Advanced biomass co-firing technologies for coal-fired boilers

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Abstract
All of the more important technical options for the direct co-firing of biomass materials in large coal-fired power plants have been implemented in Britain over the past 3-4 years. In this paper, brief descriptions of all of the available direct co-firing options, and a discussion of the preferred options for future projects, are presented. There is also a discussion of the potential impacts of co-firing on boiler plant performance and integrity, and on the means available for the assessment and minimisation of these impacts for both retrofit and new build projects.

Keywords
Biomass co-firing, combustion, mineral matter

INTRODUCTION

The British government made provision in the Utilities Act 2000 for an obligation to be placed on the licensed electricity suppliers to supply specified amounts of electricity from renewable sources. The obligation started at 3% in 2002/3 rising to 10% by 2010, and has subsequently been extended to 15% by 2015. The other key element of the scheme is that eligible generators of renewable energy receive a Renewable Obligation Certificate (ROC) for each MWh of renewable electricity generated. Electricity suppliers can either present certificates to cover their obligation, or they can pay a 'buy out' price, initially set at £30 per MWh, and inflated according to the Retail Price Index. All proceeds from the 'buy out' payments are recycled to the generators in proportion to the number of ROCs presented. ROCs can be traded freely, and the price is dependent on the ratio of ROCs generated to 'buy out' payments.

The Obligation, therefore, is intended to provide incentives for the major electricity supply companies and others to invest in renewable electricity generation, through a market-based mechanism which is consistent with the liberalised electricity sector in Britain. Since the introduction of the Renewables Obligation, there have been significant increases in electricity generation from landfill gas, on-shore wind and biomass co-firing in coal fired power plants, i.e. from those technologies which involve modest capital investment and can be implemented relatively quickly. Despite this, the total renewable electricity generated is still significantly lower than the Obligation level, with the result that ROCs have been trading at a healthy premium.

In this context, biofuels, e.g. all types of biomass, including the biodegradable fraction of energy from waste, landfill gas, sewage gas, agricultural and forestry residues and energy crops, are eligible as renewable sources, and the following definitions apply:

- biomass' means fuel used in a generating station of which at least 98% of the energy content (measured over a period of one month) is derived from plant or animal matter or substances derived directly or indirectly therefrom (whether or not such matter or substances are waste) and includes agricultural, forestry or wood wastes or residues, sewage and energy crops (provided that such plant or animal matter is not or is not derived directly or indirectly from fossil fuel).

- energy crop' means a plant crop planted after December 1989 and grown primarily for the purpose of being used as a fuel.

The co-firing of biomass in existing coal-fired power plants is eligible under the Renewables Obligation. This decision was somewhat controversial in that it was recognised that the costs of co-firing projects at existing coal-fired power plants were likely to be significantly lower than those of establishing new, dedicated biomass to energy plants. There was a risk, therefore, that the operators of existing coal-fired power plants would be in a position to purchase all of the available biomass materials for co-firing, to the exclusion of other biomass conversion technologies, and that the additional income from ROCs may distort the electricity market.

On balance, it was decided that co-firing should be eligible within the Renewables Obligation, to provide a much-needed boost to the biomass supply infrastructure in Britain, and particularly to provide secure markets in the short-medium term for energy crop materials. Because of the concerns noted above, limits were placed both on the total quantity of eligible ROCs from co-firing, and on the timescales over which co-firing is eligible under the Obligation.

One of the results of the introduction of the Renewables Obligation in April 2002 has been a dramatic increase in biomass co-firing involving all of the large coal-fired power plants in Britain. To date, the total cumulative power generation by biomass co-firing is in excess of 6.5 million MWh. The cumulative generation of ROCs from biomass co-firing at the large central coal power plants is listed in Table 1, and this represents a total additional income to the stations in excess of £300 million. All of these plants have been co-firing on a commercial basis, however the levels of co-firing on a station-by-station basis has varied markedly.

