Evaluating the Sustainability of Co-firing in the UK

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1 Executive Summary: Main objectives and Findings of the study

1.1 Objectives of the study

The objectives of the study were to:

(a) Assess the overall carbon balance for co-firing.
(b) Investigate the other sustainability issues relating to co-firing.
(c) Assess the scope for incentivising the most sustainable forms of co-firing.

The main questions to be addressed by the report are:

- Is the overall carbon balance for co-firing positive?
- What is the difference in carbon balance between energy crops and other biomass?
    - Are some kinds of energy crops better than others?
- How big a factor is transport in the carbon balance?
- Under what circumstances (fuel, transport, process, etc.) are the greatest benefits of co-firing in terms of carbon balance and sustainability?
- Are there any circumstances (as above) that could raise serious carbon balance or sustainability issues?
- How does the carbon balance compare between co-firing, dedicated biomass, and biomass heat?
- Is there any scope for encouraging the most sustainable forms of co-firing - perhaps through using existing or currently in development accreditation schemes?

1.2 Findings

This report concludes:

- Co-firing could be expanded to make a significant and low risk contribution to Government and EU renewable energy policy targets.
- Real environmental and social benefits could arise from the expansion of co-firing markets, both in the UK and in poor developing countries, given responsible development policy.
- There is no clear environmental or social case, for an arbitrary cap on the amount of co-firing .
- Co-firing could expand and enhance clean coal Carbon and Capture and Sequestration (CCS).

These upper level conclusions are derived from the following outcomes of the report's evaluation:

1. The net carbon balance for the production, transport and use of biomass for co-firing is positive in almost all circumstances, including for both imported and domestic biomass.
2. The use of domestic biomass can have positive environmental and social impacts.

3. There is a significant amount of biomass in the form of wastes and residues that could be used for co-firing. At the moment, some of this incurs an environmental, economic and social cost for disposal.
4. From an avoided GHG emissions perspective, the co-firing of biomass with coal represents one of the most effective uses of biomass resources for energy
    - Nearly 1.5 million tonnes of biomass were consumed for co-firing in 2005 showing that this is now a significant and maturing market for biomass.
5. The majority of biomass used for co-firing is derived from waste or co-products, and this is expected to continue for the following reasons:
    - Price
    - Handling characteristics
    - Combustion characteristics
    - Commodity / spot market – flexibility and reliability of supply
    - The resource base is underutilised and potentially very large.
6. The use of waste or co-product biomass for co-firing with coal is generally an effective use of this resource from an avoided GHG emission perspective because:
    - Waste / co-product materials tend to have lower lifecycle GHG emissions per unit energy than dedicated energy crops
    - Co-firing occurs in large-scale plants which efficiently convert an otherwise un-used or underused renewable resource. Lower efficiencies are likely at smaller scales
    - Unwanted GHG emissions from alternative disposal routes e.g. open air combustion or decomposition are avoided along with those that would have arisen from the use of the substituted coal.
7. Importing waste / co-product biomass is unlikely to have significant negative environmental impacts. GHG emissions associated with bulk transport by sea are low in relation to the GHG benefits from avoided fossil fuel combustion.
8. The development of a commodity market for biomass waste and co-products is generally positive because it helps producers find the best value for products that previously had limited value. There is no current evidence to suggest that the commodity market for biomass waste is impeding investment in bioenergy use in producer countries.
9. There is no current evidence to suggest that the market for biomass waste and co-products is leading to depletive / over extraction of the resources for co-firing. Indeed, there is evidence from the forestry industry in the UK that the forestry system would benefit from increased demand that would make thinning[1] more financially viable. While the value of biomass wastes and residues remains a relatively small fraction of the value of the main product then co-firing is unlikely to be a driver of unsustainable biomass development.
10. The nature of energy supply contracts within the coal industry mean that it is difficult for co-firers to provide a suitable basis for the sustainable development of dedicated energy crops such as *Miscanthus* or SRC. Dedicated energy crops require long-term contracts that are not normal for these generators and are unlikely to become so without further intervention on the part of government.
11. With current levels of usage and understanding, the existing standards for agriculture and forestry are probably sufficient to promote the establishment of energy crops

[1] There are large areas of UK forest that are not economically viable to thin. However, not thinning leads to lower long term production and lower quality output.

avoiding harmful impacts. Data from the monitoring of energy cropping systems can be used to develop standards specific to energy cropping as the use of biomass increases. Simple carbon declaration systems could be developed to reward lower carbon biomass feedstocks and penalise higher emission sources.

12. Biomass co-firing could provide a low-cost route for enhancing coal Carbon Capture and Sequestration (CCS) and further work to evaluate this potential 'future-proofing' option would be valuable.
13. A large amount of biomass now classified as waste and that could be used for energy, is currently consigned to landfill. The value of these wastes and the costs of not using them (particularly to avoid methane emissions) should be publicised, and the necessary infrastructure and modification of regulations could be put in place to maximise their utilisation.

1.3 Methodology

This report focuses solely on the carbon (GHG) and broader sustainability impacts of co-firing in the UK. It does not include an economic evaluation. It provides an overview of the existing materials being used as feedstocks for co-firing and a summary life-cycle assessment of the GHG balances and sustainability (environmental and social) impacts of the provision and use of those feedstocks.

A clear distinction is made between the use of residues and dedicated energy crops. We have used the following hierarchy to decide on the boundaries applied to the analysis and therefore on the GHG emissions allocated to the feedstock at each stage of production through to use.

Feedstock category	Boundary
Residue / Waste	GHG emissions and sustainability impacts only applied at point that feedstock arises e.g. factory gate
By-product	Allocation of GHG emissions at field to processing plant levels only made if by-product value exceeds 10% of factory gate income
Co-product	Allocation for field to processing levels made as ratio of economic value of co-product to factory gate income
Energy crop	Allocation applied across complete production – processing and use chain.

In practice, we assume that the currently co-fired feedstocks are either residues or dedicated energy crops. Therefore, the need to allocate field-to-processing level emissions and impacts by economic value has not arisen because the feedstocks are not classified as by- or co-products. A shift in classification from residue to by-product and co-product remains unlikely whilst large volumes of residues remain under-exploited globally. A re-evaluation of this assumption would be necessary where statistics began to indicate that; the residue resource was becoming significantly exploited, energy crops were producing multiple outputs of similar value e.g. through poly generation, or changes in the trading practices of buyers were emerging that added significant value to co-firing feedstocks.

2 An assessment of the types of biomass typically used in co-firing, both imported and locally-sourced.

A diverse range of biomass materials are currently being sourced indigenously and from abroad, for co-firing in UK power stations as discussed below.

2.1 Biomass materials available for co-firing in the UK

Large volumes of biomass are already used for co-firing as discussed in section 6.1. The residues and wastes from agriculture, forestry, and meat processing that are used for co-firing include:

- **Wood -** from indigenous and imported sources, including sawdust, chips and pellets
- **Olive residues** - from imported sources including residues, expeller, cake and pellets
- **Palm residues** - from imported sources, including kernel, shells, palm kernel expellers (PKE), and PKE pellets
- **Shea residues -** from imported sources, including meal and pellets
- **Tall Oil -** from imported sources
- **Sunflower pellets** - from imported sources
- **Cereal pellets** - from indigenous and imported sources principally produced from wheat and barley straw
- **Tallow** - from indigenous sources

Energy crops are those grown specifically for use as a fuel. They include:

- **Short Rotation Coppice -** from indigenous sources
- **Miscanthus -** from indigenous sources
- **Granulated willow** - from indigenous sources

In addition, **sewage sludge** and **waste derived fuels** (WDF) can also be used for co-firing.

2.2 Biomass materials currently co-fired in UK power stations

Table 1 demonstrates that virtually all coal-fired UK power stations are currently co-firing, either on a trial or commercial basis.

Table 1: Examples of materials currently or recently being co-fired at UK power stations

Company	Power Station	Installed Capacity (MW)	Primary Fuel	Co-firing Fuel
AES	Kilroot	520	Coal/ oil	Trialling olive pellets
Alcan	Lynemouth	420	Coal	Trialling wood
British Energy	Eggborough	1,960	Coal	Palm oil, PKE. Previously olive pellets and pulp, shea pellets and meal
Drax Power Ltd	Drax	3,870	Coal	Timber, *Miscanthus*, SRC. Previously olive cake, PKE, wood pellets
EDF Energy	Cottam	2,008	Coal	Wood pellets, olive cake
EDF Energy	West Burton	1,972	Coal	Wood pellets, olive cake
E.On UK	Kingsnorth	1,940	Coal/ oil	Wood chips, tall oil, PKE
E.On UK	Ironbridge	970	Coal	Wood chip, PKE
E.On UK	Ratcliffe	2,000	Coal	Wood chips, tall oil, PKE
International Power	Rugeley	1,006	Coal	
RWE NPower Plc	Aberthaw B	1,455	Coal	Palm oil, sawdust
RWE NPower Plc	Tilbury B	1,029	Coal/ oil	PKE. Previously sawdust
RWE NPower Plc	Didcot A	1,940	Coal/ gas	PKE. Previously sawdust
Scottish and Southern Energy	Ferrybridge C	1,955	Coal	
Scottish and Southern Energy	Fiddler's Ferry	1,961	Coal	
Scottish Power	Cockenzie	1,152	Coal	Wood pellets
Scottish Power	Longannet	2,304	Coal	Wood pellets
Uskmouth Power Company Ltd	Uskmouth	393	Coal	Shea meal

2.3 Physical/ energy characteristics of the main biomass materials suitable for co-firing

The following section describes the physical and energy characteristics of the biomass materials currently being used for co-firing in the UK.

It was not possible to obtain information on the exact provenance of the materials currently being co-fired in UK power stations as this information is commercially sensitive, and was not made available to our team. The following sections therefore describe the likely origin of each biomass type.

2.3.1 Wood Residues

Wood residues from forestry, arboriculture, sawmills and the furniture industry are viable options for co-firing. The material comes in the form of sawdust, shavings, bark and chips.

The physical and energy characteristics of this material are variable. The calorific value of oven dry sawdust is 20.5 MJ/kg (HHV)[2].

Wood pellets can be formed from a variety of types of wood residues. They have a higher and more standard energy density than the raw materials, as well as a uniform shape and size, making them easy to handle. The moisture content of wood pellets is around 5 -10 percent, which is considerably lower than that of wood residues.

There are indigenous sources of wood residues available. It is estimated that the UK produces over 10 Mt of waste wood each year[3]. Currently there are no large scale producers of wood pellets in the UK, but they are readily available from Russia, North America, Scandinavia and other North Eastern European countries. There are however plans for large-scale production in Scotland.

Tall Oil, also known as liquid resin or tallol, is a resinous oil produced during the treatment of pine pulp in wood pulp and paper manufacture. It is used in the manufacture of soaps, lubricants and emulsions. In Scandinavia, it is termed a ‘bio oil’ and is burnt for energy.

The physical characteristics of Tall Oil vary according to the species of tree it is obtained from, and to the method of processing to which it has been subject.

2.3.2 Olive Residues

Olive agriculture occurs throughout the world but is strongly focused on the Mediterranean, with Spain, Italy and Greece accounting for 97 percent of total production. Olives are grown in monocultures with annual yields ranging from 500 to 10,000 kg olives per hectare.

Olive residues consist of the crushed olive kernel, shell, pulp, skin, water and any remaining oil, and traditionally they are used for animal feed, as fertiliser, or they are disposed of in landfill or by incineration. Increasingly, olive processing plants are burning residues to produce heat to be used for processing.

Olive residues are imported as a cake, expeller, or as pellets. The physical and energy characteristics of olive residue vary according to the method of processing. The calorific value of oven dry olive cake is 21.2 MJ/kg (HHV)[4]. World production of crude olive cake is estimated to be 5 Mt, with over 3 Mt coming from Spain, Italy and Greece.[5]

2.3.3 Oil Palm Residues

Oil palms are grown principally in South East Asia, but also in South America, and Africa. Malaysia and Indonesia dominate the world production of palm oil where oil palms are grown in monocultures of varying scales. Palm oil is used extensively in the food and chemical industries.

Oil is extracted both from the palm fruit and the kernel. Typically, around 45 percent of the oil palm fruit is residual material that is potentially suitable for co-firing. Residual material consists of the empty fruit bunches, kernel, shell, and fibrous material.

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[2] Higher Heating Value (HHV), or gross calorific value. Taken from the Phyllis database. Available online at http://www.ecn.nl/phyllis

[3] Figure taken from wood. for good. Available online at: http://www.woodforgood.com/events/woodsrecyclinggrowsinuk.html

[4] Higher Heating Value (HHV), or gross calorific value. Taken from the Phyllis database. Available online at http://www.ecn.nl/phyllis

[5] This is based on world olive production of 14,481,279 metric tonnes and 10,026,993 tonnes produced by Italy, Spain and Greece and 35% residues. Figures derived from the Food and Agriculture Organisation of the United Nations FAOStat database. Available online at www.faostat.fao.org

This residual material is often applied to oil palm plantations as mulch, or it is left to decompose. Increasingly, palm residues are burnt in oil palm processing mills to produce power and heat. The calorific value of oven dry oil palm kernels is 17.0 MJ/kg[6]. It is estimated that over 20 Mt of palm residues were produced by Malaysia and Indonesia alone in 2005.[7]

2.3.4 Shea Residues

The Shea tree originates in Africa. Shea butter is extracted from the kernel of the shea fruit for use in the cosmetics and food industries. After the removal of the butter, the fleshy mesocarp and the shell and husk are left as residual material. This residue is used as a waterproofing agent, as a fertiliser or mulch, or as a domestic fuel.

Like other agricultural residues, the physical and energy characteristics of shea residues vary according to the method of processing.

2.3.5 Short Rotation Coppice (SRC)

Short rotation coppice consists of dense plantations of high-yielding varieties of either poplar or willow. During harvesting, which typically occurs on a 2 - 5 year cycle, only the shoots are removed, leaving behind the roots to allow for re-growth. Currently there are approximately 3,000 ha under SRC plantations in the UK.

SRC is harvested as rods, chips or billets with a moisture content of 45 – 60 percent. Yields in the UK are between 5 – 18 odt/ha.yr. However, the variation results from the species planted, the conditions of the site on which the SRC is planted, and the efficiency of harvesting. The calorific value of oven dry, untreated willow is 19.1 MJ/kg (HHV)[8].

2.3.6 Miscanthus

Miscanthus is a woody, perennial, rhizomatous grass, originating in Asia. The plant has rapid rates of growth, producing canes during the summer, which, unlike SRC are harvested every year. *Miscanthus* yields are between 7 –12 odt/ha.yr. Like SRC, this variation is due to the species planted, the conditions of the site, and the efficiency of harvesting. The calorific value of oven dry *Miscanthus* is 19.0 MJ/kg (HHV)[9].

2.3.7 Tallow

Tallow is a product of the rendering of animal by-products. Rendering describes the process of cooking animal by-products at high temperatures to drive off water, allowing the fat, or tallow, to be separated from the protein.

Rendering products typically form 32 percent of the total animal mass. Of this, 24 percent is tallow. Tallow is typically used in the food and chemical industries.

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[6] This figure is the Lower Heating Value (LHV) of palm kernels. No figure was available for the Higher Heating Value. Figure obtained from E.On UK.

[7] Based on an output of 28 million metric tonnes of palm oil. Figure obtained from United States Department of Agriculture Foreign Agriculture Service. Available online at www.fas.usda.gov

[8] Higher Heating Value (HHV), or gross calorific value of oven dry biomass (unless otherwise stated). Taken from the Phyllis database. Available online at http://www.ecn.nl/phyllis

[9] Higher Heating Value (HHV), or gross calorific value. Taken from the Phyllis database. Available online at http://www.ecn.nl/phyllis

Around 250,000 t of tallow are produced annually in the UK with an average calorific value of 40.0 MJ/kg[10].

2.3.8 Sewage Sludge

Sewage sludge is the solid component produced from the treatment of wastewater. Approximately 1.5 Mt of sewage sludge is produced in the UK each year, which, when processed, is suitable for co-firing. After the sludge component has been separated from the water fraction, it is dried and then pelletised.

One tonne of sewage sludge pellets can be produced from 20 t of sewage sludge. The calorific value of dry sewage sludge is highly variable according to its composition, however it is in the region of 12 MJ/kg (HHV)[11].

[10] Figure from the Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO). Available online at www.csiro.au

[11] Higher Heating Value (HHV), or gross calorific value. Taken from the Biobib database. Available online at www.vt.tuwien.ac.at/Biobib

3 The life-cycle carbon costs of the production and use of biomass for co-firing

The production of biomass fuels suitable for co-firing requires inputs of varying amounts of fuels and electricity, often fossil-based. As a result, the process of producing biofuels normally results in GHG emissions, although these are generally less than those associated with production of equivalent amounts of fossil fuels. Additionally, when the use of biomass for fuel involves a change to its usual utilisation or disposal route, the net changes in the amounts of GHG emitted as a result of those changes need to be accounted for.

The effects of product substitution are highly situation-specific, and may involve net increases or decreases in GHG emissions. Stopping methane emissions by using biomass which would otherwise have been left to decompose can have very significant avoided GHG emission benefits.

In this section, the carbon costs of supplying biomass fuels for co-firing are considered. An inventory of emissions associated with production of biomass fuels is presented. The analysis considers all direct and indirect emissions for all production steps from the collection of biomass materials or preparation of land for planting of energy crops, to the production of biomass fuel ready for transportation to the power plant. This section of the life cycle inventory is sometimes referred to as a “cradle-to-gate” analysis.

3.1 Types of Biomass Fuels Considered in this Study

The choice of co-firing fuels chosen for analysis in this study was based on a consideration of the types of biomass fuels that are currently being co-fired in the UK and the need to assess the relative benefits of locally-sourced energy crops. The choice was also influenced by the availability of reliable data for analysis of the production chains.

The biomass fuels analysed are:

- ***Wood pellets produced from wood-milling residues*** – Wood pellets usually make good biomass fuels for combustion and co-firing because of their high energy density relative to other solid biofuels. Residue-based fuels may also provide significant greenhouse gas benefits by avoiding methane-producing decomposition of the residues in landfills.
  In 2005, 163,961 tonnes of wood pellets were co-fired in the UK. This accounted for 11.6% of the total biomass co-fired (on a mass basis).
- ***Miscanthus*** – Miscanthus is a perennial energy grass that shows promise as an energy crop.
  In 2005, UK power stations co-fired a total of 547 tonnes of purpose-grown miscanthus. This accounted for 0.04% of the total biomass co-fired (on a mass basis).
- ***Wood chips produced from short rotation coppice (SRC)*** – Short rotation coppice is a perennial woody energy crop with a mixed history of production and use for energy in the UK.
  UK power stations co-fired a total of 3,543 tonnes of SRC in 2005. This accounted for 0.25% of the total biomass co-fired (on a mass basis).

