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The continuous discussions among the consortium regarding the topics dealt with in this task after its scheduled completion led the partners to the agreement of collecting all the new information received after the submission of Deliverable 24 in the present updated report, not foreseen in the workplan.

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1. Introduction

Biomass co-firing with coal in existing fossil fuel energy conversion plants is considered one prevailing method to increase the amounts of renewable energy sources used for power and heat generation. With such practices, total emissions per unit energy as well as greenhouse gas emissions (CO₂, etc) are reduced in comparison to single coal firing. Furthermore, consequent reductions of both NO_x and SO_x levels from existing pulverised coal fired power plants offer additional technical advantages when co-firing coal with biomass is practiced. During the last years, extensive research efforts through testing and experience were/are conducted with the aim of solving potential hinders related to technical issues occurring when biomass is used as a fuel for co-firing with coal. The main challenge using such techniques is to develop cost-effective and sustainable co-firing practices which will combine best combustion performance, minimal technical constraints with low investment costs involved, and simultaneously conducted in an environmentally sound manner (Baxter 2004, Demirbas 2003).

This report will deal with the technical challenges and problems arising after adaptation of biomass co-firing technologies with coal. There is a vast number and diversification of technical problems, constraints and things-to-consider associated with co-firing of biomass with coal in high efficiency boilers. This is mainly due to the different technological combustion options used in co-firing (e.g. blending biomass with coal on the fuel pile, co-firing with separate injection, gasification-based co-firing etc), but also due to the type of existing boilers in a co-firing plant (e.g. cyclone boilers, pulverised coal boilers, fluidised bed boilers etc), which result in different combustion processes and mechanisms (Tillman 2000), and due to different types of co-firing fuels. Furthermore, the use of many different kinds of biomass material (wood waste as sawdust, planer savings, chips, bark, firewood plantations, forestry residues, urban wood waste, short rotation woody crops as willows, poplars, black locust etc, agricultural wastes as rice hulls, straws, orchard and vineyard prunings, corn stover etc, animal waste, sewage sludge, and a range of other materials) and also the different kinds of coal used in co-firing plants (peat, lignite, bituminous coals, anthracite etc) result in a vast diversification of technical problems when co-firing is practiced (Sami et al. 2001). As a result of all the above, in many cases the technical problems occurring are “site-specific”, therefore these problems can be/have been solved only after intense experimentation or/and changes in co-firing materials and of the fuel analogies used.

The aim of this report is to identify the different technical barriers belonging to all steps of biomass co-firing practices (from preparation to ash utilisation), and to some extent also identify possible technical solutions for these constraints. In the following text, the most prevailing technical constraints that are thought of being major hinders for the implementation of biomass co-firing with coal, and some technical barriers discussed within the consortium, are going to be presented and further analysed. Some solutions to these technical problems will be also mentioned, as an effort to identify the seriousness of each barrier. In the preliminary report of technical barriers produced for NETBIOCOF (D10), the identified technical barriers were categorised in relation to the step of the process-chain constraints occurring, as a means to avoid classifying these technical barriers based on the different co-firing methods/products used. The different categories of technical barriers mentioned in the preliminary report were related with problems occurring during fuel preparation and pre-processing, combustion system and operation, flue gas clean-up system, and finally related with the sustainable use of the by-products at a later stage. In the following report, the categorisation will in large stay the same, except the addition of a category named “Barriers

related to insufficient infrastructure for biomass for energy”. Furthermore, additional efforts will be put to analyse and describe the technical problems and the possible solutions and measures that could be adapted to tackle a barrier. Moreover, further barriers that have been discussed during the project’s mid-term meeting in Estonia and the discussions followed within the NETBIOCOF forum are going to be included in this report.

2. Technical barriers

In the following text, the most noticeable and frequently mentioned technical barriers occurring while co-firing biomass with coal are discussed. The below mentioned technical barriers and constraints are categorised according to their relation to different stages of the co-firing process; related to insufficient infrastructure for biomass for energy, related to biomass fuel pre-processing and preparation, related to combustion system and operation, related to flue gas clean-up system and finally related to by-product use. In many cases, and due to the site-specific conditions, differences in technological combustion options, type of existing boilers, and type of coal or biomass used in a co-firing plant, the below-mentioned individual barriers do not apply to all co-firing plants and therefore cannot be generalised as a common technical problem. In cases where a constraint applies only to one type of boiler, biomass material etc., this will be specified in the text in order to avoid generalisations. Therefore, this report will try to list and analyse a broad spectrum of technical problems and possible solutions related to all kinds of experiences from biomass co-firing, attempting to cover all kinds of technical constraints for every biomass co-firing with coal.

