Final Report

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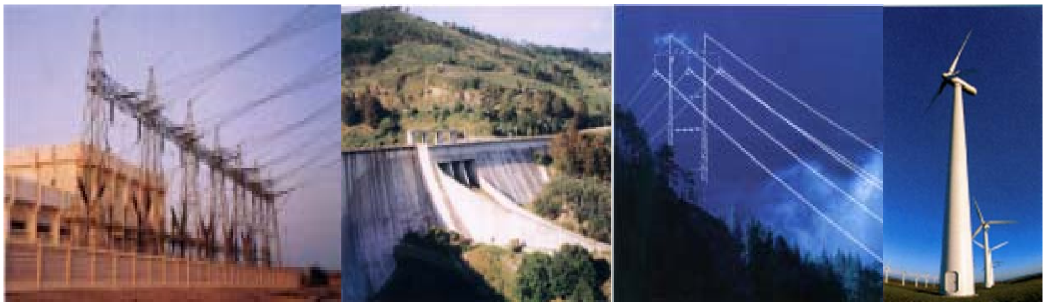

The Economics of Co-Firing

to

Department of Trade and Industry

July 2006

IPA Energy Consulting

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The Economics of Co-Firing

to

Department of Trade and Industry

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EXECUTIVE SUMMARY

This study has undertaken an investigation into the economics of co-firing biomass, to inform the UK Government as part of their ongoing co-firing review. The report focuses on solid biomasses at coal stations but also comments briefly on HFO substitution at both coal and oil stations. The report has investigated the non-fuel costs of co-firing at coal plant for both the current practices and potential developments for co-firing at power stations, the economics and availability of different types of biomass fuels, and the financial support required to incentivise biomass co-firing.

Our findings and a summary of our conclusions is presented below.

- **Background**
  - The number of coal plants co-firing has increased following the introduction of the Renewables Obligation, from two in 2002/03 to sixteen in 2005/06.
  - The majority of co-firing has been fuelled by imported bio-wastes such as olive pits and palm kernels. The use of energy crops has been limited due to the scarcity of this type of fuel.
  - Caps on the maximum volume of co-fire ROCs that can be surrendered and an increasing requirement to utilise energy crops within the biomass fuel mix may reduce the volume of co-firing in the future.

- **Station Costs of Co-firing**

  Co-Milling of Biomass

  - In the main, biomass materials have been co-fired by co-milling the biomass with the coal. This approach to co-firing involves relatively low levels of capital expenditure and can be implemented relatively quickly.
  - There are, however, limitations on the range of biomass materials that can be co-fired in this way, and on the co-firing ratios that can be achieved.
  - The majority of the problems encountered to date have been associated with the fuel supply arrangements, and with the on-site storage and handling of the biomass materials.
  - The co-firing of a range of biomass materials, at low co-firing ratios has been successfully introduced to coal-fired power stations in Britain, and the impacts on the performance, integrity and environmental performance of the plants have been small.

  Direct Co-firing of Biomass

  - In order for coal plant to operate at higher co-firing ratios, coal power plant operators will need to invest in new equipment for the direct co-firing of biomass materials.
  - There are a number of technical options for the direct co-firing of biomass materials in coal-fired boilers, each of which have significant implications on the capital and operating costs of the systems.

- In most cases, the facilities for the reception, storage and handling of the biomass have to be upgraded substantially, or new facilities have to be installed, to cater for the significant increase in the biomass throughput.

Co-firing of Energy Crops

- As co-firing plant begin to utilise energy crops they may have to develop systems that can process and handle baled material and chipped wood materials with relatively high moisture contents or, alternatively source the fuel in a pelletised form
- Costs associated with co-firing high moisture content chipped SRC are likely to be lower than for baled materials. However, to increase co-firing burn additional capital expenditure may be required, and it may be desirable to undertake processing and, potentially, drying on-site.
- It is likely that energy crops will be delivered to the power stations in a pelletised form, increasing fuel costs but reducing plant investment.

- **Biomass Fuels – Economics & Availability**

Imported Biomass Fuels

- The markets for these products are not liquid and prices can vary. The delivered price at the station gate for currently imported biomass products range between around £3.80/GJ and £5.00/GJ.
- There are sufficient potential volumes of fuel to satisfy any reasonable UK fuel requirement from co-firing.
- However, not all of these potential fuel sources will be available for UK generation due to competing markets and increasing demand from generation across the EU and internationally.

Domestic Biomass Fuels

- There are a number of domestic biomass products that could be used in co-firing.
- Assuming a collection radius of 40km around the power station, the delivered costs of domestic biomass fuels is between £4.35/GJ and £4.80/GJ, depending on the type of fuel.
- There is sufficient domestic biomass waste to meet the co-firing requirements. However, not all of this waste is available for co-firing due to competing markets.

Domestic Energy Crops

- The economics of burning Energy Crops are dependent upon several parameters such as the yield, cultivation costs, grants and transport costs.
- One of the main factors that could influence the choice of crop will be the certainty over the long term market for the energy crops.
- The diffuse nature of domestic energy crop cultivation is likely to mean that energy crops are typically delivered by road, which significantly increases the cost of energy crops relative to other fuel sources.

- Assuming a collection radius of 40km around the power station, the delivered cost of Energy Crops (in a pelletised form) to the station gate would range from around £3.80/GJ for Miscanthus with a £1,000/ha establishment grant to around £5.30/GJ for SRC with no grants (at 10 year investment time scale and 10% real discount rate).
- Despite the significant potential for domestic cultivation of energy crops, experience of cultivation within UK is still relatively limited.
- There is an increasing interest in developing energy crops and there have been indications from industry that contracts for up to 60,000ha might be available for 2007/8/9.
- It should be borne in mind that at least some of the energy crop cultivation could be developed for use within dedicated biomass plant and so may not be available for co-firing.
- To meet the maximum demand from Energy Crops required by the RO (2.03TWh(e) in 2015/16) would require around 91,000ha of Miscanthus. This is around 13 times the total planned to be planted by the end of 2006.

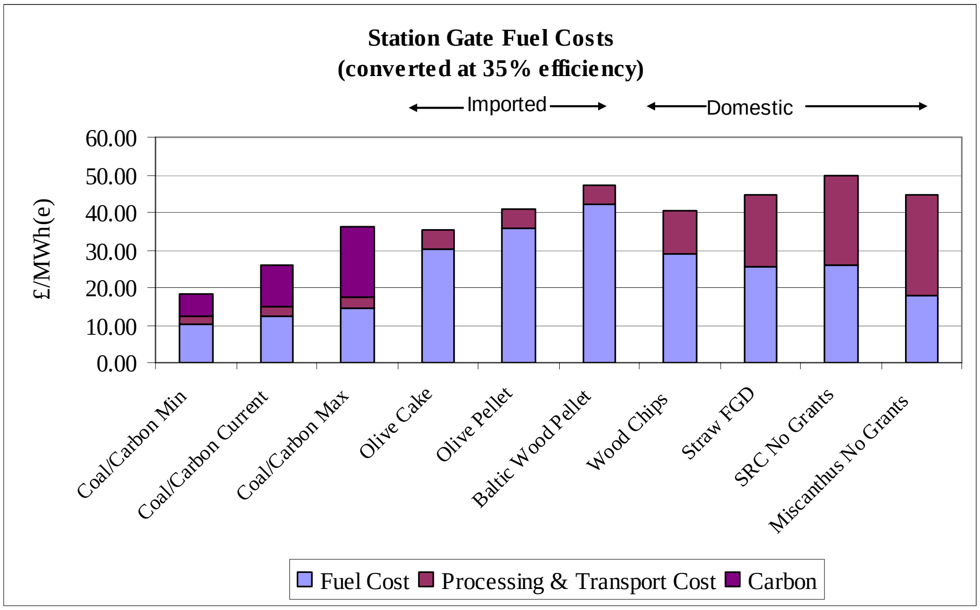
Imported Energy Crops

- Availability of imported energy crops is currently relatively limited, although there is an expected growth in energy crop production, there is also likely to be growing demand for supply.
- The cost structure of energy crops are unlikely to be significantly different abroad, however, lower overhead costs added to the greater yields and volumes may make them attractive for co-firing in the UK.
- There is therefore a possibility that energy crop products could be sourced internationally, thereby limiting the growth in the UK domestic market.

Economics & Availability Conclusions

Final delivered costs (current costs) for each of the fuels investigated are shown in the figure below.

Figure 1 -'Station Gate' Costs for Biomass Fuels



Increasing demand from other European electricity generation activities may tend to put upward pressure on these prices in the future, particularly for the imported fuels.

Transport costs also play a large part in the delivered cost of the fuels.

The total potential volumes of biomass available indicate sufficient volumes to satisfy the maximum co-firing requirements stipulated by the constraints in the RO.

However, particularly in the case of domestic Energy Crops, the volumes available will be affected by the levels of grants available to suppliers and for imported energy crops the demand from international markets. In addition, demand from dedicated biomass plants may also reduce the volumes available for co-firing.

- **Economics of Co-firing**

  - The economics of co-firing are complex and are affected by a wide variety of factors including biomass fuel costs, coal costs, carbon costs, capital and operating expenditure.

Fuel Costs Comparison

- The costs of generation using coal are lower than the costs associated with generation using biomass.
- However, if the costs of carbon are included there have been times over the last year when the costs of coal generation have been broadly equivalent to the costs of generating using some of the cheaper biomass fuel sources.

Current Co-firing Experience

- The economic decision determining whether a station co-fires biomass is whether the net costs and benefits associated with burning biomass will be less than the costs of burning coal.
- The required level of support to equalise net costs of generation with biomass and coal fuel varies considerably, dependent on the combined coal and carbon price and the biomass fuel source.
- The current support required to incentivise co-firing at the current market prices for an average biomass cost is around £18/MWh(e).
- If it were assumed that there was no support from ROCs the carbon price would need to rise from its current level of €18.40/tCO_2 to €47.65/tCO_2 to make this form of co-firing economic, for an average biomass fuel price.

Co-firing with Domestic Fuels

- To enable investment in developing the supply chains there will need to be reasonable regulatory certainty over the level and duration of any support mechanism.
- The current support required to incentivise co-firing at the current market prices is around £17/MWh(e) for Wood Chips and around £35/MWh(e) for baled straw.
- If it were assumed that there was no support from ROCs the carbon price would need to rise from its current level of €18.40/tCO_2 to €46/tCO2 to make co-firing of wood chips economic and to €75.30/tCO_2 to make co-firing of baled straw economic.

Co-firing with Energy Crops

- To enable investment in developing the cultivation of energy crops a reasonable degree of certainty over the level and duration of any support mechanism is required.
- Agricultural support varies the levels of support required.
- The required level of support to incentivise co-firing varies between energy crops at different levels of agricultural support by around £10/MWh(e), lower than the uncertainty in the level of support due to the volatility in the market price of coal and carbon (~£15/MWh(e)).
- The current support required to incentivise co-firing at the current market prices is around £16/MWh(e) for Miscanthus with a £500/ha grant and around £26/MWh(e) for SRC without any grants.
- If it were assumed that there was no support from ROCs the carbon price would need to rise from its current level of €18.40/tCO_2 to €44.40/tCO2 to make co-firing of Miscanthus with a £500/ha grant economic and to €60.65/tCO_2 to make co-firing of SRC without any grants economic.

Direct Co-firing

- Plant investment is required to enable direct co-firing operations. This investment will require to be recovered from the increased co-fired electricity generated.
- The level of agricultural grants, as well as the level of regulatory certainty (resulting in longer investment horizons), can have a significant impact upon the level of support required to incentivise energy crop co-firing operations.
- The current support required to incentivise co-firing at the current market prices is around £18/MWh(e) for Miscanthus with a £500/ha grant and around £28/MWh(e) for SRC without any grants, assuming a ten year investment recovery timeframe.
- Increasing the investment recovery timeframe to 20 years reduces the required support to £15/MWh(e) for Miscanthus with a £500/ha grant and around £17/MWh(e) for SRC without any grants.
- If it were assumed that there was no support from ROCs, and with an investment recovery timeframe of 10 years, the carbon price would need to rise from its current level of €18.40/tCO_2 to €47.70/tCO2 to make co-firing of Miscanthus with a £500/ha grant economic and to €63.90/tCO_2 to make co-firing of SRC without any grants economic.
- Increasing the investment recovery timeframe to 20 years reduces the required carbon prices to €42.80/tCO_2 and €47.65/tCO_2 respectively.

Summary

A summary of the levels of support required for the various options investigated above is shown in Table 11 below, assuming the current commodity and biomass prices.

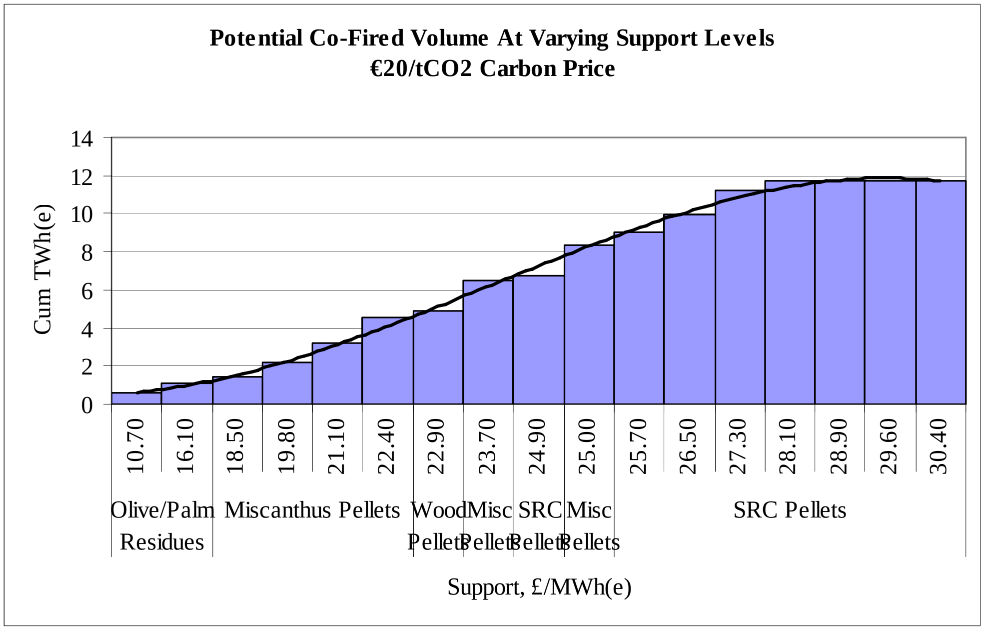
Table 1 - Support levels Required To Incentivise Co-Firing

Option	Fuel	Support Required, £/MWh(e)	Equivalent Carbon Price, €/tCO_2
Co-Milling	Imported Biomasses	18	47.65
Co-Milling	Wood Chips	17	46.00
Direct Injection (10 year investment recovery timeframe)	Baled Straw	35	75.30
Co-Milling	Miscanthus Pellets£1,000/ha Grant	16	44.40
Co-Milling	SRC Pellets No Grant	26	60.65
Direct Injection (10 year investment recovery timeframe)	Miscanthus Pellets £1,000/ha Grant	18	47.70
Direct Injection (10 year investment recovery timeframe)	SRC Pellets No Grant	28	63.90
Direct Injection (20 year investment recovery timeframe)	Miscanthus Pellets £1,000/ha Grant	15	42.80
Direct Injection (20 year investment recovery timeframe)	SRC Pellets No Grant	17	46.00

Resource Cost Curve

- The following figure shows the co-firing volumes at different levels of support, based upon a range of assumptions

Figure 2 - Co-Firing Volumes At Different Levels of Support



- A support level of at least £11/MWh(e) is required to incentivise co-firing.
- A support level of around £30/MWh(e) could potentially deliver around 12TWh(e) of co-fired electricity.
- The cost of Carbon has a significant impact on the level of support required. The lower the Carbon price then the more support that is required.

- **Final Remarks**

From the analysis presented in the previous sections it is clear that, assuming co-fired electricity receives the full value of a ROC, the current forms of co-firing are economic under the Renewables Obligation for a wide range of fuels and stations. In particular, at high coal/carbon prices the level of support required is significantly lower than the full ROC value.

Although the majority of the current co-firing operations are burning imported biomass the relative costs between imported fuels and domestic biomass sources are not great and the economics of burning domestic fuels is not significantly different.

The extra capital costs involved with handling fuels that require more pre-treatment or moving to direct injection to increase the amounts of biomass burnt are not prohibitive,

Overall the modelling suggests that a wide variety of forms of co-firing, with a wide variety of different biomass fuels, would be likely to remain economic at support levels below the current ROC price, assuming CCL and relatively modest support from a carbon price.

It is clear that the commodity prices play an important role in the economics of co-firing, and the level of support required. The range of commodity prices over the last eighteen months show that their effect potentially impacts the level of support required by around £15/MWh(e).

This analysis suggests a range of support between £11/MWh(e) and £30/MWh(e), dependent on the volume of co-firing targeted.

1 INTRODUCTION

As part of the current Energy Review the UK Government is undertaking a review of the co-firing rules in the Renewables Obligation (RO). IPA Energy Consulting, in consortium with Mitsui Babcock, was appointed by the DTI to undertake an investigation into the economics of co-firing biomass at coal plant, the results of which will be used to inform the co-firing review.

Although this report primarily focuses on the co-firing of solid biomass at coal stations, industry has also investigated the use of bio-oils such as palm oil, talloil, as well as burning bio-diesels, to replace the use of liquid fossil fuels such as HFO and gas oil and this report briefly comments on this aspect of co-firing.

The development of co-firing has been stimulated by the introduction of the RO in 2002, the Climate Change Levy (CCL) in 2001, and the European Emissions Trading Scheme (EU ETS) in 2005, all of which provide financial benefits for coal plant to co-fire with biomass. A large number of coal plant within the UK have developed biomass co-firing facilities, and the volume of electricity produced by co-fired biomass has increased significantly to an estimated 2.5TWh over 2005/06. However, caps on the maximum volume of co-fire ROCs that can be surrendered, and an increasing requirement to utilise energy crops within the biomass fuel mix, may reduce the volume of co-firing in the future.

The rules relating to co-firing coal plant were originally developed to stimulate the domestic biomass industry and supply chains, with particular emphasis on the development of a domestic energy crop industry. Initially take-up of co-firing was low but has increased significantly as experience in working with these fuels has increased. It has now become clear that co-firing has the potential to deliver a significant volume of low carbon generation, and with the current high volume of coal plant running, investment in FGD and improved co-firing facilities, co-firing could continue to make a significant contribution in the future.

This report provides an economic analysis of co-firing with biomass at coal plant. It provides an analysis of the economics of current co-firing operations and investigates the economics for future investment options and co-firing with alternative domestic biomass sources and energy crops. The analysis has been undertaken to calculate the economic support required for co-firing with biomass in the absence of the RO mechanism. The analysis has been informed by both primary research and information provided by industry.

The report is structured as follows:

- **Section 2**: Provides a background to co-firing and the Renewables Obligation.
- **Section 3**: Provides a discussion of the technical issues associated with co-firing at coal plant, examining the operational and capital expenditure required for co-firing operations. It examines a range of current and future methods for co-firing, including potential increases in costs associated with burning energy crops and increasing the proportion of biomass in the fuel mix.
- **Section 4**: Provides an investigation into the price and availability of a range of biomass fuels, including a range of imported bio-wastes and bio-fuels, domestic fuels and energy crops.
- **Section 5**: Provides an investigation into the economics of co-firing and examines the levels of support required to enable co-firing to be economic. It investigates the economics over a range of fuel sources and the impact of a range of commodity price assumptions.

In addition, the appendices contain the questionnaire sent to the co-firing companies and information relating to the technical characteristics of boilers under varying co-firing regimes.

2 BACKGROUND

The economics of co-firing have been supported by the introduction of the Renewables Obligation (RO) in 2002, the Climate Change Levy (CCL) in 2001, and the European Emissions Trading Scheme (EU ETS) in 2005, all of which provide financial benefits for coal plant co-firing with biomass. However, it was the introduction of the Renewables Obligation which provided the main stimulus for the development of co-firing. A large number of coal plant within the UK developed biomass co-firing facilities between 2002 and 2005, and the volume of electricity produced by co-fired biomass increased significantly to an estimated 2.5TWh over 2005/06. However, caps on the maximum volume of co-fire ROCs that can be surrendered and an increasing requirement to utilise energy crops within the biomass fuel mix may reduce the volume of co-firing in the future.

Under the Renewables Obligation the percentage of co-fire ROCs that can be redeemed reduces over the period to zero in 2016/17. In addition, the minimum proportion of energy crops within the co-fire biomass fuel increases over this timeframe. The table below shows these constraints.

Table 2 - UK RO Co-Firing Restrictions

Year	Max % of Co-fire ROCs	Min % of Energy Crops in Co-Fired ROCs
2002-2005	25	0
2006-2008	10	0
2009	10	25
2010	10	50
2011-2015	5	75
2016 onwards	0	100

The maximum volumes of electricity that could be produced by co-firing fuels, dictated by the constraints in the table above, are shown in the following table. The table provides the maximum generation potential assuming that the RO is met, there is a sufficient supply of energy crops and demand growth is based on growth indicated by the NGC's Seven Year Statement (2005).