It is clear that, from a standing start, the electricity supply industry in Britain has responded relatively rapidly to the financial incentives represented by the introduction of the Renewables Obligation. The purpose of this paper is to summarise the biomass co-firing experience in Britain to date, and to provide some speculative comments as to the potential role of biomass co-firing within the British electricity supply industry and elsewhere, in the short-medium term future.

THE TECHNICAL OPTIONS FOR CO-FIRING BIOMASS IN LARGE PULVERISED COAL-FIRED BOILERS

Co-firing by Pre-mixing the Biomass with the Coal and Co-milling

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-mixing of the biomass with the coal and the feeding of the mixed 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 boiler 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 or firing through new biomass burners.

The indirect or parallel options for co-firing, i.e. those that involve the installation of a separate biomass gasifier or biomass boiler, which have been implemented in continental Europe, have so far been considered to be too complex and expensive to be relevant to the British market.

To date, the majority of the biomass co-firing in Britain is by pre-mixing the biomass with the coal in the coal handling system, and processing the mixed fuel through the installed coal mills and firing equipment. The maximum achievable co-milling ratio, and hence the level of co-firing, without significant mill throughput constraints, is limited, and depends on the design of the coal mill and the nature of the biomass material. In most cases, co-firing of the biomass at up to around 10% or so, is possible, although co-firing ratios up to 5% on a heat input basis are more commonly applied on a commercial basis.

The principal technical problems encountered by the power plant operators have been with the storage and handling of the biomass, and in particular with the tendency of some biomass materials to generate significant dust levels.

The Direct Injection Co-firing of Biomass

A number of projects involving the direct injection co-firing of pre-milled biomass materials, which avoid the biomass throughput constraints associated with co-milling and can allow operation at higher co-firing ratios, have also been completed in Britain. All of the relevant technical approaches to direct injection co-firing involve the pre-milling of the biomass, and all involve the pneumatic conveying of the milled biomass from the handling/milling facilities to the boilers. There are three basic direct co-firing options for the pre-milled biomass in retrofit applications, viz:

- The direct injection of the biomass into the furnace, with no flame stabilisation and no additional combustion air,
- The installation of new dedicated biomass burners, with the associated combustion air supplies, and
- The injection of the biomass into the pulverised coal pipework or at the burner, and co-firing with coal through the existing burners.The first option involves **direct injection through the furnace wall** and is relatively inexpensive and simple to install, although it does involve the installation of new, small diameter, furnace penetrations. This has been demonstrated in a downshot-fired furnace in Britain, however the application in conventional wall or corner-fired furnaces is considered to be limited.

The installation of **new, dedicated burners** for the biomass in existing plants may have some attractions, however there are a number of problems to be resolved, viz:

- New burner locations, generally within the existing burner belt, have to be identified and significant new furnace penetrations made,

- A secondary air supply for the biomass burners is required, i.e. there are significant modifications required to the existing draft plant.
- The impacts of co-firing on the performance of the existing pulverised coal combustion system and on the furnace and boiler performance need to be assessed.
- The dedicated biomass burners are based either on conventional pulverised coal burners or on cyclone burners, and these have not been extensively demonstrated commercially for this type of application in a relatively demanding environment, i.e. in a large, multi-burners furnace in tandem with conventional co-firing systems.
- This approach to the direct firing of biomass is complex, both in terms of the mechanical and control interfaces with the boiler, and is relatively expensive to install.

There are a number of co-firing systems in Europe based on the installation of dedicated biomass burners, although it is fair to say that the accumulated plant experience to date is not extensive.

The third option, which has proved to be more popular, involves **the pneumatic injection of the pre-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, additional air and fuel are introduced to the mill group of burners, and the mill primary air and coal flow rates have to be reduced accordingly, to maintain both the coal mills and burners within their normal operating envelopes. This option has proved to be relatively inexpensive and simple to implement, however there are significant interfaces with the mill and combustion control system, which have to be carefully managed. The options for the location of the biomass injection point are:

- Directly into the burner.
- Into the pulverised coal pipework, just upstream of the burner, and
- Into the mill outlet pipework local to the mill outlet,

The first option involves significant modification of the coal burners and this approach is necessary for some biomass materials, where there is concern about the potential for the blockage of the pulverised coal pipework system, and particularly of splitters, riffle boxes, and of the coal burners.