Some of the most commonly co-fired biomass fuels in the UK are co-products and residues of the oil palm and olive processing industries in South-East Asia and the Mediterranean respectively. The availability and implications of the use of oil palm residues are discussed in more detail in section 6.1.1.

Due to a lack of reliable data on these production processes, life cycle inventories have not been carried out for olive and oil palm-based biomass fuels. However, for broad comparison purposes, the 'wood pellets produced from sawdust' chain is the most appropriate proxy, although transport-related GHG emissions may be significantly different as a result of longer, and possibly, more complex logistics.

3.1.1 System boundaries for life-cycle inventory

Biomass production chains are often associated with other upstream, parallel or downstream production activities. It is therefore important that the boundaries of the production chain being analysed are clearly and precisely defined, and that all procedures for allocating emissions to that chain are made explicit. The biomass fuels analysed in this study are derived either from residues of other operations or from dedicated energy crops. The rules by which the system boundaries for these types of fuels are defined in this study are described in the following sections.

Residue-based Fuels

For residues, the system boundary starts at residue collection and finishes with a prepared biomass fuel ready for transportation as shown in Figure 1. Emissions from the main process from which residues are derived are outside the system boundary applied. However, any local effects of removal of residues from the default disposal system must be considered. Thus, when a residual biomass material that would ordinarily be disposed of via landfills or by field-burning is instead used as a fuel, the greenhouse gas emissions that would have resulted from decomposition in landfills or from open burning must be subtracted from the total emissions of the other activities within the system boundary. Since the mostly anaerobic decomposition of biomass in landfills produces significant emissions of methane, a powerful greenhouse gas with a global warming potential of 21 times that of carbon dioxide (100-year basis), the credit for avoided landfilling can be large.

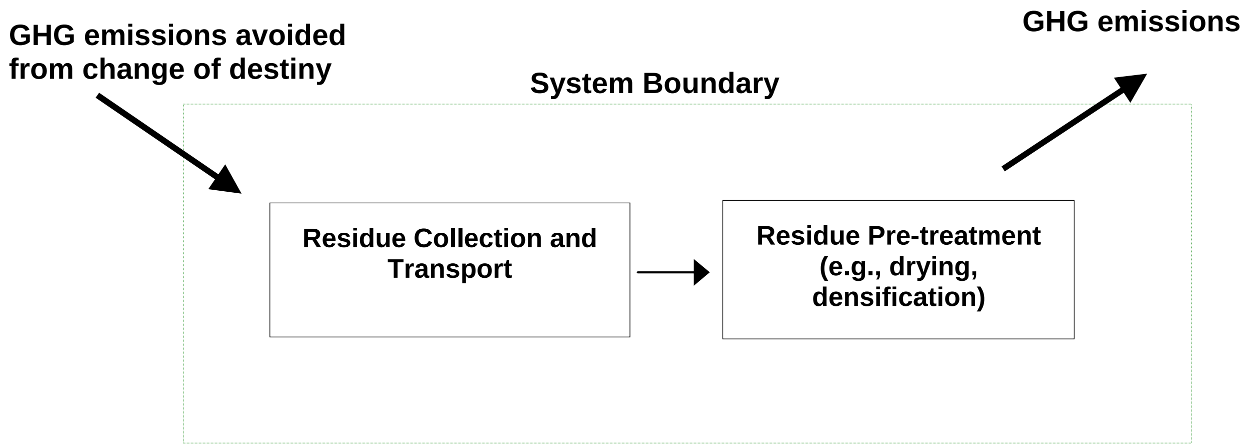

Figure 1: System boundary for residue-based feedstocks for co-firing

Note that the carbon dioxide emissions avoided at landfills are included in the credit for avoided landfilling, and direct carbon dioxide emissions from biomass combustion are included in the inventory, since a credit is not applied for CO_2 absorption during biomass growth (the biomass is not grown for co-firing, and biomass growth is outside the system boundary).

Energy Crops

For energy crops, the entire biomass production chain from land preparation and planting through to processing the biomass as a fuel ready for delivery to the power station is within the system boundary (Figure 2). Direct and indirect emissions from all processes along the chain are summed to derive the total greenhouse gas emissions resulting from production of that biomass fuel. Indirect emissions include those resulting from production of materials used in biomass production, such as chemical fertilizers, are also included. Carbon dioxide absorbed during biomass growth provides a credit to be applied against direct CO_2 emissions during biomass combustion later in the bioelectricity production chain.

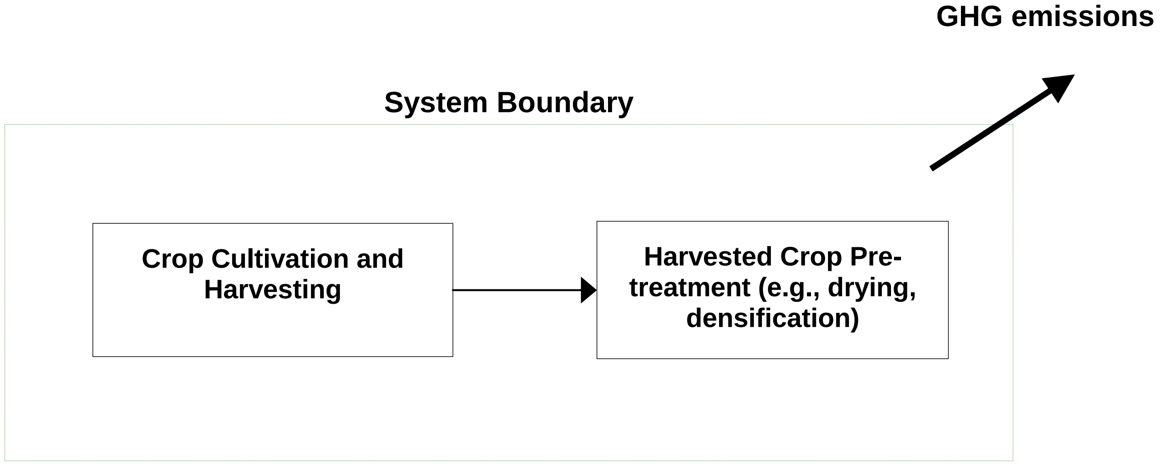

Figure 2: System boundary for energy crops for co-firing

3.1.2 Greenhouse Gases and global warming potentials

Emissions of the most significant greenhouse gases, carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) are considered in this study. The relative 100-year global warming potentials of these gases are given in Table 2.

Table 2: Global warming potentials used for GHGs

Gas	CO_2	CH_4	N_2O
Global Warming Potential	**1**	**21**	**310**

3.1.3 Functional Unit

For deriving the greenhouse gas inventory of biomass fuel production, the functional unit used is ‘prepared biomass fuel at place of production’, ready for transport to place of use. That is all greenhouse gas emissions are calculated per kg of prepared biofuel.

3.2 Greenhouse Gas Emissions Inventory for Biomass Production

A brief summary of the GHG emissions arising from the use of Miscanthus, SRC and wood pellets derived from residual sawdust is provided below.

3.2.1 Miscanthus

The greenhouse gas emissions for production of miscanthus in the UK are given in Table 3. The emissions are dominated by those resulting from cultivation.

Table 3: Greenhouse gas emissions resulting from production of miscanthus (based on Elsayed, et. al.)

	Unit	Value	Notes
Cultivation	gCO_2eq/kg miscanthus fuel	12.4	*a + b*
Harvesting	gCO_2eq/kg miscanthus fuel	3.4	*c*
Storage	gCO_2eq/kg miscanthus fuel	3.4	
Total	**gCO_2eq/kg miscanthus fuel**	**19**	

Notes:
a. Emissions from production and use of fertilizers, lime, pesticides and diesel fuel – equivalent to 241 $gCO_2eq/ha.yr$
b. Yield of miscanthus 36 tonnes per hectare per year, 50% moisture at harvest. After 10% losses during baling and 10% losses during storage, annual yield is 19.4 t of miscanthus fuel at 25% moisture per hectare
c. Miscanthus cut and collected into Hesston bales

3.2.2 Short Rotation Coppice

The greenhouse gas emissions for production of short rotation coppice in the UK are given in Table 4 below.

Table 4: GHG emissions arising from the production of short rotation coppice [based on Elsayed, et. al.]

	Unit	Value	Notes
Cultivation	gCO_2eq/kg dried wood chips	18	*a + b*
Harvesting and Chipping	gCO_2eq/kg dried wood chips	8	*c*
Total	**gCO_2eq/kg dried wood chips**	**26**	

Notes:
a. Emissions from production and use of fuels and agrochemicals – equivalent to 144 $gCO_2eq/ha.yr$
b. Overall yield of 18 tonnes dried wood chips at 25% moisture per hectare per year
c. Combined harvesting and chipping

3.2.3 Wood Pellets from Residues

The greenhouse gas emissions arising from the production of wood pellets from sawmill residues are given in Table 5. Although the direct emissions per tonne produced of this fuel are greater than in the cases of miscanthus and short rotation coppice, the emissions avoided by diverting the wood residues from landfills to fuel production are very large, and therefore, this production chain has large net negative greenhouse gas emissions.

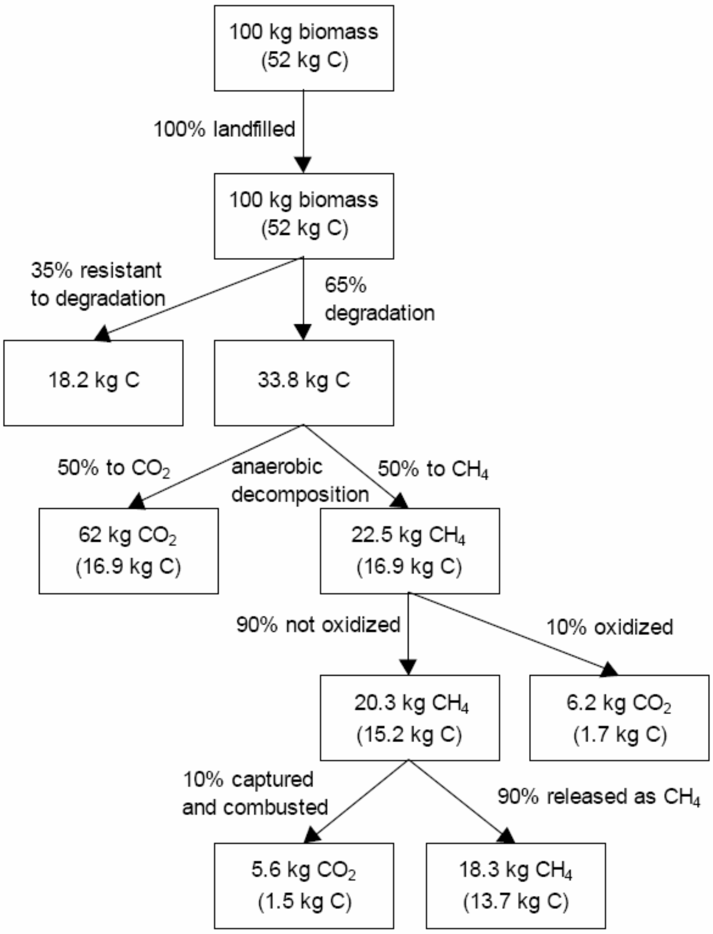

Figure 3: Carbon balance for residues disposed in landfills (Damen and Faiij, 2003)

Figure 3 shows a carbon balance for wood residues disposed to landfill. Anaerobic decomposition of organic residues in landfills results in significant emissions of methane. In the carbon balance shown, 65% of the biomass is assumed to decompose, with the remaining 35%, mainly lignin, being resistant to decomposition. Anaerobic decomposition of the degradable portion results in 50% methane and 50% carbon dioxide. 10% of the formed methane is oxidised by soil microbes to CO_2, and of the remainder, 10% is captured and burned for energy. For the overall carbon balance, each 100 kg of biomass (oven dry) produces 73.8 kg CO_2 and 18.3 kg CH_4. Conditions in landfills and levels of landfill gas utilisation vary, but this example illustrates the extent of greenhouse gas emissions that may be expected from disposal of wood residues in landfill and the potential for GHG reductions if this type of disposal is avoided.

Although not directly comparable to the other residue-based chains for the provision of fuels for co-firing in the UK, it is clear that avoiding methane emissions from either in-field burning or decomposition of residues is a major opportunity for co-firing to act as a GHG mitigation option. Even where UK co-firing is sourcing residues that were already being used and not disposed of as a waste, co-firing is unlikely to result in significantly greater emissions than the existing alternative use.

Table 5: Greenhouse gas emissions arising from the production of wood pellets from residues which would otherwise have been disposed in landfills as per Figure 4

	Unit	Value	Notes
Credit for avoiding landfill	**gCO_2eq/kg pellets**	**-4215**	***a***
Comminution, drying and pelletisation	**gCO_2eq/kg pellets**	**98**	***b***
Total	**gCO_2eq/kg pellets**	**-4117**	

Notes:

a. Avoided emissions based on Damen and Faiij, 2003.

b. Emissions data from Ryckmans, et. al. 2005, for a Swedish wood pellet plant with a production capacity of 140 000 tonnes pellets per year.

4 The carbon cost of transporting biomass fuels

The greenhouse gas (GHG) emissions associated with the transportation of biomass materials that are suitable for co-firing can form a significant part of total lifecycle emissions.

The relative impact of transportation on overall emissions associated with a biomass material depends on its classification as either a waste or a product. This is because when a material is classified as a "waste or secondary product", no GHG emissions associated with the primary production of the biomass that the fuel originates from need to be allocated to it as a co-firing feedstock. Therefore, the only emissions associated with "waste or secondary products" are those that relate to transportation and any further processing.

Figure 4 illustrates this 'boundary' issue using sawdust as an example. The system boundary for sawdust used for co-firing begins when the sawdust leaves the sawmill. If the sawdust is pelletised, then the emissions associated with the pelletisation are allocated.

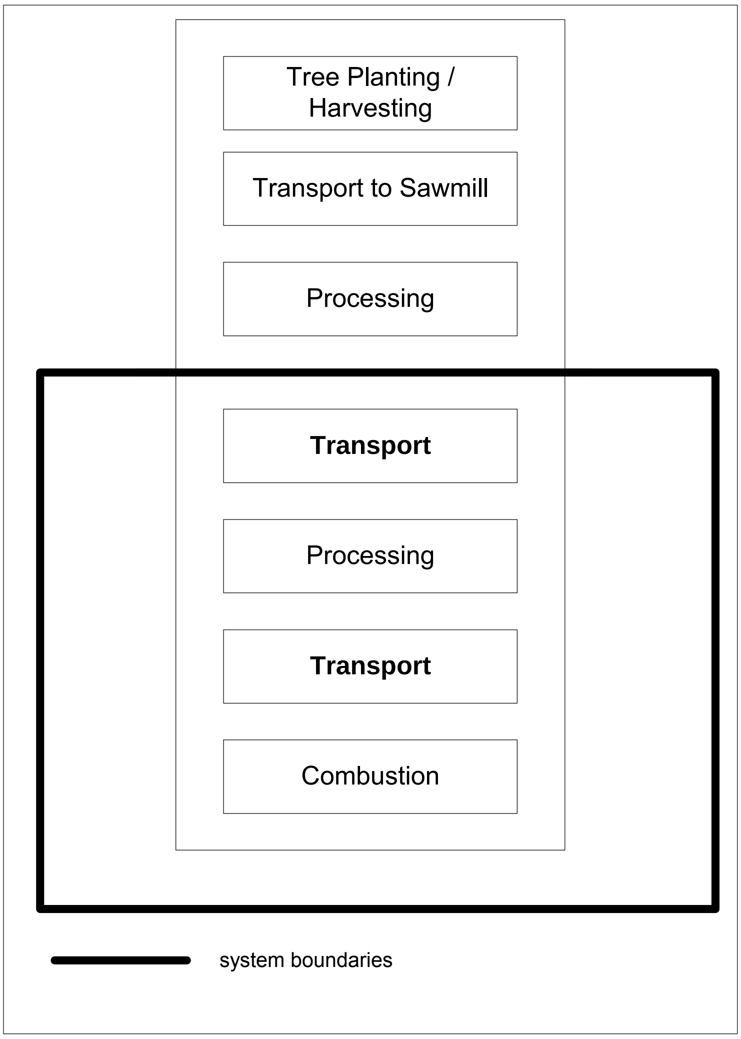

Figure 4: System boundaries for the assessment of emissions associated with sawdust

Where a biomass material is grown/ produced specifically for the purpose of co-firing, as in the case of energy crops such as *Miscanthus*, all associated emissions must be assessed. Transportation emissions will therefore form a relatively smaller portion of overall emissions.

Transportation related emissions are also more significant for biomass materials that are imported. Some materials, such as palm residues from Malaysia and Indonesia, are transported over large distances. The relative impact of transportation on their associated emissions will be greater when compared to biomass material sourced locally to the power plant.

4.1.1 Methodology

The GHG emissions associated with the transportation of the major forms of biomass materials were calculated on a 'kilograms of CO_2 emitted per tonne of biomass' transported basis.

It is possible to source most of the biomass materials listed from a variety of different countries. As no information is currently available on the geographic origin of the fuels used for co-firing, an estimate of the most likely origin of each of the materials has been carried out. Using this geographic origin the likely route, the distance and the mode(s) of transport by which they are likely to be transported has been derived as listed in Table 6.

Table 6: the likely geographic origin, mode and distance of transportation for the major biomass materials suitable for co-firing

Co-firing product	Likely Country of Origin	Mode of Transport	Total Distance Transported (km)
Palm residues (palm kernel expeller, shell, pellets)	Malaysia	road haulage and ship	14,837
	Indonesia	road haulage and ship	14,719
Wood products (pellets, sawdust, raw, tall oil)	Scandinavia	road haulage and ship	1,303
	Latvia	road haulage and ship	2,241
	UK	road haulage	200
	Canada	road haulage and ship	6,525
Olive residues (cake, expeller, pellets)	Spain	road haulage and ship	2,528
Cereal pellets	UK	road haulage	200
Energy crops	UK	road haulage	200
Sewage sludge	UK	road haulage	200
Shea residues (meal, pellets)	Ghana	Ship	7,410
Sunflower pellets	Romania	road haulage and ship	6,268
Tallow	UK	road haulage	200
WDF	UK	road haulage	200

For imported materials, it has been assumed that materials are transported by ship and that in addition, the biomass is hauled a further 100 km by road from the processing facility to the nearest port in the country of origin, and an additional 50 km by road from a UK port to the power station.

