DEVELOPMENT OF LOW COST SYSTEMS FOR CO-UTILISATION OF BIOMASS IN LARGE POWER PLANT

MID TERM REVIEW REPORT

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EXECUTIVE SUMMARY

There has been a fairly dramatic increase over the past two years in the interest in the co-firing of biomass materials with coal in the large coal-fired power plants in Britain, in response to the significant additional incomes available from the generation of Renewables Obligation Certificates. All of the operators of coal-fired plants have registered with Ofgem, and by the end of 2003, it is anticipated that most, if not all, of the coal-fired power plants in Britain will have the capability to co-fire biomass materials. The major constraint on co-firing activities will be the availability of suitable supplies of biomass materials at acceptable delivered fuel prices.

The route to fully commercial operation of a coal-fired station on biomass co-firing involves a number of stages, viz:

- The securing of the biomass fuel supply,
- The preparation of the application to the Environment Agency/SEPA for a Variation to the Authorisation under Section 11 of the EPA, the definition of the test burn requirements and obtaining agreement to hold the test burn from the EA/SEPA,
- The performance and reportage of the test burn, and
- The final agreement from the Environment Agency/SEPA on the variation to the Authorisation, and proceeding to commercial operation on co-firing.

At the present time, all of the operators of coal-fired power plant have embarked on this process, a number have performed trials, and a small number are involved in fully commercial co-firing activities.

To date, the biofuels that have been considered for co-firing projects, or have been utilised in test burns, have included:

- The solid waste materials from the olive and palm oil industries, imported from the Mediterranean and the Far East,
- Dried sewage sludge,
- Dried sawdust and cereal straw pellets, imported from North America and/or Northern Europe,
- Forestry residues and other wood materials in various forms, of British origin, and
- Bovine products of British origin.

The only significant biomass materials that have not been considered seriously are cereal straw and other biofuels in baled form, because of the relatively high investment cost associated with the fuel reception, handling and feeding equipment required for these materials.

In the short term, and for most of the currently available biomass materials, there has been a preference for the pre-blending options for co-firing. These are options which involve the delivery of a pre-blended biomass coal mixture, or the mixing of the biomass material with the coal at low co-firing ratio in the coal yard, and then processing the blended fuel through the existing coal milling and firing system. These options can be implemented very quickly, with little or no capital expenditure. Power plant operators have been reluctant to proceed with the installation of dedicated biomass comminution and firing equipment to allow co-firing at higher levels, until there is sufficient confidence in the biofuel supply infrastructure to justify the level of capital investment required. There is evidence that one or two power utilities are beginning to give this option serious consideration, however no significant investment in new biomass handling and firing equipment has yet been made on any British coal-fired power plant.

As commercial biomass co-firing increases, the focus, at least in the short term, will be on fuel flexibility, to ease fuel procurement in a resource-constrained market, and to provide some control over the delivered fuel prices. This will involve further trial work, however the Environment Agency/SEPA have indicated that the qualification of further similar fuels will be less onerous than obtaining the Variation for the initial biofuel. In the longer term, power plant operators will wish to continue co-firing beyond the current 2006 deadline. This is likely to help to stimulate the market in energy crops in Britain, provided that these materials can be supplied to the power plants at acceptable prices.

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1. INTRODUCTION

The Renewables Obligation Order is a Statutory Instrument, introduced by the British Government on the 1st of April 2002, to encourage the generation of electricity from renewable sources. The order places an obligation on the suppliers of electricity to obtain an increasing proportion of the electricity supplied from renewable sources. Electricity suppliers that are unable or unwilling to secure sufficient electricity from qualifying renewable sources must pay a 'buy-out' price of £30 per MWh (2002 basis, indexed to the RPI). These penalty payments are pooled, and the pool is shared between those companies that are supplying renewable electricity. This arrangement means that renewable electricity can attract a premium in excess of the buy-out price if the demand for electricity under the Obligation is greater than the renewable electricity available. This is an effective means of providing a subsidy to the generators of electricity from renewable sources. The intention is to create a market in Renewable Energy Certificates (ROCs) in Britain.

The co-firing of biomass materials in the existing large coal-fired power plants is eligible under the Renewables Obligation, however a number of specific provisions covering co-firing have been introduced, viz:

- No more than 25% of the renewables obligation of an individual electricity supplier can be discharged by the production of certificates issued in respect of generating stations which are partly fired by fossil fuel and partly by biomass.

- After 31 March 2006, co-firing biomass with fossil fuels will only be eligible, if more than 75% of the energy content of the biomass derives from energy crops.

- The co-firing of biomass with coal will only be eligible until 31 March 2011.

In the short term, the co-firing of biomass at existing coal-fired power plants offers a number of advantages over the development of new, dedicated biomass plants, principally by avoiding the lead times necessary for planning and construction. In the context of the 2006 deadline for the co-firing of any qualifying biomass material, this is of obvious importance. In addition, the relatively low cost of implementing co-firing projects, and the high generation efficiencies of large central power plants, will serve to promote the rapid development of biomass-fired capacity, and will contribute significantly to the achievement of government renewable energy targets.

In the short term, it is clear that the implementation of co-firing projects will be instrumental in the development of the infrastructure for the supply of biomass materials as fuels in Britain. Currently, the demand for biofuel for co-firing projects outstrips the supply. Over the next 3-5 years, the stimulus to the indigenous biomass market may also facilitate the development of new, dedicated biomass-to-energy projects, particularly after the 2006 deadline, when the range of biomass fuels which qualify for ROCs, when co-fired, will decrease significantly.

For most operators of coal-fired power plants, there are, therefore, significant incentives to initiate co-firing activities as soon as is practicable, because of the April 2006 time limit for the co-firing of the currently available biofuels, and the 2011 limit for all co-firing activity. In this context, the co-firing options that lend themselves to speedy implementation at minimum capital costs have important attractions.