2.1. Barriers related to insufficient infrastructure for biomass for energy

There is a series of problems for implementing biomass co-firing due to the fact that the large scale use of biomass for energy purposes is a relatively new concept. As a consequence, the existence of current infrastructure to accommodate easy availability and distribution of biomass as a fuel without obstacles is limited and in most cases high investment costs should be made to create stability in the biomass chain. In countries where the use of biomass as a fuel has been traditionally seen as an energy source and has been used in power plants, (e.g. the Nordic countries), these problems are not as pronounced as in countries which recently have started (or intend to start in the near future) implementation of biomass co-firing. A number of such technical barriers related to the lack of developed markets for biomass materials used for energy purposes occurring in the different European countries are mentioned below.

One concern is the availability of biomass that could be used in a co-firing plant. A constant demand of biomass with a constant quality is required by the power plants and therefore future biomass availability needs to be identified and ensured. Especially when biomass is coming from forest residues or dedicated biomass agricultural crops, new tools for complex biomass availability estimations need to be developed. New technologies, as Geographic Information System (GIS) should be more efficiently exploited to examine short- and long term biomass availability and ensure the safe future demands of power plants for biomass (Veijonen 2006). The collection of wood biomass from forest or agricultural land has in some cases proved problematic and costly. The use of advanced harvesting technologies and equipment is a prerequisite for efficient collection of biomass. However, in many countries considerable forest areas exist, but modern high-efficient high-capacity equipment as

harvester, forwarders, chippers, chip track and trailers, are not available, as e.g. in the Eastern European countries (Greibenkov 2006). Therefore, collection of biomass becomes a restricting factor if the demand for biomass is high and constant, unless high amounts of money for equipment are invested. Additionally, in countries as Spain, Portugal, Austria etc, where a high share of forest is located in mountainous terrain, special demands for harvesting machinery are required due to ground morphology, and in many cases harvesting in large scale is too difficult and too costly. The lack of adequate long term experience on forest residue exploitation and management can result in unwanted environmental effects related to nutrient balance disturbances after practices like forest residue logging or collection. These parameters need also to be taken into account to achieve a sustainable use of biomass for energy (Veijonen 2006).

The distribution of biomass to the power plants can in some cases be problematic due to inappropriate positioning of a co-firing plant. The distance of the biomass source from the power plant using biomass as a fuel is considered of utmost importance for the logistics. Appropriate distribution and transport equipment is important to achieve lower costs. In many countries, insufficient established infrastructure for biomass exploitation is in total an important barrier (Ivanov 2006). Logging technologies, transport and logistic systems, but also fuel storage systems and fuel receiving stations need to be developed in order to guarantee a fluent fuel supply all year round. Implementation of energy densification technologies, e.g. pelletising or pyrolysis, could offer solutions to these barriers. In most countries, lack of technological means in one of the above-mentioned sectors results in unsatisfactory or costly biomass supply and therefore can be a limited factor for biomass co-firing implementation. In technologically advanced countries with a long tradition in forest biomass handling and use, as e.g. Finland and Sweden, most of these barriers are not actual since economy of scale has solved some of these issues, but even there additional measures (as e.g. for buffer storage systems) need to be taken to ensure fluent fuel supply.

Limitations due to technological barriers can be also related when wood biomass crops dedicated for energy purposes, as short rotation willow/poplar coppice, black locust, miscanthus, elephant grass etc, are cultivated to provide biomass fuel. Planting, harvesting and other management issues must be conducted cost-effectively to improve the logistics of the whole operation. In most cases lack in appropriate and simultaneously “cheap” technology for cultivation of such crops leads to less than calculated commercial plantations which would contribute to uncertain delivery and consequently limited implementation of biomass use as a fuel in power plants. An increase of cultivated areas and development of a transparent and viable market for such crops is possible to result in cheaper use of available technology and in overcoming these problems.

As a conclusion, it should be mentioned that technological barriers related to poor infrastructure of biomass-for-energy chains is evident in most countries where biomass is only now starting to compete as alternative energy source with other “conventional” fuels. In more developed (from the biomass use point of view) countries, economy of scale has contributed to overcome these barriers. However, the logistic chains for energy biomass need to be optimised in all countries, since different problems occur depending on the geographical position within Europe; e.g. in a northern European country as Finland special attention in fuel storage should be paid due to cold climate, problem that does not exist in other countries. In countries with limited new investment opportunities, less advanced problems might occur, as it is the lack of biomass material for use in power plants due to problems in collection, distribution etc, or risk of overloading the existing plants due to bad current infrastructure.