For biomass materials sourced from within the UK, it is assumed that a local source will be utilised with a standard transportation distance of 40 km roundtrip (Elsayed et al, 2003).

4.1.2 Transport-related GHG Emissions

Table 7 shows the emissions associated with transporting the major biomass materials for co-firing in UK power stations from both local and overseas sources.

Table 7: Transport emissions associated with each type of biomass (kg CO_2 / t biomass)

Co-firing product	Likely Country of Origin	Arising from road transport	Arising from transport by ship	Total transport-related emissions
Palm residues (palm kernel expeller, shell, pellets)	Malaysia	6.3	101.1	**107.4**
	Indonesia	6.3	100.2	**106.5**
Wood products (pellets, sawdust, raw, tall oil)	Scandinavia	5.3	6.3	**11.6**
	Latvia	6.3	12.9	**19.2**
	UK	1.7	-	**1.7**
	Canada	6.3	42.9	**49.2**
Olive residues (cake, expeller, pellets)	Spain	6.3	14.9	**21.2**
Cereal pellets	UK	1.7	-	**1.7**
Energy crops	UK	1.7	-	**1.7**
Sewage sludge	UK	1.7	-	**1.7**
Shea residues (meal, pellets)	Ghana	6.3	21.0	**55.4**
Sunflower pellets	Romania	6.3	41.1	**47.1**
Tallow	UK	1.7	-	**1.7**
WDF	UK	1.7	-	**1.7**

Note: standard DEFRA conversion factors were applied.[12]

Transportation by ship has very low associated GHG emissions per unit distance when compared to transportation by road haulage. However, for biomass materials that are transported over the longest distances, such as palm residues from Malaysia, emissions from shipping dominate – 101 kg CO_2, with only 6.3 kg CO_2 coming from road haulage.

Where the road haulage component of the journey starts to take up a greater fraction of the total transport distance, emissions from road haulage may become significant. This is the

[12] DEFRA 2005. Environmental Reporting: guidelines for company reporting on greenhouse gas emissions. Department of the Environment, Transport and the Regions, London. www.defra.gov.uk

case for wood residues that are transported by ship and road from Scandinavia, where 6.3 kg CO_2 per tonne is emitted by the ship, and 5.3 kg CO_2 by the truck.

The transport component of the biomass chains evaluated in this report comprise less than 5% to over 50% of the total chain emissions. However, because the life-cycle emissions of the biomass (and the carbon density) are significantly lower than the coal it is substituting, the emissions arising from the transport and delivery of the biomass represent between 0.2 to 14% of the GHG emissions abated.

Transport, is therefore considered to be a small component of the GHG emissions resulting from the co-firing of biomass even where relatively bulky biomass is transported over long distances. It should be noted that this assumption only holds true for imported biomass, where good logistics are employed and the road transport (truck) makes up relatively small share of the total journey.

5 Integrating the overall carbon (GHG) balance of co-firing

In this section the carbon costs of producing and transporting biomass are integrated with data and models on coal-biomass co-firing to provide a complete life cycle inventory of the greenhouse gas emissions resulting from the co-firing of the different types of biomass in the UK.

5.1 Reference System

For calculating the effects of co-firing biomass with coal and comparing the greenhouse gas emissions from coal-biomass co-firing with 100% coal-fired electricity generation, a representative coal-to-electricity production chain is used as the reference system (baseline). In this production chain, coal is mined in South Africa and shipped 11,000 kilometres to the UK, where it is burned in a power station with net efficiency of 37% (on net calorific value).

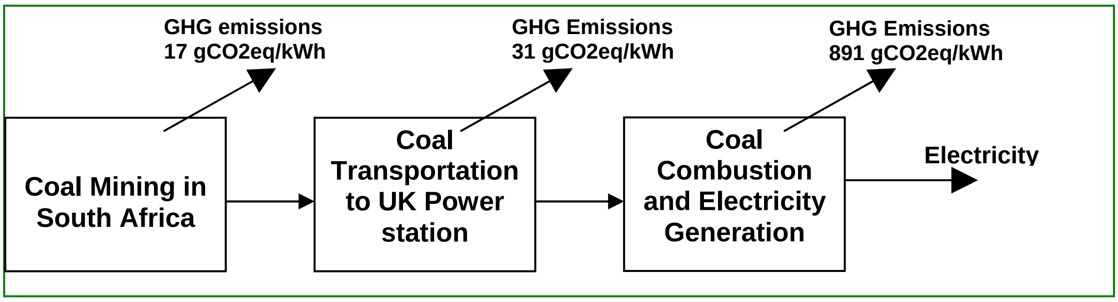

Figure 5: System boundary for the reference UK coal-to-electricity production chain

This reference production chain emits a total of 939 gCO_2eq per kilowatt-hour of electricity (gCO_2eq/kWh_e) delivered to the grid, as shown in Table 8.

Table 8: Greenhouse gas emissions from production, transport and combustion of coal for electricity in the UK (gCO_2eq/kWh)

Source of Emissions	gCO_2eq/kWh_e	Notes
Coal Mining	17	a
Coal Transport	31	b
Coal Combustion in UK Power Plant	891	c
Total Life-cycle GHG Emissions	**939**	

Notes :
a. Source: Berry et. al., 1998
b. Coal assumed transported 11,089 km from South Africa
c. Source: DUKES 2005

5.2 Functional Unit

The functional unit, the unit to which all calculated emissions are normalized in the life cycle inventory, is 1 kWh of electricity (kWh_e) delivered to the UK grid.

In addition, to illustrate the benefits gained by electricity generation with biomass at the operating conditions of large-scale coal-fired plants, the emissions resulting from generation of each unit of coal-based electricity under normal 100% coal-fired operation are compared to the emissions from generation of each unit of biomass-based electricity.

5.3 Type of Co-firing Considered

The options for implementing biomass co-combustion in pulverised coal power stations may be divided into three categories:

Direct co-firing, where the appropriately prepared biomass is fed directly into the coal furnace. There are a number of ways in which this may be done. The simplest approach involves blending the biomass with coal on the fuel pile and providing the mixed fuel as input to the coal mills before supply to the boiler's coal feeding system. This method is generally used at low biomass blend percentages.
Alternatively, the biomass fuel preparation and feeding may be handled by separate systems which then feed the prepared biomass to the coal burners or to separate, dedicated burners.

Indirect co-firing involves separate gasification of the biomass to produce a low calorific value fuel gas which is then burnt in the coal-fired boiler furnace. The gasifier is usually of the air-blown, atmospheric pressure, circulating fluidised bed type. Indirect co-firing avoids risks to burner and boiler operation associated with direct combustion, but is more expensive than direct co-firing and is currently only available for wood fuels.

Parallel co-firing, where biomass is combusted in a separate boiler and the steam produced is fed to a coal-fired power station where it is upgraded to the higher temperature and pressure conditions of the large coal plant. The overall efficiency of conversion from energy in biomass to electrical energy is thereby increased.

In an alternative form of parallel co-firing, the flue gases from combustion of biomass in a separate combustion chamber are fed into the boiler of the coal power plant. The need for a separate biomass combustion installation in such parallel co-firing leads to higher costs.

Neither indirect nor parallel co-firing is currently practised in the UK. The system modelled for life cycle assessment in this study is a direct co-firing system.

5.4 Co-firing Impacts on Efficiency

Co-firing of biomass in coal-fired power plants can result in a small decrease in power plant efficiency, although this effect is normally minimal at modest co-firing ratios and for well-dried biomass. This effect is mainly due to the normally higher moisture content and lower energy density of biomass compared with coal. No specific data was available on the efficiency reductions for UK co-firers, so published data for US co-firing tests were used to provide factors for use in emissions calculations (Tillman, 2000).

5.5 Greenhouse Gas Emissions Reductions from Co-firing

Having defined the system boundaries, specific calculations for the life-cycle GHG emissions of the selected co-firing chains are summarised below. Where uncertainty exists in the methodology or factors used, it is pointed out.

The life cycle greenhouse gas emissions resulting from the three 5% (by mass) biomass co-firing scenarios considered are compared, along with the emissions from firing 100% coal in a standardised UK power station (as discussed above) are provided in Figure 6. The data shows that even at the relatively low inclusion rate of 5%, significant reductions in GHG emissions are achieved. The greatest reduction is achieved by co-firing with residue-derived wood pellets, and which is primarily a result of the assumed avoided methane emissions that would have occurred if, instead of being co-fired, the sawdust used to produce the pellets was sent to landfill, as discussed above.

It should be noted that this analysis assumes that the support for co-firing through the RO does not drive a higher level of switching from gas to coal within the electricity market or impact on long-term decisions about the life of coal plant. In theory, it is possible that high levels of subsidy for co-firing could have an impact in this area, potentially resulting in a loss of some of the GHG reduction benefits from co-firing. We are aware that this concern has been raised in the past. Although an analysis of this issue is outside the scope of this work, it seems unlikely that such switching will be a significant factor, particularly given the low fractions of biomass being burned in coal plant and technical constraints on large scale expansion of that fraction in the older plants. A number of other factors are likely to be more significant in determining the overall levels of coal generation in the electricity market. For example, underlying electricity prices and demand trends, the relative costs of coal, gas and other forms of generation; the price of carbon under the EU ETS and other regulations, such as the Large Combustion Plant Directive, are likely to play a larger role in determining the relative profitability between coal, gas-fired and other forms of electricity generation.

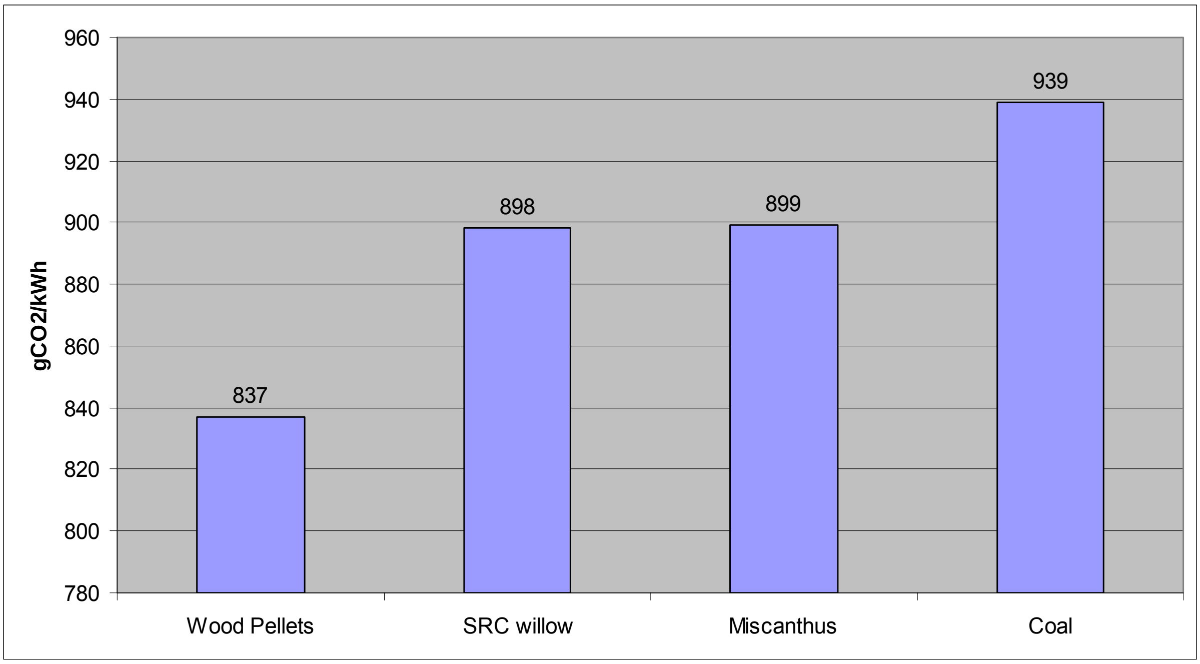

Figure 6: Comparison of greenhouse gas emissions per kWh of electricity delivered to the grid for 5% co-firing (by energy) with wood pellets, short rotation coppice or miscanthus, and 100% firing with coal

System Boundary

The system boundaries for coal-only and coal-biomass systems are outlined in Figure 7 and Figure 8.

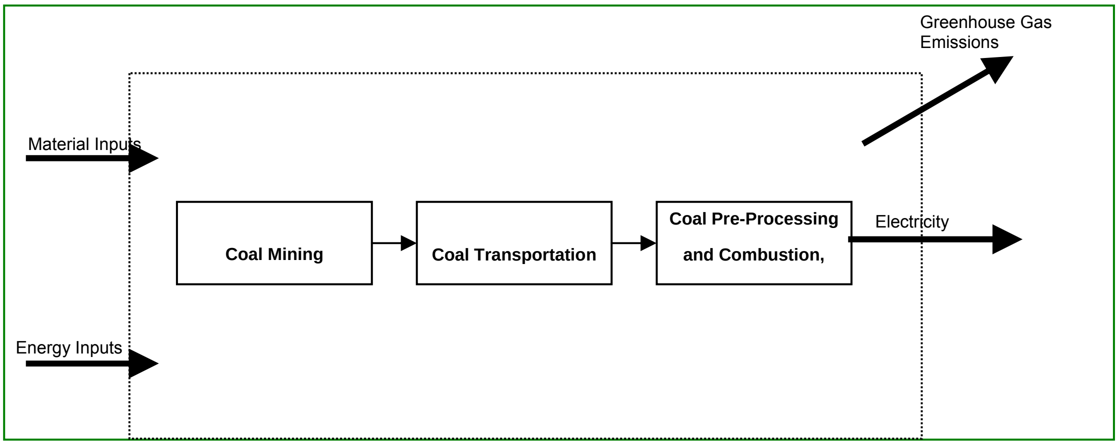

Figure 7: Electricity Production from Coal: System Boundary for Life-cycle Analysis of Greenhouse Gas Emissions

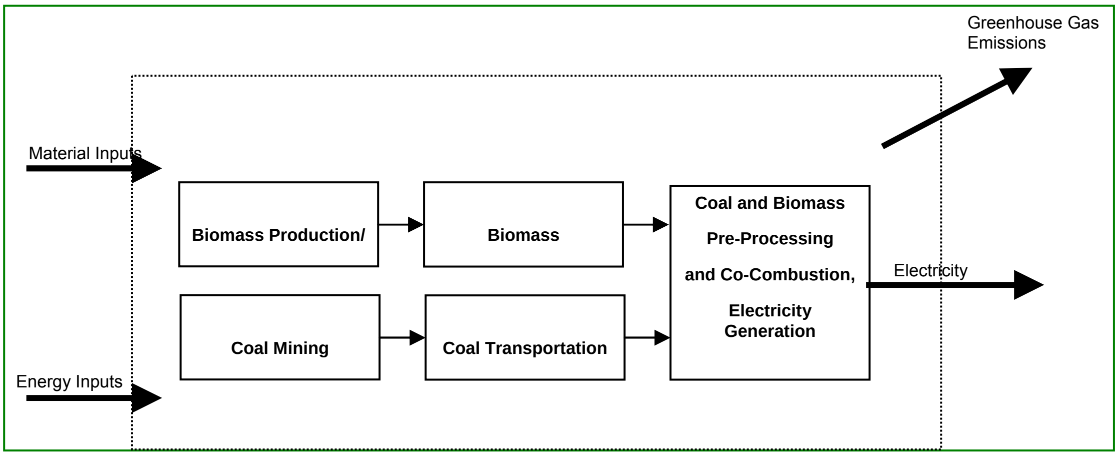

Figure 8: Electricity Production from Coal-Biomass Co-combustion : System Boundary for Life-cycle Analysis

5.5.1 Life-cycle GHG emissions from co-firing: calculations

The LCA GHG emissions arising from the co-firing of UK-produced *Miscanthus* and SRC are provided in Table 9 and Table 10, respectively. Emissions arising from the use of residue derived wood pellets sourced in Scandinavia are provided in Table 11.