2. THE PROCESS FLOW CHART FOR THE IMPLEMENTATION OF BIOMASS CO-FIRING PROJECTS

At the present time, all of the operators of large coal-fired power plants have expressed interest in the co-firing of biomass materials, and the great majority are actively pursuing co-firing projects. The current situation is summarised in Table 1, which indicates the intensity of co-firing trial activity within the electricity supply industry in Britain over the past year or so.

A brief description of the route being followed towards the implementation of commercial co-firing projects, including obtaining the Variation to the EA/SEPA Authorisation to operate the plant with biomass co-firing, under Section 11 of the Environmental Protection Act, a key step in the process, is presented below.

STEP 1 The securing of the fuel supply

The key decision at the start of the process involves fixing the fuel supply, i.e. ensuring, in a biofuel market that is only just beginning to develop, and which is likely to be resource-constrained, that there is a secure supply of the preferred biofuel materials at predictable prices, for the period of time relevant to the co-firing project. This is easier said than done. The biofuel market conditions bear no resemblance to the normal contracting arrangements for power plant fuels, where there is diversity of supply and fierce price competition. This issue is forcing power generators into some interesting decisions, and biofuels are being purchased from a wide variety of sources. There is clearly, for obvious reasons, a desire to build fuel flexibility into the planned co-firing arrangements. It is also clear at the present time, however, that an Application for a Variation to the EA/SEPA Authorisation can refer to one fuel only, at least in the first instance. The Environment Agency has indicated that applications for the co-firing of further similar fuels may be treated favourably, and that the qualification process may be less onerous.

STEP 2 Preparation of the application to the Environment Agency/SEPA for a Variation to the Authorisation under Section 11 of the EPA

The Application is in two parts, i.e. an application to perform a test burn and an application for commercial, long-term operation on co-firing. With most biomass materials, it is possible to make the case that they have lower concentrations of most of the prescribed pollutant species than coal, and hence co-firing will bring significant environmental benefits.

The drafting of the Application for the test burn is relatively straightforward, however a number of things have to be specified, i.e.

- The fuel and the quantity of fuel required for the test burn,
- The target co-firing ratio, and
- The proposed method of co-firing.

There must be sufficient information provided to allow the EA/SEPA to understand what they are agreeing to, in terms of the test burn and future plant operations, should the test burn be successful.

STEP 3 The definition of the test burn requirements and obtaining agreement to hold the test burn from the EA/SEPA

A simple protocol for the burning of biomass materials in power stations was issued by the Environment Agency in July 2003. It is necessary to prepare a fairly detailed programme and protocol for the test burn, and this will normally mean that the power generator will require specialist help, i.e. from experienced boiler test engineers and environmental monitoring laboratories.

It is a requirement that the fuel reception and storage/handling arrangements, and the co-firing equipment, installed for the test burn reflect the arrangements planned for long-term co-firing.

The test burn programme can be divided into a number of parts, viz:

- The proving of the fuel reception/delivery/blending system, i.e. does it work and can it deliver a consistent, controlled feed of biomass to the plant,
- The proving of the co-firing system at the preferred co-firing ratio, both in terms of the technical and the Health and Safety aspects, and
- The measurement of the environmental impacts of co-firing, against a coal baseline.

The details of the trial programme obviously depend on the fuel, the co-firing option adopted and the specific requirements of the Environment Agency/SEPA inspector.

STEP 4 The performance and reportage of the test burn

The test burn itself will normally take at least 2-3 weeks to perform, and will require the services of a specialist test team and environmental monitoring laboratory. The precise scope of the test burn, and hence the costs, will depend on the requirements of the EA/SEPA inspector.

The reportage of the test burn, and responding to comments and further requirements from the EA/SEPA, may take a further 3-4 months, provided that the results of the test burn are favourable. There are a number of risk areas, associated principally with the fuel handling and feeding system, and with the results of the environmental monitoring work.

STEP 5 The final agreement from the Environment Agency/SEPA on the variation to the Authorisation, and proceeding to commercial operation on co-firing

In some instances, only temporary arrangements may have been made for the reception and the storage/handling of the biofuel, to permit performance of the test burn. It may be necessary at this stage to install and commission the new equipment for the long term, commercial co-firing project.

Having established a successful co-firing system for one biofuel, there will be a desire to provide an element of fuel flexibility, and for the qualification of other fuels. The feasibility of the achievement of fuel flexibility will depend on early (**STEP 1**) decisions made on the fuel supply and the preferred co-firing option.

3. THE AVAILABILITY OF SUITABLE BIOMASS MATERIALS IN BRITAIN AND THE TECHNICAL OPTIONS FOR CO-FIRING

Overall, it is apparent that there are a number of basic options available for the direct co-firing of biomass materials at coal-fired power stations, viz:

- The **pre-blending** of the biomass with the coal and the feeding of the blended fuel into the bunkers, with the further processing of the fuel through existing coal milling and firing equipment.

- The **modification of one or more of the existing coal mills** on each unit to mill the biomass material on its own, and the firing of the milled material through the existing pulverised coal pipework and burners, although it is clear that this option is only available for a limited number of biomass materials and in certain power plants.

- The installation of **new, dedicated biomass milling equipment** and the introduction of the milled fuel into the existing coal firing system.

- The **milling of the biomass material off-site,** and the delivery of the milled product to the station, for on-site handling and firing.

The indirect options for co-firing, i.e. those that involve the installation of a separate gasifier or boiler, are too expensive, and will take too long to implement, to be relevant to the British market, certainly in the context of the 2006 deadline.