Table 3 – Maximum Co-Firing Under the RO

Year	Potential TWh Produced From Co-Fired Biomass	TWh Required From Energy Crops
2005/06	4.46	0.00
2006/07	2.18	0.00
2007/08	2.58	0.00
2008/09	2.98	0.00
2009/10	3.19	0.80
2010/11	3.43	1.72
2011/12	1.90	1.43
2012/13	2.10	1.58
2013/14	2.30	1.73
2014/15	2.50	1.88
2015/16	2.71	2.03

The number of coal plants co-firing has increased following the introduction of the Renewables Obligation, from two in 2002/03 to sixteen in 2005/06, which represents all of the major coal plants in the UK. The volume of co-firing has also increased significantly: around 1TWh of co-fired ROCs were produced in 2004/05 and this volume has already doubled in the first ten months of 2005/06, with around 2.11TWh co-fired ROCs generated between April and January.

Currently the majority of co-firing has been fuelled by imported bio-wastes such as olive pits and palm kernels, as well as other biomass. The use of energy crops has been limited[1] as there has been limited availability of this type of fuel. The table below gives an indication of the stations that have recently been co-firing and the kind of biomass fuels that they have used.

Table 4 - UK Transmission Connected Co-Firing Capacity and Fuels[2]

Station Name	Station Size, MW	Co-Firing Fuel
Solid Biomass		
Aberthaw	1,553	Wood/Sawdust/Tallow
Cockenzie	1,200	Wood Pellets
Cottam	2,000	5% Blend Biomass - Olive Cake, Wood & some Energy Crops
Didcot A	2,100	2% Energy Crops
Drax	4,000	3% Energy Crops/Wood Pellets
Eggborough	2,000	3.5% Palm Kernels
Ferrybridge	2,035	10% Biomass
Fiddlers Ferry	1,995	10% Biomass
Ironbridge	964	Palm Kernel Expeller
Kilroot	390	Olive Pellets
Kingsnorth	2,034	Cereal Residues
Longannet	2,400	Sewage Sludge/Wood Pellets
Ratcliffe	2,000	None
Rugeley B	1,000	None
Tilbury	1,085	3% Palm Kernel Expeller
West Burton	2,000	5% Biomass Blend – Wood, Shea, Miscanthus
Liquid Biomass		
Littlebrook	685	Palm Oil

Many of these stations have only generated small amounts of electricity from the renewable fraction of the fuel, whilst others have been co-firing commercially for a few years and have produced a significant amount of co-fired electricity. Responses to our questionnaire provided a variety of views on future co-firing operations with some indicating that with the price for co-firing ROCs diverging from the price for ‘normal’ ROCs no further co-firing will take place under the current arrangements, and others looking to increase the amount of biomass burnt e.g. by using ‘direct injection’ burners.

In addition to these large coal-fired transmission connected stations there is a further 377MW of smaller stations that have been co-firing recently. These are shown in the table overleaf.

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[1] In 2005 the amount of Energy Crops burned in the co-firing stations was less than 1% (by mass) of the total biomass burned. Information provided by the DTI.

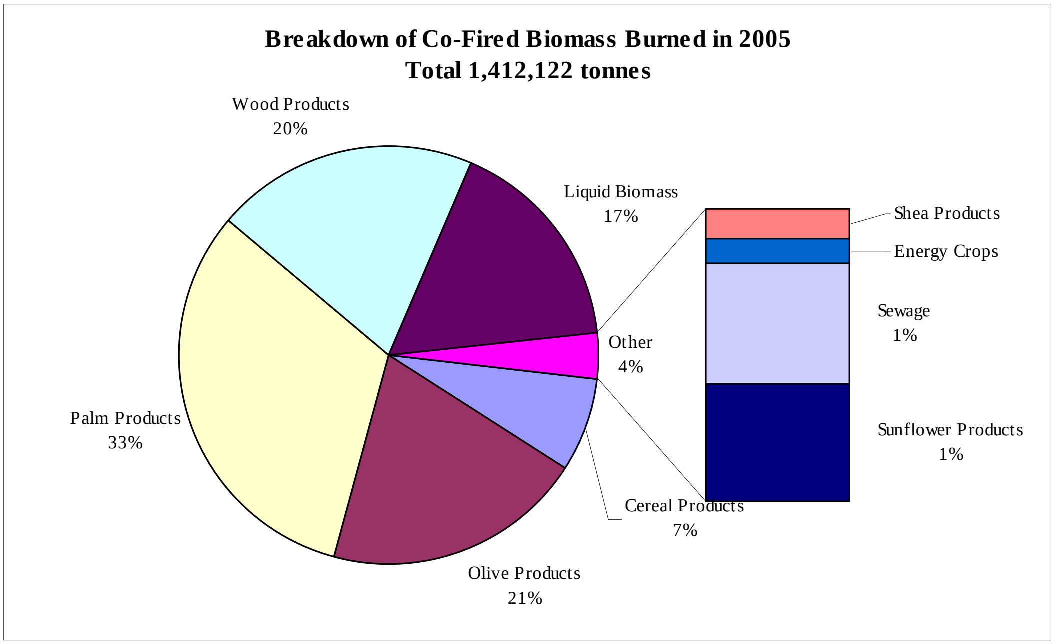
[2] Data provided by respondents to questionnaire and Platts’ Power UK

Table 5 - Other UK Co-Firing Plants[3]

Station Name	Station Size, MW
Avonmouth STW CHP Generation	5.75
Beckton STW Sludge Powered Generator	11.4
Beddington STW	2.52
Crossness STW Sludge Powered Generator	5.9
Deephams STW	3.32
Longreach STW	2.3
Maple Lodge	2.88
Npower Cogen Ltd (Aylesford) CHP	99.8
Shell Green Generation Plant	4.2
Slough Electricity Contracts Ltd	35
The Heat Station	7.14
Wilton International	196.65
Total	376.86

A breakdown of the total biomass burned during co-firing operations for the calendar year 2005 is shown in the following figure. A significant volume of the fuel burnt was imported olive and palm residues. Of the wood fuel used for co-firing the majority was also imported[4].

Figure 3 – Breakdown of 2005 Co-Fired Biomass[5]



It is expected that increasingly UK coal stations will have to compete for the biomass fuels, as there is a growth in co-firing and dedicated biomass generation internationally, with most EU

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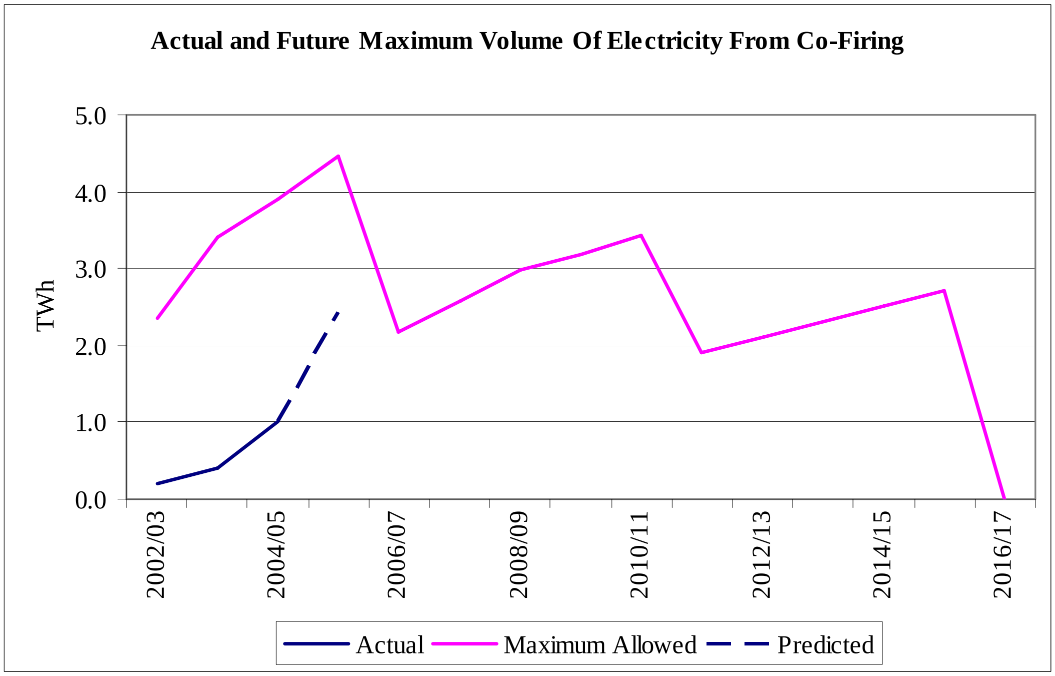
[3] Based on data in Ofgem's list of RO accredited generating stations.
[4] There are no wood pellet manufacturing plants in GB and only one in Northern Ireland.
[5] DTI Information provided to IPA

countries providing some support mechanisms to incentivise the use of biomass in generation (over and above the economic incentives as a result of the EU ETS). There is also evidence from the biomass markets that increasing demand is already beginning to result in upward pressure on the prices of internationally traded biomass fuels. The availability and price of internationally traded biomass fuels could have a significant impact on future co-firing operations in the UK.

It is interesting to compare the volume of co-firing against the RO limits on co-firing volume. Figure 4 compares the actual amounts produced against the *maximum* constraints assuming that the RO is met. It can be seen that the volume of co-firing has been increasing since the introduction of the RO.

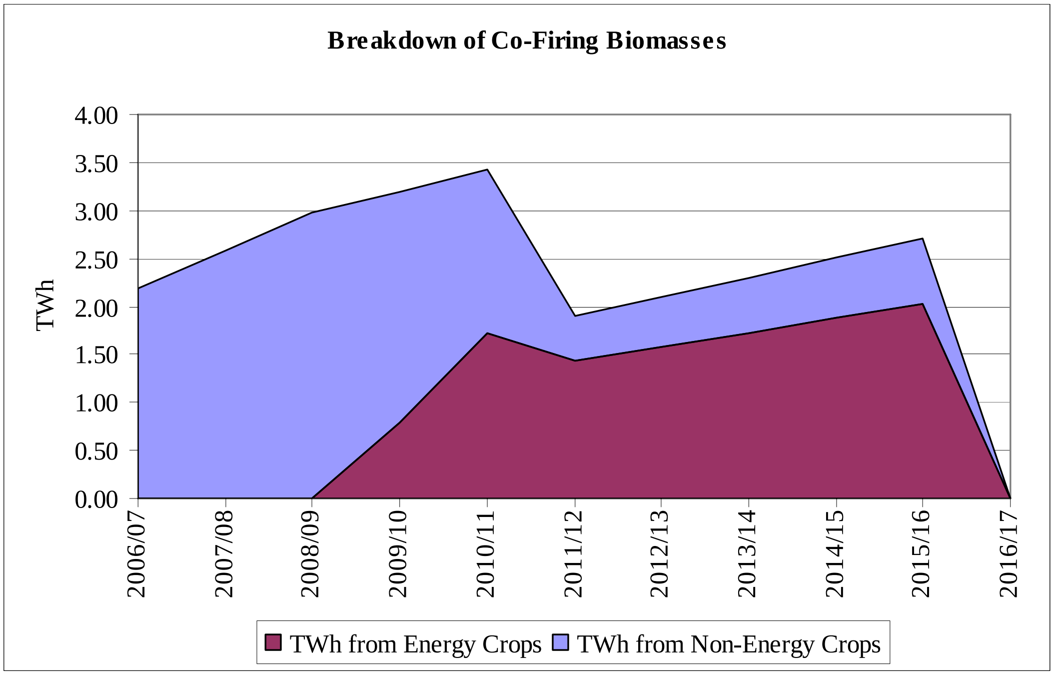
Figure 4 – Actual and Future Maximum Volume of Electricity From Co-Firing Biomass



Until 2006/07 co-fire ROCs have traded at equity with normal ROCs, but the potential to oversupply co-fire ROCs will lead to a collapse in the co-fire ROC price, forcing them to trade at a discount to normal ROCs, with there being no value to ROCs produced in excess to the RO cap. Economic theory suggests that the value of co-fire ROCs should collapse to the marginal additional net costs associated with co-firing, and there is evidence from the market that co-fire ROCs are trading at a significant discount to normal ROCs.

The RO also specifies that an increasing proportion of the fuel used in co-firing has to be derived from energy crops. The maximum potential for co-firing, and potential demand for energy crops are shown in Figure 5. It can be seen that the demand for energy crops to fuel co-firing is likely to increase significantly over the coming years.

Figure 5 –Breakdown of Future Co-Firing Biomasses



This report focuses on the co-firing of solid biomass at coal stations. However, there has also been co-firing of bio-oils such as palm oil, tall oil and tallow (although a number of these products are classified as wastes which raises issues under the Waste Incineration Directive) as well as some interest in burning bio-diesels. The co-firing of bio-oils has been undertaken at a range of different units:

- Coal Stations: A number of coal stations have used bio-oils to replace HFO used for start-up and flame stabilisation;
- Oil Stations: Littlebrook has run a trial using palm oil to replace HFO fuel.
- Gas Turbines: A few GTs with the capability to fire using gas oil have investigated using bio-oils and bio-diesels, with one accredited for ROCs.

The use of bio-oils tends to be simpler than the use of solid bio-fuels for co-firing. Indeed in many cases the experience has been that HFO can be completely replaced by liquid bio-oils with minimal investment and minimal impact on system performance. Littlebrook has been investigating co-firing with palm oil, with the technical potential existing for a dedicated palm oil unit.

As with solid biomass, most of the liquid biomass used for co-firing has been imported, and there are issues associated with both the economics and availability of bio-oils, with international demand for these fuels likely to increase in the future.

3 STATION COSTS OF CO-FIRING

This section investigates the non-fuel costs associated with co-firing, in terms of required capital investment as well as any increase in the level of operating costs. It investigates both the current procedures employed at power stations for co-firing biomass, as well as potential developments to co-firing systems to enable plant to receive, process and fire different types of biomass as well as to increase the level of co-firing possible. This is based on direct involvement in biomass co-firing implementation projects at a number of stations and responses to our consultation to the operators of coal-fired power plants. Our understanding of the current status of co-firing in the UK is shown in the following table.

Table 6 - Current Status of UK Co-Firing Technology[6]

Station Name	Company	Direct Injection/Co-Milling
Aberthaw	RWE	Direct Injection
Didcot A	RWE	Co-Milling
Tilbury	RWE	Co-Milling
Littlebrook	RWE	Co-Milling
Cockenzie	SP	Co-Milling
Longannet	SP	Co-Milling
Cottam	EDF	Co-Milling
West Burton	EDF	Co-Milling
Drax	Drax	Direct Injection
Eggborough	BE	Co-Milling
Ferrybridge	SSE	Direct Injection Planned
Fiddlers Ferry	SSE	Direct Injection Planned
Ironbridge	E.ON UK	Co-Milling
Kingsnorth	E.ON UK	Co-Milling
Ratcliffe	E.ON UK	Not Co-firing
Kilroot	AES	Co-Milling
Rugeley B	IP	Not Co-firing
Uskmouth	Uskmouth Power	Co-Milling

3.1 Co-Milling of Biomass

Most of the coal plant in mainland Britain are currently co-firing biomass materials on a commercial basis. In the main, the biomass materials have been co-fired by pre-mixing the biomass with the coal, either on or off-site. The blended fuel is then processed through the existing coal handling and firing equipment at relatively low co-firing ratios, generally less than 10% on a heat input basis.

This approach to co-firing involves relatively low levels of capital expenditure and can be implemented relatively quickly. This is attractive to the power plant operators because of the uncertainties about long-term biomass fuel supplies, and the time limitations on the eligibility of co-firing within the Renewables Obligation, which put a premium on rapid implementation of co-firing projects.

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[6] Responses to questionnaire

There are, however, limitations on the range of biomass materials that can be co-fired in this way, and on the co-firing ratios that can be achieved. The pre-mixing of the biomass with the coal means that only materials that can be handled using relatively conventional equipment, similar to that employed for coal handling, and that will not “hang up” in the coal conveyors, bunkers and feeders, can be used. Baled biomass materials, for instance, are not considered to be suitable for this approach. To date the principal solid biomass materials utilised for co-firing in Britain have included:

- Imported dry residues from the olive oil and palm oil industries;
- Imported dry sawdust pellets; and
- Indigenous clean wood materials.

To date, the principal constraints on the co-firing ratio have been:

- The availability of the biomass fuel;
- The capacity of the on-site biomass reception, storage, and handling/mixing system, and
- The limitations on the ability of the installed coal milling equipment to process the mixed biomass-coal material.

In general terms, the biomass co-firing projects at the power plants have been reasonably successful, both technically and commercially, and there have been relatively modest impacts on the technical and environmental performance of the boilers at the co-firing ratios that have been employed to date. The majority of the problems encountered to date have been associated with the fuel supply arrangements, and with the on-site storage and handling of the biomass materials.

3.1.1 Capital Costs

The capital costs associated with this pre-mixing approach are almost entirely associated with the requirement for the installation of new on-site reception, storage and handling facilities for the biomass materials, and these have varied significantly. In some cases, the operators initially installed a very basic, temporary biomass handling system, using hired equipment with manual operation, or made use of existing coal handling equipment, to allow the performance of the co-firing trial work required by the environmental regulators at minimum costs, and for the initial phase of commercial co-firing operations.

In most cases, when there was increased confidence in the security of the biomass supplies and the profits available from co-firing, there was investment in more permanent biomass reception, storage and handling equipment. The objectives of these developments were:

- To allow operation at higher co-firing ratios, where the capacity of the biomass handling system was a constraint,
- To provide a higher level of biomass fuel flexibility, and
- To reduce the operating costs of co-firing, for instance the costs associated with off-site biomass storage and delivery, and the additional labour or contract services costs associated with the on-site co-firing activities.

The capital costs of the biomass co-firing systems for the pre-mixing and co-milling option are associated principally with the biomass reception, storage and handling systems. The systems generally comprise:

- The biomass reception area, i.e. the roads and turning areas for the delivery trucks, etc.
- The biomass storage hall and hoppers, etc.,
- The biomass feeders and conveyors, and
- The biomass hopper/feed chutes above the main coal conveyors.

The capital costs of the new equipment depend on a number of factors, the majority of which are fuel and site specific, viz:

- The biomass fuel quality, and bulk density,
- The fuel storage volume requirements,
- The biomass feed rate,
- The coal yard layout and the siting of the reception areas, the biomass storage and handling equipment and the location of the biomass feeding system to the coal conveyors, and
- The extent to which it is possible to utilise existing fuel handling facilities for biomass handling and feeding.

This means that the capital costs, primarily related to costs associated with biomass reception, storage, handling and feeding systems, have varied significantly.

Industry responses to the co-firing consultation yielded costs in the range £200/MW-£1,700/MW of capacity, with costs highly dependent on site specific factors listed above. However, caution is required when comparing these costs as there is likely to be some differences in the way the costs have been reported.

3.1.2 Operating Costs

The operating costs of pre-mixing systems are associated principally with the additional direct labour and contract services costs, with the hire charges for front loaders, etc. and the power and fuel requirements of the handling equipment. These are also highly variable, again depending on the throughput and the site-specific factors.

Perhaps the best way to express the operating costs of the biomass co-firing activities is on the basis of the cost per tonne of biomass co-fired. This will clearly depend on the biomass throughput, the manning levels and the site specific biomass reception, storage and handling arrangements. These factors vary fairly widely from site to site and industry responses to the co-firing consultation gave a range of costs between £3-14/tonne. However, caution is required when comparing these costs as there may be some differences in reporting, for instance some stations may have simply reported the direct operational costs associated with feeding of biomass, whereas others may have included the costs of procurement, monitoring and audit (required for ROC accreditation of output).

In addition to the direct operating costs associated with co-firing with biomass, there can be indirect costs associated with efficiency and reliability, which are discussed further below.

3.1.3 Impacts of Co-Firing on Efficiency and Integrity

The general experience of co-firing of biomass materials with coal by pre-mixing and co-milling has been that provided the mill product is acceptable, i.e. that there are no very large biomass particles, say with a topsize in excess of 2-5 mm, passing to the burners, then the combustion behaviour of the blended fuel has been acceptable. Biomass materials are inherently more reactive in combustion systems than are most coals and, in general, the unburned carbon levels in bottom and fly ashes are similar to, or less than, those that apply when firing coal alone.

- ***Boiler Load***

  The co-firing of biomass materials, and particularly of wet biomass, can have an impact on the maximum achievable boiler load, depending principally on the draft plant and mill constraints, and on the boiler efficiency. At low biomass co-firing ratios and with dry biomass materials with less than 10% total moisture content, the impacts have generally been modest, although there is a tendency for some operators to reduce the biomass co-firing ratio when attempting to maximise the plant output for commercial reasons.