2.2. Barriers related to biomass fuel pre-processing and preparation

Biomass as every other fuel requires certain processes to be undertaken in the power plant facilities, e.g. storage, cleaning, comminution etc. for further use in the boilers. The type and consistence of the biomass used as co-combustion fuel and the type of boiler used in the plant play a decisive role for the pre-processing and preparation procedures required. Most of the technical constraints occurring in co-firing plants are related to the fact that the existing power plants were not designed for biomass handling when constructed. Consequently, modifications in the existing structure of the co-firing plant must be suggested and performed to overcome these constraints. From a technical point of view, modifications might be relatively easy to achieve, but it is the investment costs required that are critical for the plant operator to undertake such changes. Moreover, investment costs for installation of new equipment for biomass handling etc are a big constraint that add to the total cost and can be a reason for not applying the technology. Most differences in the technical problems related to preparation of biomass are based upon the differences in the nature of biomass; woody and herbaceous material behave differently while pre-processing than coal, but also different with each other, and therefore technical constraints regarding different biomass material need to be individually treated and should not be generalised. The identified technical barriers related to biomass fuel pre-processing and preparation before co-fired in the boiler, and possible solutions to these problems are mentioned in the following text.

One general technical problem occurring irrespective of the type of boiler or biomass used in co-firing power plants is related to the limited existing available space for fuel long-term operational storages and for the installation of additional equipment. Furthermore, the possible absence of automatic wood fuel handling mechanisms and the lack of specific ancillary equipment including conveyers, silos etc that would accommodate fuel preparation, can also be responsible for difficulties in co-firing operations. This occurs due to lack of designing from the beginning power plants with regard to the possibility of using biomass as a fuel some time in the future. In all cases, storage of biomass is required for a constant feeding of the boiler, which implies additional cost for building and operating the required storage facilities. Especially in Northern European countries, where extreme cold during winter period prevails, additional costs for operational storage is required for securing appropriate fuel quality (Veijonen 2006). Better design of the power station to accommodate storage of high volumes of e.g. wood biomass for long-term storage, with attention for the risk of spontaneous heating, offers a solution, as well as purchase of appropriate equipment for better fuel preparation.

A series of technical problems for biomass co-firing are related to the quality and special features of the biomass material used for burning. For instance, the uneven quality of the received biomass (and its implications related to differing moisture content, size distribution etc) can be responsible for problems to several co-firing operations. For instance, the differing size distribution, especially in the case of wood biomass, is reported to cause problems in the fuel supply to the boiler. Fuel supply problems can be also caused when straw bales are used, since the possible uneven distribution of moisture content can be responsible for malfunction to the boiler (Overgaard et al 2004). Moisture content is acknowledged as one of the main influences on the handleability of materials. The relative high moisture content of the biomass material can be proved responsible for problems during storage. The consequent rapid biological activity might cause deterioration of fuel quality and in some cases risk for spontaneous ignition and fires in the storage facilities. The need of establishing means of ensuring better consistency in the water content of materials that may be stored for varying

periods is a challenge for better operation. Substantial initial reduction of moisture contents of green material such as wood chips, without the need for heat addition, has been achieved by careful construction of piles, but more trials of natural drying are needed for more satisfactory results (Peksa 2006). To tackle problems related to uneven biomass quality, constant surveillance with e.g. visual inspections, regular sampling and screening equipment should be promoted. Furthermore, contract agreements between the plant operator and the provider of biomass must include rejection criteria regarding moisture and size distribution (Sander 2006). Implementation of biomass input specifications with the form of e.g. certificates would further ensure a constant good quality of biomass products. Storage of biomass in larger pieces (e.g. pellets, briquettes etc) and covered short-term storage is recommended in most cases to reduce the biological activity. During receiving and handling of biomass, appearance of dust, micro-organisms (when biomass is used as fuel), methane or odours (when waste is used as fuel) might cause occupational health problems. Therefore, biomass handling in closed and overpressure ventilated cabins to accommodate better aeration of the stored biomass e.g. for straw and wood biomass, or indoor receiving of waste biomass is recommended. General health precautions (protection masks etc) for the personnel should be implemented to avoid such problems.