In the short term, and for most of the currently available biomass materials, there has been a preference for the pre-blending options for co-firing, i.e.

- Options which involve the mixing of the biomass material with the coal at low co-firing ratio in the coal yard or on the main coal conveyors, and then processing the blended fuel through the existing coal milling and firing system, or

- Options which involve the delivery of a pre-blended biomass-coal mixture at the appropriate co-firing ratio to the power plant, for handling and firing through the existing system.

All of the operators of coal-fired power plants have recognised this, and the majority have made applications to the Environment Agency for Variations to their Section 11 Authorisations to permit biomass co-firing on this basis. A number have been, or are currently, involved in co-firing trial work. At the present time, a small number of coal-fired power plants are involved in the co-firing of biomass on a continuous, commercial basis, (see Table 1) and it is anticipated that a number of others will be at this stage within a number of months.

To date, therefore, the co-firing experience in Britain has been concerned principally with the pre-blending of the fuel and the handling and firing of the blended fuel through the existing coal handling and firing system.

3.1 The availability of suitable biomass materials in Britain

In Britain, the principal biomass materials, which are available as fuels for energy conversion plants in sufficient quantities to be relevant to co-firing in coal-fired power plants, can be listed as follows:

- **Surplus cereal straws and other baleable, dry agricultural residues**, are available in large quantities, principally in the east and south of England. The most significant cereal crops in this context are wheat and barley. A number of dry residue materials from other crops are also of interest, including oats, oilseed rape and linseed crops.

  The straw is collected and handled in baled form, and suitable equipment for the handling and transportation of straw in this form is commercially available. The baled straw has relatively low moisture content, and can be stored for long periods without significant dry matter losses and deterioration in fuel quality.

- **Poultry litter,** is a relatively dry waste product of the barn rearing of chickens and turkeys, which consists of a mixture of the poultry excrement and the bedding material (usually wood shavings or a similar material). It is available all year round, so there is no requirement for long-term storage. The litter can be purchased directly from the producers at low cost. The availability of the fuel, however, is limited to the more intense poultry rearing areas of the country, i.e. the Midlands, Eastern England, and the South West.

- **Forestry and sawmill residues** are available in certain parts of the country. The largest areas of managed woodland are in Scotland and Wales, in the North of England, and particularly the Kielder Forest, and in the South-east of England, and particularly in East Anglia. As produced, the residue materials have high moisture content, and are variable in quality. The long-term storage of wood in chip form is problematic, as rapid biological activity can lead to loss of dry matter and a significant deterioration in the physical quality of the fuel. The infrastructure for the collection, storage and supply of these materials is not currently in place in Britain, however there are a number of companies looking seriously at the development of a secure supply chain for suitable wood biofuels.

- **Urban and industrial wood wastes**: generated in significant quantities in most urban and industrial areas of Britain. These materials are mostly dry and easy to store and handle in chipped form. They are, however, usually contaminated with tramp materials or have been treated with chemicals. These materials need significant pre-treatment prior to their supply as a fuel. There is little information about the availability of these materials as fuels, and there is no significant infrastructure for the supply of these materials in Britain.

- **Specific industrial, agricultural and other waste materials of plant or animal origin**, are available in specific locations, and may be worthy of consideration. A number of these are dried or partially dried sludges from agricultural sources, paper and food processing, and from municipal sewage works.

- **Energy crops** are plants grown specifically for use as fuels. Short rotation coppice and perennial crops are currently preferred, as they require relatively low energy inputs in the form of fertilisers and other chemicals. Short rotation coppice (SRC) is harvested on a 2-4 years cycle as wet chipped material or perhaps in larger pieces. Perennial crops, which are harvested annually, such as miscanthus, switchgrass and reed canary grass, are also perceived as being potential candidate plant species. Miscanthus is being cultivated in Britain at present, but only in small quantities for test purposes. It is considered to be suitable for cultivation only in the Midlands and the south of England. None of the energy crop materials are currently available in Britain in the quantities relevant to co-firing in large power plants, and this situation is likely to apply for a number of years.

- **Tallow and meat/bone meal** are produced in Britain both from the processing of animals slaughtered for consumption, and from the products of the rendering of the carcasses of animals slaughtered in connection with the disease eradication programmes operated in Britain.

- It is also possible to co-fire **imported biofuels** such as dried and pelletised wood fuels, which are produced in large quantities in North America and Scandinavia, and can be imported, albeit at relatively high delivered fuel prices. Other imported agricultural waste materials are also available, viz:

- **Olive processing wastes** are available in large quantities from countries with large oil production industries such as Spain, Italy, Greece, Turkey, Tunisia and Portugal. The quality and particularly the moisture content and calorific value of the solid residue material are dependent on the oil extraction process.

- The solid residues of the **palm oil production** industry in far eastern countries, principally Malaysia and Thailand, are also available for import into Britain in large quantities.

- Solid residues from the **citrus fruit juice production** industries.

The availability of the more important biomass materials relevant to co-firing in coal-fired power plants is presented in Table 2.

To date, the biofuels that have been considered for co-firing projects, or have been utilised in test burns, have included:

- The solid waste materials from the olive oil industry, imported from the Mediterranean countries,

- Dried sewage sludge,

- The solid waste materials from the palm oil industry, imported from the Far East,

- Dried sawdust pellets, imported from North America and/or Northern Europe,

- Dried cereal straw pellets, imported from Europe,

- Forestry residues and other wood materials in various forms, of British origin, and

- Bovine products of British origin.

This is a fairly extensive list, but it does not, as yet, include any significant quantity of fuels that would qualify as energy crops, i.e. practically all of the biofuel currently being considered for use in co-firing projects will be ineligible after the 2006 deadline without the balancing energy crop material required by the legislation.

