distances within individual fields. Unfortunately, this can be very important in life cycle assessment calculations as a result of the relatively high global warming potential of N_2O. In the current version of BEAT 2, the latest recommendation from the Inter-governmental Panel on Climate Change has been incorporated for the estimation of N_2O emissions from soils. In particular, using on the Tier 1 approach, N_2O emissions from soils are based on a given percentage of the nitrogen fertiliser application rate. Since it is highly likely that new data will emerge over time as knowledge of soil emissions increases and methods of modelling become more sophisticated, it is a fairly easy task to modify relevant calculations at the most detailed level of the workbooks.

Finally, it should be noted that for certain biomass energy technologies, it has been necessary to adopt approximate estimates for the primary energy inputs and greenhouse gas emissions associated with plant construction (as well as maintenance and decommissioning). In certain instances, it has been necessary to use capital costs estimates and general, cost-based multipliers. Although it is suspected that calculations incorporating such data result in significant over-estimates, it has been necessary to adopt this approach in the absence of representative data based on actual studies of plant construction. Such studies, which were available for most of the other biomass energy technologies, rely on relatively detailed physical breakdowns of plant components, equipment, etc. Occasionally, it has been possible to extend the results of such studies for specific plants to other biomass energy technologies on the basis of similarity. Over-estimation resulting for the unavoidable use of cost data and cost-based multipliers also affects the calculation of primary energy inputs and greenhouse gas emissions associated with plant maintenance and decommissioning due to the assumption that these are proportional to the initial inputs and emissions of plant construction. Whatever the method for calculating inputs and emission associated with plant construction, it should be appreciated that variations in plant rating are accommodated by assuming a simple 2/3 power function for scaling purposes.

6 References

6.1 References for Section 4

4.1 "Environmental Management – Life Cycle Assessment – Principles and Framework" European Standard ISO 14040, European Committee for Standardisation, Brussels, Belgium, 2006.

4.2 "Environmental Management – Life Cycle Assessment – Goal and Scope Definition and Inventory Analysis" European Standard ISO 14041, European Committee for Standardisation, Brussels, Belgium, 1999.

4.3 "Environmental Management – Life Cycle Assessment – Life Cycle Impact Assessment" European Standard ISO 14042, European Committee for Standardisation, Brussels, Belgium, 2000.

4.4 "Environmental Management – Life Cycle Assessment – Life Cycle Interpretation" European Standard ISO 14043, European Committee for Standardisation, Brussels, Belgium, 2000.

4.5 "Environmental Management – Life Cycle Assessment – Data Documentation Format" European Standard ISO 14048, European Committee for Standardisation, Brussels, Belgium, 2002.

4.6 "Environmental Management – Life Cycle Assessment – Examples of Application of ISO 14041 to Goal and Scope Definition and Inventory Analysis" European Standard ISO 14049, European Committee for Standardisation, Brussels, Belgium, 2000.

4.7 "Energy Analysis Workshop on Methodology and Conventions" International Federation of Institutes for Advanced Study, Report No. 6, Guldsmedhyttan, Sweden, August 1974.

4.8 "Workshop on Energy Analysis and Economics" International Federation of Institutes for Advanced Study, Report No. 9, Lidingö, Sweden, June 1975.

4.9 "Methodology for Environmental Profiles of Construction Materials, Components and Buildings" Centre for Sustainable Construction at the Building Research Establishment Ltd., CRC Ltd., London, United Kingdom, 2000.

4.10 "Evaluation of the Comparative Energy, Global Warming and Socio-Economic Costs and Benefits of Biodiesel" by N. D. Mortimer, P. Cormack, M. A. Elsayed and R. E. Horne, Contract Reference No. CSA 5982/NF0422 by the Resources Research Unit, Sheffield Hallam University, Sheffield, United Kingdom, January 2003.

4.11 Third Assessment Report" Intergovernmental Panel on Climate Change, www.grida.no/climateipcc_tar/wg1, 2001.

4.12 "Energy and Greenhouse Gas Benefits of Liquid Biofuel Technology Options" by N. D. Mortimer, M. A. Elsayed and R. E. Horne, Submission to the House of Commons Environment, Food and Rural Affairs Select Committee on Alternative Crops (Biofuels), Resources Research Unit, Sheffield Hallam University, Sheffield, United Kingdom, March 2003.

4.13 Energy and Greenhouse Gas Emissions for Bioethanol Production from Wheat Grain and Sugar Beet" by N. D. Mortimer, M. A. Elsayed and R. E. Horne, Final Report for British Sugar plc., Resources Research Unit, Sheffield Hallam University, Sheffield, United Kingdom, January 2004.

4.14 "Expert Paper on the Global Impacts of Road Transport Biofuels: A Contribution to the Government's Analysis" by A. Bauen, N. Eyre, M. Fergusson, D. Hart, D. Martin, N. Mortimer, J. Skea and A. Veitch, joint publication by the National Society for Clean Air, Institute for European Environmental Policy and the Cleaner Transport Forum, London, February 2004.

4.15 "Well-to-Wheel Evaluation for Production of Ethanol from Wheat: A Report by the LowCVP Fuels Working Group. WTW Sub-Group" by G. Punter, D. Rickeard, J.-F. Larive, R. Edwards, N. Mortimer, R. Horne, A. Bauen and J. Woods, Report FWG-P-04-024, Low Carbon Vehicle Partnership, London, United Kingdom, November 2004.

4.16 "Digest of United Kingdom Energy Statistics" Department of Trade and Industry, London, United Kingdom.

4.17 "Guidelines for Company Reporting on Greenhouse Gas Emissions", Department for the Environment, Food and Rural Affairs, London, United Kingdom, www.defra.gov.uk/environment/envrp/gas/05.htm, accessed 20 August 2004.

4.18 "Guidance Note 24: Determination of Scheme Quality" Quality Assurance for Combined Heat and Power, www.chpqa.com, accessed 10 November 2004.

6.3 References for Section 5

5.1 "Carbon and Energy Balances for a Range of Biofuels Options" by M. A. Elsayed, R. Matthews and N. D. Mortimer, Project No. B/B6/00748/REP, URN 03/836, for the Department of Trade and Industry by the Resources Research Unit, Sheffield Hallam University, Sheffield, United Kingdom, March 2003.

AEA Energy and Environment
329 Harwell
Didcot
Oxfordshire
OX11 0QJ

Tel: 0870 190 6151
Fax: 0870 190 6318