GHG emissions from co-firing miscanthus

Table 9: Greenhouse gas emissions resulting from electricity production from coal co-firing with 5% (mass) Miscanthus

	Unit	Value	Notes

Description of Biomass Fuel		Miscanthus	a
Origin		UK	
NCV	MJ/kg	18	b
Co-firing ratio (energy basis)	%	5	
Power Plant Efficiency (on NCV)	%	36.8	c
GHG Emissions from Biomass Production and Combustion			
GHG Emissions from Cultivation, harvesting and storage	gCO_2eq/kg miscanthus fuel	19.2	
GHG Emissions from Transport	gCO_2eq/kg miscanthus fuel	3.4	d
Direct emissions	gCO_2eq/kg miscanthus fuel	23	e
Total Life-cycle GHG Emissions from Production and Combustion of Biomass Fuel	gCO_2eq/kg miscanthus fuel	45.6	
Total Life-cycle GHG Emissions from Biomass-based Electricity	**gCO_2eq/kWh_{bio}**	**24.8**	
Total Life-cycle GHG Emissions from Co-firing	**gCO_2eq/kWh**	**899**	

Notes:
a. *Miscanthus* at 25% moisture (wet basis)
b. Source; Elsayed, *et. al.* (2003)
c. Power plant efficiency 37% on 100% coal. No actual test data describing the effect of co-firing on plant efficiency was available, so the formula given in Tillman (2000) was used.
d. Average round trip distance 40km
e. Direct methane and nitrous oxide emissions from combustion of miscanthus assumed equivalent to those from coal on energy basis

GHG emissions from co-firing SRC

Table 10: Greenhouse gas emissions from electricity production from coal co-firing with 5% (mass) SRC chips

	Unit	Value	Notes
Type of Biomass Used		SRC chips	a
Origin		UK	
NCV	MJ/kg	20	b
Co-firing ratio (energy basis)	%	5	
Power Plant Efficiency (on NCV)	%	36.8	c
GHG Emissions from Biomass Production and Combustion			
GHG Emissions from Cultivation, Harvesting and Chipping	gCO_2eq/kg dried wood chips	26	
GHG Emissions from Transport	gCO_2eq/kg dried wood chips	4	d
Direct emissions	gCO_2eq/kg dried wood	18.5	e

	chips	
Total Life-cycle GHG Emissions from Production and Combustion of Biomass Fuel	gCO_2eq/kg dried wood chips	48.52
Total Life-cycle GHG Emissions from Biomass-based Electricity	**gCO_2eq/kWh**	**23.7**
Total Life-cycle GHG Emissions from Co-firing	**gCO_2eq/kWh**	**898**
% Reduction in GHG Emissions relative to 100% coal firing	**%**	**4.4%**

Notes:

a. SRC willow or poplar chips at 25% moisture (wet basis).
b. Source: Elsayed, et.al. (2003)
c. Power plant efficiency 37% on 100% coal. No actual test data describing the effect of co-firing on plant efficiency was available, so the formula given in Tillman (2000) was used.
d. Average round trip distance 40km
e. Direct methane and nitrous oxide emissions from combustion of SRC assumed equivalent to those from coal on energy basis

GHG emissions from co-firing residue-derived wood pellets

Table 11: Greenhouse gas emissions from electricity production from coal co-firing with 5% (mass) wood pellets

	Unit	Value	Notes
Type of Biomass Used		Wood Pellets	a
Origin		Scandinavia	
NCV	MJ/kg	19	b
Co-firing ratio (energy basis)	%	5	
Power Plant Efficiency (on NCV)	%	36.8	c
GHG Emissions from Biomass Production and Combustion			
Landfill GHG Emissions Avoided	gCO_2eq/kg pellets	-4215	d
GHG Emissions from comminution, drying and pelletization	gCO_2eq/kg pellets	98	e
GHG Emissions from Transport	gCO_2eq/kg pellets	21	f
Direct emissions	gCO_2eq/kg pellets	1759	g
Total Life-cycle GHG Emissions from Production and Combustion of Biomass Fuel	gCO_2eq/kg	-2336	
Total Life-cycle GHG Emissions from Biomass-based Electricity	**gCO_2eq/kWh_{bio}**	**-1204**	
Total Life-cycle GHG Emissions from Co-firing	**gCO_2eq/kWh**	**837**	
% Reduction in GHG Emissions relative to 100% coal firing	**%**	**10.8%**	

Notes:

a. Wood pellets at 8% moisture (wet basis)
b. Source; Obernberger and Thek, 2002
c. Power plant efficiency 37% on 100% coal. No actual test data describing the effect of co-firing on plant efficiency was available, so the formula given in Tillman, 2000 was used to provide an estimate.
d. Avoided emissions at landfill of 738 g CO_2 and 18.3 g CH_4 per kg of oven dry biomass (based on Damen and Faiij, 2003)
e. Emissions data from Ryckmans, et. al. 2005, for a Swedish wood pellet plant with a production capacity of 140 000 tonnes pellets per year.
f. Average round trip distance 40km
g. Direct carbon dioxide, methane and nitrous oxide emissions from combustion of pellets assumed equivalent to those from coal on energy basis

5.6 Comparing the carbon reduction benefit of co-firing with dedicated biomass generation and biomass heat

Often, individual biomass resources may be feedstocks for multiple markets. For example, sawdust and forestry residues can be used for electricity or heat generation, electricity and heat generation (CHP), particle board manufacture, animal bedding etc.

This section of the report evaluates the alternative potential energy (dedicated electricity and heat) uses of biomass feedstocks from a GHG emission perspective. Figure 9 highlights the different GHG performances of the alternative options for the provision and use of the biomass. The best performing chain, and which results in negative emissions, i.e. a net removal of GHG from the atmosphere, is the wood pellets chain, where the wood pellets are made from residual sawdust and so avoiding disposal in landfill with its associated methane emissions. It is important to note that similar or greater benefits could occur compared to co-firing, if these wood pellets were used to produce heat or dedicated electricity. Dedicated electricity production from energy crops emits the greatest levels of GHGs. However, even these emissions represent very significant reductions in GHG when compared with coal-fired electricity generation at 920gCO_2eq/kWh$_e$.

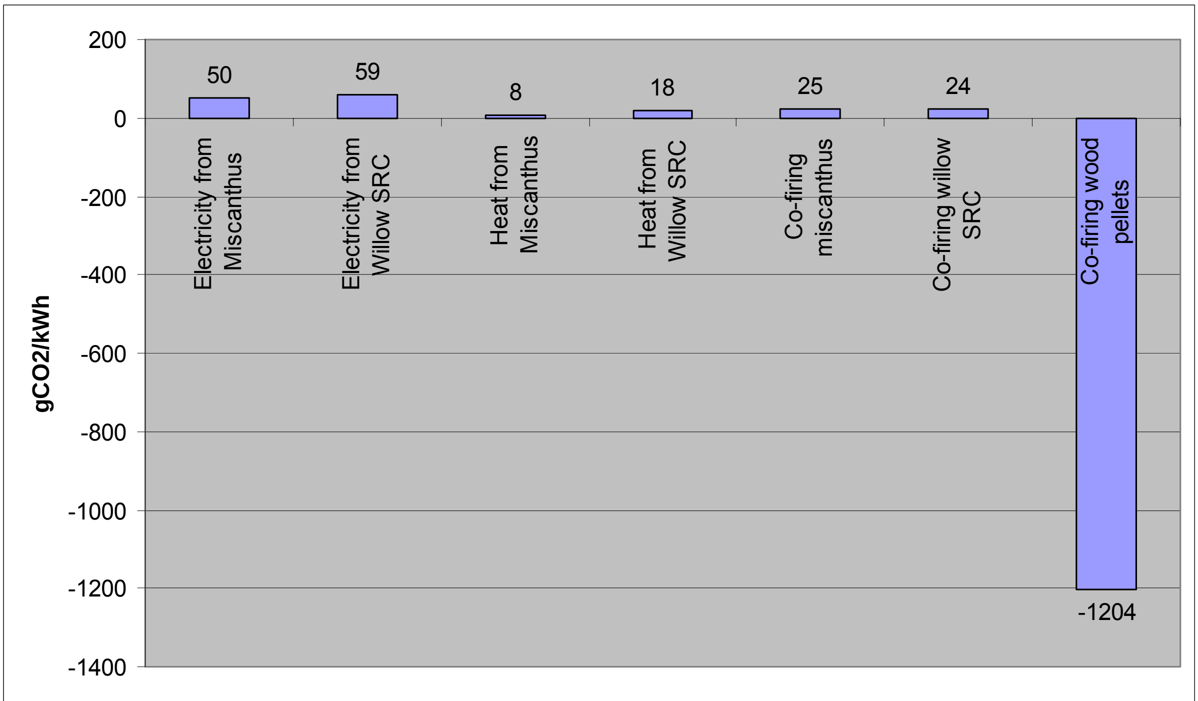

Figure 9: Comparative GHG emissions arising from using biomass for co-firing, dedicated electricity or dedicated heat supply

5.6.1 GHG balances for dedicated biomass heat plants

This analysis is taken from Elsayed *et al* (2003) and assumes that the biomass is grown an average distance of 33km (20 miles) from the heat plant.

Table 12: GHG emissions for dedicated biomass heat supply

Biomass Combustion Supply Chain	GHG Emissions ($gCO_2eq./kWh$)
Heat from Wheat Straw	88.6
Heat from Miscanthus	8.2
Heat from Willow SRC	18.0

Notes:Elsayed et al (2003) transport emissions are based on a round trip distance of 66 km, and emissions factors calculate as 0.0728 kgCO2eq/t.km.

5.6.2 GHG Balances for Dedicated Biomass Power Plants

Again, based on Elsayed et al (2003) and assumes that the biomass is grown an average distance of 33km (20 miles) from the heat plant.

Table 13: GHG emissions for dedicated biomass electricity generation

Biomass Combustion Supply Chain	GHG Emissions ($gCO_2eq./kWh$)
Electricity from Wheat Straw	237.6
Electricity from Miscanthus	49.7
Electricity from Willow SRC	58.9

Notes:Elsayed et al (2003) transport emissions are based on a round trip distance of 66 km, and emissions factors calculate as 0.0728 kgCO2eq/t.km.

6 The sustainability of land use practices for biomass production

Confidence that the biomass resource-base (residues and energy crops) is sufficiently large to meet future requirements for co-firing, and its multitude of other markets, is an important pre-requisite to establishing the level of future targets. In addition, a number of issues arise when estimating the impacts of a substantive increase in biomass use for energy. These issues include, concerns over the amount of land that would be required for producing electricity and biofuels for transport from energy crops, and the effect that the large scale cultivation of energy crops and use of residues may have on biodiversity, soils, hydrology and landscape.

This section assesses the literature base on the current and potential biomass resource base at the national and global levels, and the options for the sustainable cultivation and harvesting of biomass for co-firing. It concludes that the availability of sustainably supplied biomass is unlikely to be a constraint for the foreseeable future and that the impacts of efficiently exploiting biomass residues may have environmental benefits where it is done well.

6.1 The Biomass Resource Base

Electricity generated from biomass in coal co-fired stations is now in excess of 1.5 million MWh_e requiring over 1.4 million tonnes of biomass with a total energy content of 0.014 EJ. Figure 10 shows that renewable energy generation (electricity and heat) has risen substantially over the period 1990 – 2004, over 80% of which is from biomass.

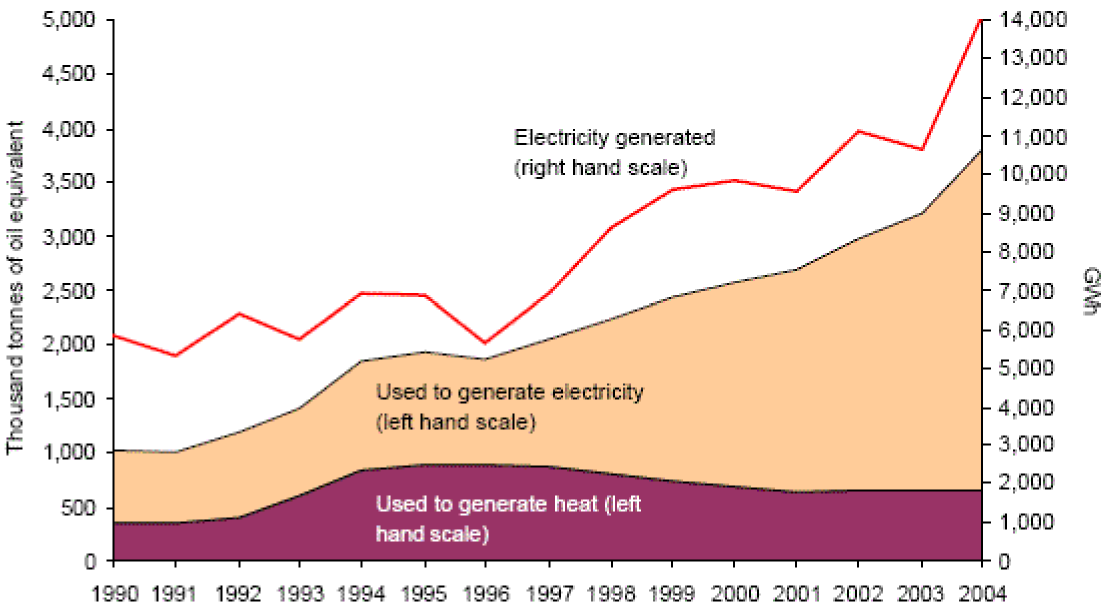

Figure 10: Trends in the Use of Renewable Energy for both Heat and Electricity (1990-2004)[13]

[13] RESTATS database at www.restats.org.uk

Whilst the co-firing of such large amounts of biomass has generated a substantial supply industry, these amounts of biomass remain relatively trivial in terms of the total quantities that could be exploited globally. A number of authoritative studies have now been carried out providing global estimates for the potential availability of biomass residues. These estimates are well summarised in a major review of the potential for biomass energy carried out by Moreira (2006).

Table 14, shows that the estimates of the potentially available residues globally range from 30 to 90 EJ for the period between 1990 and 2030. When compared to global primary energy consumption in 2005 of 440EJ, residues could theoretically provide between 10 and 20% of the world's current primary energy supply. With the addition of energy crops, even where protected land, existing agriculture, and high value landscapes are excluded, the potential could rise to over 1000 EJ per year. However, it should be noted that this scale of bioenergy provision is equivalent to a demand of about 62.5 billion air dry tonnes of biomass annually and would represent a significant fraction of the global terrestrial net primary production (NPP).

Table 14: Estimates from the literature on the Global Potential of Biomass Energy (Moriera, 2006)

Source[a]	**Types of Residue[b]**	**BIOMASS RESIDUE POTENTIALLY AVAILABLE (EJ/yr)**			
		YEAR			
		1990	**2020-2030**	**2050**	**2100**
1	FR, CR, AR		31		
2[c]	FR, CR, AR, MSW		30	38	46
3	FR, MSW		90		
4					272
5	FR, CR, AR, MSW			217 – 245	
6		88			
7[c]	FC, CR, AR, MSW		62	78	
8	FR, CR, AR		87		
A1[d]	Energy crops			660	1118
A2[d]	Energy crops			310	396
B1[d]	Energy crops			449	703
B2[d]	Energy crops			324	485

Notes:
[a] 1: Hall et al., 1993. 2: Williams, 1995. 3: Dessus et al., 1992. 4: Yamamoto et al., 1999. 5: Fischer & Schrattenholzer, 2001. 6: Fujino et al., 1999. 7: Johansson *et al.,* 1993. 8: Swisher and Wilson, 1993.
[b] FR = forest residues, CR = crop residues, AR = animal residues, MSW = municipal solid waste.
[c] These studies rather estimated the potential contribution, instead of the potential available.
Source: Johansson et al., 2004.
[d] IPCC 2000.

For comparison, the quantities of the main biomass feedstocks used in co-firing in UK power stations are given in Table 15, whilst Figure 11 shows that the quantity of residues produced worldwide are, in theory, more than sufficient to provide feedstocks to co-fire the UK's power stations. Although extremely uncertain, it is estimated that only around 4 percent of the wastes potentially available globally are utilised. However, in the future, residues for energy may have to compete in markets for alternative uses for these wastes, for example animal feed and fertiliser.

Table 15: Quantities of biofuels used for co-firing (2005)

Biofuel	Quantity (t)
CCP and pellets	102,246
Granulated willow	216
Miscanthus	547
Olive wastes	283,222
Palm waste	449,657
Sawdust	19,928
Sewage sludge	21,059
Shea meal & pellets	5,420
SRC	3,543
Sunflower pellets	20,331
Tall Oil	120,129
Tallow	119,828
WDF and Wood	102,034
Wood pellets	163,961
Total mass	1,412,122
Total energy (PJ)	14.1

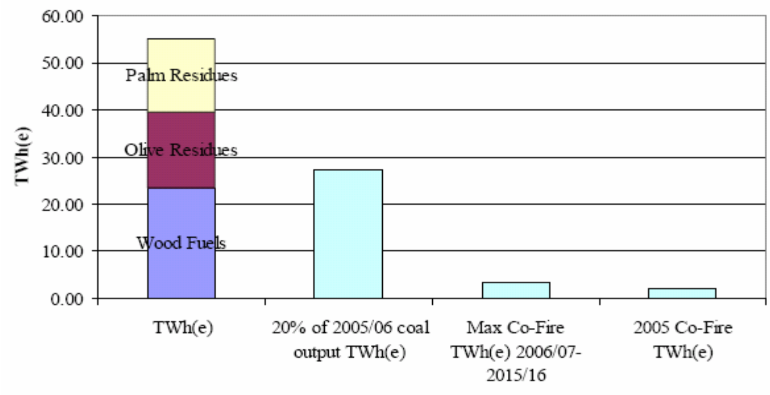

Figure 11: Current global production and use of biomass residues used for co-firing in the UK[14]

There is also increasing competition for these residues from co-firing plants in Europe and elsewhere, and accessing these residues efficiently can require complex logistics and supply chains. Together these factors could result in fluctuating availability and price but may also help to expand their markets, making them more mature and therefore reliable. At times, problems in transporting some biofuels have also been reported but, again, it is expected that as these markets mature such problems will become less commonplace, with intermediary traders becoming established based on their ability to ensure quality and reliability parameters.

6.1.1 Co-firing oil palm feedstocks – a case study of Malaysia

This section aims to put in perspective the implications of the developing co-firing markets in the UK for a country such as Malaysia with its very extensive, and sometimes controversial, oil palm industry.

Over 30% (by mass) of the co-firing feedstocks for UK coal-fired power stations were derived from oil palm resources in 2005, including some direct firing of palm oil. Although the data

[14] Draft Report DTI May 2006

does not currently allow the origin of these co-firing fuels to be known it is likely that much of the palm-derived fuels arise in Malaysia and Indonesia. Malaysia currently has slightly less than 3.5 Mha of land under oil palm plantations which produce over 12 million tonnes of palm oil per year, with a gross energy content of over 485 PJ. This is the equivalent of nearly 6% of the UK's primary energy consumption in 2004.

In addition to the palm oil, very substantial masses of biomass residues are produced, some of which arise in-field and some at the mill where the oil is extracted. At the mill, the harvested fresh fruit bunches are processed to produce the oil and a range of by-products including the palm kernel expeller residue (PKE; a mixture of shell fragments and fibre), empty fresh fruit bunches and a liquid pulp residue resulting from the initial oil extraction from the mesocarp. The mass balance of these biomass streams is provided in Figure 12 which shows the relative abundance of each stream arising from each tonne of oil produced.