The only significant biomass materials that have not been considered seriously are cereal straw and other biofuels in baled form, because of the relatively high investment cost associated with the fuel reception, handling and feeding equipment required for these materials. The pre-blending option is not suitable for the direct utilisation of biomass materials in baled form.

3.2 Biomass co-firing Case Studies

Within the current project, three Case Studies have been examined. These were selected as being relevant to the co-firing options available to power plant operators in Britain, viz:

- The co-firing of a dried and pelletised sawdust, imported by sea to Tilbury Power Station in the Thames Estuary,
- The co-firing of cereal straw materials at Kingsnorth Power Station, and
- The co-firing of a wood fuel, pre-blended off-site, and delivered by train for co-firing at a Power Station in Scotland.

The results of the Case Study work can be summarised as follows:

The Tilbury Case Study

In the case of the direct co-firing of imported pelletised sawdust firing at Tilbury, the initial engineering assessment concluded that co-firing of biomass and coal would necessitate the installation of a separate unloading, storage, and conveying system for the biomass fuel.

A large number of options for the co-firing of the pelletised wood material into the Tilbury boilers were examined, and the preferred option, on both technical and economic grounds, involved the installation of a new, dedicated biomass mill under the existing (redundant) 'A' bunker, and the supply of the milled biomass to one of the existing coal burner rows i.e. the selected row of coal burners would have the capability to fire either the pre-milled biomass or coal.

The results of the Tilbury Case Study can be summarised as follows:

- The fuel selected for the Tilbury Case Study was a high grade, pelletised and dried sawdust, imported from North America or Northern Europe, and delivered by sea, at a relatively high delivered fuel price, i.e. in excess of £4 GJ^{-1}.
- There is significant capital expenditure associated with the installation of a new, purpose-designed unloading, covered storage and handling system for the biofuel,
- The preferred co-firing option also involves significant capital expenditure associated with the installation of a new biomass milling facility, with fuel feeding equipment, and of new pulverised wood pipework to distribute the milled biofuel to all burners in one existing burner row.
- The total capital expenditure for the preferred option is of the order of several million pounds, and the project implementation programme is in excess of 12 months.

Overall, the results of the Tilbury Case Study indicated that it was not easy to make a very robust business case for the preferred biomass co-firing option. The principal reasons for this were:

- The relatively high delivered fuel price for the high grade pelletised sawdust fuel,

- The high capital expenditure requirement for the fuel reception, storage and handling facilities,
- The relatively high capital investment requirement for the new milling and firing facilities for the biomass, and
- The time taken for project implementation.

In the context of the 2006 deadline for the co-firing of non-energy crop materials, it was not possible to obtain a reasonable return on the capital employed for the project.

The Kingsnorth Case Study

The Kingsnorth Case Study involved an examination of the direct co-firing of surplus cereal straw materials at up to 10% on a heat input basis into the 500 MW_e boilers at the station. A number of delivered forms of the cereal straw fuel and co-firing options were examined. The preferred option was the co-firing of a pre-chopped and pelletised straw material, although the delivered price for this material was high, in excess of £4 GJ^{-1}. Because of the concerns about the 2006 deadline for the co-firing of surplus cereal straw in the Renewables Obligation and the relatively high delivered fuel price, a low capital cost option, which was suitable for rapid implementation, was favoured.

For this reason, it was considered that co-firing by pre-blending the pelletised biofuel with the coal in the coal handling system, and firing the blended material through the existing coal handling and firing system, was the preferred option. It was considered to be preferable to pass the risks and costs associated with the handling and pre-processing of the cereal straw materials to the fuel supplier, and to pay for this in the form of an increased delivered fuel price.

A fairly detailed study of all of the relevant potential impacts of the straw co-firing on the boiler operation and performance was performed, employing Fuel Quality Impact Modelling and computational Fluid Dynamic (CFD) modelling techniques. The impacts of co-firing the biomass material on the environmental performance of the power plant were also assessed.

Overall, the results of this assessment work indicated that the co-firing of the pelletised straw fuel, at co-firing ratios less than 10% on a heat input basis, into the boilers at Kingsnorth was technically viable, and that the risks of having a significant impact on plant performance were modest.

Powergen have subsequently proceeded to trial work at Kingsnorth Power Station with this fuel.

The Case Study of the co-firing of wood at a Scottish power plant

The third Case Study is concerned with the co-firing of wood in a large coal-fired power plant in Scotland. The wood fuel was selected on the basis of the availability of forestry residues and other wood materials from the large-scale commercial forestry operations in Scotland.

In this case, it was proposed to pass all of the responsibility for the off-site storage and pre-processing of the fuel to the fuel supplier, i.e. the biofuel is to be pre-blended with coal and delivered to the power station by train, as for the normal coal supplies to the station. There are suitable facilities for the pre-blending of the biomass with coal in Scotland, and this approach does offer a higher degree of control over the blend ratio and the quality of the blend than can be achieved with most of the on-site blending options. No capital expenditure on storage and handling facilities on the power plant site is proposed.

The pre-blended fuel is delivered in the normal way, and can be handled and fired through the existing coal handling and firing equipment. There is no requirement for any significant modification of the installed equipment on-site and no requirement for the installation of new equipment. This approach to co-firing has been adopted on a short-term trial basis in Britain, but has not, as yet, been demonstrated in longer term-operation. The co-firing ratio that can be achieved in this way is unknown, but is very unlikely to be greater than 10% on a mass basis. The principal constraint on the co-firing ratio will be the milling behaviour of the blended fuel, and this will be ascertained during the test burn programme. At these low co-firing ratios, and with a clean, low ash content wood fuel, the impacts on the plant operations and plant integrity, and on the technical and environmental performance of the plant will be modest.