One example of a 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 Doosan Babcock Mark III Low NO_x burners. The pulverised coal is fired through the primary air annulus, as normal.

In this case, the biomass material is cereal straw, which is delivered to the station in baled form and processed on-site to produce a chopped straw material, which is carried along four independent pneumatic conveying lines, at a rate of 5 tonnes per hour per line, from the straw handling plant to the boiler.

The biomass is then injected directly through the core air tubes of the burners. Significant modification of the coal burners was required, including relocation of both the oil lance and the flame scanner to clear the core air tube for the biomass injection. This approach has the disadvantages that it inevitably involves some interference with performance of the tertiary air swirlers, and it means that both the oil lance and the flame scanner positions are in non-ideal positions. At Studstrup, the engineers were forced down that particular route because of the perceived requirement to provide a clear passage down the core air tube for the relatively large straw particles, to avoid blockages.

A description of the experience with this system to date was given by Overgaard et al. (2004) In general terms, the experience at Studstrup has been positive, with no significant negative impacts on the combustion efficiency, the NO_x emission levels, or the furnace ash deposition. This approach may have some attractions, particularly for pre-milled biomass prepared from baled materials, which are difficult to mill to small particle sizes, and for materials that may have a tendency to blockage of the pneumatic conveying pipework. The modification of pulverised coal burners of other designs, to permit biomass co-firing, has also been successfully applied at power plants in Britain and elsewhere.

The principal alternative to the approach taken at Studstrup is to introduce the biomass into the pulverised fuel pipework upstream of the coal burners, i.e. options 2 and 3 above. In this case, the pulverised coal/biomass mixture is carried forward along the pulverised coal pipework, through the burner and then enters the combustor via the primary air annulus as normal. This type of approach is, in principle, applicable to all burner designs. As stated above, two potential locations for the introduction of the biomass into the pulverised coal pipework are apparent, viz:

- The introduction of the biomass into the pulverised coal pipework just upstream of the non-return valves local to the furnace, i.e. downstream of the pulverised coal splitters, if any, and

- The introduction of the biomass into the mill outlet pipework, downstream of the mill product dampers, and upstream of the pulverised coal splitters, if any.

The first of these options, i.e. injection of the biomass stream local to the burner inlet, has a number of potential attractions, viz:

- In general, the point of introduction of the biomass and the shut-off valve etc. will be readily accessible from the burner galleries, for inspection, maintenance, etc.,

- The potential process risks associated with the introduction of a significant quantity of biomass into the pulverised coal pipework are minimised, by having the shortest possible length of pipework carrying the mixed fuel stream, and avoiding any splitters in the coal pipes, and

- The introduction point for the biomass is well away from the coal mill, and hence the potential impact of mill incidents on the biomass conveying and injection system is reduced.

In some cases, however, the routing of the biomass pipework through the normally congested region local to the boiler front, and the arrangements for supporting the biomass pipes, can become overly complex and expensive. It should be noted also that the pulverised coal pipework local to the coal burners has to move with the burners as the furnace expands with increasing temperature, and sufficient flexibility must be introduced into the biomass conveying pipework to allow for this movement.

For some applications, the second approach may be preferred, i.e. the introduction of the biomass stream into the mill outlet pipework just downstream of the mill product dampers and upstream of any pulverised coal splitters. This approach is much easier to engineer and has the advantage that the number of biomass pneumatic conveying pipes may be reduced. The movement of the pulverized coal pipework close to the mill is relatively small. The mixed biomass/pulverised coal stream is then carried forward to the burners, via any splitters in the pulverised coal pipework.

The principal disadvantages of this system are that the injection point for the biomass is closer to the coal mill, i.e. there are greater risks of interference with the pulverised coal transport system, and particularly at the pulverised coal bifurcators, and the impact of any mill incident on the biomass conveying system may be greater. There may also be relatively poor access to the point of introduction of the biomass for inspection and maintenance, depending on the details of the pipework layout.