  The reduction in the mill throughput is a result of the lower energy densities of the biomass materials, and of the impact of the biomass material on the mill performance. In general terms, conventional coal mills break up the coal by a brittle fracture mechanism, and most biomass materials tend to have relatively poor properties in this regard. There is a tendency, therefore, for the larger biomass particles to be retained within the mill to some extent, and this can act to limit the co-firing ratio that is achievable in this way. In vertical spindle coal mills, there may be a tendency for the mill differential pressure and the mill power consumption to increase with increasing biomass co-firing ratio, and this may represent a limiting factor.

  This energy density effect has a direct impact on the coal feeder, and possibly the mill throughput, dependent on the physical form of the biomass. Normal power station bituminous coals have an energy density of around 24 MJ m^{-3}. For wood pellets the value is around 14 MJ m^{-3} and for sawdust, either wet or dry, values as low as 4-5 MJ m^{-3} are common. Mixing the biomass materials with coal, therefore, has the effect of reducing the energy density, and hence the volumetric feed rate, of the mixed fuel, at any given feeder speed, depending on the co-firing ratio. The reduced energy density of the mixed fuels will have an impact on the feeder calibration, and may have an impact on the maximum mill throughput.

  The co-firing of wet biomass materials can also have an impact on the heat balance across the coal mills, and this can represent a constraint on the mill throughput, in certain circumstances. Large coal mills employ hot primary air to dry the coal within the mill, and the mill outlet temperature, commonly in the range 70-100ºC, is normally a key mill control parameter. If the fuel is very wet, there may be insufficient heat available in the system, and the mill outlet temperature will tend to drift downwards, out of control. This can present problems for the operator, and this can be a limiting factor on the mill throughput, with wet biomass fuels.

Results of the consultation showed that co-firing especially with higher biomass proportions can result in load reduction, or malfunctioning of mills and feeder systems, resulting in relatively significant additional costs. However, most respondents indicated that load reduction was not a significant issue at co-firing levels currently achieved.

- ***Efficiency***

The co-firing of biomass, and particularly wet materials, can also have an impact on the boiler efficiency. The thermal efficiency of a boiler is normally calculated by summation of the estimated heat losses, viz:

- The losses due to unburned material in the ash discards;
- The heat losses from the chimney; and
- An allowance for radiation and other heat losses, generally around 0.5%.

If a few reasonable assumptions are made, the general effect of biomass co-firing on the boiler efficiency can be calculated solely from the fuel analysis data. The key assumptions are:

- The unburned matter in the boiler ash discards are not affected by the biomass co-firing, this has normally been the case in the biomass co-firing trial work carried out in Britain to date; and
- The boiler efficiencies are compared at the same burner excess air level, and at the same flue gas temperature at the chimney.

These assumptions infer that the only significant impact of the co-firing of the biomass is on the heat losses in the water emitted from the chimney, which is dependent on the total moisture content of the fuel, as fired, and the water generated in the combustion reaction, which is a function of the chemical composition of the fuel. For general comparative purposes, for biomass co-firing at modest co-firing ratios, these assumptions are not unreasonable.

The losses in boiler efficiency increase with increasing mass co-firing ratio and with increasing wood moisture content, as would be expected. In the worst case studied, i.e. with 20% wood co-firing and at a wood total moisture content of 50%, the loss in boiler efficiency, on a Gross Calorific Value basis, is around 1.3%, which is significant, but not excessively high. Effectively, this means that up to 1.3% extra fuel has to be burned to achieve the desired boiler output. The costs of the extra fuel fired can be estimated, and the impact on the economics of co-firing can be estimated fairly accurately. A more common scenario would be the co-firing of relatively dry biomass at 10% moisture at a mass co-firing ratio of 5%. This would result in an efficiency loss of around 0.1%, which is not significant.

The detailed results of these calculations for wood material are presented in Appendix C.

The consultation showed that the impact of co-firing on plant efficiency was minimal, at current co-firing ratios, and was likely to be un-measurable, compared to the natural variations in efficiency with coal quality, temperature etc.

- ***Corrosion and Ash***

  There have been some concerns about the impact of the biomass ash on the performance of the boiler and the flue gas clean-up systems however, with the low ash biomass materials and at the relatively low co-firing ratios currently being applied, the effects have been modest. The same applies to the concerns about the potential impact of co-firing biomass, and particularly those biomass materials that have significant chlorine contents, on the high temperature corrosion of boiler surfaces. To date, no significant impacts have been detected, however these are relatively long-term processes and co-firing is a relatively recent activity. Having said that, the great majority of the biomass materials co-fired in Britain to date have had modest or low sulphur and chlorine contents, and no significant increase in high temperature corrosion rates of boiler components are anticipated.

Overall, it is clear that the co-firing of a range of biomass materials, at low co-firing ratios has been successfully introduced to coal-fired power stations in Britain, and that the impacts on the performance, integrity and environmental performance of the plants have been small.

3.2 Direct Co-Firing of Biomass

Direct co-firing can allow a higher proportion of biomass to be co-fired and can be used to allow co-firing of different biomass fuels that could be problematic for co-milling operations.

In order for coal plant to operate at higher co-firing ratios, a number of the more ambitious coal power plant operators in Britain have begun to invest in new equipment for the direct co-firing of biomass materials, i.e. by-passing the coal mills. Two systems have been in commercial operation for a few months or so, and a number of new direct firing projects will be commissioned and will start commercial operations during 2006. The different technical options for direct co-firing include:

- The direct co-firing of pre-milled biomass materials by pneumatic injection into the pulverised coal pipework.
- The direct co-firing of pre-milled biomass materials by pneumatic injection into modified coal burners.
- The direct co-firing of pre-milled biomass materials through new, purpose designed burners.

This is a relatively novel activity in Britain, and the capital and operating costs of these systems are less well understood than for co-milling.

In most cases, the facilities for the reception, storage and handling of the biomass have to be upgraded substantially, or new facilities have to be installed, to cater for the significant increase in the biomass throughput.

All of the proposed direct co-firing systems involve the pre-milling of the biomass, and all involve the pneumatic conveying of pre-milled biomass from the handling/milling facilities to the boilers. This means that new on-site facilities for the pre-milling and pneumatic conveying of the biomass materials have to be installed or that the biomass is milled off-site and delivered in milled form.

Overall, there are three basic direct co-firing options for the milled biomass, viz:

- Direct injection into the furnace with no combustion air;
- Installation of new dedicated biomass burners; and
- Injection of the biomass into the pulverised coal pipework or at the burner, and co-firing with coal through the existing burners.

A system for the direct injection of the milled biomass into the furnace without a combustion air supply has been installed in a British coal power plant. This power plant has downshot-fired furnaces, which are specifically designed for the firing of low volatile coals. This direct co-firing option is relatively inexpensive and simple to install, but its application in more conventional wall or corner-fired furnaces is considered to be limited for technical reasons.

At the other extreme in capital costs terms, one of the new direct co-firing projects at a British station involves the installation of new, dedicated biomass burners into existing multi-burner coal-fired furnaces. There are a number of technical issues associated with this approach, viz:

- New burner locations, generally within the existing burner belt, have to be identified, and the installation of the biomass burners requires new furnace penetrations;
- New biomass and combustion air supply systems are required, i.e. there are significant modifications required to the existing boiler draft plant;
- The impacts on the performance of the existing pulverised coal combustion systems and the furnace need to be assessed;
- The dedicated biomass burners are based either on modified pulverised coal burners or on cyclone burners, and have not been extensively demonstrated commercially for this type of application, i.e. for the fairly demanding environment in a multi-burner coal furnace; and
- This approach to direct co-firing is relatively complex, and is relatively expensive to install.

The project has not yet been completed, although it is expected that this system will be commissioned in 2006. This approach to the direct co-firing of biomass has been demonstrated in continental Europe with pulverised wood, but not yet in Britain.

The third direct co-firing option involves the injection of the milled biomass into the pulverised coal firing system downstream of the coal mills, i.e. into the pulverised coal pipework or directly into the burners. In both cases, both additional air and additional fuel are being introduced to the mill group, and the mill primary air and coal flow rates have to be reduced accordingly. This should be done in such a way that both the mills and the burners are maintained within their normal operating envelopes, when the biomass co-firing system is both in and out of service. This option is relatively cheap and simple to implement, however there are significant interfaces with the mill control system and risks of interference with mill operation.

The options for the location of the biomass injection point into the pulverised coal firing system are:

- Into the mill outlet pipes local to the mill outlet, which tends to be simplest to engineer since the routing of the biomass pipework is usually easier and the mill outlet pipework is cold, i.e. does not move when the boiler is in service;
- Into the pulverised coal pipework just upstream of the burner, which tends to be relatively more congested and the injection point is into hot pipework, i.e. at this point the pulverised coal pipework moves with the expansion of the furnace, and a suitable degree of flexibility has to built in to the biomass pipework; and
- Directly into the burner.

The first two of these options are very simple and self-explanatory. There are a number of current projects based on these options in Britain and Northern Europe.

The third option involves significant modification of the existing coal burners. There is a current project based on this approach at a coal power station in Britain, and a number in continental Europe.

This approach can also be applied to baled biomass materials. One example of burner modification for this type of application is at Studstrupvaerket in Denmark, where chopped straw is co-fired through the core air tubes of four Low NO_x burners. The pulverised coal is fired through the primary air annulus as normal. This system has been in successful operation for the past three years.

It is fair to say that, in Britain, the progression from co-milling to direct biomass co-firing systems at elevated co-firing levels has only just begun, and a general consensus about the preferred options has not yet emerged. This may occur over the next year or two, as commercial operating experience with the current direct co-firing projects in Britain and elsewhere is gained. Since the direct projects are not yet in full commercial operation, in most cases, the capital and operating costs of the systems are not well understood.

It is clear from the above that there are a number of technical options for the direct co-firing of biomass materials in coal-fired boilers, each of which have significant implications on the capital and operating costs of the systems. In all cases, however, there is a requirement to install new facilities for the reception, storage, handling and milling of the biomass. This is common to all of the options, and the capital costs will depend largely on the nature of the biomass, and on the biomass throughput.

The following estimates of the capital costs of systems capable of providing up to 10% co-firing ratio on a heat input basis (based on conversion of a $500MW_e$ boiler) using dry granular and pelletised material. However, it should be noted that evidence suggests that lower costs may be achievable at some installations.

Direct firing by injection into the coal firing system	£4,000-6,000/MW
Direct firing with significant burner modifications	£6,000-10,000/MW

- Direct firing with new dedicated burners £10,000-14,000/MW

This would mean that the cost for a 500MW unit to install equipment to allow direct firing by injection into the coal firing system, would be between £2M - £3M. This would enable them to burn up to 10% biomass by heat. However, it is important to note that these costs have been derived for a 500MW unit and so are not directly scaleable for larger or smaller plant.

It is anticipated that the additional operating costs of these systems will be associated principally with the reception, storage and handling of the biomass materials, i.e. the direct labour and contract services, the hire of equipment, the fuel and power consumption of the biomass mills, conveyors and blowers, handling plants etc. and will be similar to those for the co-milling systems.

3.3 Co-Firing Energy Crops

The co-firing scenarios investigated so far in this section have primarily investigated co-firing with dry granular and pelletised material that is delivered to the station gate. However, as co-firing plant begin to utilise energy crops they may develop systems that can process and handle baled material (miscanthus) and chipped wood materials with relatively high moisture contents (SRC).

Systems for the processing of baled biomass need specialised bale handling systems and storage arrangements[7], the systems required for the breaking of the bales, and the handling and comminution of the loose material. These systems tend to be relatively expensive. As a rule, baled materials can not be fired readily through dedicated burners, but generally need to be fed into the pulverised coal pipework just upstream of the burner, so firing is supported by coal firing through the same burner.

The following are estimates of the capital costs of systems capable of providing up to 10% co-firing ratio on a heat input basis (based on conversion of a $500MW_e$ boiler) using baled materials.

- Direct firing of baled materials £20,000-28,000/MW

The costs associated with co-firing high moisture content chipped SRC are likely to be lower than for baled materials, and it is possible to co-mill high moisture wood chips at relatively low biomass fuel mixes. However, to increase co-firing burn additional capital expenditure may be required, and it may be desirable to undertake processing and, potentially, drying on-site.

3.4 Additional Co-firing Options

3.4.1 Manufactured Fuels

There is potential to manufacture fuels for co-firing that are coal-biomass mixtures. This approach has not been pursued in Britain largely due to the perceived difficulties associated with the required auditing under the Renewable

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[7] Although it is likely that storage would occur "on the farm" and only short term storage would be required.

Obligation. However, these manufactured fuels could provide a methodology for burning higher volumes of biomass whilst avoiding significant Capex expenditure at plant.

3.4.2 Gasification or Separate Combustion

There are also other methodologies for co-firing at existing coal plant, including:

- The indirect biomass co-firing systems involving gasification of the biomass and firing of the product fuel gas, with or without prior cleaning; and
- The indirect biomass co-firing systems involving the combustion of the biomass in a dedicated boiler, with integration of the steam with the installed coal boiler steam circuits.

However, we are not aware of any proposals to investigate these types of operations at any of the existing coal plant in Britain, and so it is difficult to provide meaningful and authoritative capital and operating cost estimates for these future options. These co-firing options are not explored further in this report.

4 BIOMASS FUELS – ECONOMICS & AVAILABILITY

A wide range of different types of biomass fuels can be used for co-firing, although the qualities of the fuel can have a significant impact on the equipment required for handling, milling and combusting the material. Under the RO, biomass fuel sources have been categorised either as biomass or as energy crops, with energy crops defined as “a plant crop planted after 31st December 1989 and grown primarily for the purpose of being used as fuel”[8]. Currently co-firing has been predominantly focused on utilising general biomass due to its superior availability, physical characteristics and cost. However, currently under the RO, stations will have to have an increasing proportion of energy crops within the fuel mix to enable the output to qualify for ROCs.

This section investigates the economics and availability of different types of biomass, which are critical to the economics and practicality of co-firing both now and in the future.

4.1 Imported Biomass Products

To date most co-firing operations at coal fired plant have focused upon using imported biomass waste products as the biomass component of the fuel stream. The main solid biomass products that have been used include:

- Wood Products (sawdust, wood shavings, wood pellets, wood chip);
- Olive Products (cake, pellets); and
- Palm Products (kernels and residues)

The use of these biomass materials reflects price, availability and the ability to fire the materials by pre-mixing with coal and co-milling (requiring limited capital investment).

4.1.1 Imported Biomass Prices

There is an international market in these biomass waste products; quoted prices for these products are shown in Figure 6 below. However, the markets for these products are not liquid and prices can vary with supply and demand. Both Olive and Palm residues may be diverted to animal feed and demand levels can impact upon market prices. Wood Pellets are typically imported from Scandinavia, the Baltic states and North America, and some countries such as Sweden and Austria have developed standards for the properties of wood pellets, with the moisture content of the Swedish pellets less than or equal to 12%.

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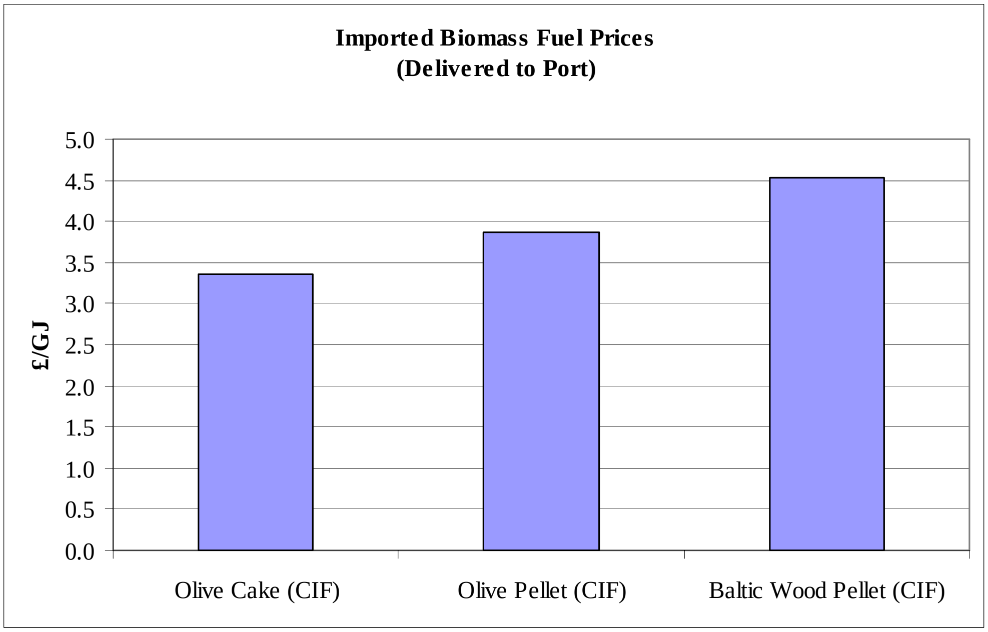
[8] The Renewables Obligation Order 2006, Statutory Instrument 2006 No. 1004

Figure 6 - Biomass Prices (CIF)[9]



An advantage of sourcing biomass from international markets is that it can be delivered in bulk and so frequently can utilise the transport routes that have been used for importing coal, which enables stations to minimise the additional transport costs.

Biomass prices are typically quoted as CIF[10] prices, so in addition to the price for the biomass, the station has to factor in UK port costs and handling charges and inland rail freight costs. These costs vary significantly across the different coal stations, dependent upon the location of the plant and the contractual arrangements for deliveries through the nearest port and shortest rail infrastructure. The responses to our questionnaire reported a significant range for these costs from around £0.10/GJ to £0.90/GJ. Our analysis uses the mid-point of this range: £0.50/GJ.

Incorporating these transport costs into the delivered price at the station gate gives a delivered price for imported biomass products between around £3.80/GJ and £5.00/GJ.

Responses from the consultation process indicated delivered fuel costs within the range of £3.50/GJ to £5.40/GJ: a slightly wider range than those derived from public information. Indications of future biomass costs also showed a wider range.

4.1.2 Imported Biomass Availability and Volumes

This section looks at the availability and volumes of biomass sources currently used for co-firing.

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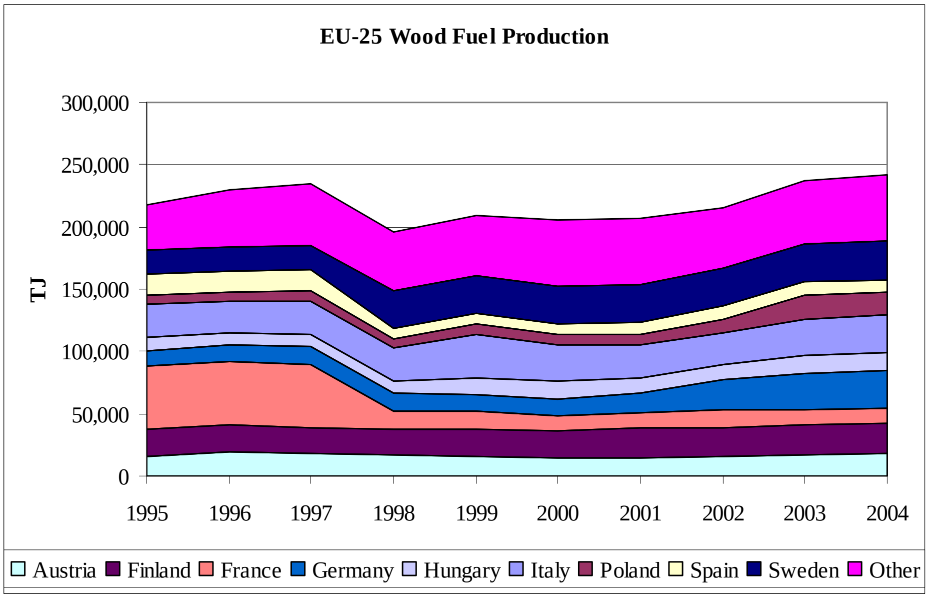
[9] CIF – Carriage, Insurance & Freight. Prices delivered to Immingham, from Platts, Power UK, July 2005
[10] ie inclusive of sea freight, insurance etc

- ***Wood Fuel and Residues***

Wood Fuel Production in the EU has increased slightly over the last ten years. The graph below shows the production from the various EU-25 countries[11] converted to TJ using a net calorific value of 19.25MJ/kg[12] for dry material. The three main producers of wood fuel are Sweden, Italy and, more latterly, Germany, with almost 40% of the total production in 2004 between them. Finland also produces around 10% of the total production.

Data from the United Nations Economic Commission for Europe (UNECE) indicates that in 2000 around 35 million cubic metres of Wood Fuel was produced in Western Europe[13]. This accounted for around 13% of roundwood production in Western Europe[14]. It also predicts that wood fuel production in Western Europe will remain around the 2000 levels over the period from 2000 to 2020. However, this seems to be rather conservative, given the recent growth.

Figure 7 - EU-25 Wood Fuel Production



As most of the wood fuel grown is used in heating applications throughout the countries in which they are grown it is unlikely that significant volumes would be readily available for co-firing. However, given sufficient economic pull increases in production could be possible and further volumes could be made available.