This approach has a number of important attractions to the power plant operator, although it will result in increased delivered fuel prices. The logistics of providing a high proportion of the total fuel supplies to the station in this form are not established, however since the quantities of biofuel available may be the principal constraint on co-firing activities, and the fuel supplier has a incentive to maximise the quantity of fuel supplied in this form, this may not be a significant issue. This approach is also eminently suitable for the supply of wood energy crop materials, such as short rotation coppice, when these become available in reasonable quantities, i.e. there is significant scope for the extension of the co-firing activities beyond the 2006 deadline.

General Comments on the results of the Case Studies

Overall, the results of the three Case Studies indicate that there are a number of technically feasible approaches to the direct co-firing of biomass materials with coal in large coal-fired power plants in Britain, based either on a pre-blending approach or on the installation of dedicated biomass comminution and firing equipment. The co-firing options covered in the Case Studies are of direct relevance to the current situation in the British electricity supply industry, since all of the current co-firing projects or the proposed projects are based on one or other of these options.

The results of the Case Studies also indicate that, provided that reasonably clean, low ash biomass material are employed, and that the co-firing ratio is less than 20% or so, the impacts on the performance and integrity of the boilers, and on the environmental performance of the plant, will be modest.

The implementation of biomass co-firing projects in coal-fired power plants in Britain over the next few years will most likely be based on one or other of these approaches. The specific co-firing option adopted at a particular station will depend on the geographical location, on the security of supply of suitable quantities of biofuels, either imported or from indigenous sources, and on the co-firing project economics, in the context of the Renewables Obligation.

In the short term, the pre-blending approach to co-firing appears to be favoured, and a number of power plants have performed test burns based on this option, according to the requirements of the Environment Agency. It is likely that a number of power plants in Britain will proceed to commercial co-firing of biomass materials on this basis over the next few months.

It is unlikely that power plant operators will proceed with the installation of dedicated biomass comminution and firing equipment until there is sufficient confidence in the biofuel supply infrastructure to justify the level of capital investment required. There is evidence that one or two power utilities are beginning to give this option serious consideration, however no significant investment in new biomass handling and firing equipment has yet been made on any British coal-fired power plant.

It is clear, therefore, that the current plans of the majority of the power plant operators are focussed almost exclusively on the ROC income available in advance of the 2006 deadline. One or two future trends, particularly within some of the more forward looking power companies, are beginning to become apparent, however, viz:

- There is a clear desire for fuel flexibility, in view of the resource constraints on the eligible biofuels, and the risks of price increases for the currently available biofuels,

- A number of the power plant operators have a clear interest in direct firing systems which allow operation at higher co-firing ratios than can be achieved by pre-blending. A number of power companies have recently issued preliminary enquiries for fuel handling and firing equipment, to test the availability and price levels of suitable systems,

- There is also some interest in the likely availability of energy crop fuels for co-firing after the 2006 deadline. The power companies will be unhappy with the prospect of the loss of the additional ROC income at that time. Provided that energy crops can be supplied to the power plants at appropriate prices, this may provide a significant market, albeit over a period of five years or so, for these fuels.

4. THE ECONOMICS OF BIOMASS CO-FIRING IN LARGE COAL-FIRED BOILERS

It is clear, from the very simplest economic analysis of biomass co-firing projects, that the profits available to the power plant operators from co-firing will be affected, to a first approximation, by two key variables, viz:

- The delivered price and availability of the biomass fuel, and

- The market value of the Renewables Obligation Certificates.

4.1 The delivered price of biofuels

The delivered price of the biomass materials over the short term will be dependent on the biomass type, source, availability and storage/transport requirements, and it is essential to take great care when attempting to provide estimates of future biofuel prices in a market which is currently so underdeveloped. With this caveat in mind, estimates of the current energy cost of a range of biomass materials are presented in Table 3. These data indicate that the current delivered prices of the more relevant biomass materials, delivered to British power plants, are of the order of £2.0-5.0 GJ^{-1}.

In general terms, the currently available materials such as cereal straws and chipped, wet forestry residues are towards the bottom end of this range, as are the imported agricultural waste materials such as olive residues and milled palm nuts. The premium, highly processed, biomass materials, such as the dried and pelletised sawdusts and cereal straws, imported from North America and continental Europe, are at the top end of this price range. To place these prices in the proper context, it should be noted that the current delivered price for power station coal is of the order of £1.0-1.2 GJ^{-1}.

The existing supplies of indigenous biomass materials are a limited and, in some cases, dispersed resource. The current coal procurement and supply to power plants are characterised by large volume fuel supply contracts and bulk deliveries by train, whereas, to date, biomass fuel supplies commonly involve numerous contracts with fuel delivery by lorry or, in one or two cases, by ship to an existing coal jetty. The utilisation of imported biomass materials may only be appropriate for those coal-fired power plants that have their own fuel reception jetties, or are within reasonable transport distances of suitable port facilities.

The volumes of biomass required to service a co-firing project of the type described above are substantial. The current biomass to energy plants in Britain have been sized according to the fuel supply and have been very carefully sited to exploit locally available biomass resources. The coal-fired power plants, on the other hand, have been sited local to cooling water sources and at convenient locations for the receipt of coal, and not on their proximity to biomass resources.

It is possible that the increased utilisation of biomass may cause biomass prices to increase, particularly where there are local or seasonal shortages. Where shortages of biomass or unacceptable price increases do occur, the power plant operators have the option of temporarily suspending the co-firing activities until the fuel supply situation improves. The operators of small, dedicated biomass to energy plants do not have that luxury.