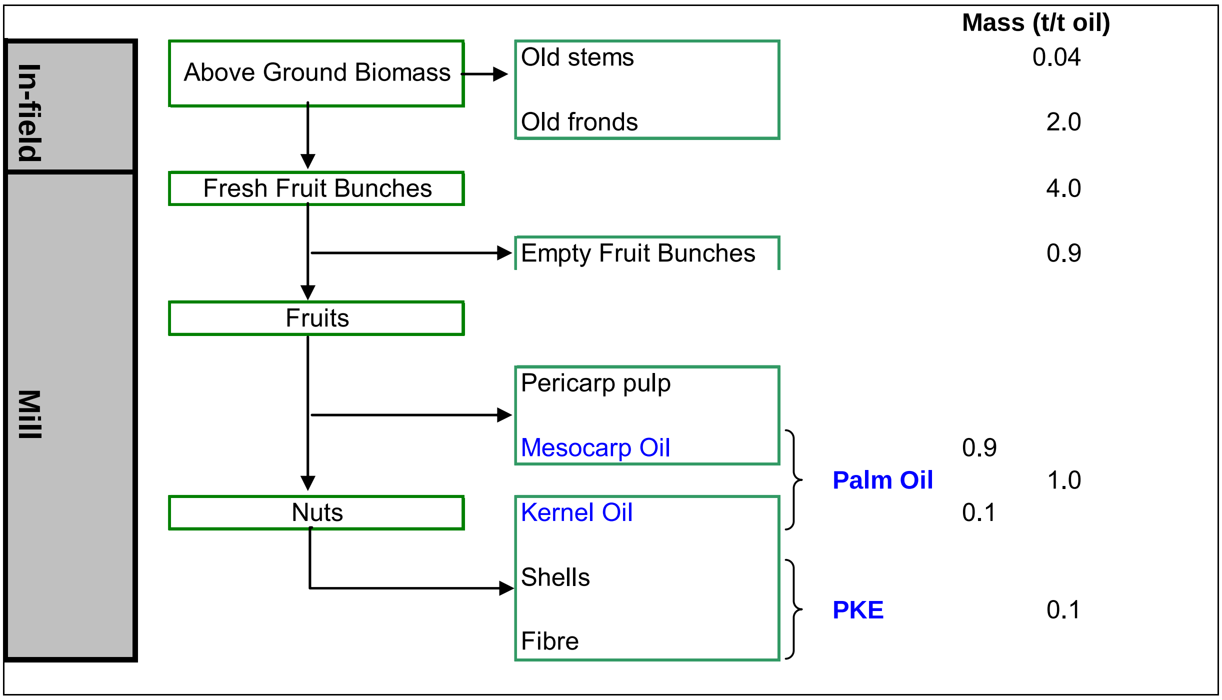

Figure 12: Biomass streams arising from palm oil production

Caution should be used when assessing the energy potential of exploiting these biomass streams as reported on a mass basis because of the large differences in composition and moisture content. When corrected for these distortions and extrapolated to the national level some notable points arise as discussed below.

Energy outputs from oil palm production

The total energy content of the products, by-products and residues arising annually from Malaysian oil palm production is approximately 1.0 EJ, 70 times larger than the energy content of the feedstocks currently used for co-firing in the UK. The oil alone accounts for 50% of this total and the fronds, which arise in-field, for another 38%. PKE, which provided about 16% of co-firing feedstocks in 2005, only accounts for 2% of the gross energy potential of the existing palm industry in Malaysia.

Severe constraints, practical and environmental, may apply when exploiting the in-field residues such as the fronds, currently used as a mulch. However, broadly, research into other crop types e.g. sugarcane, has shown that about 50% of in-field residual biomass may be removed with no negative, and sometimes positive, impacts on soil fertility and biodiversity.

Environmental and economic constraints to greater oil palm exploitation

The high energy density (40 MJ/kg) and favourable chemical composition of palm oil make it an ideal fuel for co-firing; it can also be directly injected into gas turbines as was reported to have occurred in the Netherlands last year. However, palm oil has a range of competing markets, primarily food, which currently allow it to command a market price of c. £5.10 per GJ, which is generally too high for co-firing.

The energy density (14 to 17 MJ/kg depending on moisture content) and composition of PKE also lends it to co-firing, and pelletisation can improve the energy density and ease of handling. PKE also has alternative markets to co-firing, including as an animal feed and an energy feedstock in mills where it arises. Despite these limitations, sufficient PKE is produced in Malaysia to more than double the current levels of co-firing in the UK. Were this to occur, then PKE sales would represent between 3% and 4% of the factory gate revenue if valued between £3.50 and £5.50 per GJ by UK power stations. Co-firing markets for PKE-alone are therefore considered unlikely to drive an expansion of oil palm production.

The energy content of in-field residues, such as fronds and old stems, represents a very substantial additional potential energy resource. However, such residues typically have a low energy density (between 8 and 15 MJ/kg) and are difficult to harvest, transport and process economically. In addition, a significant fraction of these residues must be retained on-site as a soil conditioner and to provide physical protection from rainfall in order to prevent soil erosion. Despite these limitations, were it possible to access about 10% (mass basis) of the in-field residues, an energy feedstock with a similar potential to PKE would be available and would represent between 4 and 7% of factory gate revenue.

The oil palm industry in Indonesia is of a similar size to the Malaysian industry and so roughly doubles the palm-derived potential for co-firing feedstocks.

In summary, assuming the value of ROCs maintains co-firing feedstock prices below GBP 5.00 per GJ, co-firing is unlikely to represent more than 10% of factory-gate revenue to oil palm mills and is therefore considered unlikely to be a driver for expansion of palm plantations onto new land. Should ROC values increase such that co-firing would be economic at feedstock prices for palm oil of much above £5 per GJ[15], then co-firing could provide an economic alternative to food markets for palm oil and without capping (in the UK and elsewhere), could provide a new driver for expansion. Such expansion, deemed to be at least partially a result of the added value arising from co-firing markets, could then provide the justification of re-classifying these palm-derived feedstocks from residues to energy crops and applying the appropriate energy crop boundaries for reporting or certification.

6.1.2 Availability of domestic biomass

A number of UK-based studies have been carried out estimating the availability of indigenous biomass resources for energy. Non-woody biomass includes agricultural, industrial and municipal wastes. Table 16 shows that there are substantial volumes of wastes produced, which could substitute for around 5Mt of coal per year (Brown 1998). However, much of this waste is locally produced and is often only available at relatively low densities, and is therefore likely to be more suitable for generating heat or for powering small CHP facilities.

[15] A ROC value of £47.50 per MWh_e is approximately that required to support co-firing of feedstocks at prices of £5.00 per GJ assuming a conversion efficiency of 38% for biomass.

Table 16: Estimated non-forest biomass available in the UK (000 odt)[16]

Biomass material	Estimated current arisings	Potential available for co-firing
Abattoir wastes	600	10 - 20
Surplus cereal straw	14000	4000 - 6000
Poultry litter	1700 - 2000	1000 - 6000
Other agricultural wastes	3500 - 5000	25 - 40
Paper and paper mill wastes	5000 - 6500	1500 - 2000
Demolition/construction wood	2500	500 - 1000
Discarded pallets	1300	80 - 100
SRC willow	30 - 45	30 – 45
Total *(million tonnes)*	**28 - 32**	**7 - 15**

Figure 13 shows that the potential electricity that could be generated from available domestic residues could more than double the peak co-firing power generation if the entire resource is used exclusively for co-firing.

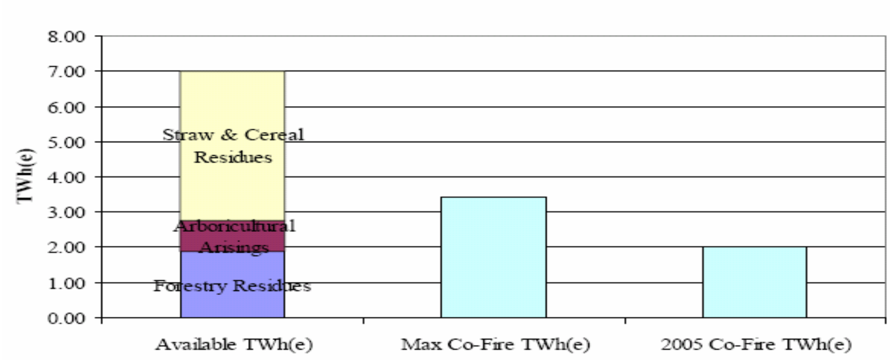

Figure 13: Current availability and use of domestic UK biomass fuels[17]

Woody biomass

Table 17 gives Forestry Commission estimates of woody biomass currently available in the presence and absence of competing markets. The current total domestic woody biomass available is 3.2 million odt per year, which could produce over 6 TWh of electricity (assuming co-firing), almost double the peak amount of electricity historically generated through co-firing. When the woody biomass currently used in other industries is deducted, the quantity that could be available for generating energy is 1.26 M odt. This is still sufficient to produce about 2 TWh_e per year.

In addition, there is a considerable quantity of used wood produced from urban and industrial sources. A report by the Biomass Task Force (2005) suggests that about 3 Mt/year could be available, which could generate up to 8.5 TWh of heat, saving 0.85 Mt of carbon (DTI 2004 and Biomass Task Force 2005). However, used wood is often contaminated. The recent changes in the regulations (DTI January 2006) reducing the required purity of biomass to

[16] DTI report 2004.

[17] DTI May 2006

qualify for ROCs from 98 to 90 percent may make it easier to employ used wood for co-firing.

Table 17: Availability of woody biomass with and without competing markets (000 odt) [18]**.**

Wood Product	Availability, no other market	Percentage contribution	Availability, competing market	Percentage contribution	Percentage availability with competing markets
Stemwood (7-14 cm)	1032	*33.1*	104	*8.24*	10%
Poor quality stemwood	277	*8.88*	277	*21.95*	100%
Stem tips	31	*0.99*	31	*2.46*	100%
Branches	409	*13.12*	409	*32.41*	100%
Sawmill product	860	*27.58*	86	*6.81*	10%
Aboricultural arisings	492	*15.78*	341	*27.02*	70%
SRC	17	*0.55*	14	*1.11*	80%
Total	**3,188**		**1,262**		

Current and future production of woody biomass

The Forestry Commission figures given in Table 18 suggest that the total supply of forestry wood will increase over the next 15 years as trees planted in the 60s and 70s become productive. However, the quantity of forest residues is predicted to decrease, although domestic sawmill products will increase if use is made of the extra production of domestic wood.

Table 18: UK Wood production (odt) 2003 - 2021[19]

Time Frame	Total Wood Biomass	Wood Residues*
2003 – 2006	6,308,350	2,064,377
2007 – 2011	6,490,152	1,927,646
2012 – 2016	7,055,031	1,963,592
2017 – 2021	7,343,917	1,900,241

* wood residues composed of stemwood with a diameter 7–14 cm, poor quality wood and brash.

Energy crops

A broad range of plant species could be used to provide feedstocks for co-firing. Options include: willow and poplar, cultivated under short rotation coppice; aspen, poplar, ash and even Eucalyptus produced under short rotation forestry; perennial crops such as *Miscanthus* and reed canary grass; and even annual cereals such as barley and oats and indirectly

[18] Table modified from DTI 2003

[19] Forestry Commission 2005, and Forestry Commission website database.

wheat if the co-products of wheat-to-ethanol chains are used for co-firing e.g. DDGS. Some of these options are summarised below.

Short rotation coppice. SRC trials using willow have produced yields of 8 – 17 odt/ha.yr, although the theoretical yield is 33 odt/ha.yr. There is now some commercial production of willow. The Forestry Commission estimates current production from SRC at 16,689 odt[20] although increasing production significantly is likely to require markets which generate long term contracts for supply of around 10 years. Under the current regulatory systems, co-firing does not currently provide such a long term opportunity for a substantial increase in dedicated energy cropping. With current yields, willow and *Miscanthus* would only be economically viable on set aside land, returning a gross margin of £434 and £401 per hectare respectively. However, with a 30 percent increase in yields, willow would give a gross return of £500 per hectare, making it competitive with barley (which has a gross return of £473/ha) (LEK Consulting 2004).

Short rotation forestry. SRF crops are grown on 8-20 yr cycle, and typically felled when they reach a diameter at breast height of between 10 and 20 cm. A recent study (Hardcastle 2006) estimates that wood produced under SRF could replace up to 5% of coal in existing power stations.

Energy grasses. Yields for *Miscanthus* in the UK have been between 11 and 16 odt/ha.yr, although the theoretical maximum is 55 odt/ha.yr (DTI 2006).

The establishment of energy crops have been slow for a number of reasons:

- A low demand for biofuels from energy plantations because power plants for electricity and or heat have not come on-line as quickly as once anticipated.
- Co-firing facilities require a reliable supply of a large amount of feedstock before investing in plant, whereas growers require firm and a long-term contract in order to invest in an energy plantation.
- Energy plantations are a long-term investment with fairly low economic returns. Initial costs are high, and grants only cover 40 percent of establishment costs for *Miscanthus*, or 50 percent of costs for SRC. Farmers have less risky options available to them (Britt *et. al.* 2002).
- Energy cropping is still fairly new in the UK, and yields from trial plantings have not been very good. Expected increases in yield of 30 percent for willow coppice would make SRC a more viable option.
- There is low confidence in commercial viability of energy plantations.

Annual crops - wheat. About 6 million ha, or nearly a quarter of the UK's land is dedicated to annual arable production of which wheat occupies just under 2 million ha. UK-wheat production is highly productive and globally competitive with about 3 million tonnes of grain being exported annually. The low prices of agricultural commodities, including grains, has promoted a search for alternative higher value markets, including energy. This section assesses the potential GHG emissions associated with the use of wheat grain as a co-firing feedstock in comparison to SRC-derived wood chips. It should be noted that conventional wheat grain is currently grown for higher value food markets which require high protein contents and as a result need higher nitrogen fertiliser applications than might be the case for either wheat grown as an energy crop, or for other arable crops such as oats, barley and rye.

The use of conventionally-produced wheat as a fuel for electricity production would result in higher greenhouse gas emissions than the production and use of short-rotation coppice. The emissions associated with the farming stage of a wheat-to-electricity chain constitute the major portion of these higher emissions. These emissions result primarily from the production

[20] Forestry Commission website at www.woodfuel.org.uk

and use of fertilisers and agrochemicals used in conventional wheat farming. Increased diesel fuel use in annual wheat cultivation relative to coppicing of perennial crops such as willow also contributes to the relatively higher emissions from wheat production. The differences in GHG emissions are highlighted in Table 19 and Table 20.

Table 19: Life-cycle GHG emissions from short rotation coppice co-fired electricity

Stage of SRC-to-electricity production chain[1]	GHG emissions ($g\ CO_2eq/kWh_{bio}$)[2]
Cultivation, Harvesting and Chipping	*12.7*
Transport	*2.0*
Direct emissions	*9.1*
Total SRC-to-electricity chain	**24**

Notes:
1. Electricity generation from co-combustion of SRC with coal in power plant with37% efficiency
2. kWh_{bio} refers to electricity generated from biomass fuel, not total generated in coal-biomass plant

Table 20: Life-cycle GHG emissions from wheat co-fired electricity

Stage of wheat-to-electricity production chain[1,2]	GHG emissions ($g\ CO_2eq/kWh_{bio}$)[3]
Farming	*224.8*
Grain handling and storage	*32.2*
Transportation of dried grain	*2.1*
Direct emissions	*9.1*
Total wheat-to-electricity chain	**268**

Notes:
1. Electricity generation from co-combustion of wheat with coal in power plant 37% efficiency
2. Emissions from wheat production based on Rickeard, et. al.
3. kWh_{bio} refers to electricity generated from biomass fuel, not total generated in coal-biomass plant

The emissions from wheat-based electricity production would nevertheless be considerably lower than those from coal. Each kWh of electricity generated from combustion of coal results in 939 kg CO_2eq., while the figure for wheat is 268 and for SRC, 24 (Figure 14).

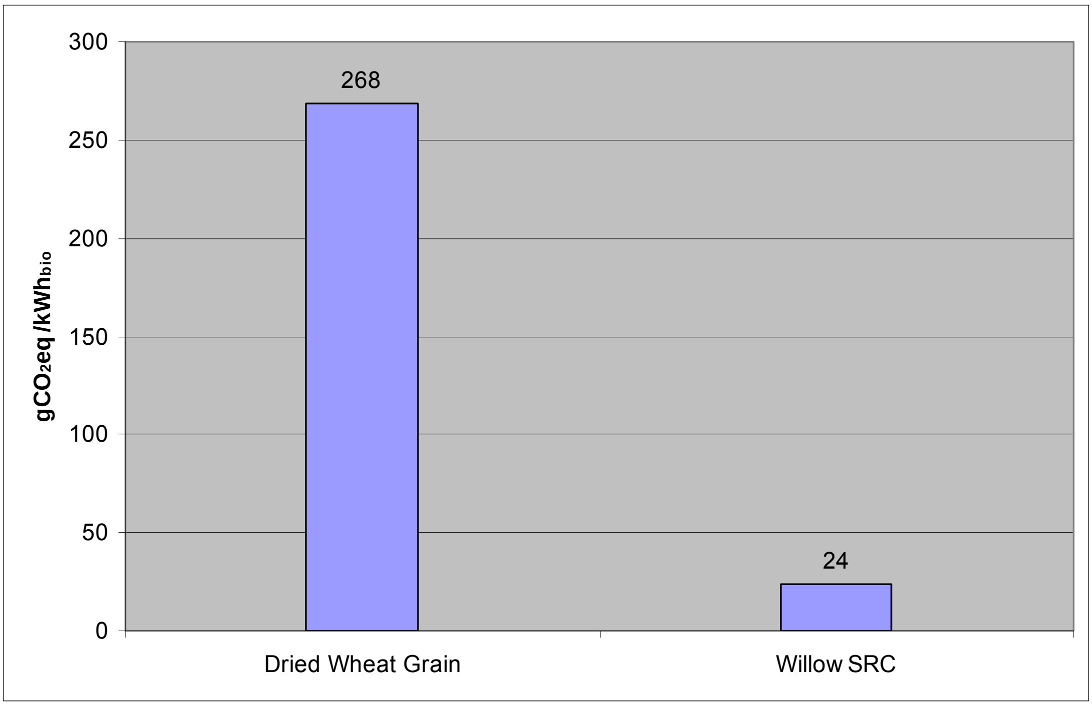

Figure 14: Comparison of life-cycle greenhouse gas emissions from wheat-to-electricity and SRC-to-electricity production chains via co-combustion with coal

6.2 Land requirements for energy crops.

Assuming a 35 percent conversion efficiency, around 60Mt of wood are required to generate 16 GWh of electricity. If an annual average yield of 10 odt/ha.yr were achieved, 7 Mha would be required out of a total of 17 Mha of agricultural land (Royal Commission on Environmental Pollution 2005).

Land that may be available for energy crops will probably be lowland marginal agricultural land or improved pasture at a height of between 150 and 200 metres above sea level (Hardcastle 2006). A considerable but currently unknown area of land is likely to become available as a result of the current reforms to the Common Agricultural Policy. However, farmers will not cultivate energy crops unless they receive an incentive that is greater than that available for not growing anything on this land.