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[11] Food and Agricultural Organisation of the United Nations FAOSTAT Data 2005. http://faostat.fao.org/faostat/collections?version=ext&hasbulk=0&subset=forestry

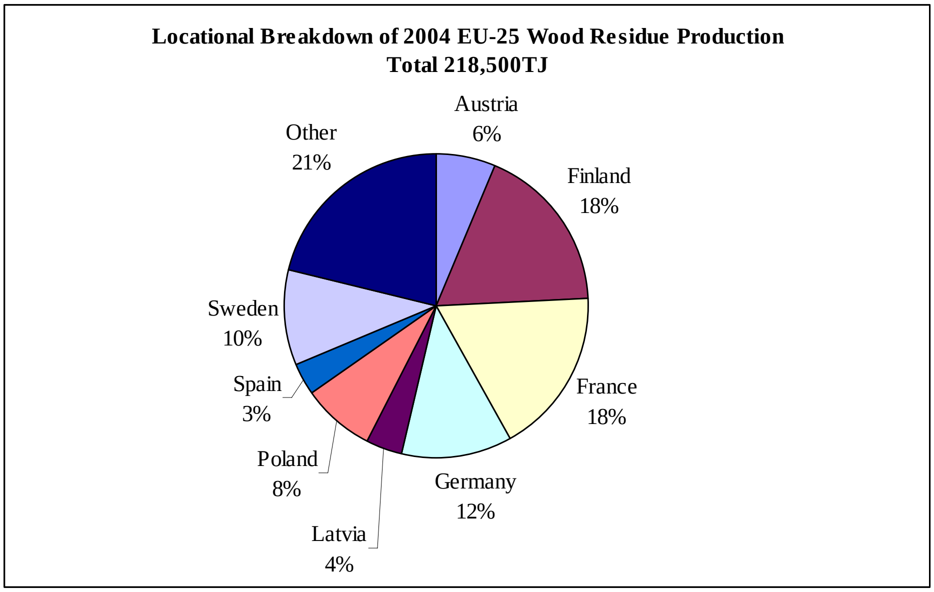
[12] Wood Fuels Basic Information Pack, Jyvaskyla, 2000

[13] Western Europe is defined as comprising the 18 countries of: Austria, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and United Kingdom.

[14] Derived from data from United Nations Economic Commission for Europe, European Forest Sector Outlook Study 1960-2000-2020, http://www.unece.org/trade/timber/docs/sp/sp-20.pdf

Perhaps more applicable to co-firing would be Wood Residues, which are produced as the by-product of forestry operations and roundwood production. Data from the FAOSTAT[15] indicate that similar volumes of wood residues are produced. The locational distribution of these residues for 2004 is shown in the following figure.

Figure 8 – Locational Breakdown of 2004 EU-25 Wood Residues Production



These residues could be manufactured into pellets and used in co-firing applications. However, not all of the resource will be available as it already has alternative markets such as for animal bedding and chipboard manufacturing.

In addition to the EU production of wood fuel and wood residues, wood pellets/chips have been imported from some of the non-EU Baltic states, which have significant resource potential. However, there have been some issues with the availability of imports of Wood Products, particularly in the winter months when the Baltic ports are liable to become ice-bound.

- ***Olive Residues***

Olives are only produced in seven of the twenty-five EU countries and production is dominated by Spain and Italy which, between them, produced around 75% of the total produced in 2005.

The residue from olive oil production constitutes more than 80% by mass of the olives collected[16] and has a net calorific value of around 20MJ/kg[17]

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[15] Food and Agricultural Organisation of the United Nations FAOSTAT Data 2005. http://faostat.fao.org/faostat/collections?version=ext&hasbulk=0&subset=forestry

[16] Utilisation of Olive Husks For Energy Generation: A Feasibility Study, Dr Bassam Dally & A/P Peter Mullinger, University of Adelaide

[17] http://www.ieabcc.nl/database/biomass.php

dry. Using these conversions and historic olive production figures[18] gives the following historic potential energy from olive residues in the EU-25.

Figure 9 - EU-25 Olive Residue Production

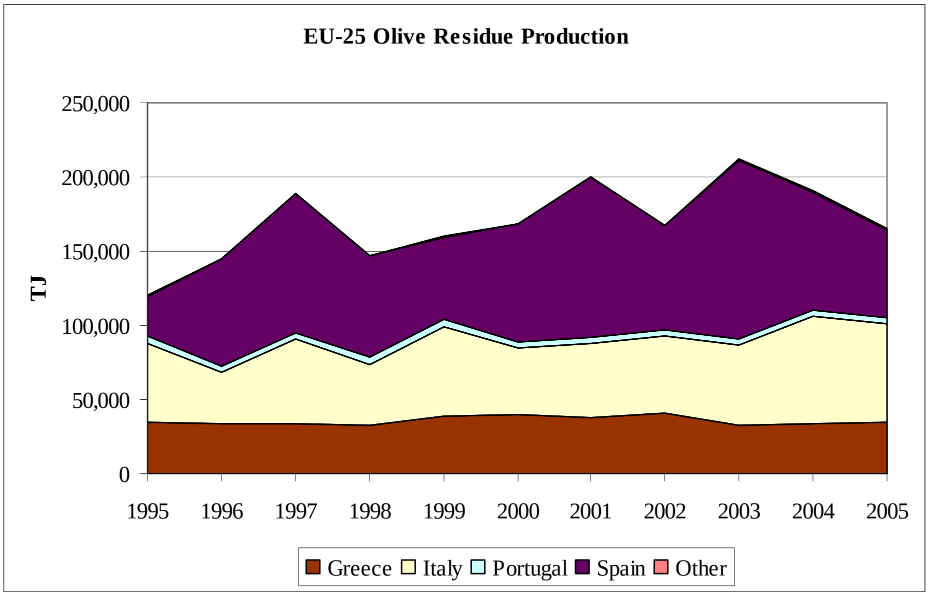
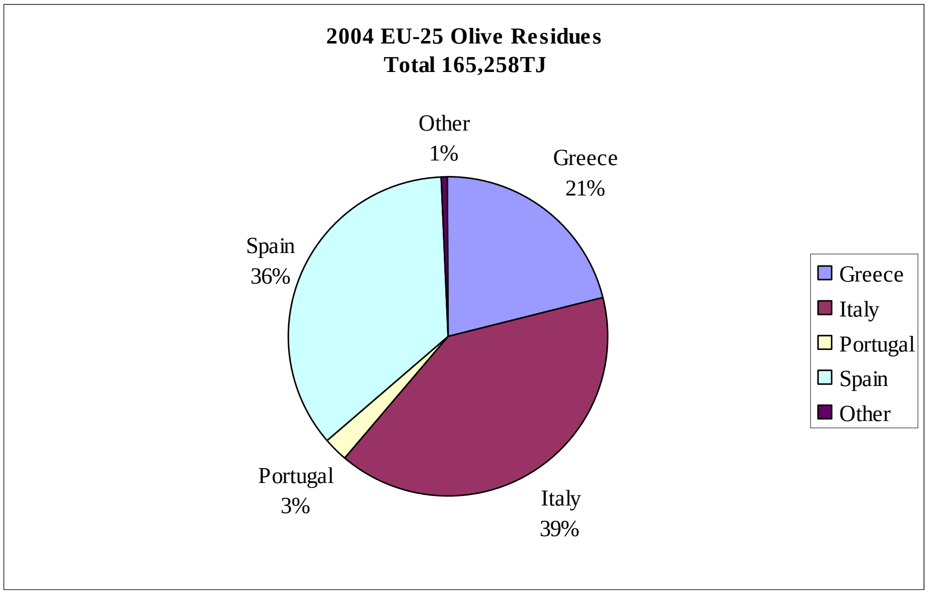


Figure 10 – Locational Breakdown of 2005 Olive Residue Production



- ***Palm Oil Residues And Palm Kernels***

Residues from oil palm production comprise around 44% of the fruit production; this takes the form of Empty Fruit Bunches (EFBs), shell and

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[18] http://faostat.fao.org/faostat/form?collection=Production.Crops.Primary&Domain=Production&servlet=1&hasbulk=0&version=ext&language=EN

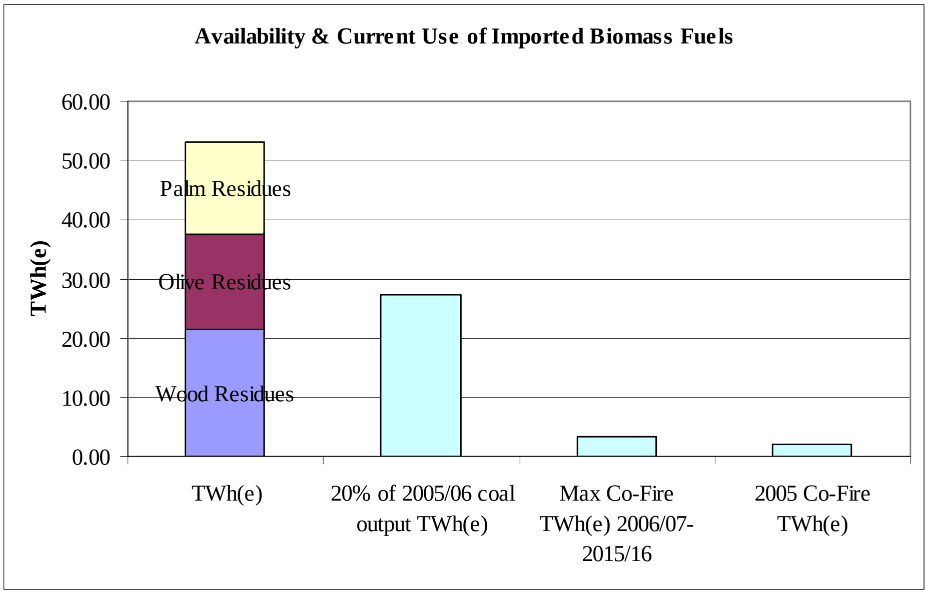
fibre[19]. The energy content of these residues depends on the moisture content, with EFBs having a net calorific value of around 4.4MJ/kg and shells having a net calorific value of around 13.4MJ/kg. The shells make up around 7% of the fresh fruit bunches.

World production of oil palm has almost doubled over the past ten years, from 88 million tonnes in 1995 to 173 million tonnes in 2005[20], and this is likely to continue to increase as the potential for use of palm oil as a liquid biomass fuel is further developed. Assuming that shells make up 7% of the production, the mass of palm shells available has risen from 6 million tonnes in 1995 to 12 million tonnes in 2005. This is equivalent to approximately 168,800TJ.

- ***Summary***

A comparison of the volume of biomass wastes available against potential demand from UK coal stations is shown in Figure 11[21]. It can be seen that there is sufficient potential fuel to satisfy any reasonable UK fuel requirement from co-firing. Although current demands from co-firing have only used in the order of 4% of the resource, UK plant could theoretically utilise a significant proportion of this resource. However, not all of these potential fuel sources will be available for UK generation. Many of the fuel sources have alternative markets: olive and palm residues can be used as supplements to animal feeds and wood fuel has a range of alternative markets ranging from heating fuel to animal bedding. In addition, all of these biomass fuel sources are likely to see increasing demand from dedicated biomass generation and co-firing coal generation across the EU and internationally.

Figure 11 - Availability & Current Use of Biomass Fuels



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[19] The Bronzeoak Group, Maximising Energy Recovery From Palm Oil Wastes
[20] The Food and Agriculture Organization of the United Nations, www.faostat.fao.org
[21] Using a station efficiency of 35%.

4.2 Domestic Biomass Products

There are a number of domestic biomass products that could be used in co-firing. These include

- Forestry & Wood Processing Residues;
- Arboricultural Arisings; and
- Straw and Cereal Residues.

However, a number of potential biomass fuels are classified as wastes and so cannot be used in a non-compliant Waste Incineration Directive[22] plant, which includes most coal plant in the UK and so any biomass product that is classified as a waste could not be utilised as a fuel. This means that although biomass (or the biomass component of waste (BMW) or refuse derived fuel (RDF)), sewage sludge/pellets, poultry & pig manure, treated wood waste, and meat & bone meals could all be used as fuel for electricity generation, they are unlikely to provide a fuel source for co-firing[23].

4.2.1 Forestry

Forest cultivation is primarily focused on producing round wood for the wood processing industry. However, there is a sufficient amount of waste material that could be used as fuel for electricity generation. This includes forestry residues as a result of thinning operation and harvesting (stem tips and branches), sawmill wastes (sawdust and chips) and untreated wood from processing/manufacturing (shavings, chips).

There is a significant volume of forestry and processing residues (in the order of 2.6m odt/y[24,25]). However, a significant volume of this is utilised for different purposes ranging from chipboard manufacturing to animal bedding and onsite fuel for boilers. It is estimated that around 83% of total conversion (processing) products (sawdust, bark and chips) are already sold to the wood processing industries, with around 50% of forestry residues also being provided to competing markets. This would give a potential resource that could be available for co-firing of around 1m odt/yr, although there is the potential to increase this volume with increased collection and utilisation of harvesting residues[26]. At a net calorific value of 19.25MJ/kg (dry) this gives a resource of around 19,250TJ/yr.

The volume of available wood fuel varies significantly across the UK, with Wales and Scotland having areas with significant resource availability. Forestry residues require collection from point of harvest which, by its nature, is dispersed and, while processing residues can be relatively large point sources of material

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[22] Directive 2000/76/EC of the European Parliament and of the council of 4 December 2000 on the incineration of waste.

[23] Scottish Power are currently co-firing sewage with coal at their 2,300MW Longannet station. Although a court ruling in 2004 said Longannet must be upgraded to meet the requirements of the EU Waste Incineration Directive, SP have reached an agreement with the Scottish Environment Protection Agency that co-firing, the burning of sludge, is currently the best practical option for the immediate future while a longer term solution is sought.

[24] Oven Dried Tonnes refers to the weight of the product at 0% moisture content.

[25] Woodfuel Resource in Britain, FES B/W3/ 00787/REP/1, DTI/Pub URN 03/1436, 2003 Volume in the absence of competing markets.

[26] REC109-05 EU Commission biomass action plan, December 2005

(saw mills are a major source), these sources are predominantly relatively close to forestry areas.

Wood residues are basically waste products and so have very limited production costs. However, additional collection of forestry residues could have a production cost associated with collection and roadside chipping[27] of around £0.80/GJ. However, most of the residues have alternative markets which set a price for the products. A study commissioned by the Scottish Enterprise Forest Industries Cluster[28], indicated that wet sawdust ranges in price from £3-6/t ex-mill and wet Wood Chips around £10/t. However dry materials are sold for a variety of different purposes from chipboard manufacturing to animal bedding, which has a market value in the order of £40-50/t. With a net calorific value of around 14MJ/kg[29] this gives a fuel cost of around £3.20/GJ.

The relatively diffuse nature of wood residues means that transportation to the power station gate is likely to require road haulage, which adds a significant delivery cost to the price. Road haulage costs are likely to be in the range 1.6-2.0p/GJ/km[30]. In addition there may be some handling costs both at forest/sawmill and station, increasing delivery costs by around 2.8p/GJ.

Assuming a collection radius of 40km around the power station, the delivered cost of Wood Chips to the station gate would be around £4.40/GJ.

- ***Arboricultural Arisings***

  Trees and Woodlands are managed intensively in urban areas due to their proximity to roads, buildings, structures and services. Arboricultural arisings refer to the woody arisings from harvesting, pruning and safety operations that are carried out in urban areas, semi-rural areas and at rail and road sides on single trees or small copses. Much of this work is done by Councils and Local Authorities, but private arboricultural and forestry contractors also harvest and process significant quantities of biomass each year.

  Data from the DTI indicates that there are around 472,170odt/yr of Arboricultural Arisings available in GB[31]. Assuming a net calorific value of 19.25MJ/kg (dry matter) this equates to 9,100TJ/yr, although in practice this is likely to vary significantly depending on the composition of the arisings. Much of the arboricultural arisings collected in GB are used for composting. However, if the price was sufficient, and the quality of the fuel could be guaranteed, there is the potential that this could be diverted for co-firing.

- ***Straw and Cereal Residues***

  Straw is mostly regarded as a low-value waste. The value of straw depends upon the crop, with high quality barley straw having a value, and wheat straw typically being treated as a waste with a cost of disposal. The most common method for disposal (particularly for wheat straw) is incorporation

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[27] Wood Fuels Basic Information Pack, Jyvaskyla, 2000

[28] “Wood Pellet Manufacture in Scotland” A Report Produced for Scottish Enterprise Forest Industries Cluster, November 2003.

[29] Net CV at 25% moisture content, Wood Fuels Basic Information Pack, Jyvaskyla, 2000

[30] Calculation based upon Transport Cost Tables, Motor Transport, 17-11-05, Reed Business Information

[31] Woodfuel Resource in Britain: Appendices FES B/W3/ 00787/REP/1, DTI/Pub URN 03/1436, 2003

into the land where straw is chopped and incorporated into the soil during tillage operations after harvest, although it provides little nutrient value for growing crops. Alternatively it can be used as a fuel in a suitable on-farm boiler, raising heat for hot water and buildings, and grain drying and other operations such as protection of horticultural crops. High-quality straw (mainly barley straw) is baled and used for forage and for bedding of stock. Recent information indicates that farmers can sell straw at between £20-70/t[32].

Straw can also be baled for power generation, although haulage logistics limit this trade. There is currently one straw burning power station in operation near Ely in Cambridgeshire. This £60-million, 36MW facility generates 271.5GWh of electricity a year. The 200,000t/yr (about 2% of UK straw production) of straw needed, is procured through long-term contracts with local farmers with costs around £35/t at the power station door. The price paid to farmers for straw in the field was £2/t (long term contracts), the rest of the cost was made up of baling, storage, transportation etc.

It is estimated that another 2-3 million tonnes of straw could be available to power stations without influencing supply or prices for livestock farmers. The seasonal nature of straw production may limit its use for co-firing, since it is unlikely to be economic to provide long term storage, especially as there is likely to be some degradation of the biomass fuel stock. The availability of straw varies considerably over the UK, with large straw surpluses in Norfolk, Cambridgeshire, Lincolnshire and East Yorkshire, meaning that at least some power stations could have a reasonable volume of straw available within an economic catchment area.

Straw has a net calorific value of around 17.5MJ/kg[33] (dry). Thus, there is around 43,650TJyr of energy available from straw.

Straw would likely to have to be collected from the farm gate and transported to the power station by road. The costs of road transport are likely to be in the range 1.9-2.3p/GJ/km[34], with handling costs of the baled materials both at the farm and station costing around 11p/GJ.

Assuming a collection radius of 40km around the power station, the delivered cost of straw to the station gate would be around £4.80/GJ.

- ***Summary***

A comparison of the volume of domestic biomass wastes available against potential demand from UK coal stations is shown in Figure 12 below[35]. It can be seen that there is sufficient domestic biomass waste to meet the co-firing requirements. However, not all of this waste is available for co-firing due to alternative markets, such as animal bedding and chipboard manufacture. Also, the resource economically available to power stations may be less than the total amount available. The further away from the power station that the resource is located, the higher the transport costs and

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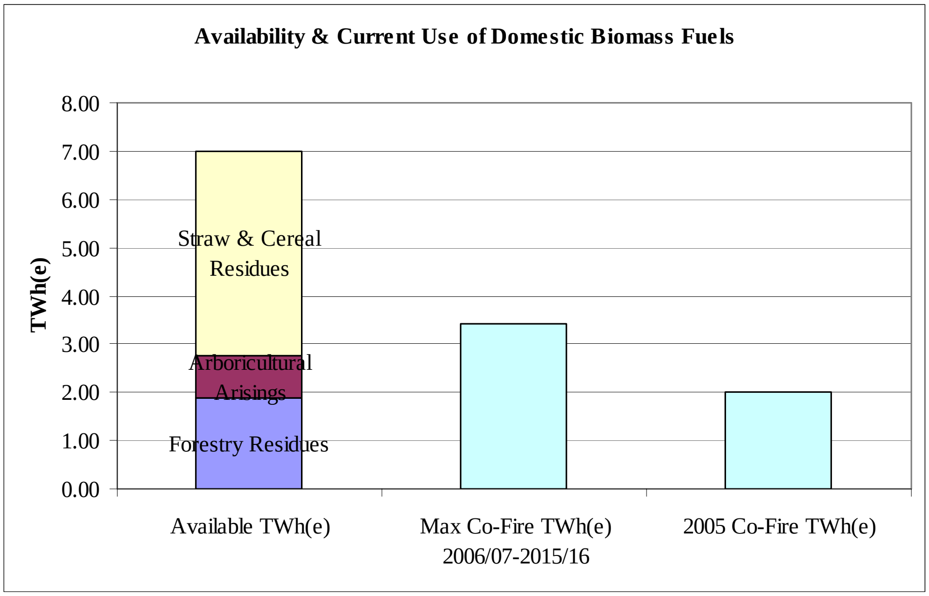
[32] Stackyard news, Dec 05, www.stackyard.com/news/2005/12/crop/spring_barley_trials.html
[33] http://www.ieabcc.nl/database/biomass.php
[34] Calculation based upon Transport Cost Tables, Motor Transport, 17-11-05, Reed Business Information
[35] Assuming a station efficiency of 35%.