The risks associated with the biofuel supply may be such that the power generators could be obliged to invest directly in the fuel supply infrastructure, and to adopt a more pro-active role in creating new supply structures on a site-by-site basis, in order to protect the investment in new plant, to meet contractual obligations and to provide a degree of control over the delivered fuel price and quality. This is not normally an attractive prospect for the generators. It may be possible, however, to delegate the responsibilities for fuel procurement to an agent, or to the coal suppliers, who have experience in the procurement and transportation of fuels in large quantities, and this may become increasingly attractive to plant operators.

All plant operators, involved in the co-firing of biomass materials, will clearly wish to exercise the maximum degree of fuel flexibility to help to ensure continuity of the biomass supply and to minimise fuel costs. This will, of course, be dependent on the terms of the Section 11 Variation from the environmental regulation authorities, and may have an impact on the technical risks to the performance and integrity of the power plant, and the level of capital investment required.

4.2 The future value of ROCs

The second factor that will affect the profitability of biomass co-firing is the future value of ROCs. As of January 2003, the market price for stand-alone ROCs was in the region of £45.50-47.00 MWh^{-1}. As stated above, the future value of ROCs will be dependent on the rate at which new, eligible generation comes on line, relative to the increasing size of the obligation. This is, of course, subject to a degree of uncertainty, however the sentiment in the industry is fairly pessimistic, i.e. the feeling within the industry is that the rate at which new renewable energy projects will come on line will be slow.

Platts and the Renewable Power Association regularly publish the Renewables Obligation Certificate (ROC) Marker. The current values of this marker are presented in Table 4. The projected ROC Marker values over the period 2003-2006, indicate that the market value of ROCs will be in the range £45-56 in the medium build rate scenario, and in the range £35-56 for all scenarios, i.e. this indicator suggests that there will be a significant shortfall in ROCs over the period in question.

4.3 The development costs of co-firing projects

The project development costs for small, dedicated biomass to energy plants on new sites can run into several million pounds, and project development can take a number of years, from the initial work on the project to completion of the commissioning of the power plant. For projects that involve the co-firing of the biomass in existing coal-fired plant, much of the infrastructure is already in place, and the project development costs are more modest.

There are, however, significant costs associated with the following activities:

- The selection and securing of the biomass fuel supply,
- The preparation of the application to the Environment Agency for the Variation to the Authorisation under Section 11 of the EPA,
- The definition of the test burn requirements,
- The performance and reporting of the test burn, and
- Obtaining final agreement from the Environment Agency to proceed to commercial operation on co-firing.

Recent experience has indicated that this process can take at least six months, and can cost hundreds of thousands of pounds.

The capital expenditure requirement for biomass co-firing projects varies widely, depending on the biofuel, the approach to co-firing adopted by the station and the site-specific conditions, viz:

- For biomass co-firing projects involving the pre-blending approach, the capital expenditure can be modest and is associated principally with the reception and on-site storage of the biofuel, and with the provision of suitable fuel blending facilities, if these are required.
- For biomass co-firing projects involving dedicated biomass comminution and firing systems, the capital investment requirement can be substantial, and can

run into several million pounds for the new fuel handling and milling equipment and the new firing system.

4.4 The 25% ceiling on co-firing

One further factor, which may affect the expansion of biomass co-firing activities in Britain, is the provision in the Renewables Obligation, which states that no more than 25% of the obligation of a supplier can be discharged by the production of certificates issued in respect of generating stations which are partly fired by fossil fuel and partly by biomass. In principle, the 25% limit represents a ceiling on the extent of co-firing, and it is interesting to consider whether co-firing activities are likely to be constrained by this limit in the short-term.

The current Renewable Obligation in financial year 2003/2004 is estimated to be of the order of 13.5 TWh. The ceiling is 25% of that value, i.e. is of the order of 3.4 TWh.

The total coal-fired power generation capacity, 14 power stations, is of the order of 24 GWe. If all of the coal-fired power plants were to have the capability to co-fire biomass at the 5% level, this would represent a co-firing capability of around 1,200 MW. At an overall 50% load factor, this would be equivalent to 4.2 TWh. This means that, in order to reach the 25% co-firing ceiling for 2003-2004, around 80% of the coal-fired capacity would have to be co-firing at 5% for all of the current financial year.

On the basis that only a small number of the coal-fired power plants are currently in a position to co-fire biomass materials continuously and on a commercial basis, this situation is extremely unlikely to occur during this current year, or at any time up to the 2006 deadline. The 25% ceiling is not likely, therefore, to represent a real constraint on the expansion of biomass co-firing activity over the next year or so, and is very unlikely to have any significant impact up to the 2006 deadline.

This analysis is in general agreement with a similar analysis reported by the Renewable Power Association. They estimated that if all of the coal-fired power plants, that were registered with Ofgem under the Renewables Obligation in December 2002, were to be involved in biomass co-firing continuously at the 5% level, that would represent only 16.6% of the renewable electricity generation capacity required to meet the obligation, i.e. well short of the 25% ceiling.

4.5 The economics of co-firing by a pre-blending route

By way of illustration, let us examine the situation where a 2000 MW_e coal-fired power plant is co-firing a biomass material at a co-firing ratio of 5% on a heat input basis, i.e. the station will have the capability of generating 100 MW_e from qualifying renewable sources. This is not untypical, both in terms of the generating capacity of the coal-fired power plants in Britain, and of the co-firing ratio achievable by the pre-blending approach.

The base case assumptions are listed in Table 5. For the purpose of the basic analysis, the effects of inflation have been ignored and all costs are assumed to be constant in real terms.