Price will dictate the share of individual biomass fuels in the co-firing mix. However, the price of biomass depends on a number of factors, with transport costs critical in determining the economic viability of a locally produced biomass fuel. The most suitable biomass will therefore depend on its availability within a given radius around the co-generation facility.

A study carried out for the Scottish Executive (IPA Energy Consulting and the Scottish Agriculture College 2005) estimates that if energy crops are cultivated on 2 percent of the land in the catchment area of a power station they are likely to be produced in sufficient quantities and at an economic price for co-firing. Most locations in the UK could support a 20-30MW generating facility powered by SRC willow, as shown in Table 21.

Table 21: Land required for energy crops for power plants of different capacities. [21]

	Proportion of Arable Land Available (percent)				
	40	30	20	10	5
Plant Size	Radius of Required Land (km)				
2	6	6	8	11	16
5	9	10	12	18	25
10	12	14	18	25	35
20	18	20	25	35	50
30	21	25	30	43	61

Woody biomass remains an underutilised indigenous resource for co-firing, and energy plantations need support and commitment in order to become established. The development of smaller scale local plants for generating electricity and heat could make a useful contribution to both mitigating carbon and helping to secure domestic energy supplies, as well providing economic and social benefits to rural areas.

7 Non-GHG sustainability issues relating to co-firing

The very large size of the global residue resource (see Table 14), relative to the rate of use implies that except for in certain local situations, the exploitation of residues and wastes for co-firing is not likely to be excessive. It is therefore considered that the use of residues for co-firing is unlikely to cause any notable negative environmental or social impacts for the foreseeable future.

Although the over-exploitation of in-field biomass (including residues) can cause severe soil degradation and have broader negative environmental impacts which arise from decreasing soil carbon, and particularly organic matter levels, such impacts are considered outside the boundaries of the evaluation. However, the application of these tight boundaries can only be justifiable where the residues to be exploited for co-firing are not the primary cause of the agricultural or forestry activity from which they arise i.e. the crop is not being grown to provide those 'residues'. An arbitrary limit of 10% of factory gate revenue has been adopted as a threshold value for the residues (or by-products) above which they can no-longer be classified as residues or 'by-products'. Above this level of economic return, the boundaries are then expanded to include primary production factors (e.g. in-field impacts). In effect, what were previously 'residues' or 'by-products' become re-defined as 'energy crops' and the full LCA methodology must be applied.

It is therefore considered that it will be necessary to monitor the origin, amount and type of residue being used for co-firing, which in-turn provides a justification for reporting / declaration by the co-firers of the type and origin of the fuels being used. Should these reports provide an indication that the exploitation of a specific residue type was likely to be exceeding the 10% threshold a switch in impact calculation methodology would be required using the broader energy crop boundaries as discussed for oil palm (section 6.1.1). In turn this would imply a possible closer alignment to the RTFO which may itself require assurance and certification in the future.

[21] Source: LEK Consulting, 2004.

As a result of the differing boundaries for 'residues' or 'energy crops' feedstocks, this section is restricted to summarising the likely impacts of energy cropping. The impacts of energy plantations are primarily related to biodiversity, hydrology and soils and landscape. Each of these factors is interrelated to a greater or lesser degree. This section is based on information relating to short rotation forestry in Hardcastle (2006), but which is also pertinent to SRC.

7.1 Biodiversity

The impact of an energy plantation on biodiversity will depend on the system the energy crops are replacing. Biodiversity is likely to increase if it is replacing grassland or annual agricultural crops, and decrease if planted on land with high species diversity, such as unmanaged wetlands. However, the biodiversity of animals and plants is generally higher in areas where there are diverse habitats. The careful siting of an energy plantation is therefore crucial. It is important to leave a buffer zone between the plantation and established woodland or hedgerows to preserve the important edge habitat important for a diversity of species. Catenas of different, species, varieties and age cohorts is also beneficial to biodiversity by proving a broad range of niches. Energy plantations can also provide corridors between isolated habitats. Overall, careful planning and judicious siting of an energy plantation within the landscape can enhance biodiversity.

7.2 Hydrology

Water availability. Due to their large leaf area, willow and poplar intercept more rainfall than agricultural crops, reducing the amount of water reaching the soil and the aquifer. In addition, these species have high transpiration rates and deep root systems. As a result, willow and poplar SRC has higher water usage than any annual agricultural crop, and can tap into underground water in times of low rainfall. Careful siting of SRC plantations is therefore needed in areas of low rainfall, or in areas where there is a high human consumption of water such as the south east of England. SRC will utilise all the available water where precipitation is around 600mm or less. However, the effects of SRC on hydrology can only be assessed through location-specific analysis that includes the species grown, soils, topography, and rainfall and management practices. For example, even in low rainfall areas SRC may be useful in reducing excess runoff and can help mitigate local flooding.

Water quality. On good land, SRC is likely to increase water quality compared with land used for agriculture because of its lower agro-chemical requirements. There is some evidence that in particular locations, nitrate leaching could be a problem from applications of fertilisers and sewage sludge. However, it has also been suggested that mixtures of trees and grasses used as energy crops could be cultivated along waterways to act as a buffer preventing nutrient runoff from agricultural land (Hall 2003).

Soil maintenance. Energy plantations remain in place for many years, establish good root systems and develop leaf litter layers, all of which will help to conserve or promote soil fertility and help to prevent soil erosion.

7.3 Landscape

The way that issues relating to landscape are handled may also impact on public acceptance of energy crops. Hardcastle (2006) summarised important considerations, which are given in Table 22.

Table 22: Key Elements of Landscape Guidance that could apply to Energy Plantations

Landscape Types	Management and Mitigation
Flat landscape with level views and existing landscape framework	• Retain existing trees and hedgerows • Keep plantation size in scale with existing landscape framework • Aim for varied age structure for visual diversity • Maintain proportion of open space to plantation
Flat landscape with level views and no strong landscape framework.	• Larger scale plantations possible • Aim for varied age structure to give diversity of colour and texture • Irregular rather than geometrical shapes • Retain and build around existing woodlands
Undulating landscape with existing field pattern	• Planting should respect existing field patterns where appropriate • Planting should reflect landform
Undulating landscape of more open character	• Greater flexibility possible in design of new planting • Planting related to landform where appropriate • Make plantation of different sizes to achieve variety of scale and texture.
Landscape of longer slopes with more elevated viewpoints	• Avoid very strong geometrical shapes and straight edges • Aim for interlocking plantation/field pattern • Use landform, where present, to achieve variation, e.g. of plantation shape.

7.4 Soil carbon sequestration by energy crops

In the UK, soils and litter are the largest carbon pools, holding some 10,000Tg of carbon. The turnover of carbon in the soil pools is generally slow, so that even small increments in carbon can have long-term implications for carbon sequestration. One initial preliminary modelling exercise suggests that SRC systems may sequester as much or more carbon in the soil as naturally regenerating woodland, and are greater than for regenerated woodland. However, the initial carbon content of the soil dictates the sequestration, to the extent that an SRC system planted on soils with a high soil carbon content could possibly lead to a net loss in soil carbon. Using the minimal data available, the indications are that SRC plantations can produce annual soil carbon sequestration rates of between 0 to 1.6 Mg of Carbon per hectare (Grogan and Matthews 2001).

Fertilising energy crop plantations with organic agricultural or municipal wastes could also make a “modest contribution” of carbon sequestered to the soil (Britt *et al* 2002). Furthermore, systems could be developed which link bioenergy to carbon capture and sequestration. One example of this is where a portion of the above ground biomass is deliberately returned to the soil as charcoal which has beneficial effects on soil moisture and nutrient holding capacity and is long-lived (half life of c. 1 000 years). Such bioenergy with carbon sequestration (BECS) systems are evaluated in more detail in a special edition of the international journal on Mitigation and Adaptation Strategies (e.g. Lehmann, 2006; and Ogawa, 2006).

7.5 Certification and Standards

Full-blown assurance and certification may become necessary if UK co-firing leads to the significant changes in land use due to rapidly expanding domestic energy crop production and/or where traditional food crops play a greater role in co-firing. It may also be valuable where in-field residues start to become exploited at a greater level than currently seen, or where public concern over increasing imports and the resulting perception that harm to habitats outside of the UK arises from their use in co-firing (ADAS, 2006).

Under such circumstances existing assurance schemes and their associated accreditation and certification systems might be amenable to biomass supplied for co-firing as evaluated below and for the impending Renewable Transport Fuels Obligation (Tipper et al, 2006).

7.5.1 Existing standards of relevance to co-firing feedstocks

In the UK, certification under the *UK Forestry Standard* is mandatory for all Forestry Commission approved planting/felling, and there is potential to extend this to energy crops. The more rigorous voluntary *UK Woodland Assurance Standard* is recognised by the Forest Stewardship Council (FSC), and would allow UK forest biomass to be FSC certified.

The International Energy Agency and the British Standards Institute (IEA, 2001) has developed specifications and standards for solid biofuels (CEN TC335) and for solid recovered fuels (CEN TC343). The BRE and the British Pellet Club are seeking to develop a Wood Pellet Accreditation Scheme based on the CEN technical specifications (ADAS, 2006). In addition, life-cycle assessment (LCA) provides a means of certification by quantifying the total environmental impact for each feedstock from production to final disposal.

Agricultural standards and certification schemes are used worldwide. However, with the exception of the Roundtable on Sustainable Palm Oil (RSPO, 2005), there are no schemes specific to biomass production for biofuels e.g. biodiesel or bioethanol. An example is the lack of standards in soybean plantations which, along with palm oil, play an important role in the economic development of many countries and are already, or likely to become, significant feedstocks for bioethanol and biodiesel production (WWF, 2006).

In the UK, the Assured Combinable Crops Scheme (ACCS, 2005) covers the production of cereal crops. Its focus is mainly on crop management and the handling of crops for human use, and takes account of a number of different national regulations. Table 23 shows the different biofuels used in co-firing, highlighting the possibilities of applying the Standards and criteria used in the ACCS Certification system for biofuels used in co-firing.

Forest Certification Schemes such as the Rainforest Alliance / Smartwood scheme, which has generic standards for assessing forest management and general standards for any type of crop management, or the Rainforest Alliance certification body accredited by the Forest Stewardship Council, may also be applicable to biofuels.

The Basel Criteria (ProForest, 2004) for responsible soy production provides a set of criteria, but has no system for certification. The RSPO system (RSPO, 2006) mentioned above is the only system that has direct relevance to the production of biomass for biofuels. It presents eight non-quantitative principles with respective indicators. Table 24 and Table 25 show the RSPO and Basel criteria respectively, as applied to the biofuels used for co-firing.

The Royal Commission on Environmental Pollution (2004), recommends that the grant system for farmers producing biomass for co-firing and biomass stand-alone plants, should be dependent on farmers meeting set environmental standards in landscape, biodiversity and water assessment when planning and planting energy crops. In return, the grant payments should reflect fully the biodiversity value of these crops.

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Hardcastle (2006) suggests that current guidelines for forestry and agricultural practices could be used as the basis of a code of practice for SRF. The aim would be to develop an integrated code of practice that would incorporate measures to minimise negative impacts on biodiversity, soil conservation, hydrology and landscape. Specifications for biofuels, such as form, moisture content and homogeneity, could be developed according to the preferences of the power generator and the restrictions of the producer. Currently, therefore, there may be no need for developing complex codes of practice for biofuels for co-firing.

As discussed above, because of the major differential between energy cropping and residues in terms of the GHG and environmental impacts and the boundaries that need to be applied to evaluating those impacts, it may be beneficial for the Government to apply a simple reporting / declaration requirement on co-firers. Such a declaration could include information about the origin of the biomass to be co-fired, its physical composition (moisture, energy content and density) and if it is defined as a 'residue' or an 'energy crop'.

Table 23: UK Assured Combinable Crops Scheme (ACCS) – assessment of the application of ACC criteria to co-firing feedstocks

BIOFUELS/ ACC CRITERIA	LITERATURE REQUIREMENTS	CROP PROTECT-ION	GRANULAR/ DUST APPLICATION OF PESTICIDES	SEED / SEED TREATMENT	FERTILISER AND CROP NUTRITION	CROP STORAGE AND HANDLING	HYGIENE	HAULAGE	CONTRACT-ORS	GENETICALLY MODIFIED CROPS / MATERIALS	COMPLAINTS	FUEL STORAGE
Total												
CCP	√	√	√	√	√	√	√	√	√	√	√	√
Cereal pellets	√	√	√	√	√	√	√	√	√	√	√	√
Granulated willow	√	√	√	√	√	√	√	√	√	√	√	√
Miscanthus	√	√	√	√	√	√	√	√	√	√	√	√
Olive cake	√	?	?	?	?	√	√	√	√	√	√	√
Olive expeller	√	?	?	?	?	√	√	√	√	√	√	√
Olive pellets	√	?	?	?	?	√	√	√	√	√	√	√
Olive residue	√	?	?	?	?	√	√	√	√	√	√	√
Palm kernel	√	?	?	?	?	√	√	√	√	√	√	√
Palm oil	√	Ð	Ð	Ð	Ð	√	√	√	√	√	√	√
Palm shell	√	Ð	Ð	Ð	Ð	√	√	√	√	√	√	√
PKE	√	Ð	Ð	Ð	Ð	√	√	√	√	Ð	√	√
PKE pellets	√	Ð	Ð	Ð	Ð	√	√	√	√	Ð	√	√
Sawdust	√	Ð	Ð	Ð	Ð	√	√	√	√	Ð	√	√
Sewage sludge	√	Ð	Ð	Ð	Ð	√	√	√	√	Ð	√	√
Shea meal	√	Ð	Ð	Ð	Ð	√	√	√	√	Ð	√	√
Shea pellets	√	Ð	Ð	Ð	Ð	√	√	√	√	Ð	√	√
SRC	√	Ð	Ð	Ð	Ð	√	√	√	√	Ð	√	√
Sunflower pellets	√	√	√	√	√	√	√	√	√	√	√	√
Tall Oil	√	Ð	Ð	Ð	Ð	√	√	√	√	Ð	√	√

Tallow	√	Ð	Ð	Ð	Ð	√	√	√	√	Ð	√	√
WDF	√	Ð	Ð	Ð	Ð	√	√	√	√	Ð	√	√
Wood	√	√	√	√	√	√	√	√	√	√	√	√
Wood pellets	√	Ð	Ð	Ð	Ð	√	√	√	√	√	√	√

Notes:

√ Possibility of applying the ACC Standard

? Questionable but plausible

Ð Difficult to consider the application of the Standard

Table 24: RSPO criteria applied to biofuels for co-firing.

Biofuels/ RSPO Principles	Principle 1 Commitment to transparency	Principle 2 Compliance with applicable laws and regulations	Principle 3 Commitment to long-term economic and financial viability	**Principle 4 Use of appropriate best practices by growers and millers**	Principle 5 Environmental responsibility and conservation of natural resources and biodiversity	Principle 6 Responsible consideration of employees and of individuals and communities affected by growers and mills	Principle 7 Responsible development of new plantings	Principle 8 Commitment to continuous improvement in key areas of activity
CCP	√	√	√	√	√	√	√	√
Cereal pellets	√	√	√	√	√	√	Ð	√
Granulated willow	√	√	√	√	√	√	Ð	√
Miscanthus	√	√	√	√	√	√	√	√
Olive cake	√	√	√	√	√	√	Ð	√
Olive expeller	√	√	√	√	√	√	Ð	√
Olive pellets	√	√	√	√	√	√	Ð	√
Olive residue	√	√	√	√	√	√	Ð	√
Palm kernel	√	√	√	√	√	√	√	√
Palm oil	√	√	√	√	√	√	√	√
Palm shell	√	√	√	√	√	√	√	√
PKE	√	√	√	√	√	√	Ð	√
PKE pellets	√	√	√	√	√	√	√	√
Sawdust	√	√	√	√	√	√	Ð	√
Sewage sludge	√	√	√	√	√	√	Ð	√
Shea meal	√	√	√	√	√	√	Ð	√
Shea pellets	Ð	Ð	Ð	Ð	Ð	Ð	Ð	√
SRC	√	√	√	√	√	√	√	√

Sunflower pellets	√	√	√	√	√	√	Ð	√
Tall Oil	√	√	√	√	√	√	Ð	√
Tallow	√	√	√	√	√	√	√	√
WDF	√	√	√	√	√	√	√	√
Wood	√	√	√	√	√	√	Ð	√
Wood pellets	√	√	√	√	√	√	√	√

√ Possibility of applying the ACC Standard

? Questionable but plausible

Ð Difficult to consider the application of the Standard

Table 25: Basel Criteria for responsible soy production applied to biofuels for co-firing.