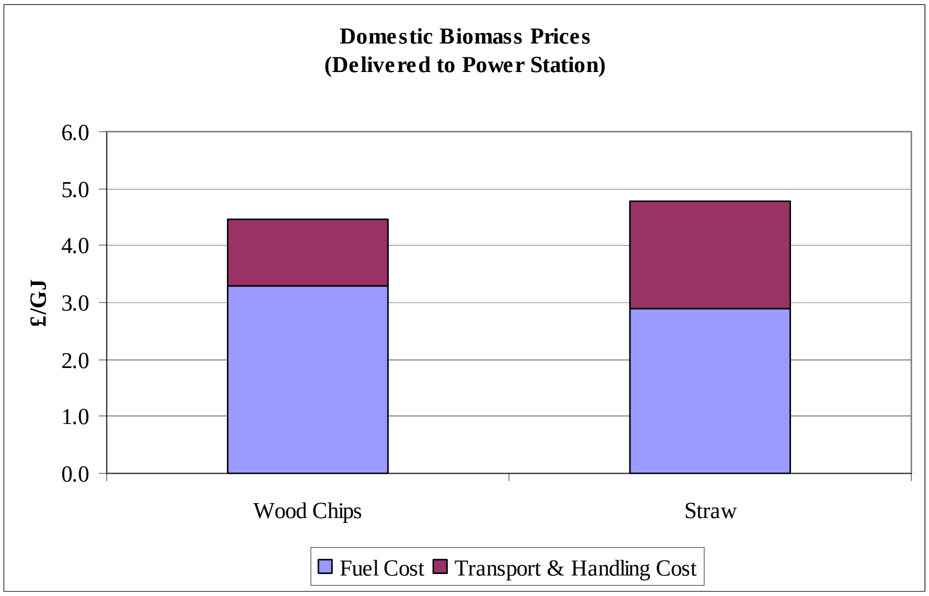
there will be a distance from the station beyond which it will not be economic for the station to transport the fuel.

Figure 12 – Potential Availability of Domestic Biomass Fuels



Estimates for the delivered prices of the associated fuels are shown in the following figure.

Figure 13 - Prices of Domestic Biomass Fuels



4.3 Energy Crops

To date the cultivation of energy crops within the UK has been extremely limited and, as a result, there have not been significant volumes of energy crops co-fired at coal generating stations in the UK, or indeed at dedicated biomass stations.

There have been a number of studies both within the UK and internationally on the merits of the use of different solid biomass energy crops for power production. The crops thought to be most suited to conditions within the UK are Short Rotation Coppice (SRC) – for example Willow and Poplar, and giant grasses, such as Miscanthus. Other grasses such as Reed Canary Grass, Switchgrass and Spartina have also been studied, but Miscanthus is the crop that is likely to dominate planting plans.

The economics of burning Energy Crops are dependent upon several parameters such as the yield, cultivation costs, grants and transport costs. These are discussed in more detail below.

4.3.1 Yields

Yield, cultivation practices and energy contents for different crops have a significant impact on the economics of cultivation. The yield patterns and net calorific values for SRC and Miscanthus are discussed below.

- ***Short Rotation Coppice***

  SRC may be harvested 6 – 10 times and has a productive life of between 25 – 30 years, although yields may decline over time. SRC typically has a relatively long establishment period with the first crop available 3-4 years after planting. The theoretical yield of SRC is equivalent to 33 oven dried tonnes (odt) /ha/year, which has been achieved by small scale trials in Sweden. However, yields vary due to variations in soils and climate and UK trials have yielded between 8-17 odt/ha/year at the first harvest.[36]

  The Calorific Value of SRC varies by species and moisture content. Willow has an average energy content of 18.6MJ/kg (dry) or 10.5MJ/kg (wet) at an average moisture content of 43.5%[37].

- ***Miscanthus***

  Miscanthus is harvested annually, with the exception of the first year when the plant is being established. The theoretical maximum yield of *Miscanthus* is 55 odt/ha/year. However, trials in Europe have achieved around 24 odt/ha whilst in Ireland and the UK yields of between 11 and 16 odt/ha have been achieved.

  The timing of maximum production will depend on location and climatic conditions and may last between 2 to 5 years. Yields will tend to decline from 10 years onwards, although Miscanthus plants will survive up to 20 years. The calorific value of Miscanthus is around 17MJ/kg (dry)[38].

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[36] Short Rotation Coppice and Wood Fuel Symposium, Forestry Commission Edinburgh, Armstrong, 2000.

[37] Energy from Crops, Timber and Agricultural Residue, Towers *et al*, 2004.

[38] Best Practice Guidelines for planting and growing *Miscanthus*, DEFRA.

4.3.2 Cultivation Costs

The costs of cultivation include:

- Planting: SRC/Miscanthus are not farmed from seed, so the cost of purchasing and planting the cuttings/rhizomes is significantly greater than with many other crops;
- Land maintenance: Including preparation of land, application of fertiliser, spraying, etc. There could be some limited increased costs associated with land preparation where set-aside land is being brought back into cultivation; and
- Harvesting: Cost of harvesting crops and any on-site processing (chipping/baling/air drying) of the crop.

Establishing cultivation of energy crops has relatively high costs due both to the costs of purchasing the rhizomes/cuttings and the costs associated with planting (in addition, commencing cultivation of a new crop may also require purchase of new agricultural equipment).

It is important to note that the SRC establishment period can be up to a period of four years before the first harvest. This would mean that coppice planted in 2006 would not be harvested until 2010. *Miscanthus*, however, can be harvested after the first year of planting. However, the plants provide a perennial crop, and in the case of SRC can be cultivated for up to 30 years. This means that the economics of cultivation have to be investigated in terms of the cash flows over the crop lifetime.

The costs of energy crop cultivation have been estimated using a bottom-up approach[39] and this has been developed here to calculate a typical farm-gate price at which energy crop cultivation is economic. The farm-gate prices are investigated in Table 6, using different investment time scales and a discount rate of 10% real. The cost calculations do not include any subsidies or agricultural support payments.

Table 7 - Typical Farm-Gate Energy Crop Cost (No Grants)

Investment Time Scale	SRC £/GJ	Miscanthus £/GJ
10 Year	2.93	2.15
15 Year	2.43	1.86
20 Year	2.05	1.76

It can be seen that due to the high establishment costs and the ability to harvest the crop over relatively long periods, the costs of the crop decrease with a longer discounting period. Miscanthus tends to be a lower cost crop than SRC especially when economics are calculated over relatively short investment time-scales (<10years), due to the higher initial costs and longer crop cycles associated with SRC. However, the costs of SRC decrease significantly with longer investment time scales and SRC may be the cheaper crop for some locations when

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[39] "A Review of the Potential of Giant Grasses for UK Agriculture", Scottish Agricultural College, DEFRA Project Code NF0419, 2001

considered over a 30 year horizon (local conditions may determine the most economic crop).

This analysis suggests that one of the main factors that could influence the choice of crop will be the certainty over the long term market for the energy crops, (as well as the lead time for the delivery of the first crop). SRC is unlikely to be developed unless there is a reasonable prospect for a long term market for the energy crop.

There are a range of subsidies and grants related to the cultivation of energy crops. The funding comes from a variety of sources including the EU, HM Treasury as well as the Devolved Administrations. The value can vary significantly, dependent upon the categorisation of the land, the energy crop and the administration. Most of the UK grants are currently under review, but it is understood that the current schemes are likely to be continued in some form in the future. There is typically greater support for cultivation of SRC reflecting the higher establishment costs, with England being the only administration providing support for cultivation of Miscanthus.

The analysis presented here investigates the impact of different levels of establishment grant on the economics of cultivation for SRC and Miscanthus. Table 7 shows results for a range of establishment grants between £500/ha and £1,000/ha, which spans the range of grants currently available.

Table 8 - Typical Farm-Gate Energy Crop Cost with Range of Grant Values

10Year @ 10%	SRC £/GJ	Miscanthus £/GJ
No Grants	2.93	2.15
£500/ha	2.35	1.66
£750/ha	2.06	1.42
£1,000/ha	1.77	1.18

Cultivation of crops for energy use is permitted on set-aside land in the UK as this constitutes a non-food source. The Single Farm Payment Scheme (SFPS) includes a payment for set aside land. However, since set-aside land could be eligible for these grants, irrespective of whether they are used for energy crops cultivation, they have been excluded from this analysis.

As energy crops are a relatively new crop, farmers may attach a “risk premium” to the option – meaning that they could be looking for higher initial returns than for some more established crop options. Farmers are also likely to compare the returns for planting energy crops against other food or industrial crop options (such as biomass products for the Renewable Transport Fuel Obligation) – thus persuading a farmer to plant may not be simply a case of meeting a calculated return threshold – or the threshold may be higher than a pure costs against revenue calculation might suggest.

4.3.3 Storage & Processing Costs

Energy crops will typically provide a seasonal fuel source, with Miscanthus harvested between January and March and SRC during the winter, after leaf fall and before bud-break, usually mid-October to early March. The type of harvesting machinery used will depend on the biomass fuel and end-user's requirements, but it is likely to be provided in either a chipped or pelletised form. Additionally, the energy crops will need to be stored both to smooth out the supply and to reduce the moisture content of the energy crop. Different harvesting options for SRC and Miscanthus are discussed below.

- ***SRC***
  - **Rod Harvesting**

    Once harvested, rods are typically offloaded into heaps on the headlands or on farm. There is some wastage with this method as rods are left in the field and after collection from headlands. However, loose rods dry by natural convection and do not deteriorate with time. Chipping of dried whole rods or bundles, however, tends to result in shattering of the material rather than chipping. Chipping of the fresh material is therefore usually undertaken.

  - **Direct Chip Harvesting**

    Here the stems are cut, chipped and then blown into an accompanying trailer. This method is currently more efficient than Rod Harvesting, but the storage and drying of the fresh wood chip can cause problems. Stored, fresh wood chip can heat up to 60°C within 24 hours and start to decompose. The use of grain driers, ventilated-floor-driers and low rate aeration using ducts are all being investigated, although it is considered to be uneconomic[40] to dry wood chip on the farm by any other method than natural air drying.

  - **Billet Harvesting**

    Intermediate between rod and direct chip harvesting is billet harvesting. The stems are cut whole, cut further into billets (sticks of 100mm – 250mm long) and blown into an accompanying trailer. Due to the spaces between billets, natural ventilation occurs within storage piles preventing the difficulties associated with chip storage. Under typical European conditions, the moisture content will eventually fall to 15% to 25% unless the material is re-wetted by rain.

- ***Miscanthus***

  For energy cropping, a baled product is the most desirable. However, this type of harvest involves two operations before the bale is produced and this can result in high biomass losses.

  The crop is first cut with a mower conditioner. Conditioning breaks up the rigid stems allowing accelerated moisture loss, and provides a light, rectangular windrow. This not only makes baling easier, but also helps in the drying of the material, by increasing the surface area and increasing air circulation in the swath.

A critical factor for an energy crop is the moisture content at harvest. The drier the crop, the higher the energy yield and bale value. Moisture contents as low as

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[40] Defra, Best Practice Guide - SRC

15% have been reported in southern Europe - although the lowest moisture content achieved in the UK has been around 20%, with the average closer to 50%. This may be partly because, in the UK, plants are still in the vegetative phase when the first frost induces die back. By conditioning and allowing to dry in the field, the stem moisture content can be halved from 50% to 25%

For the purpose of the modelling it is assumed that the energy crops are air dried and stored on site, either "in the field" or covered storage with appropriate ventilation. The energy crops will then be delivered to the station gate in a pelletised form, which further reduces the moisture content to around 7-10%. The estimated costs for air drying, storage and pelletising is assumed to be £2/GJ.

4.3.4 Transportation Costs

Transportation is a limiting factor in the financial viability of biomass as a fuel, due to their lower density and calorific value relative to conventional fossil fuels. Although most coal fired power stations have access to rail or shipping for transportation of fuel, the diffuse nature of domestic energy crop cultivation is likely to mean that energy crops are typically delivered by road, which significantly increases the transport cost of energy crops relative to other fuel sources.

The cost of road transport is dependent on a large number of factors; for energy crops transport will typically be volume rather than weight limited. Miscanthus typically costs more to transport than chipped SRC due to its lower bulk density, and baled grasses also typically have higher handling costs. Costs for road transportation of pelletised SRC are estimated to be in the range 0.2-0.6p/GJ/km with pelletised Miscanthus costing 0.4-0.8p/GJ/km[41]. However, the amount of processing of the fuel before transportation will affect the costs significantly, with lower density products costing more to transport than heavier, less processed materials.

In addition, handling costs both at the farm and station will likely increase these costs, with costs in the region of 2.8-11.1p/GJ, with baled materials toward the upper end of this range.

Assuming that energy crops are grown within a catchment area extending to around 40km[42] from the power station gate, these calculations imply a transportation cost to the power station gate of around £0.31 -0.51/GJ, with chipped SRC toward the lower end of the range and baled Miscanthus toward the higher end of the range.

4.3.5 Delivered Costs

Assuming a 10 year investment time scale, a 10% real discount rate and a collection radius of 40km around the power station, the delivered cost of Energy Crops to the station gate would range from around £3.80/GJ for Miscanthus with a £1,000/ha establishment grant to around £5.30/GJ for SRC with no grants. The range is shown in the following figure.

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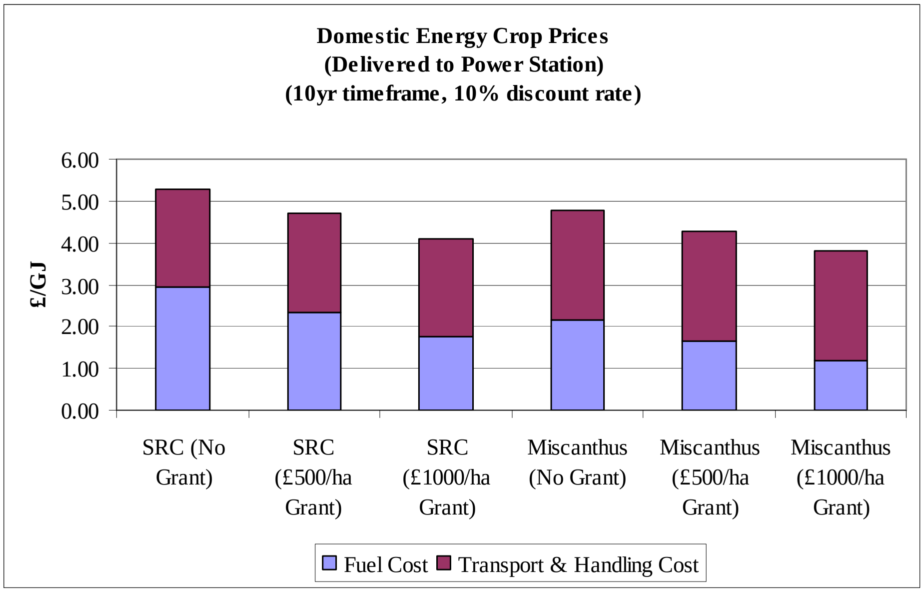
[41] Calculation based upon Transport Cost Tables, Motor Transport, 17-11-05, Reed Business Information

[42] For energy crops to be eligible for existing UK grants they must be grown within a radius of 25 miles (40km) from the power station

Figure 14 - Delivered Energy Crop Prices



4.3.6 Availability and Volumes

There is huge potential for the domestic cultivation of energy crops within the UK.

Average yields depend on the type of land available and how much of this land is available to grow energy crops.

The current rules governing grant aid state that the end use must be within 25 miles of the growing location. It is interesting to note that many of the coal fired power stations are in relatively close proximity, and this could create competition for farmland for energy crop cultivation.

Despite the significant potential for domestic cultivation of energy crops, experience of cultivation within UK is still relatively limited. There is currently around 7,000ha of energy crop cultivation planned for 2006 (including that already planted prior to 2006), with cultivation approximately equally split between SRC and Miscanthus, and predominantly within England.

However, there is an increasing interest in developing energy crops and data for 2006 and 2007 from DTI, DARDNI, Scottish Executive and the Welsh Assembly, shows a potential doubling of land area under cultivation for energy crops. In addition there have been indications from industry that contracts for up to 60,000ha might be available for 2007/8/9, although this will be dependent on future support measures. These future plans for energy crop cultivation are summarised in Table 8 below.

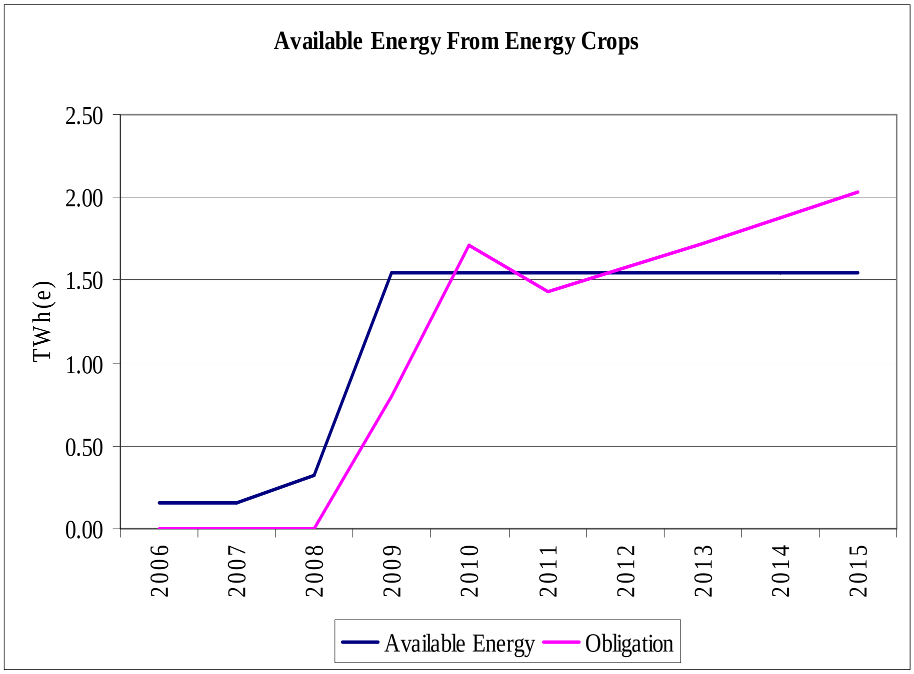
Table 9 - UK Energy Crop Cultivation, Current and Planned

	ha	TWh(c)	TWh(e)[43]
2006	7,148	0.515	0.160
2007	14,262	0.913	0.319
2008/09	69,327	4.424	1.548

It is interesting to compare the level of energy crop cultivation relative to the level of energy crops required by the RO for co-firing to contribute a maximum level to the obligation. This is investigated in Figure 15, which shows that if all planned energy crop cultivation is developed then the volumes available should broadly be sufficient for co-firing to make a maximum contribution to the RO in 2009, with additional cultivation required beyond this point. However, it should be borne in mind that at least some of the energy crop cultivation could be developed for use within dedicated biomass plant (such as the EoN plant at Lockerbie, which plans to develop 3,700ha of SRC over the next 6 years), and so may not be available for co-firing.

To meet the maximum demand from Energy Crops required by the RO (2.03TWh(e) in 2015/16) would require around 91,000ha of Miscanthus. This is around 13 times the total planned to be planted by the end of 2006, and about 60% of the area of London[44].

Figure 15 - Availability of Energy Crops and the RO Limits



It is interesting to note that a typical 2,000MW coal station burning 20% biomass (by heat input) would be likely to require energy crop cultivation of around 80,000ha (10% of land within a 50km radius) to have enough to meet its

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[43] Assuming a station efficiency of 35%.
[44] National Inventory of Woodland and Trees, England, Regional Report for London, 2002, Forestry Commission.

requirements[45]. This would produce 1.87TWh(e) from energy crops, marginally less than the total Energy Crop requirement in 2014/15.

4.3.7 Cereal Crops

Alternative energy crops, such as cereal crops, could be used for co-firing. These have the benefit that the production of these crops will be able to use the existing agricultural knowledge, needs no further agricultural investment and requires no change in land use.

Although this is a possibility and is being investigated[46] it is not believed to be the preferred choice at the moment but might be pursued in the event that other energy crops are not available.

4.3.8 Imported Energy Crops

The current definition of Energy Crops in the RO does not prohibit the co-firing of imported energy crops. However, availability is currently relatively limited and there is likely to be growing demand for materials across the EU with the requirements under the EU directive[47], which obliges Member States to take appropriate steps to encourage greater consumption of electricity produced from renewable energy sources. The Commission also encourages Member States to harness the potential of all cost effective forms of biomass electricity generation through the EU Biomass Action Plan[48].

Much of the biomass production, however, especially in Northern Europe, has focused on wood pellets from forestry, which would not qualify under the current RO definition of energy crops.

The 2003 reform of the CAP, which has meant that income support for farmers is no longer linked to the crops produced, allows farmers to respond freely to increasing demand for energy crops. This reform also introduced a special aid for energy crops[49] and maintained the possibility of using mandatory “set-aside” land for growing non-food crops (including energy crops). There is therefore now more potential for UK coal generators to source energy crops from overseas.