In all cases, the introduction point of the biomass to the pulverised coal pipework or directly to the burner, is fitted with a fast-acting, actuated biomass isolation valve to allow rapid isolation of the biomass system from coal firing system.

Overall, it is clear that there are a number of viable technical options for the direct co-firing of pre-milled biomass. The preferred technical option for any particular application will depend on the type of biomass to be co-fired, on the desired co-firing ratio and on a number of site-specific factors. A number of these direct firing systems are in commercial operation, however it is fair to say that, to date, operational experience of these systems is limited.

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.

The straws are 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.

Despite their availability on large quantities, however, the baled materials have not, as yet, been utilised for co-firing in Britain because of the relatively high investment cost associated with the fuel reception, handling pre-processing and feeding equipment.

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 Thetford Forest 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. There are a number of companies involved in the development of secure supply chains for wood biofuels suitable for co-firing.

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 in the form of meals, dried or partially dried sludges from agricultural sources, paper and food processing, and from municipal sewage works. To date these have only been utilized for co-firing in relatively modest quantities.

Energy crops are plants grown specifically for use as fuels. Short rotation coppice wood and perennial crops are currently preferred, as they require relatively low energy inputs in the form of fertilisers and other chemicals. Short rotation coppice wood (SRC) is harvested on a 2-4 years cycle as a wet, (40-60% moisture content), chipped material, or perhaps in larger pieces. Perennial crops, which are harvested annually, such as miscanthus, switch grass 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 and small-scale commercial 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, as yet, available in Britain in the quantities relevant to co-firing in large power plants.

A number of power stations have been co-firing imported biofuels such as **dried and pelletised wood fuels**, which are produced in large quantities in North America, Scandinavia, Russia and in some other Northern European countries, and can be imported, albeit at relatively high delivered fuel prices. Cereal straws, in chopped and pelletised form, are also available in significant quantities.

Olive processing wastes are available in large quantities, as dry granular or pelletised materials, from countries with large olive 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 dry **solid residues of the palm oil production industry** in far eastern countries, principally Malaysia and Thailand, are also available for import into Northern Europe in large quantities.

To date, the biofuels that have been utilised in commercial co-firing projects at British power stations have included:

- The solid waste materials from the olive oil industry, imported from the Mediterranean countries,
- 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 sewage sludge,
- Dried cereal straw pellets, imported from Europe, and
- Forestry residues, sawmill residues and other wood materials in various forms, 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. This situation may change over the next few years in response to specific British government policy instruments intended to encourage both the production and utilisation of energy crops.

THE IMPACTS OF CO-FIRING ON POWER PLANT OPERATIONS

When considering the potential impacts of biomass co-firing on power plant operations, in the broadest sense, there are a number of areas of technical interest (Colechin et al. 2005), including,

- The reception, storage and handling of the biomass,
- The behaviour of the biomass materials in the coal mills,
- The impacts of co-firing on the performance and integrity of the boiler, and
- The environmental impacts of biomass co-firing.

Materials Reception, Storage and Handling Issues

In general terms, the majority of the technical problems experienced to date with the retrofitting of biomass co-firing capabilities to existing pulverised coal-fired plants in Britain, have been associated with the reception, storage and handling of the biomass materials and, where relevant, the preparation of the biomass-coal blends. The nature of the problems depends largely on the type of biomass, however it is possible to derive some general conclusions from the experience to date of large-scale biomass handling and storage on power plant sites.

One of the key properties of biomass materials, from the storage and handling point of view, is the total moisture content. This can vary widely up to around 60% or so for some green biomass materials. Dried biomass materials are hydrophilic and have a tendency to absorb moisture from the atmosphere, even in covered storage.

The long-term storage of wet biomass can be problematic in that at moisture contents in excess of 20% or so, on a wet basis, relatively rapid microbial respiration activity can lead to heating of the storage pile, loss of dry matter and a significant deterioration in the physical quality of the fuel. There is also a possibility that high dust and spore concentrations in the stored fuel can give rise to Health and Safety issues during subsequent fuel handling operations, which will require the appropriate personal protection equipment to be issued to the affected staff. This can be particularly troublesome during and after fuel drying operations, when dust and spores can be released into the working environment.