Biofuels/ Basel Criteria	Legal Compliance	Technical management (soil and water quality)	Environmental Management (ecosystems, environmental impacts, waste and pollution management)	**Social management (social impacts, welfare and security, land tenure)**	Continuous improvement (to achieve full compliance with criteria)	Traceability of product
CCP	√	√	√	√	√	√
Cereal pellets	√	√	√	√	√	√
Granulated willow	√	√	√	√	√	√
Miscanthus	√	√	√	√	√	√
Olive cake	√	√	√	√	√	√
Olive expeller	√	√	√	√	√	√
Olive pellets	√	√	√	√	√	√
Olive residue	√	√	√	√	√	√
Palm kernel	√	√	√	√	√	√
Palm oil	√	√	√	√	√	√
Palm shell	√	√	√	√	√	√
PKE	√	√	√	√	√	√
PKE pellets	√	√	√	√	√	√
Sawdust	√	√	√	√	√	√
Sewage sludge	√	√	√	√	√	√
Shea meal	√	√	√	√	√	√
Shea pellets	√	√	√	√	√	√
SRC	√	√	√	√	√	√

Sunflower pellets	√	√	√	√	√	√
Tall Oil	√	√	√	√	√	√
Tallow	√	√	√	√	√	√
WDF	√	√	√	√	√	√
Wood	√	√	√	√	√	√
Wood pellets	√	√	√	√	√	√

√ Possibility of applying the ACC Standard

? Questionable but plausible

Ð Difficult to consider the application of the Standard

8 Providing Incentives for sustainability in co-firing

A number of conclusions arise from the analysis carried out for this report including:

- From an avoided GHG emission perspective, the co-firing of biomass with coal represents one of the most effective uses of biomass resources for energy
    - To maximise the GHG benefits, simple carbon-declaration systems could be put in place to encourage the use of low carbon biomass feedstocks and discourage poorly performing ones
- There is a sufficiently large global and UK resource base for co-firing to be expanded significantly based on accessing the global residue resource base. Doing so:
    - Would make a major and low risk contribution to Government and EU renewable energy policy targets
    - Would help to address energy security issues, even were co-firing to rely on imported biomass, because the resource base is large and diverse in geographic and phyto-origin
    - In the longer term, regional constraints may emerge on the availability of bio-resources (energy, food and materials) and monitoring systems may need to be developed to provide an early warning system for such events.
- Real environmental and social benefits could arise from the expansion of co-firing markets, both in the UK and in poor developing countries, given responsible development policy
    - Assurance and certification for sustainably supplied biomass should be encouraged, but it is not clear to the authors that major benefits, or reductions in risk, would result from full-blown assurance for co-firing residue-based feedstocks.
    - For dedicated energy crops, the justification is stronger for applying assurance and certification, but it is noted that SRC production in the UK would already fall under the UK Woodland Assurance Scheme
    - There is value in establishing consistency between the different biomass markets for energy in terms of environmental and social assurance as being developed under the Renewable Transport Fuels Obligation, for example.
- There is no environmental or social case for an arbitrary cap on the amount of co-firing.
- Should government wish to encourage the development of energy crops by using co-firing to generate a large enough market to enable significant cost-reductions to arise in biomass production then policy intervention will be required
    - The nature of energy supply contracts within the coal industry mean that it is difficult for co-firers to provide a suitable basis for the sustainable development of dedicated energy crops such as *Miscanthus* or SRC. Dedicated energy crops require long-term contracts that are not normal for these generators and are unlikely to become so without further intervention on the part of government

- Data from the monitoring of energy cropping systems could be used to develop standards specific to energy cropping as the use of biomass increases
- A large amount of biomass now classified as waste and that could be used for energy, is currently consigned to landfill. The value of these wastes and the costs of not using them (particularly to avoid methane emissions) could be publicised, and the necessary infrastructure and modification of regulations could be put in place to maximise their utilisation
- The co-firing of biomass is likely to be compatible with coal Carbon Capture and Sequestration (CCS) systems and could enhance their impact
    - Quantifying the potential and understand the technical aspects of such an integrated coal-biomass-CCS approach, is considered important.

References

ACCS. 2005. Assured Combinable Crops Standards 2005-2006. http://www.assuredcrops.co.uk/ACCS2/. Accessed 1/03/06.

ADAS, Potential **Impacts of future Renewable Energy Policy on UK Biodiversity.** Report No. CR0295. Final Report to the Department for Environment, Food and Rural Affairs (Defra) and the Scottish Executive Environment and Rural Affairs Department (SEERAD) as part of the Defra Horizon Scanning Programme. UK, 2006.

Baggott, et. Al. UK Greenhouse Gas Inventory 1990 to 2004: Annual Report for submission under the Framework Convention on Climate Change; AEA Technology National Environmental Technology Centre (NETCEN), pg. 246. April 2006.

Bauen, A., Howes, J., Chase, A., Tipper, R., Inkinen, A., Lovell, J. and Woods, J. Feasibility Study on Certification for a Renewable Transport Fuel Obligation. Eds: Archer, G. (Fuels Working Group). London, UK: LCVP. FWG-P-05-07: 1-80, 2005. http://www.lowcvp.org.uk/resources/agendasandminutes/working.cfm?catid=3&catName=Fuels

Biomass Task Force. Report to the Government. DEFRA. UK. 2005. http://www.defra.gov.uk/farm/crops/industrial/energy/biomass-taskforce/index.htm

Boyle, S., The biomass fuel and Technology Markets in the UK. Renewable Heat and Power Ltd. Presentation at the CHPA, 2005.

Britt, C., Bullard, M., Hickman, G., Johnson, P., King, J., Nicholson, F., Nixon, P., and Smith, N. Bioenergy Crops and Bioremediations – A Review. Final Report, 2002.

Brown, A., 2005. Energy from the Combustion of Wastes. In: Energy from Biomass Vol. 3: Converting Wood Fuel to Energy, 2005.

Canadian Pollution Prevention Information Clearinghouse (CPPIC). *Glossary.* Available at: www.ec.gc.ca/cppic/En/glossary.cfm

CONCAWE, EUCAR & JRC. *Well-to-Wheels analysis of future automotive fuels and powertrains in the European context.* Version 1b. European Commission. Brussels 2004.

CONCAWE, EUCAR & JRC.. *Well-to-Wheels analysis of future automotive fuels and powertrains in the European context.* Version 1a. Appendix 1. European Commission. Brussels. 2003

Defra, Energy Crops as part of Rural Development Programme England. 2006.

Defra. Annexes to Guidelines for Company Reporting on Greenhouse Gas Emissions. 2005.

Defra. The British Survey of Fertiliser Practice. Fertiliser Use on Farm Crops Year 2002. ISBN 1-86190-128-3. p.65, 2003.

DOE, Biomass Co-firing: A Renewable Alternative for Utilities. Biopower Factsheet. US Department of Energy, UK, 2000.

DTI. Digest of United Kingdom Energy Statistics 2005. UK Energy Statistics. DTI. 2005. http://www.dti.gov.uk/energy/statistics/source/renewables/page18513.html

DTI,. Woodfuel Resource in Britain. 2003.

DTI. The Economics of Co-Firing. Draft Report. DTI, London. May 2006.

DTI. Renewables Obligation Order 2006 – Final Decisions. DTI, London. January 2006

Ekins, P., Biomass as a Renewable Resource. Planning Resource**.** Royal Commission on Environmental Pollution Report EAG/6/3. www.PlanningResource.co.uk accessed 15/04/06.

Elsayed, M.A., Matthews, R. and Mortimer, N.D. Carbon and Energy Balances for a Range of Biofuel Options" Energy Technology Support Unit, Harwell, United Kingdom, Report B/B6/00784/REP, March 2003.

EU- Commission of the European Communities. Directive 2003/30/EC - on the promotion of the use of biofuels or other renewable fuels for transport. Brussels, Belgium: DG Environment. 2003/30/EC: 1-5, 2003.

Forestry Commission, Forestry Facts and Figures, 2005.

Forestry Commission. The UK Forestry Standard. The Government's Approach to Sustainable Forestry. Forest Service. Pp. 74, 2004.

GM & LBST. *Report: GM Well-to-Wheel Analysis of Energy Use and Greenhouse Gas Emissions of Advanced Fuel/Vehicle Systems – A European Study.* L-B-Systemtechnik GmbH. Germany. 2002. Available at: www.lbst.de/gm-wtw

GM & LBST. Annex "Full Background Report – Methodology, Assumptions, Descriptions, Calculations, Results to the GM Well-to-Wheel Analysis of Energy Use and Greenhouse Gas Emissions of Advanced Fuel/Vehicle Systems – A European Study. L-B-Systemtechnik GmbH. Germany. 2002. Available at: www.lbst.de/gm-wtw

Grogan, P and Matthews. R, Review of the Potential for Soil Carbon Sequestration under Bioenergy Crops in the UK. MAF report, 2001.

Hall, R.L., Short Rotation Coppice for Energy Production: Hydrological Guidelines. DTI Report, 2003.

Hardcastle, P. (Ed). Final Report on Short Rotation Forestry, LTS International, February 2006.

Hope, A and Johnson B, General Committee of Council. Discussion Paper on Biofuels. English Nature Report. GC p326, 2003.

Howard et. al. The BRE Methodology for Environmental Profiles of Construction Materials and Components, BRE/DETR

http://ite.massey.ac.nz/researchandconsultancy/EnergyResearchWebsite/report2.htm. Accessed 10/05/06

http://www.chpa.co.uk/news_downloads/2005/CHPA%20briefing%20April%202005.ppt#380,24, Biomass Fuels. Accessed 19/05/06.

http://www.defra.gov.uk/environment/business/envrp/gas/envrpgas-annexes.pdf

http://www.english-nature.org.uk/about/meetings/GCP0326.pdf#search='biomass%20crops. Accessed 17/05/06.

IEA, IEA Bioenergy Annual Report 2001. New Zealand, 2001.

Integrated Pollution Prevention & Control (IPPC), 1996.

IPA Energy Consulting and the Scottish Agriculture College, An Analysis into a Proposal for an Amendment to the Renewables Obligation Definition o f Energy Crops to the Scottish Executive, April 2005.

IPA Energy Consulting and Mitsui Babcock, The Economics of Co-Firing. Draft Report to the Department of Trade and Industry, May 2006.

IPCC. Climate Change 2001: The Scientific Basis. Eds: Houghton, J.T., Ding, Y., Griggs, D.J., Noguer, M., van der Linden, P.J., Da, X., Maskell, K., and Johnson. C.A. NY, USA: Cambridge University Press; Working Group I, 2001. http://www.grida.no/climate/ipcc_tar/index.htm

IPIECA. *Climate Change: A Glossary of Terms. 2nd Edition.* International Petroleum Industry Environmental Conservation Association. London. 2000.

ISO. About International Organization for Standardisation. http://www.iso.org/iso/en/ISOOnline.frontpage. Accessed 6/03/06. 2006.

ISO. ISO 14040: Environmental management - Life cycle assessment - Principles and framework. International Standards Organisation, Geneva, Switzerland. 1997. http://www.iso.org/iso/en/CatalogueDetailPage.CatalogueDetail?CSNUMBER=23151

J.E. Berry, M.R. Holland, P.R. Watkiss, R. Boyd and W Stephenson. Power Generation and the Environment - A UK Perspective. AEA Technology Environment Report AEAT 3776, 1998

LCVP. Well-to-Wheel Evaluation for Production of Ethanol from Wheat. A Report by the Low Carbon Vehicle Partnership (LowCVP) Fuels Working Group. London. 2004. http://www.lowcvp.org.uk [see Rickeard et al. 2004, for more details].

Lehmann, J., Gaunt, J., and Rondon, M. Bio-char Sequestration in Terrestrial Ecosystems: a review. *Mitigation and Adaptation Strategies for Global Change* 11 (2):403-427, 2006.

LEK Consulting. Review of the Economic Case for Energy Crops in the UK, January 2004.

Livingston, W.R., Development of Low Cost Systems for Co-Utilisation of Biomass in Large Power Plant. Mid-Term Review Report to the DTI, 2004.

Mann, M.K. and Spath, P.L., A life cycle assessment of biomass co-firing in a coal-fired power plant, Clean Production Processes, 3:81-91, 2001

McKay, H. Woodfuel Resource in Britain, Forestry Commission, 2003.

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.

Moreira, J.R. Global Biomass Energy Potential. *Mitigation and Adaptation Strategies for Global Change* DOI: 10.1007/s11027-005-9009-2:313-342, 2006.

Mortimer, N.D., Elsayed, M.A. and Horne, R. Energy and Greenhouse Gas Emissions for Bioethanol Production from Wheat Grain and Sugar Beet. Resources Research Unit of the School of Environment and Development, Sheffield Hallam University, UK. Report No. 23/1 for British Sugar, 2004.

Mosier, A.R., Syers, J.K., Freney, J.R. Nitrogen Fertilizer: An Essential Component Of Increased Food, Feed, And Fiber Production. Book Chapter in: A.R. Mosier, J.K Syers And J.R. Freney (Eds). Agriculture And The Nitrogen Cycle: Assessing The Impacts Of Fertilizer Use On Food Production And The Environment. Scope Vol. 65, Island Press, Washington, D.C. Pp. 15. 2004.

NREL. *HOMER - The Micropower Optimization Model. Help.* Golden Colorado, USA. 2003.

Obernberger, I., and Thek, G.; Physical characterisation and chemical composition of densified biomass fuels with regard to their combustion behaviour. Proceedings of the 1st World Conference on Pellets, Sept 2002, Stockholm, Sweden, ISBN 91-631-2833-0, pp. 115-1222, Swedish Bioenergy Association (ed.), Stockholm, Sweden, 2002.

Ogawa, M., Okimori, Y., Gaunt, J., and Takahashi, F. Bio-char Sequestration in Terrestrial Ecosystems: a review. *Mitigation and Adaptation Strategies for Global Change* 11 (2):429-444, 2006.

ProForest, The Basel Criteria for Responsible Soy Production. Report by ProForest for Coop Switzerland and the WWF Switzerland, 2004

Renewables Obligation Order, 2005.

Rickeard, D.J., Punter, G., Larivé, J. F., Edwards, R., Mortimer, N.D., Horne, R., Bauen, A., and Woods, J. WTW Evaluation for Production of Ethanol from Wheat. London: LCVP. Pg: 1-39, 2004.

Royal Commission on Environmental Pollution. *Biomass as a Renewable Energy Source*. A Report to Government, UK, 2005.

RSPO. 2005. RSPO Principles and Criteria for Sustainable Palm Oil Production. Round Table on Sustainable Palm Oil, p. 6. Public Release Version 17Oct 2005.

Ryckmans, Y., Marchal, D. and Andre, N., Energy balance and greenhouse emissions of the whole supply chain for the import of wood pellets to power plants in Belgium. Proceedings of the 2nd World Pellets Conference 2006.

Sims, R and K Richards, Delivering the Bioenergy Triple Bottom Line to the Global Community. Centre for Energy Research, 2006.

SPA; SAC; pSPA; cSAC; Ramsar; SSSI; National Nature Reserve; National Park; Local Nature Reserve; Marine Nature Reserve; Areas of Special Protection (AoSP) applied from high water mark to 3nm from baseline of the territorial sea; non-statutory local authority wildlife sites.

Tillman, D.A., Biomass co-firing: The technology, the experience, the combustion consequences. Biomass and Bioenergy 19(6): 365-385, 2000.

Toyota Motor Corporation. *Well-to-Wheel Analysis of Greenhouse Gas Emissions of Automotive Fuels in the Japanese Context. Well-to-Tank Report.* 2004.

Turley, D., McKay, H., and Boatman, N. Environmental Impacts of Cereal and Oilseed Rape Cropping in the UK. London, UK: HGCA. Research Report No: 54:1-124, 2005.

Wood, J. Feel the Burn. The Truth behind Co-firing Biomass. *IEE Power Engineer*. October November. Pp. 19-21, 2004.

Woods, J. and Bauen, A. Technology Status Review and Carbon Abatement Potential of Renewable Transport Fuels (RTF) in the UK. DTI; AEAT. B/U2/00785/REP URN 03/982: Pp 150, 2003. http://www.dti.gov.uk/energy/renewables/publications/pdfs/B200785.pdf

WWF, WWF & EU Biofuels Communication. Agriculture European Policy Office. Belgium, 2006.

Definitions and terminology

The following glossary of definitions and terminology has been derived from a series of existing glossaries[22].

Accreditation refers to the formal recognition by a specialised body – an accreditation body – that a certification body is competent to carry out certification. See also: ‘assurance’ ‘standards’ and ‘certification’.

Alternative Energy is the energy derived from non-fossil fuel sources.

Alternative Transportation Fuel. Under the *Alternative Fuels Act, 1995*, alternative transportation fuel must include, but is not limited to, ethanol, methanol, propane gas, natural gas, hydrogen or electricity, and these must be used as a sole source of direct propulsion energy (see also **Renewable Transport Fuel**).

Alternative Fuel Vehicle is a vehicle purchased or leased from an original equipment manufacturer (or converted in the aftermarket) that is capable of operating on an alternative transportation fuel. Flex-fuel and bi-fuel vehicles are also considered to be alternative fuel vehicle, as are vehicles that operate on blended fuels, when an alternative transportation fuel makes up at least fifty percent of the blend.

Analysis the process of dividing up the landscape into its component parts to gain a better understanding of it.

Anthropogenic Emissions is the emissions of greenhouse gases associated with human activities. These include burning of fossil fuels for energy, deforestation and land-use changes.

Approach is the step-wise process by which landscape assessment is undertaken.

Assessment is a term to describe all the various ways of looking at, analysing, evaluating and describing the landscape.

Assurance. An ‘assurance scheme’ is the overall framework relating to the development of a standard, the accreditation of certification bodies, and the certification of products and services. See also: ‘assurance’ ‘standards’ and ‘certification’.

Baseline is a projected level of future emissions against which reductions by project activities could be determined, or the emissions that would occur without policy intervention.

Biofuel is a fuel produced from dry organic matter or combustible oils produced by plants. Examples of biofuel include alcohols (from fermented sugar), black liquor from the paper manufacturing process, wood and soybean oil.

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[22] Adapted from 1) IPIECA. 2000. *Climate Change: A Glossary of Terms.* 2nd Edition; 2) NREL. 2002. *HOMER - The Micropower Optimization Model. Help.* Golden. CO; 3) Canadian Pollution Prevention Information Clearinghouse (CPPIC). *Glossary.* Available at: www.ec.gc.ca/cppic/En/glossary.cfm

Biological Diversity is the variety of life and the natural processes of which living things are a part. This includes the living organisms, the genetic differences between them, and the communities in which they occur (Audubon Nature Institute).

Biomass is the total dry organic matter or stored energy content of living organisms. Biomass can be used for fuel directly by burning it (e.g., wood), indirectly by fermentation to an alcohol (e.g., sugar) or extraction of combustible oils (e.g., soybeans).

Carbon Cycle is the natural processes that govern the exchange of carbon (in the form of CO_2, carbonates and organic compounds etc.) among the atmosphere, ocean and terrestrial systems. Major components include photosynthesis, respiration and decay between atmospheric and terrestrial systems (approximately 100 billion tonnes/year (Gt); thermodynamic invasion and evasion between the ocean and atmosphere, operation of the carbon pump and mixing in the deep ocean (approx. 90 billion tonnes/year). Deforestation and fossil fuel burning releases approximately 7 Gt into the atmosphere annually. The total carbon in the reservoirs is approximately 2000 Gt in land biota, soil and detritus, 750 Gt in the atmosphere and 38,000 Gt in the oceans. (Figures from IPCC WGI Scientific Assessment 1990.) Over still longer periods geological processes of outgassing, volcanism, sedimentation and weathering are also important.

Carbon Dioxide, or CO_2 is a naturally occurring gas. It is also a by-product of burning fossil fuels and biomass, as well as land-use changes and other industrial processes. It is the principal anthropogenic GHG that affects the earth's temperature. It is the reference gas against which other GHGs are indexed and therefore has a 'Global Warming Potential' of 1. Carbon dioxide constitutes approximately 0.036 per cent of the atmosphere. The mass ratio of carbon to carbon dioxide is 12:44.

Carbon Dioxide Fertilization is an enhancement of plant growth or yield as a result of an increase in the atmospheric concentration of CO_2.