The analysis ignores any capital expenditure required to permit co-firing of the biomass. In reality, the capital expenditure requirement will depend on the nature of the biofuel and the arrangements made for reception, storage and blending of the fuel. In most cases, the capital expenditure will be modest, and will be associated principally with the provision of new facilities for the reception and on-site storage of the fuel. As far as is possible, the power plant operators will wish to minimise the capital expenditure. They will also attempt to pass responsibility for the storage of the fuel to the fuel supplier or to others, i.e. to arrange for deliveries of the biofuel on an as-required basis, and to pay for the associated storage costs in the delivered fuel price.

The analysis also ignores any additional, non-fuel, operating costs associated with the co-firing activity, and assumes that the implementation of the co-firing system does not involve significant capital expenditure.

The non-fuel operating costs associated with co-firing will include:

- The additional costs of marshalling the biomass on-site, of the on-site fuel blending, if appropriate, and the costs of any additional cleaning required to avoid the build-up of biomass dust in the fuel handling system,

- The costs of the management of the biomass supply contracts, of routine biomass fuel analysis, and of the accounting and reporting associated with the ROC claims,

- The costs of any ongoing additional O&M activities associated with the co-firing and of the impacts of co-firing on plant availability and flexibility of operation.

In reality, the non-fuel operating costs will be highly site and fuel specific, however they are likely to be relatively modest compared to the delivered fuel costs, and compared to the revenues available from the generation of ROCs.

The results of this simple analysis indicate that the net income from biomass co-firing, based on the assumptions described in Table 5 are of the order of £10 million p.a., which would represent a profit level in the range £5-10 million p.a., depending principally on the delivered fuel price. The results of this analysis also indicate that the co-firing activities are profitable provided that the delivered fuel price is less than around £5-6 GJ^{-1}.

All of the operators of coal-fired power plants in Britain have performed similar economic calculations, and have concluded that there is significant profit available from biomass co-firing activities, provided that supplies of qualifying biomass materials can be obtained at these delivered fuel prices. They have also recognised the importance of the 2006 deadline in this context. This has provided the motivation for the flurry of co-firing trial work and other activities over the past year or so.

5. AN OVERVIEW OF THE CURRENT STATUS OF BIOMASS CO-FIRING IN BRITAIN

5.1 A summary of the results of the co-firing trial work to date

As stated above, a number of the operators of coal-fired power plants in Britain have performed biomass co-firing trials over the past year or so, and these activities are ongoing. In general terms, the objectives of the trial work have been:

- To establish the practical feasibility of the arrangements made for the storage, transport, reception and blending of the biomass fuel with the coal,

- To test the flow characteristics of the biomass-coal blends in the existing coal handling system, the coal bunkers and the feeders, and to establish whether or not there is a tendency for the generation and accumulation of dust at transfer points in the conveying system and at the bunkers.

- To study the behaviour of the biomass-coal blends in the coal mills, and to establish whether or not modifications to the mill operating regime will be required for the processing of the blended fuel.

- To measure any impacts of the co-firing of the blended fuel on boiler operation and performance,

- To establish the maximum biomass-coal co-firing ratio that can be achieved without unacceptable impacts on plant performance, and to test the ability to maintain this co-firing ratio on all mills, and

- To monitor the environmental performance of the test unit when co-firing biomass at the preferred co-firing ratio, to satisfy the requirements of the Environment Agency/SEPA.

In general terms, the trials have comprised three phases, viz:

The initial phase, during which the biomass-coal blend has been supplied to one mill in the test unit. During this period, the main focus of the testwork is generally on the impact of co-firing on the mill performance. It is considered that if the correct mill product fineness can be delivered to the combustion equipment, then good quality combustion is likely to be assured, and the impacts on downstream processes in the boiler will be minimal.

One of the key objectives of this phase of the work is to attempt to establish the maximum co-firing ratio that could be maintained without significant deterioration in mill performance. Normally, a series of specific mill tests, i.e. mill load line tests, mill shutdowns and restarts, etc. are performed.

The second phase of the test burn, involves rolling out the co-firing activities to all of the mills on the tests unit, at the preferred co-firing ratio. This is usually done in stages, i.e. starting at low co-firing ratio on all mills, and then increasing the co-firing ratio in a controlled manner.

The final phase, involves performance of the environmental monitoring of the test unit, when co-firing biomass at the preferred level, and on coal alone to provide a baseline, and other testwork, to satisfy Environment Agency/SEPA requirements.

The Environment Agency have recently issued a short document entitled ‘Protocol for the burning of biomass fuels in power stations’, which is intended to provide guidance for operators in this regard. The document lists the Minimum Assessment Requirements for substitute fuels in power stations, covering releases to air, water and land, and a number of more general requirements associated with the technical and environmental performance of the power plant when co-firing biomass materials.

In general terms, the biomass co-firing trials held to date have involved the co-firing of pre-blended fuels. The blending of the biomass has been accomplished in a number of ways:

- For a number of the trials, the biomass fuel has been blended off-site by the coal supplier, and has been delivered as a blend to the site by train for handling and firing in the normal way using the installed equipment.

- In other cases, the biomass has been blended with the coal in the coal yard or has been fed on top of the coal on the main coal conveyors, using the existing reclaim hoppers or using other types of variable speed feeder.

There have been some problems with fugitive dust generation in the coal yard when handling dry, fine biomass materials, and with the accumulation of biomass dust at transfer points on the coal conveyors and in the coal bunker hall. This type of problem is not uncommon when handling dry coal, and is relatively easily dealt with using conventional dust suppression techniques and improved housekeeping. There have also been some difficulties with the control over the biomass-coal blend ratio, and with the blend consistency. This has given rise to some problems with the control of the mill and boiler trials.

In general terms, the technical aspects of the trials have been successful in that the maximum sustainable biomass co-firing rate has been established on a single mill, and this has been rolled out to all the mills on the test unit. Generally this has been at less than 10% on a heat input basis, although this will depend both on the nature of the biomass material and on the type of coal mill. At this level of co-firing, the impacts on the boiler performance and on the gaseous gas-borne emission levels have been modest.