To minimise biological activity during long-term storage of wood and other biomass fuels, four courses of action are available, viz:

- The storage of the biomass in billets or larger pieces, if appropriate, to reduce the surface area of cut surface available for biological activity,
- The use of fungicides and other chemical agents to suppress biological activity,
- The pre-drying of the fuel to a moisture content at which biological activity is reduced, and
- The cooling of the stored fuel to temperatures at which biological activity is reduced, by forced air ventilation.

All of these options will add significantly to the delivered costs of the fuel.

In terms of their handling characteristics, **granular and pelletised agricultural materials**, such as the solid residues from the palm oil and olive oil industries, handle reasonably well at normal delivered moisture contents, and their flow behaviour can be characterised using conventional test methods. The handling behaviour of woody biomass, in the form of chips, chunks and sawdust, is generally more difficult to characterise, due mainly to the wide range of particle sizes and moisture contents, and because these material may exhibit some degree of elasticity. Pelletised biomass (e.g., cereal co-product, dry sawdust, olive residue, etc.) is generally free flowing, but some of these materials handle very poorly when wet. Pellets can absorb moisture from the surrounding air, and can grow mould and swell. They are best stored in a dry condition and storage times should be minimised, if there is a risk that they may absorb atmospheric moisture. The generation of dust is probably the most important problem area when storing and handling pelletised materials in bulk.

Herbaceous (grassy) biomass and straws are generally handled, transported and stored in baled form. Specialised equipment for the handling and storing of baled materials in bulk is available but tends to be relatively expensive. Baled materials are generally not suitable for co-firing by pre-mixing and co-milling. These materials can be pelletised successfully, but this process can be relatively expensive and when the pellets break up during handling, the liberated fine material can cause major handling problems.

Overall, the single most important issue when handling and storing biomass materials has been the **generation and accumulation of dust**. Dust extraction systems have been used successfully, however the fine materials collected in these systems can be very cohesive in nature, and there can be problems with the disposal of dusts collected, particularly when using wet removal systems. Special arrangements, including explosion vents and fire suppression systems may be required in biomass storage and handling areas.

If the accumulated dust in the fuel store or handling system gets wet, it can swell and there can be mould growth. The experience with water misting systems for dust suppression has been mixed. These systems tend to increase the relative humidity in the store, and this can further encourage mould growth.

The co-milling of biomass materials with coal

The pre-mixing and co-milling of chipped, pelletised and granular biomass materials with coal in large coal mills has been practised in a number of British coal-fired power stations on a commercial basis for a number of years. The maximum achievable co-milling ratio, and hence the level of co-firing, is limited and depends on the design and operation of the coal mill and the nature of the biomass material. In most cases, co-firing of the biomass at up to around 10% or so, on a mass basis, is technically possible. In practice, however, the normal co-firing ratio is lower than this.

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. There may also be an increase in the particle size of the mill product when co-milling biomass, due to the relatively low particle density of most biomass materials. When co-milling very wet biomass materials, there is a significant impact on the mill heat balance, and this can also be a limiting factor.

There may be a mill safety issue in most conventional coal mills, where hot air is applied to dry the coal in the mill. The biomass materials tend to release combustible volatile matter into the mill body at temperatures significantly lower than those which apply when milling bituminous coals. It may be necessary, therefore, to modify the mill operating procedures to minimise the risks of overheating the coal-wood mixture, and thereby causing temperature and pressure excursions in the mill.

Despite these potential difficulties and limitations, the co-milling and co-firing of a number of chipped, granular and pelletised biomass materials through most of the more common designs of conventional coal mill has been carried out successfully on a fully commercial basis in a number of coal-fired power plants in Britain and elsewhere.