Importing energy crops would enable power stations to make use of existing rail and shipping transportation facilities currently used for importing coal. Whilst the cost structure of energy crops are unlikely to be significantly different abroad, the cheaper overhead costs added to the greater yields and volumes that may be able to be sourced as a result of the more favourable climatic conditions, may make them attractive for co-firing in the UK.

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[45] Assuming a load factor of 51.57% as published by the DTI as a representative load factor for coal stations fitted with FGD, and a station efficiency of 35%.

[46] IEA Database – The Schwandorf facility in Germany is reported to be co-firing cereals.

[47] EU Directive 2001/77/EC on the promotion of electricity produced from renewable energy sources in the internal electricity market.

[48] The EU Biomass Action Plan 7.12.2005 COM(2005) 628 Final

[49] The “energy crop payment”, under which a premium of €45 per hectare is available, with a maximum guaranteed area of 1.5 million hectares as the budgetary ceiling, for the production of energy crops.

The following table, which is taken from the EU's Biomass Action Plan[50], assesses the EU's potential to produce biomass for energy use. It should be noted that the estimates are conservative as they are based on the following assumptions:

- no effect on domestic food production for domestic use;
- no increase in pressure on farmland and forest biodiversity;
- no increase in environmental pressure on soil and water resources;
- no ploughing of previously unploughed permanent grassland;
- a shift towards more environmentally friendly farming, with some areas set aside as ecological stepping stones;
- the rate of biomass extraction from forests adapted to local soil nutrient balance and erosion risks.

Table 10 - EU Biomass Production Potential

Mtoe	Biomass Consumption, 2003	Potential, 2010	Potential, 2020	Potential, 2030
Wood direct form forest (increment and residues)		43	39-45	39-72
Organic wastes, wood industry residues, agriculture and food processing residues, manure	67	100	100	102
Energy crops from agriculture	2	43-46	76-94	102-142
Total	**69**	**186-189**	**215-239**	**243-316**

The first column of the table shows the quantities of EU-produced biomass being used for energy purposes. The following columns show the potential contribution in 2010, 2020 and 2030. In terms of energy crops from agriculture it can be seen that the potential in the EU25 countries is likely to be significant over the forecast horizon, with around 43-46 Mtoe (~500,000-530,000 GWh) in 2010. The figures also do not include the contribution of Bulgaria and Romania, which will be EU members by 2010, and have high biomass production potential. It can therefore be seen that there is likely to be significant availability of energy crops for use in UK co-firing stations from abroad. However, there is likely to be an uplift to prices of imported energy crops as a result of higher transport costs.

There are also a number of other products that could be grown as energy crops such as cereals and sugarcane. Sugarcane can be used for the production of bio-ethanol and the residues left over from this process could feasibly qualify as an energy crop. Bagasse is the biomass remaining after sugarcane stalks are crushed to extract their juice. Each tonne of sugarcane can yield 250kg of bagasse[51]. The

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[50] Commission of the European Communities, Biomass Action Plan, 2005.

[51] Bagasse Co-generation - Global Review and Potential, World Alliance for Decentralised Energy (WADE), June 2004

three largest sugarcane producers are Brazil, India and China who, between them produce around 192 million tonnes bagasse. Assuming a net CV of around 16GJ/tonne[52] this equates to around 3million TJ.

However, bagasse is currently used in a variety of operations: about 1/3rd of the bagasse produced in a mill is used to provide enough steam and electricity for the mills requirements, leaving 2/3rds available for other uses such as:

- As a raw material for the production of paper;
- As feedstock for cattle; and potentially
- The production of biodegradeable plastics.

Costs for the raw fuel have been estimated from publicly available information[53] and are around £0.50/GJ. Transportation costs for bagasse in its raw form (as a dust, with a density of around 150kg/m^3) are likely to be relatively high and so it is likely that it would be pelletised before shipping. Using the transportation costs of soybeans as a proxy to the transportation costs of bagasse pellets[54], the delivered price would be around £5.70/GJ, which is above the price of domestically produced energy crops.

Unless high quality value energy crops can be sourced from countries that are further afield, the transportation costs are likely to be the limiting factor in the supply to the UK. However, it is feasible that closer countries where transportation costs are a less restrictive factor could provide energy crop materials to the UK. There is therefore a possibility that energy crop products could be sourced internationally, thereby limiting the growth in the UK domestic market.

4.4 Summary

In the previous sections we have investigated the range of costs for various biomass fuels and discussed potential volumes and availabilities. We now bring this information together to compare the costs of the fuels and asses the volumes available.

4.4.1 Costs

Final delivered costs for each of the fuels investigated are presented in the figure below.

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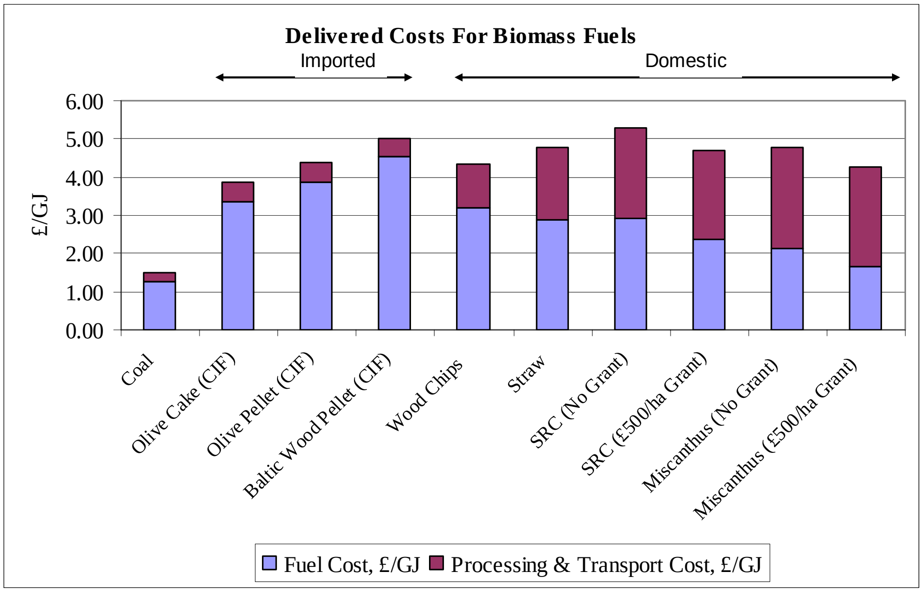
[52] www.ecn.nl/phyllis

[53] http://energyconcepts.tripod.com/energyconcepts/bagasse.htm It is acknowledged that these costs are estimates only and depend on external factors, such as the price of oil and the exchange rate at the time.

[54] Costs for the transportation of Soybeans from Brazil to Hamburg are reported to vary between US$59.55/mt – US$124.84/mt, (Brazil Soybean Transportation Guide, April 2006, United States Department of Agriculture, Agricultural Marketing Service)

Figure 16 – 'Station Gate' Costs for Biomass Fuels



The costs presented above are the current costs for the biomass fuels. Increasing demand from other European electricity generation activities, competition from 100% biomass stations and competition between stations located in close proximity may tend to put upward pressure on these prices in the future.

The transport costs also play a large part in the delivered cost of the fuels, especially for the domestic biomass and energy crop fuels as a result of the smaller volumes compared to mass transport. A significant component of these costs is fuel cost for the lorry transportation, which will vary according to fuel prices.

4.4.2 Volumes

The total potential volumes of biomass available (both general biomass and energy crops) indicate sufficient volumes to satisfy the maximum co-firing requirements (and energy crop requirements) stipulated by the constraints in the RO. However, particularly in the case of domestic Energy Crops, the volumes available will be affected by the levels of grants available to suppliers and for imported energy crops the demand from international markets. In addition, demand from dedicated biomass plants may also reduce the volumes available for co-firing.

5 LIQUID BIOMASS

In addition to the solid biomasses being burned at the UK coal fired power stations some stations have also been substituting Heavy Fuel Oil (HFO) with liquid biofuels (bio-oils). HFO is used for start up and burn stabilisation in coal plant, with typically around 1.5% of the energy input being provided by oil. A number of operators have investigated replacing HFO with bio-oils and whilst this has proven to be successful, experience has shown that there is an increase in the rate of corrosion, resulting in higher maintenance costs.

There are many bio-oils which could potentially be used to replace HFO in power stations, such as crude vegetable oils (palm oil, soyabean oil, coconut oil, olive oil and rapeseed oil), Waste Vegtable Oils such as produced in potato crisp factories, and non-edible oils like Tall Oil.

Palm Oil is currently the cheapest bulk-traded vegetable oil on world markets with total trade in excess of 23 million tonnes annually[55]. Over 80% of global production comes from just two countries, Malaysia and Indonesia, with 13.4 million tonnes and 10.1 million tonnes respectively. The majority of palm oil produced is grown for export in large tropical plantations. It is used in a huge number of prepared food products, as a cooking oil, and its derivatives are used in various non-food products and processes, mainly in the animal feed industry. The FAO reports that of the 28 million tonnes of palm oil produced in 2003, nearly 12 million tonnes were for non-food uses[56]. Global planting and production of palm oil is also on the increase so future production figures may be considerably higher than those reported. Palm Oil is not produced in the UK and so would need to be imported from abroad.

Waste Vegetable Oils (WVOs) are collected from the catering and food industries by waste recycling companies and either diverted into animal feeds or disposed of[57]. Any establishment wishing to burn WVO needs to apply for authorisation from the Environment Agency prior to commencing production to ensure that the plant operates to the necessary environmental standards and, to date, there have been no reports of WVO being used in co-firing applications.

Tall Oil is a liquid fuel produced from the paper industry and is already used in some of the UK coal stations as a substitute for HFO. As with Palm Oil, Tall Oil needs to be imported from abroad and so will incur transportation costs.

In addition to these fuels, tallow has been co-fired in the UK. However, as with WVO, any establishment wishing to burn tallow needs to apply for authorisation from the Environment Agency prior to commencing production to ensure that the plant operates to the necessary environmental standards.

The bio-oils used in co-firing applications are generally priced to be more expensive than HFO and so, as with solid biomasses, the benefits of burning these fuels would have to outweigh any extra costs incurred.

Biofuels can also replace HFO to a large extent in oil stations without requiring major modifications: We are aware that one generator has been trialling Palm Oil as a replacement for HFO at one of its oil units.

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[55] Food and Agricultural Organisation of the United Nations, FAOSTAT - http://faostat.fao.org/faostat/ Agriculture and Food Trade

[56] Food and Agricultural Organisation of the United Nations, FAOSTAT - http://faostat.fao.org/faostat/ Food Balance Sheets

[57] Waste cooking oils from the catering industry are not permitted to be used in animal feeds, however those from the food manufacturing industry can – The Animal By-Products Regulation EC 1774/2002 (ABPR).

Additionally, Centrica has conducted co-firing tests at its 272MW Brigg gas-fired station. It says that possibly half of the station's output could be eligible for co-fired ROCs, and that it is considering co-firing options at its other plants.

However, the volume of bio-oils used in power stations are likely to be relatively small compared to solid biomass fuels, and the economics very different. As a result the remainder of this report focuses on the economics of co-firing with solid biomass fuels.

6 ECONOMICS OF CO-FIRING

This section investigates the economics of co-firing and identifies the financial support required to incentivise biomass co-firing in terms of:

- Maintaining current co-firing practices and levels;
- Stimulating the use of domestic energy sources and energy crops; and
- Stimulating investment in plant to increase co-fire volumes.

Whilst co-firing support has to primarily address the financial support required to make co-firing economic, it also has to provide sufficient regulatory certainty to incentivise capital investment at plant and stimulate the domestic biomass industry and energy crop cultivation.

In the following sections we investigate the level of financial support which would be required to make co-firing economic in the *absence* of support from the Renewable Obligation. Other mechanisms which provide economic support such as the CCL and the EU ETS are assumed to be in place and are taken into account in calculating the support levels required.

6.1 Fuel Cost Comparison

The economics of co-firing are complex and are affected by a wide variety of factors including biomass fuel costs, coal costs, carbon costs, capital expenditure and operating expenditure. This section explores the electricity generation costs using coal and biomass, allowing for the impact of carbon and CCL.

Section 4 discussed the biomass fuel costs for a wide variety of biomass fuel sources. It was shown that the ‘station gate’ costs for biomass fuel sources are likely to range somewhere between £3.50/GJ and £5.10/GJ. However, electricity produced from biomass is eligible for Climate Change Levy Exemption certificates. CCL is currently set at £4.30/MWh(e) (it is set to rise with inflation from 2007), and this effectively reduces the cost of generation using these biomass fuels.

The international market price of coal has varied between \$50/t and \$70/t (£1.00/GJ and £1.40/GJ[58]) over the last year. Uplift for coal costs from the reported international price to delivery at the station gate varies from 18.5p/GJ to 30p/GJ, dependent on location, resulting in station gate prices for coal in the region of £1.20/GJ to £1.70/GJ (significantly cheaper than imported biomass). An average current delivered coal price is around £1.44/GJ.

The cost of carbon has to be factored into the cost of generating using coal to give a comparative variable cost. Carbon costs have been factored into the analysis at their variable cost (ignoring carbon allocation under the EU ETS). Coal has a carbon intensity of around 0.09tCO_2/GJ. Carbon market prices have varied between €10-€30/tCO_2 over the last year and a half, giving a cost of carbon for coal generation between £0.60/GJ and £1.80/GJ respectively (it is currently £1.10/GJ). Thus the cost of generation with coal (coal and carbon cost) has varied between £1.85/GJ and £3.45/GJ over the last eighteen months, with the current price at £2.54/GJ when the cost of carbon is included.

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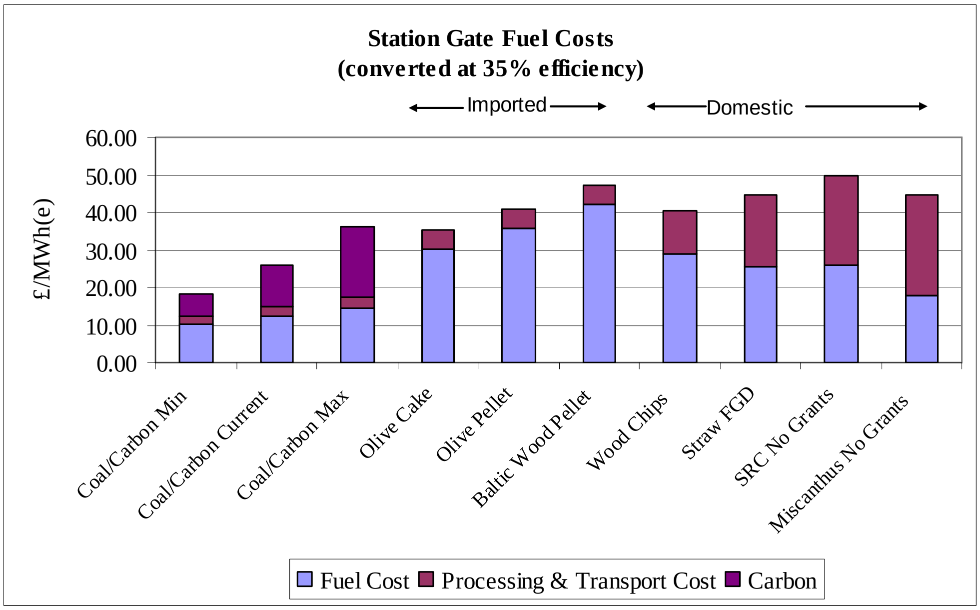
[58] Assuming a net calorific value of 24.9GJ/tonne and the current exchange rate between the US\$ and the £.

The relativity of the coal and biomass prices can be seen in the following graph, where they are presented in terms of the cost of electricity generation, assuming a station efficiency of 35%.

Figure 17 - Generation Fuel Costs with Carbon and CCL



It can be seen that the costs of generation using coal are lower than the costs associated with generation using biomass. However, if the costs of carbon are included there have been periods over the last year when the costs of coal generation have been broadly equivalent to the costs of generating using some of the cheaper biomass fuel sources. It is clear that coal and especially carbon price volatility can have a significant impact upon the relative economics of co-firing.

It is also clear that there is a significant variation in the costs of different biomass fuel sources. Thus, the ability to source different biomass fuels will have a significant impact upon the economics of co-firing at the different stations.

6.2 Current Co-firing Experience

This section investigates the financial support required to make current co-firing operations economic in the absence of ROCs. It provides an investigation of the total costs of generation including fuel, capital and operational costs, and investigates the potential support levels required.

Current co-firing operations have been discussed in Section 3.1. Current operations have been characterised as co-milling of imported biomass materials, and co-firing at relatively low biomass proportions (generally less than 5% by heat).

Co-firing at relatively low biomass proportions has resulted in relatively little change in plant capacity or efficiency. This implies that at least for relatively low proportions of biomass burn, co-firing is unlikely to have a significant effect on the targeted electrical output of the station and so does not impact upon the revenue from the sale of electricity.

This implies that the economic decision determining whether a station co-fires biomass is whether the net costs and benefits associated with burning biomass will be less than the costs of burning coal[59]. Since capital required to enable current co-firing operations has already been invested, the decision to co-fire will be based upon marginal economics. Thus, no allowance has been made in the calculations for capital cost recovery in this analysis.

The key parameters associated with current co-firing operations are itemised below.

- Biomass fuels include olive products, palm products and wood pellets with costs varying between £38/MWh(e) and £50/MWh(e) at the station gate.
- Additional operational costs associated with co-firing have been indicated to lie between £3/tonne and £14/tonne of biomass (average £5/tonne).
- Relatively small capital investment (of the order of £200/MW - £1,700/MW) has been undertaken to allow plant to co-fire using the co-milling approach.

The required levels of support to equalise the net costs of generation with biomass and coal fuel sources is investigated in Figure 18. This is the minimum level of support required to incentivise co-firing operations.

The key points from this analysis are that:-

- The level of support required varies considerably, dependent on the combined coal and carbon price and the biomass fuel source.
- The current support required to incentivise co-firing at the current market prices for an average biomass cost is around £18/MWh(e).
- Market price volatility places considerable uncertainty on the support required with volatility over the last eighteen months resulting in a range of around £15/MWh(e).
- The current ROC price (around £46/MWh[60]) gives more support than is required;
- Current operations do still need some form of support in order to be economic; and,
- The carbon price would need to rise from its current level of €18.40/tCO_2 to €47.65/tCO_2 to make this form of co-firing economic, for a typical biomass fuel price, assuming that there was no support from ROCs.

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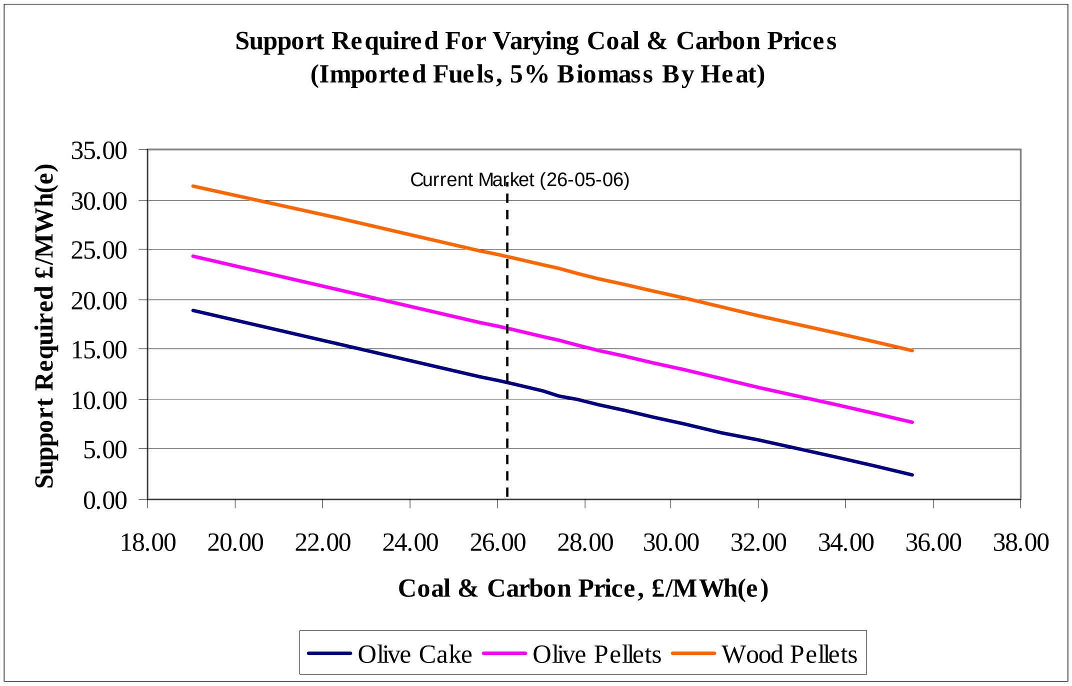
[59] This is approximately correct when the proportions of biomass burn are relatively low, and the net profits associated with burning biomass are not significantly different from burning coal (i.e biomass is not heavily over-subsidised to the extent that it subsidises output from the whole plant).
[60] Average of NFPA and NFPAS prices for the first six months of 2006/07

Figure 18 -Support Required for Biomasses at Varying Coal and Carbon Prices



6.3 Co-firing with Domestic Fuels

As highlighted in Section 4.2 there are a range of domestic biomass fuels that could also be used in co-firing operations, including arboricultural arisings, wood chips and straw. These are all by-products and so the volumes are theoretically available, although some development of collection and distribution processes may be required to allow a sufficient volume to be gathered for co-firing operations.