There have been some concerns about the safety aspects of the handling of the biomass-coal blends through the coal mills, and some specific testwork is usually carried out to demonstrate that the blend can be processed safely. If necessary, minor modifications to the power station 'Pulverised Coal Code of Practice' have been made.

Overall, therefore, the programme of testwork on the co-firing of a range of biomass materials at the coal-fired power stations, which has been carried out over the past year or so, and which is continuing at the present time, has been reasonably successful. A number of stations have obtained the Variation to the Authorisation from the Environment Agency to operate commercially, and other stations are currently engaged in the qualification process. The number of ROCs generated from co-firing has increased dramatically from a very low baseline in the first half of 2002.

By the end of 2003, it is anticipated that most, if not all, of the coal-fired power plants in Britain will have the capability to co-fire biomass materials in this way. The major constraint on co-firing activities will be the availability of suitable supplies of biomass materials at acceptable delivered fuel prices.

5.2 The future prospects for biomass co-firing in Britain

As has been stated above, as more coal-fired power plants are involved in biomass co-firing on a commercial basis, the focus, at least in the short term, will increasingly be on fuel flexibility, to ease fuel procurement in a resource-constrained market, and to provide some control over the delivered fuel prices. This will involve further trial work, however the Environment Agency has indicated that the qualification of further similar fuels will be less onerous than obtaining the Variation for the initial biofuel.

In the longer term, there are likely to be incentives for the power plant operators to continue co-firing beyond the 2006 deadline. This is likely to help to stimulate the market in energy crops in Britain, provided that these materials can be supplied to the power plants at acceptable prices.

The supply of energy crop materials as fuels is very much in its infancy in Britain, and the current growers of SRC wood fuels have suffered a significant loss of confidence in recent years. There is also a mismatch between co-firing and the supply of SRC wood in that SRC is a long-term crop, whereas co-firing becomes ineligible for ROCs after 2011. It may be difficult to recruit farmers to grow SRC fuel at acceptable prices if only short-term fuel supply contracts are available.

The annual energy crops, such as miscanthus and the perennial grasses may be more attractive, in that the commitment on behalf of the producers is shorter term, however the cultivation of these energy crops in Britain is very much in its infancy, and the pre-processing of these materials can be more expensive.

Station	**Capacity (MW_e)**	**Generator**	**Status**	**Biomass fuels**
Cottam	2,000	EdF	Trial	Forestry/sawmill wastes
Didcot A	2,100	Innogy	Trial	Wood
Drax	4,000	?	Trial	Milled palm nuts
Ferrybridge C	2,035	AEP	Commercial	Olive residue, palm nuts, shea, citrus , wood
Fiddlers Ferry	1,995	AEP	Commercial	Olive residue, palm nuts, shea, citrus, wood
Ironbridge	970	Powergen	Trial	Wood
Kingsnorth	2,034	Powergen	Trial	Cereal residues
Longannet	2,400	Scottish Power	Commercial	Sewage sludge
Rugeley	1,000	International Power	Trial	Wood, olive residues, cereal
Tilbury	1,085	Innogy	Trial	Wood

Table 1 **The current status of co-firing activities at the coal-fired power stations in Britain. (after ENDS Report, July 2003)**

Biomass material	**Estimated current total arisings (tonnes x 10^3)**	**Potential available for co-firing (tonnes x 10^3)**
Abattoir wastes	600	10-20
Surplus cereal straws	14,000	4,000 – 6,000
Poultry litter	1,700 – 2,000	1,000 - 1400
Other dry agricultural wastes	3,500 – 5,000	25-40
Forestry residues	2,000	1,100
Sawmill wastes	1,800	Negligible
Paper and paper mill wastes	5,000 – 6,500	1,500 – 2,000
Demolition/construction wood	2,500	500 – 1,000
Waste/broken pallets	1,300	80-100
SRC willow	30-45	30-45

Table 2 **Summary of the current availability of indigenous biomass materials for co-firing in Britain**

Fuel	Delivered fuel cost (£ odt^{-1})	GCV (GJ odt^{-1})	Energy cost (£ GJ^{-1})
Coal	36	30	1.2
Forestry residue	25-45	20	1.8
Surplus cereal straw	35	18	2.0
Willow SRC	40-60	20	2.5
Miscanthus	50-60	19	2.9
Switchgrass	50-60	19	2.9
Reed canary grass	50-60	18	3.0
Imported olive residues	35-45	18	2-2.5
Imported sawdust pellets	70-80	18	3.5-4.5

Table 3 The delivered costs of a number of relevant biomass materials

	ROC value (£ MWh^{-1})		
Obligation period	**High build rate**	**Medium build rate**	**Low build rate**
2002-2003	47.00	47.00	47.00
2003-2004	50.52	56.38	56.74
2004-2005	40.84	47.92	52.07
2005 2006	35.68	45.85	55.87
2006-2007	46.97	56.46	66.97
2007-2008	55.44	66.61	78.93

Table 4 The ROC Marker values

Parameter	Unit	Value
Rated output	MWe	2000
Net efficiency	% of GCV input	36%
Load factor	%	40
Co-firing rate	% of GCV input	5.0
Coal GCV	MJ kg^{-1} (as fired)	25
Biomass GCV	MJ kg^{-1} (as fired)	17
Co-firing commences	mm/yy	03/03
Co-firing ceases	mm/yy	03/06
Cost of conversion	£k	0
Cost of biomass	£ GJ^{-1}	3.0
Cost of coal	£ GJ^{-1}	1.2
ROC value	£ MWh^{-1}	50

Table 5 The base case assumptions for co-firing by pre-blending