The Impacts of Co-firing on the Performance and Integrity of the Boiler

The general experience 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 mm, or so, passing to the burners, then the combustion behaviour of the blended fuel has been acceptable. Biomass materials are much more reactive in combustion systems than are coals, and do not require particle size reduction to the same levels as for pulverised coal. At the relatively low co-firing ratios applied in the British stations to date, the impacts on the combustion efficiency, on flame stability and on the burner turndown capabilities have been modest.

The co-firing of biomass materials, and particularly of wet biomass, can have an impact on the maximum achievable boiler load, depending on the mill constraints, and on the boiler efficiency. At low biomass co-firing ratios and with dry (<10% moisture content) biomass materials the impacts have been modest.

Biomass materials generally have lower ash contents than most power station coals, but the nature of biomass ashes is very different from that of most coal ashes. In general, biomass ashes have relatively low fusion temperatures and have relatively high levels of the alkali metals, particularly potassium. They have a greater propensity towards the formation of both slagging and fouling deposits than have most coal ashes. At the low co-firing ratios that have been applied in most European plants to date, however, very few significant operational problems due to increased ash deposition on boiler surfaces have been reported. At higher co-firing ratios, and particularly with the higher ash biomass materials, the risks of excessive ash deposition are significant.

There is also a technical issue with the potential for increased fouling of Selective Catalytic Reduction (SCR) catalysts, however the experience in Europe to date indicates that at the biomass co-firing levels that currently apply in large power plants, i.e. generally lower than 10% on a heat input basis, there have not, as yet, been any significant operational problems. The results of a number of side stream tests at low co-firing ratios on operating plants have also been relatively encouraging in this regard.

In the event of significant catalyst deactivation, it is possible to water wash the catalyst blocks to remove alkali metal and other salts and recover the catalyst activity. Avedore power station in Denmark, where they are involved in the co-firing of wood pellets with Heavy Fuel Oil (HFO) and natural gas, has had such a system in commercial operation for a number of years (Ottosen, 2005).

The co-firing of biomass materials in coal-fired power plants in Britain is a relatively recent development and, to date, the biomass fuels co-fired have, in the main, had relatively low chlorine contents and are co-fired at relatively low co-firing ratios. There have been no reports, to date, of accelerated metal loss from boiler tubes due to gas-side corrosion in large pulverised coal-fired boilers. Overall, it is considered that the risks of excessive corrosion associated with biomass co-firing are considered to be modest, except perhaps at elevated co-firing ratios, where the co-firing activities have the effect of increasing the HCl concentration in the flue gases significantly.

The Impacts of Biomass Co-firing on the Environmental Performance of the Boiler

In all cases, the commercial co-firing of biomass in power plants in Britain and elsewhere is commonly preceded by the performance of trials during which the key environmental performance parameters of the boiler plant, when co-firing, are measured. If there are significant additional environmental impacts, the authorisation from the environmental regulator required for commercial co-firing may be withheld.

The general experience from the environmental monitoring testwork carried out to date on boiler plants co-firing biomass at co-firing ratios up to around 10% on a heat input basis, can be summarised as follows:

- As stated above, there has been very little negative impact on the combustion conditions or the combustion efficiency, i.e. on flame stability, burner turndown capabilities, the unburned carbon levels in the ash discards or on the emission levels of CO and the other organic pollutants, i.e. VOCs, PAHs and dioxins/furans.
- The measured NO_x emission levels when co-firing biomass have been similar to, or a few percent lower than, those measured when firing coal.
- The total dust and trace element emission levels have been similar to those when firing coal,
- The SO_2 emission levels have been similar to or lower than those when firing coal, in line with the co-firing ratio and the sulphur contents of the fuels.
- There have been no significant problems with the quality of the ash discards, or on ash sales or disposal.

Overall, it is clear that there has been little or no evidence of any significant environmental impacts associated with the co-firing of biomass at co-firing ratios less than 10% on a heat input basis.

The only significant environmental concerns have been associated with the generation of fugitive dust emissions from the biomass storage and handling facilities and, in some cases, the smell from the biomass reception and handling activities, when processing materials which have a distinctive smell.