Different biomass fuels may present challenges to station operators. Additional processing and handling equipment may be required to co-fire baled material, material with less homogenous properties, and fuels with higher moisture contents. Baled materials in particular may require dedicated processing (bi-passing coal mills) with injection into the pipework upstream of the burners. However, it should be possible to co-fire other biomass materials, assuming relative low biomass proportions in the fuel mix, without significant capital expenditure.

Here we investigate the additional cost of co-firing with domestic biomasses at levels around those currently observed (~5% by heat) and with fuel costs for non-energy crop fuels ranging from around £40.50/MWh(e) to around £44.80/MWh(e).

In the case of straw, and assuming that it is not pelletised, extra capital expenditure will be required to enable stations to accommodate baled materials (break the bales, pass the fuel through hammer mills and pneumatic injection into the boilers). These costs are estimated to be around £9,000/MW. Based on a 10 year investment horizon and a 10% real discount rate, an FGD station running at a load factor of 51.75%[61] gives a capital cost, on variable basis, of around £13.00/MWh(e) of biomass output. The corresponding

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[61] Load factors taken from Draft Phase II Nap

costs for a Non-FGD station running at a load factor of 28.54%[62] are around £23.50/MWh(e).

The fully built up cost of the different fuels (including capital costs) are compared to coal and carbon costs in Figure 19, and the required level of support under a range of commodity costs is shown in Figure 20.

It can be seen that the costs of generation using domestic biomass are likely to be more expensive than coal, and so support would be required to incentivise co-firing. It should be noted that to enable investment in developing the supply chains, and particularly investment in bale handling equipment, there will need to be reasonable regulatory certainty over the level and duration of any support mechanism.

The analysis suggests a range of support required to ensure the different fuel sources are economic. Again this range is of a similar order to the uncertainty in the level of support due to the volatility in the market price of coal and carbon. However, it is clear that the additional capital costs of the bale handling equipment has a significant impact on the levels of support required.

The key points from this analysis are that:-

- The current support required to incentivise co-firing at the current market prices is around £17/MWh(e) for Wood Chips and around £35/MWh(e) for baled straw.
- The current ROC price (around £46/MWh[63]) gives more support than is required;
- Current operations do still need some form of support in order to be economic; and,
- The carbon price would need to rise from its current level of €18.40/tCO_2 to €46/tCO_2 to make co-firing of wood chips economic and to €75.30/tCO_2 to make co-firing of baled straw economic, assuming that there was no support from ROCs.

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[62] Load factors taken from Draft Phase II Nap

[63] Average of NFPA and NFPAS prices for the first six months of 2006/07

Figure 19 - Domestic Fuel Costs

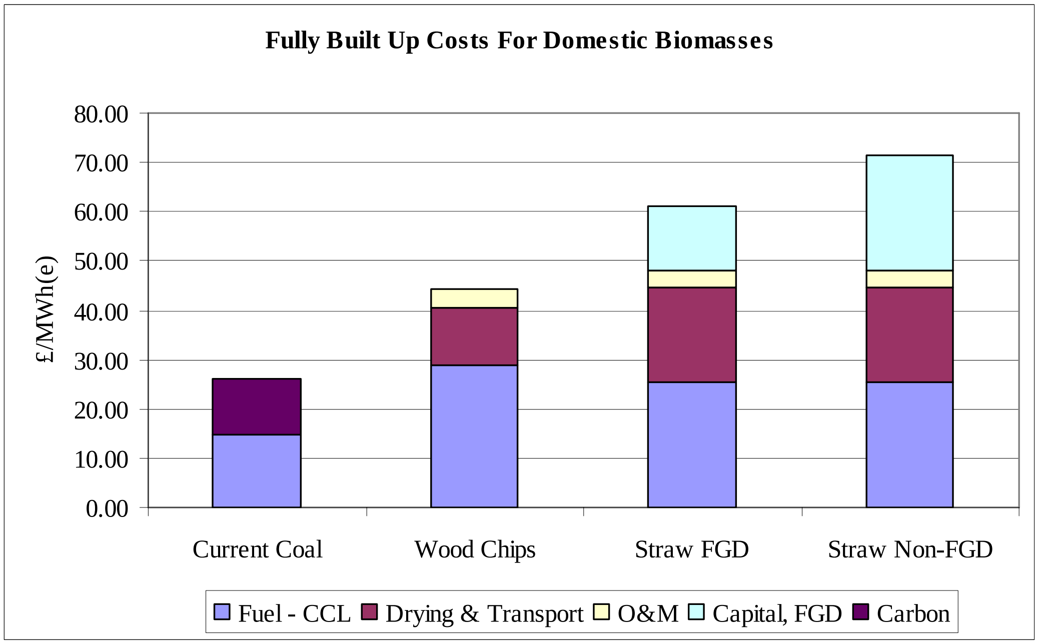
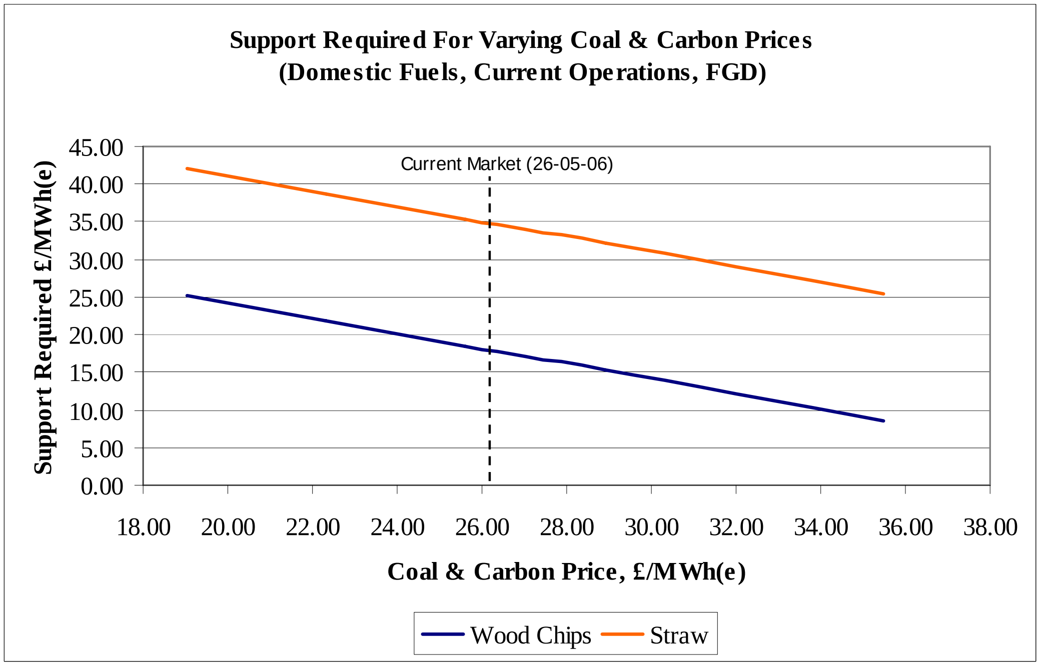


Figure 20 -Support Required For Varying Coal & Carbon Prices (10yr Timeframe)



6.4 Co-firing with Energy Crops

Co-firing with energy crops has, to date, been extremely limited, due to the low availability of energy crops. However, as discussed in Section 4.3.6 there are significant plans to increase the level of energy crop cultivation, particularly Miscanthus.

It is possible to co-fire relatively wet SRC at relatively low volumes without requiring significant capital expenditure, however where a significant volume of SRC were to be fired this could require investment in processing equipment and bi-passing of the coal mill. It has been assumed in this analysis that both the SRC and Miscanthus is delivered to the station in a dry, pelletised form and co-firing is carried out at similar levels to that currently experienced, requiring no further capital investment.

The fully built up costs of energy crops, with and without grants, are compared to the costs of coal and carbon in Figure 21. It can be seen that the costs of generation with energy crops are significantly greater than with coal, although this difference would be eroded to some extent dependent upon the level of agricultural grant, as shown in Figures 21 and 22. However additional support is likely to be required to incentivise co-firing with energy crops even with support from agricultural grants. It should be noted that to enable investment in developing the cultivation of energy crops a reasonable degree of certainty over the level and duration of any support mechanism is required. This is particularly true for SRC due to the relatively long establishment period and crop cycles. In addition regulatory certainty will be required to incentivise investment at power stations.

The required level of support to incentivise co-firing under a range of commodity costs is shown in Figure 22. This also investigates the impact of different levels of agricultural grants on the support required. It can be seen that the range of support varies between energy crops at different levels of agricultural grants and the volatility in the market price of coal and carbon also places uncertainty in the level of support required.

The key points from this analysis are that:-

- The current support required to incentivise co-firing at the current market prices is around £16/MWh(e) for Miscanthus with a £500/ha grant and around £26/MWh(e) for SRC without any grants.
- The current ROC price (around £46/MWh[64]) gives more support than is required;
- Current operations do still need some form of support in order to be economic; and,
- The carbon price would need to rise from its current level of €18.40/tCO_2 to €44.40/tCO_2 to make co-firing of Miscanthus with a £500/ha grant economic and to €60.65/tCO_2 to make co-firing of SRC without any grants economic, assuming that there was no support from ROCs.

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[64] Average of NFPA and NFPAS prices for the first six months of 2006/07

Figure 21 - Fully Built Up Costs For Energy Crops

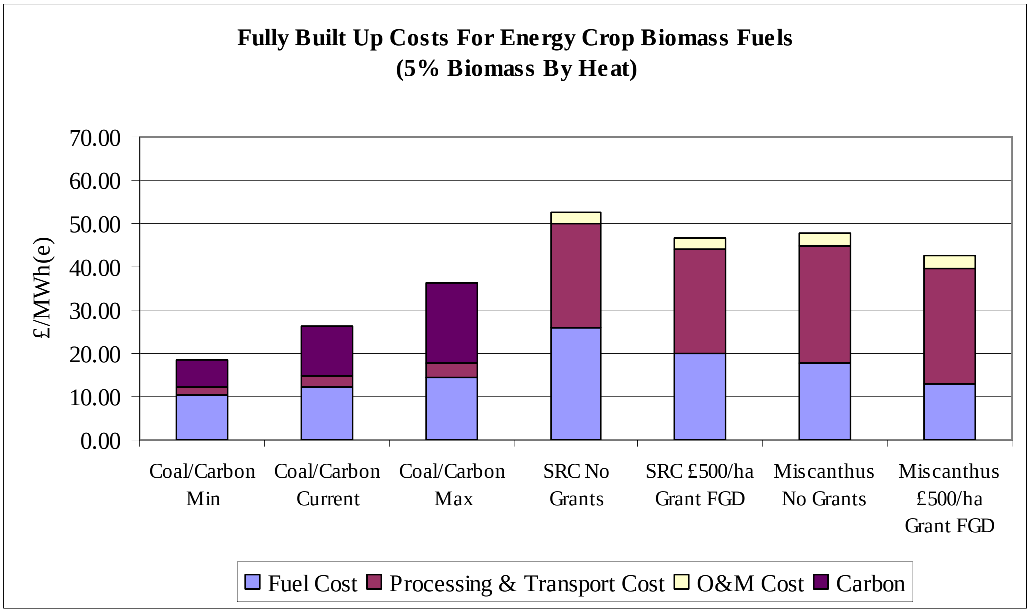
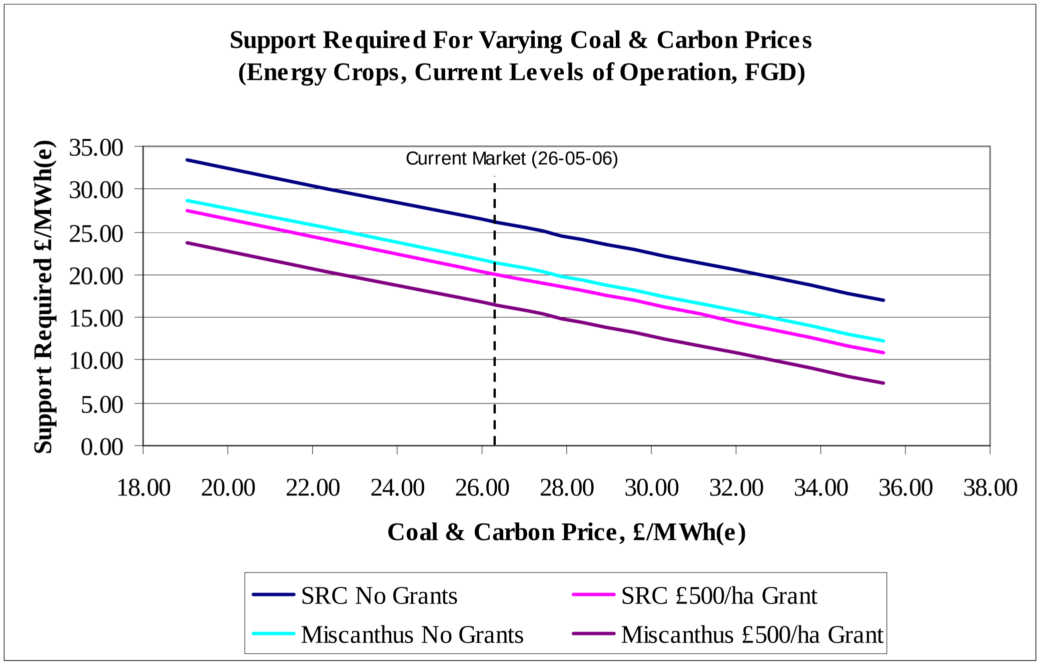


Figure 22 - Levels of Support Required For Energy Crops



6.5 Direct Co-firing

This section investigates the support levels required to incentivise coal plant to invest in direct co-firing with energy crops. This would allow plant to increase the proportions of biomass burnt to at least 10% by heat input.

Development of co-firing systems to handle large volumes of biomass will undoubtedly require capital investment in storage, processing and feed systems as well as the direct co-firing systems. Typical capex may be in the range of £4,000/MW - £6,000/MW for direct firing by injection into the coal firing system, rising to £20,000/MW - £28,000/MW for direct firing with new dedicated burners or for direct firing of baled materials.

Conversion of the capital expenditure to a variable cost is dependent upon the period to recover investment and discount rates (related to regulatory risk), volume of co-firing (dependent upon fuel supply and plant capacity for biomass) as well as the load factor of the plant (dependent upon coal, carbon & power prices as well as LCPD restrictions).

The table below shows the calculated capital costs on a variable basis over a range of investment timescales at a real discount rate of 10%, and at both stations with and without FGD fitted. FGD stations are assumed to have a load factor of 51.75% and non-FGD stations a load factor of 28.54%.

Table 11 - Capital Cost Recovery on a Variable Basis

	FGD, £/MWh(e)	**Non-FGD, £/MWh(e)**
10 yr Investment Horizon, 10% Discount Rate		
DI Non-Baled Materials	1.80	3.25
DI Baled Materials	8.60	15.60
20 yr Investment Horizon, 10% Discount Rate		
DI Non-Baled Materials	1.30	2.35
DI Baled Materials	6.20	11.28

The range of support required to incentivise direct co-firing with energy crops is investigated in Figure 23 and 24, which investigate the impact of different agricultural grants as well as the impact of 10 and 20 year investment horizons (for both energy crop cultivation as well as capital investment at coal plant) for an FGD station. It is evident that the level of agricultural grants, as well as the level of regulatory certainty (resulting in longer investment horizons), can have a significant impact upon the level of support required to incentivise energy crop co-firing operations. However, again a key variable in the level of support required is the market price of coal and carbon.

The key points from this analysis are that:-

- The current support required to incentivise co-firing at the current market prices is around £18/MWh(e) for Miscanthus with a £500/ha grant and around £28/MWh(e) for SRC without any grants, assuming a ten year investment recovery timeframe.

- Increasing the investment recovery timeframe to 20 years reduces the required support to £15/MWh(e) for Miscanthus with a £500/ha grant and around £17/MWh(e) for SRC without any grants.
- The current ROC price (around £46/MWh[65]) gives more support than is required;
- Current operations do still need some form of support in order to be economic; and,
- The carbon price would need to rise from its current level of €18.40/tCO_2 to €47.70/tCO_2 to make co-firing of Miscanthus with a £500/ha grant economic and to €63.90/tCO_2 to make co-firing of SRC without any grants economic, assuming an investment recovery timeframe of 10 years and that there was no support from ROCs.
- Increasing the investment recovery timeframe to 20 years reduces the required carbon prices to €42.80/tCO_2 and €46.00/tCO_2 respectively.

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[65] Average of NFPA and NFPAS prices for the first six months of 2006/07

Figure 23 - Support Required For Varying Coal & Carbon Prices (10yr Timeframe)

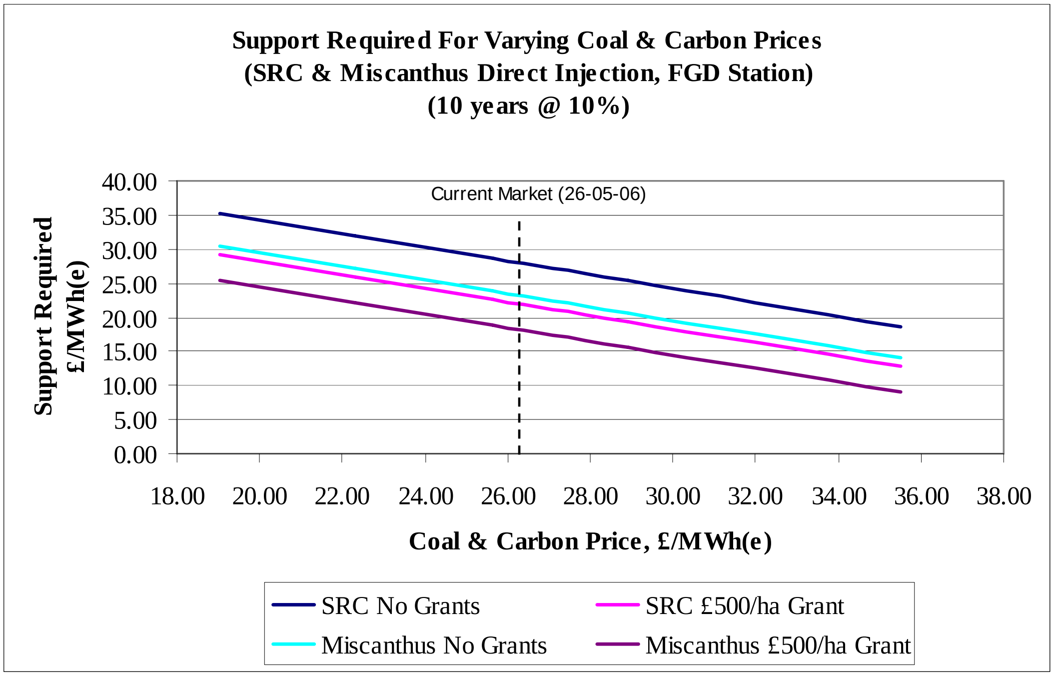
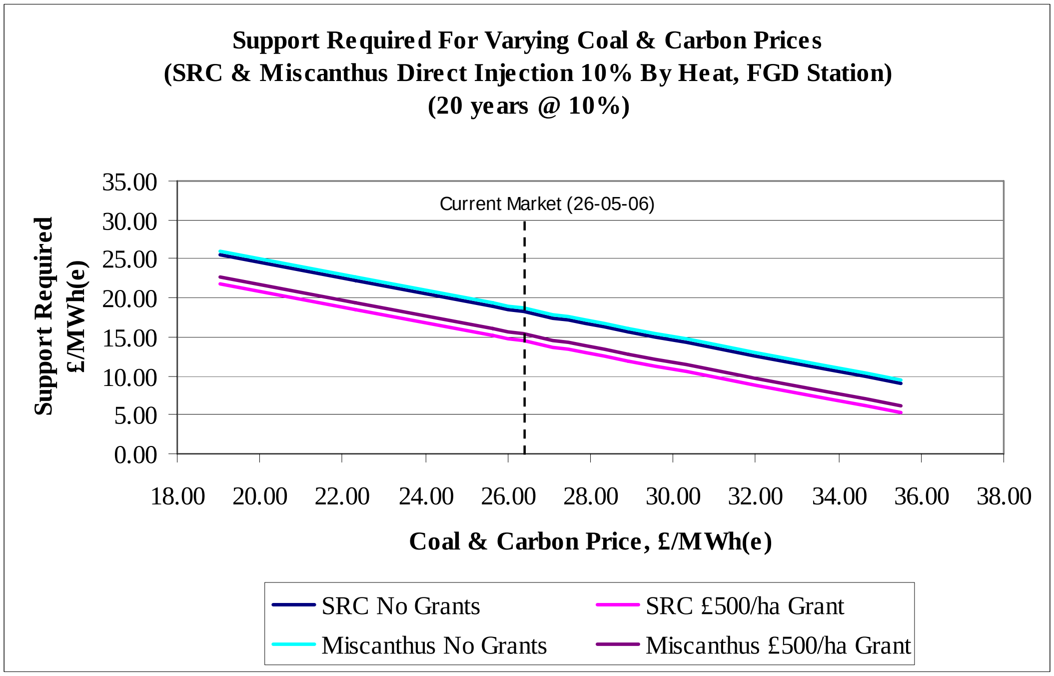


Figure 24 -Support Required For Varying Coal & Carbon Prices (20yr Timeframe)



6.6 Summary of Support Levels

Table 12 - Support levels Required To Incentivise Co-Firing

Option	Fuel	Support Required, £/MWh(e)	Equivalent Carbon Price, €/tCO_2
Co-Milling	Imported Biomasses	18	47.65
Co-Milling	Wood Chips	17	46.00
Direct Injection (10 year investment recovery timeframe)	Baled Straw	35	75.30
Co-Milling	Miscanthus Pellets£1,000/ha Grant	16	44.40
Co-Milling	SRC Pellets No Grant	26	60.65
Direct Injection (10 year investment recovery timeframe)	Miscanthus Pellets £1,000/ha Grant	18	47.70
Direct Injection (10 year investment recovery timeframe)	SRC Pellets No Grant	28	63.90
Direct Injection (20 year investment recovery timeframe)	Miscanthus Pellets £1,000/ha Grant	15	42.80
Direct Injection (20 year investment recovery timeframe)	SRC Pellets No Grant	17	46.00

6.7 Resource Cost Curve

In this section we investigate the potential levels of co-firing that could be achieved under different levels of support. This is done by estimating the resource available for the range of fuels investigated in the previous sections and by assessing the support required to incentivise their burn. A merit order is then built up to construct a curve of potential TWh(e)of co-firing at different levels of support.