Carbon emissions (t/yr) is the amount of carbon emitted annually by the power system. Carbon emissions result from the consumption of fuels (including biomass) and from the purchase of power from the utility grid. The annual carbon emission of a generator or boiler is equal to its annual fuel consumption multiplied by the fuel carbon content. The annual grid-related carbon emissions are equal to the total net grid energy purchased (which may be negative) times the grid carbon content.

> **Note:** This variable refers to *carbon* emissions, not *carbon dioxide* emissions. To calculate carbon dioxide emissions, multiply the carbon emissions by 3.67 (this assumes all carbon is released in the form of carbon dioxide).

Carbon Intensity is carbon dioxide emissions per unit of energy or economic output.

Carbon Intensity is a measure of the amount of greenhouse gas produced per unit of product over its lifecycle (or the major part of its lifecycle). Carbon intensity is normally expressed in units of CO_2 equivalent emissions per unit of the product, taking into account other greenhouse gases such as methane and oxides of nitrogen that may be emitted (Bauen, et. al., 2005).

Carbon Sequestration is the long-term storage of carbon or carbon dioxide in the forests, soils, ocean, or underground in depleted oil and gas reservoirs, coal seams, and saline aquifers. Examples include: the separation and disposal of CO_2 from flue gases or processing fossil fuels to produce H2 and carbon-rich fractions; and the direct removal of CO_2 from the atmosphere through land use change, afforestation, reforestation, ocean fertilization, and agricultural practices to enhance soil carbon.

Carbon Sinks is a natural or man-made systems that absorb carbon dioxide from the atmosphere and store them. Trees, plants, and the oceans all absorb CO_2 and, therefore, are carbon sinks.

Carbon Tax is a tax placed on carbon emissions. It is similar to a BTU tax, except that the tax rate is based on the fuel's carbon content.

Certification refers to the issuing of written assurance by an independent, external body – a certification body – that has audited an organisation's management system and verified that it conforms specifically to the standard. See also: 'assurance' 'standards' and 'certification'.

Climate is the average trend of weather, including its variability in a geographical region. The averaging period is typically several decades.

Climate Change *(UNFCCC definition)* is a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability over comparable time periods.

Combined cycle is an electricity generation where the waste heat of a gas turbine generator is used to heat water in a boiler to drive a steam-turbine generator, thereby increasing efficiency.

Cogeneration is the use of waste heat from electricity generation, such as exhaust from gas turbines, for either industrial purposes or district heating.

Coppicing is the traditional method of woodland management in which trees are cut down near to the ground to encourage the production of long, straight shoots that can be harvested.

Distillers' Dark Grains and Solubles (DDGS) is a protein-rich residue/ by-product leaves after the wheat grain processing.

Emissions *(UNFCCC Definition)* is the release of greenhouse gases and/or their precursors into the atmosphere over a specified area and period of time.

Emissions are the substances released into the atmosphere or into water. In climate change, greenhouse gas emissions are the release of gases such as carbon dioxide, methane and nitrous oxide through natural and human activities.

Emissions Cap is a mandated restraint, in a scheduled timeframe that puts a 'ceiling' on the total amount of anthropogenic greenhouse gas (GHG) emissions that can be released into the atmosphere. The Kyoto Protocol mandates caps on the GHG emissions released by Annex B, or developed, countries.

Emissions Reduction Unit, or ERU is the ERU represents a specified amount of greenhouse gas emissions reductions achieved through a Joint Implementation project or as the unit of trade in greenhouse gas emissions trading systems.

Emissions Trading is a market-based approach to achieving environmental objectives that allows those reducing greenhouse gas (GHG) emissions below what is required to use or trade the excess reductions to offset emissions at another source inside or outside the country. In general, trading can occur at the domestic, international and intra-company levels. Article 17 of the Kyoto Protocol, allows Annex B countries to exchange emissions obligations. Negotiations will determine the extent to which firms and others may be allowed to participate. International emissions trading constitutes one of the Kyoto Mechanisms, designed to provide Annex B countries cost-effective flexibility in reducing emissions to achieve their agreed commitments.

Environmental Impact Assessment is the…

Ethanol is a liquid that is produced chemically from ethylene or biologically from the fermentation of various sugars from carbohydrates found in agricultural crops and cellulosic residues from crops or wood. Depending on how it is produced, it can be used as a substitute for gasoline, and can result in significantly less greenhouse gas emissions than gasoline. It is also known as ethyl alcohol or grain alcohol.

Fossil Fuels are the carbon-based fuels, including coal, oil and natural gas.

Fuel carbon content (% by mass) is the carbon content of the fuel as a percent of its mass. This value is used to calculate the annual carbon emissions of the system.

Fuel Switching is a supplying energy services using different fuels. Often used to refer to actions that reduce CO_2 emissions from electric utilities by switching from coal to natural gas.

Global Warming is the view that the earth's temperature is being increased, in part, due to emissions of greenhouse gases associated with human activities, such as burning fossil fuels, biomass burning, cement manufacture, cow and sheep rearing, deforestation and other land-use changes.

Global Warming Potential, or GWP is a time dependent index used to compare the radiative forcing, on a mass basis, of an impulse of a specific greenhouse gas relative to that of CO_2. Gases included in the Kyoto Protocol are weighted in the first commitment period according to their GWP over a 100-year time horizon as published in the 1995 Second Assessment Report of the IPCC. In that report, methane, for example has a radiative forcing that was estimated to be about 21 times greater than that of CO_2, thus it has a GWP of 21.

Greenhouse Effect is the trapping of heat by naturally occurring heat retaining atmospheric gases (water vapour, carbon dioxide, nitrous oxide, methane and ozone) that keeps the earth about 30° C (60° F) warmer than if these gases did not exist.

Greenhouse Gases (GHG) are gases in the earth's atmosphere that absorb and re-emit infra-red radiation. These gases occur through both natural and human-influenced processes. The major GHG is water vapour. Other GHGs include carbon dioxide, nitrous oxide, methane, ozone and CFCs.

GHG certification is a process by which a product or service is delivered with a formally declared carbon intensity, which is a measure of the amount of GHGs produced expressed in units of CO_2 equivalent. The process is normally based upon a standardised method that makes use of a combination of direct information provision or measurements and assumptions taken from the scientific literature. The declared carbon intensity of each could be linked to the number of RTFO certificates issued (Bauen et. al., 2005).

Impact Assessment is the...

Intergovernmental Panel on Climate Change, or IPCC is a Panel established in 1988, by governments under the auspices of the World Meteorological Organization and the UN Environment Programme. It prepares assessments, reports and guidelines on the science of climate change, its potential environmental, economic and social impacts, technological developments, possible national and international responses to climate change and crosscutting issues. It provides advice to the UNFCCC's Conference of the Parties. It is currently organized into 3 Working Groups which address: I) Science; II) Impacts, Adaptation and Vulnerability; and III) Mitigation; there is also a Working Group to address GHG Inventories.

International Energy Agency, or IEA is a Paris-based organization formed in 1973 by the major oil-consuming nations to manage future oil supply shortfalls.

Kyoto Lands. The Kyoto Protocol describes land use, land use change and forestry activities that require or allow the net GHG emissions from sinks to be accounted for by Parties in meeting their emission reduction commitments. The lands on which these activities take place are designated as Kyoto lands (as defined in the IPCC draft report on LULUCF).

Kyoto Protocol is the Protocol, drafted during the Berlin Mandate process, that, on entry into force, would require countries listed in its Annex B (developed nations) to meet differentiated reduction targets for their greenhouse gas emissions relative to 1990 levels by 2008–12. It was adopted by all Parties to the Climate Convention in Kyoto, Japan, in December 1997.

Landscape is primarily the visual appearance of the land including its shape, form and colours. However, landscape is not purely a visual phenomenon. The landscape relies on a range of other dimensions including geology, landform, soils, ecology, archaeology, landscape history, land use, architecture and cultural associations.

Land Cover is a combination of land use and vegetation that cover the land surface.

Life Cycle is consecutive and interlinked stages of a product system, from raw material acquisition or generation of natural resources to the final disposal (ISO 14040).

Life-Cycle Analysis is an analysis of the environmental impact of a product during the entirety of its lifecycle, from resource extraction to post-consumer waste disposal. It is a comprehensive approach to examining the environmental impacts of a product or package.

Life-Cycle Assessment or LCA is a specific method for systematically identifying, quantifying and assessing inputs and outputs (i.e. sources of environmental impact) throughout a product's life cycle. It is one of a range of tools that support life cycle management, but is not a prerequisite for life cycle management (Environment Canada - Environmental Life Cycle Management: A Guide to Better Business Decisions). See also ‘Well-to-Wheel’ and ‘Well-to-Tank’ LCA.

Life-Cycle Assessment or LCA is a process of evaluating the effects that a product has on the environment over the entire period of its life thereby increasing resource-use efficiency and decreasing liabilities. It can be used to study the environmental impact of either a product or the function the product is designed to perform. LCA is commonly referred to as a “cradle-to-grave” analysis. LCA's key elements are: (1) identify and quantify the environmental loads involved; e.g. the energy and raw materials consumed, the emissions and wastes generated; (2) evaluate the potential environmental impacts of these loads; and (3) assess the options available for reducing these environmental impacts.

Life cycle assessment (LCA) is:

the overall process of assessing the life cycle impacts associated with a system, function, product or service. Sometimes considered to include the Initiation, Inventory, Impact Analysis and Improvement stages (SPOLD 93):

- A concept and a method to evaluate the environmental effects of a product holistically, by analysing its entire life cycle. This includes identifying and quantifying a-energy and materials used and wastes released to the environment, assessing their environmental impact, and evaluating opportunities for improvement (CAN 94);

- Part of an overall life cycle assessment in which only the environmental consequences are considered (CML 95);
- Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle (ISO 14040).

http://www.uni-weimar.de/scc/PRO/GLO/env.html - top**Life Cycle Impact Assessment** is a phase of LCA aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts of a product system (ISO 14040, ISO 97b).

Methane, or CH_4 is one of the six greenhouse gases to be included under the Kyoto Protocol, it has a relatively short atmospheric lifetime of 10± 2 years. Primary sources of methane are landfills, coal mines, paddy fields, natural gas systems and livestock. The SAR (1995) estimate of the Global Warming Potential of methane is 21, over a 100-year time horizon. See 'Global Warming Potential'.

Nitrous Oxide, or N_2O is one of the six greenhouse gases to be curbed under the Protocol, it is generated by burning fossil fuels and the manufacture of fertilizer. It has a Global Warming Potential of 310 over a 100-year time horizon. See 'Global Warming Potential'.

Nitrous Oxide, or N_2O is a colourless gas that occurs both naturally in the environment in plants and manure and from human-made sources such as chemical production and combustion. N_2O is a greenhouse gas that remains in the atmosphere for long periods of time, absorbing heat and radiating it back to the earth's surface instead of allowing it to pass through into space.

Ozone. Ozone (O_3) is a greenhouse gas. In the troposphere, or lower part of the atmosphere, O_3 can be a constituent of smog. It is created naturally and also by reactions in the atmosphere involving gases resulting from human activities, including NOx, or nitrogen oxides, from motor vehicles and power plants. The Montreal Protocol seeks to control chemicals which destroy ozone in the stratosphere (upper part of the atmosphere) where ozone absorbs ultra-violet radiation.

Product Life Cycle is the summary of activities that go into making, transporting, using, and disposing of a product. To determine the environmental impacts of a particular product's life cycle, a lifecycle-analysis can be conducted on the activities, to identify, quantify and assess all inputs and outputs.

Renewables are the energy sources that are constantly renewed by natural process. These include non-carbon technologies such as solar energy, hydropower and wind as well as technologies based on biomass. Life cycle analyses are required to assess the extent to which such biomass based technologies may limit net carbon emissions.

Renewable Energy is the several energy sources that have little in common from a technology standpoint, but share one characteristic: they all produce electricity or thermal energy without depleting resources. Renewable energy sources include water, biomass, wind, solar, earth and waste stream energy.

Renewable Transport Fuel is defined by the UK Energy Act 2004 as: i) biofuel, ii) blended biofuel; iii) any solid, liquid or gaseous fuel (other than fossil fuel or nuclear fuel) which is produced: a) wholly by energy from a renewable source; or b) wholly by a process powered by such energy; or iv) any solid, liquid or gaseous fuel which is of a description of fuel designated by an RTF order as renewable transport fuel (see also: **Alternative Transportation Fuel)**.

Renewable Resource is the natural resources that are capable of regeneration. Renewable resources can essentially never be exhausted, usually because they are continuously produced (e.g., tree biomass, fresh water, and fish). Renewable resources are those natural resources that are naturally replenished, but whose continued supply depends, in many cases, on proper management (e.g. tree biomass, fresh water, fish).

Second Assessment Report, or SAR is a published by the IPCC in 1995 the SAR provided a comprehensive overview of the state of knowledge on climate change at that time. It contains the widely cited statement 'the balance of evidence suggests that there is a discernible human influence on global climate'. The IPCC's Third Assessment Report was finalised in 2001 (see below).

Sequestration is an uptake of carbon dioxide from the atmosphere by plants and its subsequent storage as biomass.

Semi-natural Vegetation is any type of vegetation that has been influenced by human activities, either directly or indirectly.

Sinks *(UNFCCC Definition)* are any process or activity or mechanism which removes a greenhouse gas or a precursor from the atmosphere.

A '**standard**' refers to principles and criteria to be used consistently as guidelines, rules, or definitions of characteristics to ensure that materials, products, processes and services meet their purpose. The 'standard' will also define indicators and methods that are used to measure compliance with principles and criteria. See also: 'assurance' 'standards' and 'certification'.

Sulphur Dioxide or SO_2 is a colourless gas with a pungent odour, irritates the upper respiratory tract in humans and leads to acidic deposition/acid rain. Originates from both anthropogenic (human) and natural sources and has been identified as one of the principal precursors to fine particulate matter. The main anthropogenic sources are from combustion in transportation, industry and the electric power generation sectors, whereas emissions from natural sources are mainly from volcanoes, marine bacteria and wetlands.

Sustainability is the ability of an ecosystem to maintain ecological processes and functions, biodiversity, and productivity over time. Also a term used by governments to describe the efficient use of the earth's resources to ensure there will be adequate resources to support the economy and maintain a healthy environment for future generations to come.

Sustainability Impact Assessment (SAI) is the.

Sustainable Development is a Development that meets the needs of the present without compromising the ability of future generations to meet their own needs (World Commission on Environment and Development - the Brundtland Commission). Development is essential to satisfy human needs and improve the quality of human life. At the same time, development must be based on the efficient and environmentally responsible use of all of society's natural, human, and economic resources.

Sustainable Transportation is an integrating economic, social and environmental considerations into decisions affecting transportation activity. A sustainable transportation system is one that is safe, efficient and environmentally responsible.

System Boundary is a LCA term referring to then bounds set on a study in terms of what processes and activities will be analysed as part of the study. For example, in a study of a particular building all major materials may be within the system boundary, while minor material and worker travel may be excluded from the study and therefore left outside the system boundary. It is important to understand where people have set their system boundaries when comparing different LCA data.

Third Assessment Report, or IPCC TAR is the third in a series of Assessment Reports prepared by the Intergovernmental Panel on Climate Change which review the existing scientific literature on the subject, finalized in 2001. It contains three main sections: Science; Impacts, Adaptation and Vulnerability; and Mitigation. It includes a 50- 80 page Synthesis Report, which will draw upon the three main sections and other IPCC Special Reports to answer a number of policy-relevant scientific and technical questions (asked by UNFCCC SBSTA and refined by the IPCC Plenary). Each of the three main sections and the Synthesis Report will have a short Summary for Policy Makers. The information in the TAR will be considered by governments during UNFCCC negotiations.

The Carbon Tax (£/t) is the cost penalty applied to the system for its total carbon emissions, expressed in dollars per tonne of carbon (not carbon dioxide).

The System Fixed Capital Cost (£) is the capital cost that occurs at the start of the project regardless of the size or architecture of the power system. It is used to calculate the other annualized capital cost, so it affects the total net present cost of each system, but it affects them all by the same amount. It therefore has no effect on the system rankings.

The System Fixed Operation and Maintenance Cost (£/yr) is the recurring annual cost that occurs regardless of the size or architecture of the power system. It is used to calculate the other annualized capital cost, so it affects the total net present cost of each system. But it affects them all by the same amount, so it has no effect on the system rankings.

The Other O&M Cost (%/yr) is the system fixed O&M cost plus the cost of unmet load plus the cost of carbon emissions.

The system fixed capital cost and the capital cost associated with any primary load efficiency measures are lumped together into the **"other capital cost"**.

UN Environment Programme, or UNEP is the UN agency, established in 1972, to coordinate the environmental activities of the UN. It aims to help reinforce and integrate the large number of separate environmental efforts by intergovernmental, non-govern- mental, national and regional bodies. UNEP has fostered the development of the UNFCCC and the Convention on Biological Diversity.

UN Framework Convention on Climate Change, or UNFCCC is a treaty signed at the 1992 Earth Summit in Rio de Janeiro by more than 150 countries. Its ultimate objective is the 'stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic [human-induced] interference with the climate system'. While no legally binding level of emissions is set, the treaty states an aim by Annex I countries to return these emissions to 1990 levels by the year 2000. The treaty took effect in March 1994 upon the ratification of more than 50 countries; a total of some 160 nations have now ratified. In March 1995, the UNFCCC held the first session of the Conference of the Parties (COP) the supreme body of the Convention in Berlin. Its Secretariat is based in Bonn, Germany. In the biennium 2000–01, its approved budget and staffing level are approximately US$12M annually with approximately 80 personnel.

Used Oil is oil from industrial and non-industrial sources which has become unsuitable for its original purpose due to the presence of impurities or the loss of original properties.

Well-to-Tank (WTT) LCA covers the full production and conversion part of the biofuel chain up to delivery of the end-fuel. This is notionally to the 'tank' of a vehicle but is often simplified to encompass delivery only to a point where the renewable fuel is treated in exactly the same manner as the reference fuel (e.g. petrol). In this case ‘delivery’ is assumed to mean to the point of blending with the reference fuel or the ‘duty point’.

Well-to-Wheel (WTW) LCA covers the entire production, conversion and use biofuel chain. It therefore includes the whole ‘Well-to-Tank’ component plus delivery to the garage forecourt, fuelling of the vehicle and final use in the vehicle.