CONCLUSIONS

Overall, it is clear from the material presented in this paper that there has been very rapid development of biomass co-firing capability within the British electricity supply industry, in response to the introduction of the Renewables Obligation in April 2002. All of the large coal-fired power plants have been co-firing biomass, principally by pre-mixing the biomass with the coal and co-milling. Over the past two years, a number of operators have embarked on significant capital investment projects, aimed at increasing their biomass co-firing capabilities to levels above those that are achievable using the pre-mixing and co-milling route. This also applies in a number of other European countries.

It is anticipated that the biomass co-firing activities in Britain and Europe will continue to expand over the next few years. It is clear, however, that the scope for the expansion of co-firing activities will depend on the government policies, and the effectiveness of the policy instruments put in place to encourage CO_2 emission reductions from the electricity supply industry and the generation of renewable energies. The availability of suitable biomass materials for co-firing may also continue to represent a constraint on co-firing activities.

In a broader context, and taking a longer term view, co-firing clearly provides the most efficient and lowest risk means of the generation of electricity from biomass. This is important because biomass materials are, and are likely to continue to be in the short-medium term future, a relative scarce and expensive energy source compared to fossil fuels.

In those countries where coal will continue to be a significant portion of the fuel mix for power generation, co-firing has a key role to play in the helping to meet the challenges represented by global warming, and the imperative to develop the means of progressively reducing fossil fuel utilisation.

Overall, the principal driver for the increasing demand for the capability to co-fire biomass materials in new and existing coal boiler plants is that co-firing is regarded as representing a very attractive option for biomass utilisation, and for the delivery of renewable energy, in terms of the capital investment requirement, security of supply, power generation efficiency and generation cost. This is recognised, for instance, by IEA Bioenergy (2006), in the EC Biomass Action Plan (2005), and by a number of EC member state and other governments, who have introduced specific financial instruments to encourage biomass utilisation, in general, and co-firing activities at existing and future coal-fired power plants.

For a number of the new build coal-fired power plant project under consideration in Europe and elsewhere, the demand is for advanced co-firing systems capable of operation at elevated co-firing ratios, i.e. at up to 25% or even 50% on a heat input basis. The likelihood is that these will be based on direct injection co-firing systems, or perhaps on indirect or parallel co-firing systems.

To a first approximation, the maximum acceptable co-firing ratio in any given application will be dependent on the details of the coal and biomass specifications, and in particular the ash contents and ash qualities, and the total sulphur and chlorine contents, since the potential impacts on boiler plant performance associated with biomass co-firing are largely ash-related. The potential impacts are illustrated in the paper, using the co-firing of wood pellets and olive residues with a high quality, world-traded coal as an example. It is clear that co-firing at elevated co-firing ratios, i.e. up to 50% on a heat input basis, will tend to be limited to the higher grade biomass materials with low ash contents and low chlorine contents.

On the other hand, there will also be an increasing demand, for fuel availability and cost reasons, for co-firing systems that can provide increased fuel flexibility. The development of the appropriate responses to these potentially conflicting demands will represent a significant challenge to the power plant operators and to the technology providers for some time to come.

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Station	Capacity (MW_e)	Generator	Cumulative ROCs (GW_e)
Aberthaw	1,455	RWE npower	296
Cockenzie	1,200	Scottish Power	85
Cottam	2,000	Electricite de France	244
Didcot	2,100	RWE npower	242
Drax	4,000	Drax Power Ltd	**955**
Eggborough	1,960	British Energy	363
Ferrybridge	2,035	Scottish and Southern	**1,716**
Fiddlers Ferry	1,995	Scottish and Southern	**1,020**
Ironbridge	970	E.on UK	171
Kingsnorth	2,034	E.on UK	478
Longannet	2,400	Scottish Power	461
Ratcliffe	2,010	E.on UK	38
Rugeley	1,000	International Power	337
Tilbury	1,085	RWE npower	51
West Burton	1,980	Electricite de France	122
Total			**6,579**

Table 1 **The cumulative ROCs issued for biomass co-firing for all of the large coal-fired power plants in mainland Britain (up to January 2007).**

N.B. A ROC is equivalent to 1 MWh of electricity generated from renewable sources.