6.7.1 Resource

Current co-firing operations predominately use imported biomasses due to the advantage that they are relatively easy to handle. Potential volumes of these fuels were investigated in Section 4.1.2 where it was shown that the UK only uses a relatively small proportion (~4%) of the biomass that is potentially available. However, in future, with increased use of biomass across Europe, there is likely to be increasing competition for these fuels, putting upward pressure on prices.

Given the potential availability for imported biomass, it is almost impossible to produce a resource curve for all forms of co-firing, hence this section focuses on just energy crops and, in building the resource curve, we assume that the volumes of imported biomasses available for UK power stations, and their prices, remain at 2005 levels. The rest of this section should be seen in this context.

For domestically grown energy crops, one of the major factors in their economics is the distance the crop from the power station. Clearly the further the crop is from the station, the higher the delivered cost will be, and there will be a point beyond which it will not be economic for the station to collect the crop. In addition, many of the UK coal fired power stations are situated in close proximity to each other, thus competing for the agricultural land.

We have carried out an assessment of the volumes of energy crops which could be available within expanding radii from the GB stations, based upon varying percentages of land available on which to grow these crops. We have then calculated the price at which the crops would need to be to cover all the associated costs (including the costs of drying, storage and pelletising).

Cost – resource curves for both Short Rotation Coppice and Miscanthus are shown in Figures 25 and 26 below, where we have calculated the cost of generating electricity allowing for the station efficiency and the subsidy given by the Climate Change Levy.

Figure 25 - Cost - Resource Curve For Short Rotation Coppice

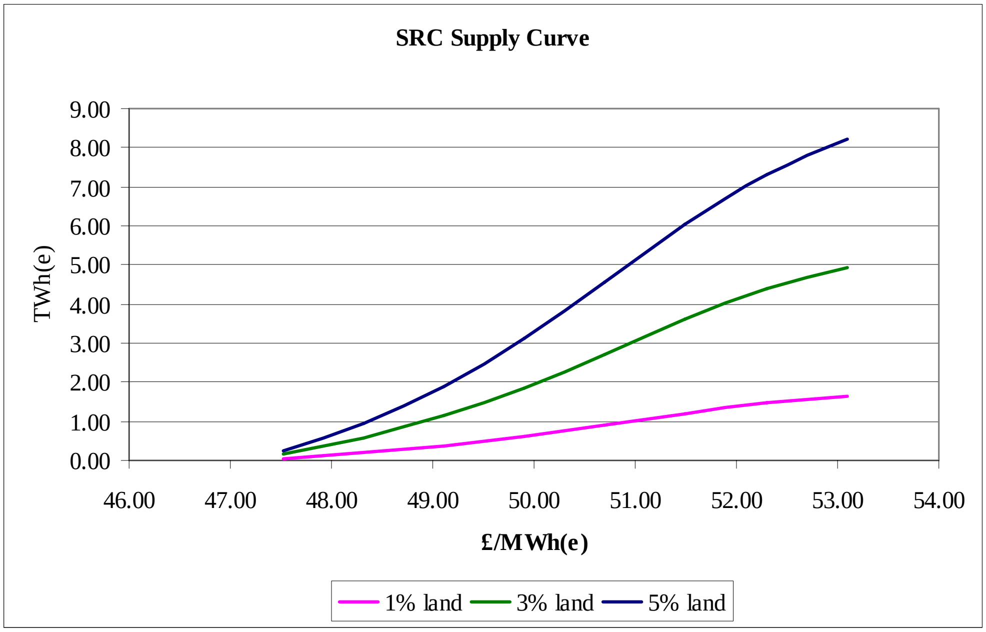
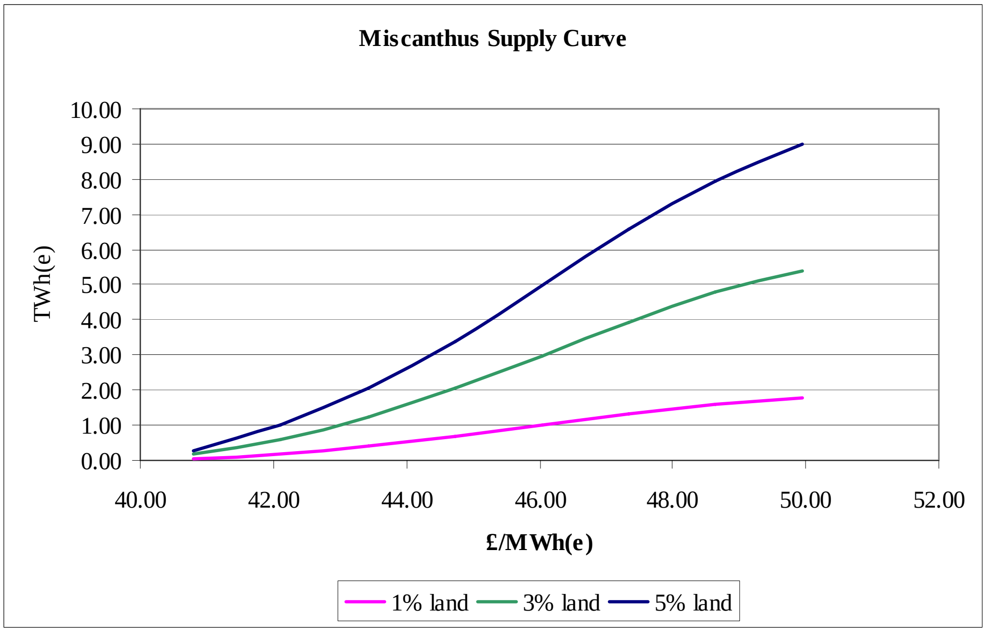


Figure 26 - Cost - Resource Curve For Miscanthus



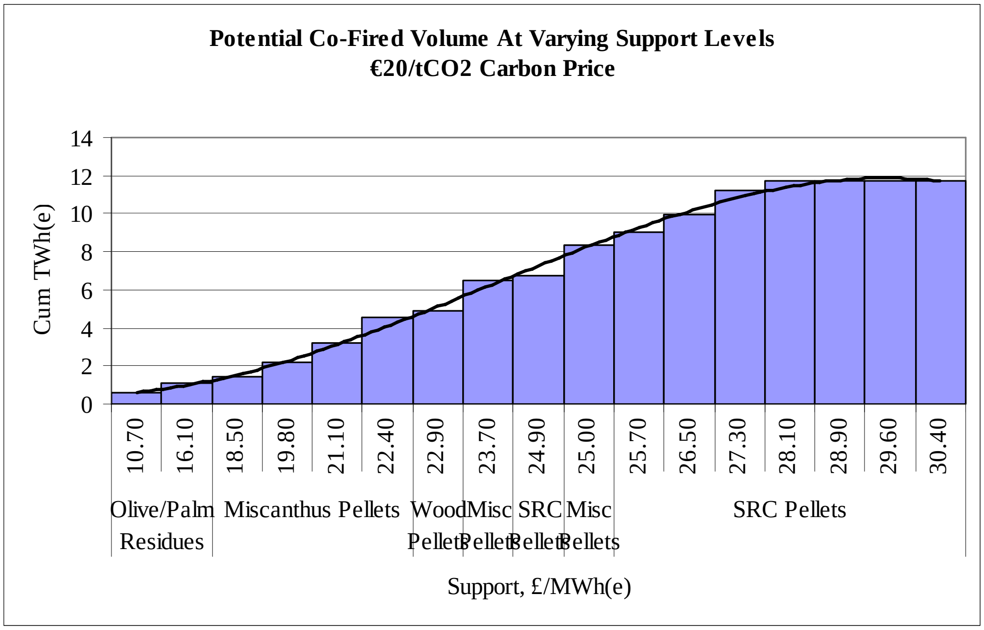
6.7.2 Resource Curve

In order to estimate the potential volume of co-firing, given various levels of support we have built up a merit order of fuels based on their associated costs. The main assumptions used in developing the resource include:-

- The coal price is fixed at $59.45/tonne;
- The carbon price is fixed at €20/tCO2;
- CCL is included in the fuel costs;
- FGD stations run at a load factor of 51.75%;
- Non-FGD stations run at a load factor of 28.54%;
- A station efficiency of 35%;
- The capital costs of installing direct injection equipment is including in the costs for the burning of Energy Crops;
- The maximum volume of co-firing is 10% by energy input;
- The volumes of biomass fuels currently imported remain constant at 2005 levels;
- 5% of land is available to grow SRC within the land area around the power stations;
- 5% of land is available to grow Miscanthus within the land area around the power stations; and
- For SRC and Miscanthus the cost of the delivered fuel increases as the distance from the station increases.

The resource curve gives an estimate of the incentive required to support different levels of co-firing and is shown in Figure 27 below.

Figure 27 - Co-Firing Volumes At Different Levels of Support



It can be seen from Figure 27 that, at the current coal and carbon prices, at least £11/MWh(e) of support is required to incentivise co-firing with the cheapest biomass fuel currently available.

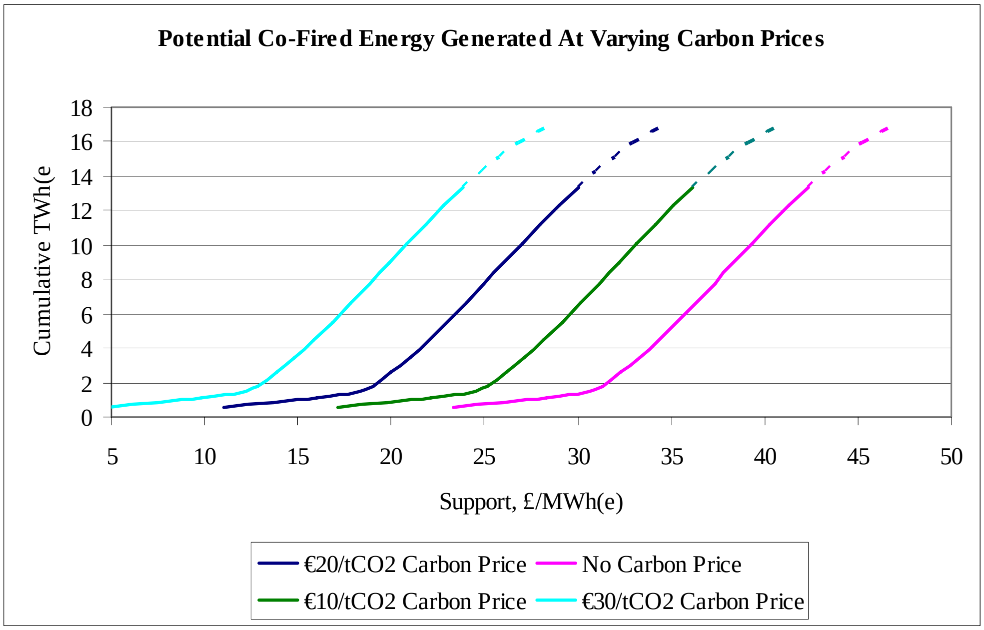
Increasing levels of support will increase volumes of co-firing with a support level of around £28.10/MWh(e) potentially being sufficient to incentivise around 12TWh(e) (approximately 10% of assumed coal burn and approximately 3% of GB supplied energy) of co-fired electricity, although it may take some time for these levels to be achieved. Higher levels of co-firing could potentially be achieved if stations invested in equipment to increase the levels of co-firing further, perhaps to 20% by heat,

It is interesting to note that the support levels indicated above are below both the current ROC price and the current ROC buy-out price.

Our analysis above assumes coal stations running at the stated load factors. However, it should be noted that the volume of co-fired electricity is related to the level of coal burn and that, if coal running reduces, for instance as non-FGD stations close under the Large Combustion Plant Directive (LCPD), the volume of co-fired electricity will also reduce.

The analysis above investigated the levels of co-firing which could be achieved given a carbon price of €20/tCO2. In addition we have explored the level of co-firing that would be incentivised at different carbon prices given no support mechanism, other than the CCL. This is shown in Figure 28 below.

Figure 28 - Support Required For Various Levels of Co-Firing at A Range of Carbon Prices

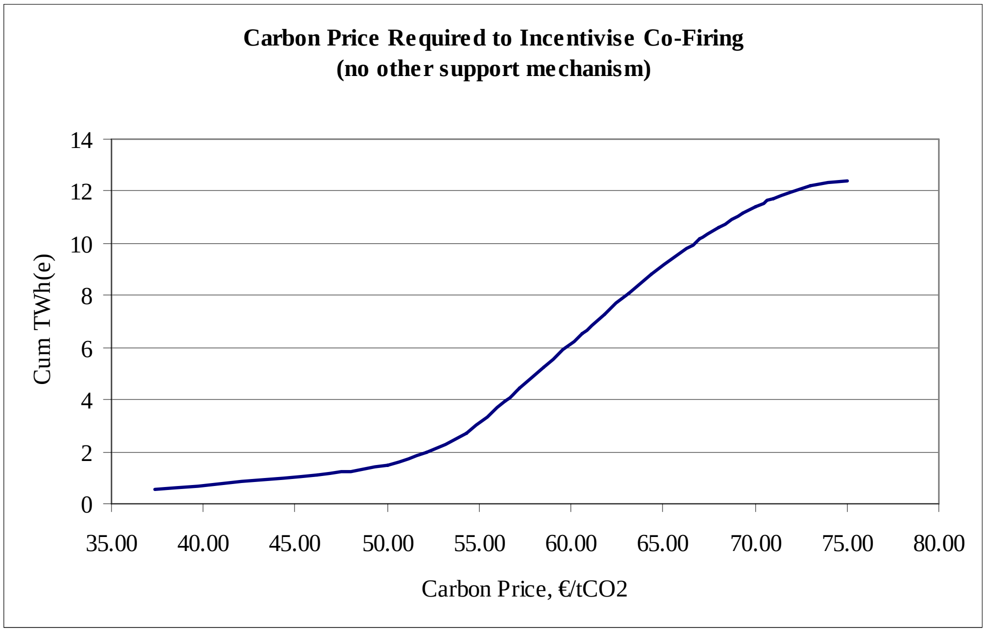


Clearly higher carbon prices reduce the level of support required in order for co-firing of the different fuels to be economic and consequently on the volumes of co-fired electricity produced.

Assuming no co-firing support mechanism, an alternative way of looking at the economics is to calculate the potential volume of co-firing incentivised at different carbon prices.

Figure 29 shows that the carbon price would have to increase beyond €35/tCO_2 to incentivise co-firing: higher than the highest level reached over the last eighteen months.

Figure 29 Carbon Price Required to Incentivise Co-Firing



6.8 Additional Issues

The analysis presented here has been based upon current experiences of co-firing which have indicated that at relative low biomass proportions, co-firing has relatively little influence on plant capacity or efficiency.

It is possible that where plant invest in equipment to allow a higher volume of biomass burn, there could be more impact on plant operations. These could include reductions in efficiency or capacity, especially where relatively wet material is being used for co-firing, or other considerations such as the impact on ash quality particularly where the fuel quality and particle size may not be homogenous. However, although increasing levels of biomass burn is likely to bring with it some operational challenges, it is likely that at least some of these would be mitigated by the investment in the co-firing systems.

The analysis has been based upon the support required to equalise the cost of coal and carbon with the net cost of biomass generation. This is effectively the support required to incentivise replacement of coal with biomass fuel. This analysis is valid where co-firing with biomass has an insignificant impact upon plant efficiency and output, where the proportions of biomass are relatively low and where the level of support for biomass burn does not provide significant over incentivisation (leading to subsidisation of coal burn) that would result in a change in plant despatch decisions. It has been shown that broadly co-firing meets these restrictions, and so the analysis should provide valid results for the calculation of support levels for co-firing at coal plant.

It should be noted that biomass fuel sources typically give rise to lower sulphur emissions than associated with coal burn. For plant that are sulphur constrained, co-firing could allow an increase their annual running levels (this is particularly likely to impact upon non-FGD plant) and, to the extent that sulphur limits become tradeable, could have a financial advantage for other coal plant. However, since the volumes of biomass co-firing proportions are likely to be relatively low, these effects are unlikely to be significant.

Assuming that support is set at approximately the correct level it should incentivise biomass burn over coal but without significant price differential. If support covers capex as well as opex and fuel will always incentivise biomass relative to coal on a marginal cost basis.

Plant that has opted out of the LCPD (Non-FGD plant) has a limited number of running hours and will have to close before 2016. It is therefore unlikely that there will be significant investment in co-firing at these plant, as any investment will have to be repaid over a relatively short investment horizon, and a relatively low number of running hours. Thus, significant investment in direct co-firing is probably most likely to be focused on FGD units. Although a support for mechanism is likely to be designed to incentivise the most cost effective (and sustainable) co-firing technologies, it should be borne in mind that where these require significant capital investment they may not be cost effective for non-FGD plant.

APPENDIX A – QUESTIONNAIRE SENT TO CO-FIRING COMPANIES

The Economics Of Co-Firing

Questionnaire

Company Information

Company Name:

Co-Firing Stations Owned:

Current Operations

Types of Fuel

- What co-firing fuels are you burning at your stations?
- Are they sourced domestically or imported?
- Have there been issues with the availability of the fuels?

Fuel Costs

- What are the current costs of the co-firing fuels burned at your coal fired power stations and how does this breakdown into raw fuel cots and delivery costs?

Capital Costs

- What level of capital investment was required to start co-firing?

Operating Costs

- What are the extra operating costs associated with the co-firing operations?

General

- What has been the effect of co-firing on the efficiency of the station?
- What level of co-firing is currently being achieved?
- What are the restricting factors?

Future Operations

Types of Fuel

- What are your plans for sourcing and burning Energy Crops?
- Are there plans to co-fire alternative fuels at the stations?
- Do you foresee any issues with fuel availability in the future?

Fuel Costs

- What is the future expected costs of these Energy Crops and any other biomass fuels, again broken down between raw fuel costs and transportation costs?

Capital Costs

- Have you any plans for further capital expenditures to enable the continuation/improvement of co-firing?
- What are the key factors that will influence your assessment of any future capital expenditure and how will you assess its economics (the Rate of Return and term) given the inherent regulatory uncertainties?

Operating Costs

- Do you foresee any changes in the co-firing operating costs in the future?

General

- Will planned investment increase the level of co-firing?
- What level of co-firing do you foresee for the future?

APPENDIX B – LOSSES IN BOILER EFFICIENCY AT DIFFERENT CO-FIRING RATIOS

Table 13 -- The calculated loss of boiler efficiency due to the co-firing of wood at up to 20% co-firing on a mass basis, as a function of the wood moisture content.

Wood co-firing ratio (%m/m)	Wood moisture content (%)	Wood co-firing ratio (%, on a GCV basis)	Change in boiler efficiency (%, on a GCV basis)
5	5	3.8	-0.07
	10	3.6	-0.10
	30	2.8	-0.19
	50	2.0	-0.28
10	5	7.5	-0.15
	10	7.1	-0.20
	30	5.6	-0.40
	50	4.0	0.60
20	5	15.0	-0.31
	10	14.3	-0.41
	30	11.1	-0.83
	50	8.0	-1.29

(The base case is a fairly typical, power station supply, British high volatile bituminous coal with 12% total moisture and 15.7% ash contents, as received.)