As described above, there can be cases for which conditioning of the received biomass is necessary in order to succeed prerequisites in terms of particle size. Increased risk for shredders or mills is possible due to the content of the received biomass in unwanted materials as stones, sand, metals etc. The installation of extra metal separation systems, sand or stone removers would be needed to avoid such hazards. In pulverised coal power plants, the required small particle size of biomass fuel is both a technical and economical barrier. It has been proved that relatively expensive technology is needed to be installed to produce fine biomass material for pf-boilers. This means that the whole energy production process is becoming less efficient. Pulverisation of a coal-biomass blend in the existing pulverisers is primarily limited by the grinding behaviour and the moisture content of biomass. Most often biomass is soft or fibrous, whereas bituminous coal is hard. New types of fuel feeding systems and burners for coarser particle size fuel need therefore to be developed. Torrefication of biomass can be an effective method to improve the grindability of biomass to enable more efficient co-firing in existing power stations, but this technology is not yet commercially available and research efforts to that direction are being practiced (Peksa 2006). Furthermore, optimisation of fuel feeding into the furnace and even fuel distribution in all sides of the furnace should be aimed for better practice.

Additionally, technical problems while conditioning of biomass include risks of spark ignition, explosion and fire. Therefore, installation of a spark detection security system and fire protection (water or nitrogen) is advisable to avoid damage from such problems. Compliance with ATEX (“Equipment intended for use in potentially explosive atmospheres”, the EU regulation on explosive risks) is required to avoid such incidents. Problems due to biomass material characteristics might also occur while conveying biomass into the combustion chamber. These problems can be related to blockage and bridging, therefore the use of reliable belts that could be in some cases covered, shorter distances for transferring with conveyers, and screening of the material to avoid blockage, might offer technical solutions to overcome such constraints. Blocking of feeders is also a potential hazard for malfunction, therefore the use of reliable feeders and experimentation with several feeding points and different feeding rates with the aim to find the optimum is needed.

The above-mentioned barriers connected to pre-processing and preparation vary substantially between different operation in different power plants, depending on the biomass materials used, the combustion technology used and the co-combustion method. A need for R&D on biomass fuel handling and preparation systems to achieve predictable feed comminution and predictable feed rates, particularly for feeding to co-utilisation systems that require a comparatively finely divided fuel (i.e. pulverised coal boilers and furnaces) and for feeding into pressurised systems such as gasifiers is evident. These difficulties are more severe with handling and preparing softer biomass, such as straw or herbaceous species (e.g. miscanthus) than with wood. Straw has been wider used than other biomass soft material and in some cases has proved relatively difficult to process. Extensive modifications in handling systems had to be implemented in many cases to avoid plant outages. Unpredictability of the behaviour of softer biomass in the relatively simple steps of pre-processing and preparation requires further research efforts.

In total, it can be commented that in most cases these technical barriers are relatively easy to handle with the proper equipment, planning and research, and the additional investments required for implementation of changes on the existing infrastructure are relatively low considering the positive effects gained with co-firing.

2.3. Barriers related to combustion system and operation

In general, most of the technical constraints belonging in this particular category are considered rather complicated and difficult to solve and are in most cases one of the important reasons behind the unwillingness of power plant operators to adapt biomass co-firing technologies. Related technical constraints arise from the nature of biomass material, which in most cases, and depended on the type biomass used as a fuel, may be more humid, may contain higher amounts of minerals, e.g. Cl, K, may be uneven in case of various types used simultaneously etc. Most of the technical barriers of this category require extensive experimental research and monitoring to identify and implement technological measures that can help to solve or minimise the problem. The technical barriers of biomass co-firing included in this category are highly depending on the combustion technology used in the plant and on physical and chemical properties of biomass material used for co-firing, respectively. These barriers are in most cases a result of boiler design and of boiler and burner behaviour. The formation of different hazardous compounds in the boilers and the heaters can be proved problematic for the operation of the whole plant. In the following text, some of the main technical barriers of this category and possible solutions are identified and commented.

The heating value of biomass is typically lower than that of fossil fuels, and therefore the use of biomass in boilers designed for coal causes in most cases a reduction to the maximum output capacity of the boiler. Due to the above, other types of problems might occur during such operations; in cases where biomass with high wet content is used for direct co-firing (e.g. wood chips from forest residues, biomass from dedicated energy crops etc), the amounts of gas volumes are increasing, which means that the flue gas blower capacity is not sufficient as they have been dimensioned for fossil fuels (Veijonen 2006). An increase of the water content in the gas causing problems to the boiler equipment is also evident. To solve the problem of this increase, keeping the same boiler in use, only a reduction of the part of biomass co-fired can be proposed; a reduction to less than 10% can lead to a minimisation or extinction of the problem, but this is hardly ideal if the aim is the use of as high biomass mixtures as possible; therefore this can constitute a clear restriction to biomass co-firing in direct co-firing.

However, this is only relevant when wet biomass is used, and not for dryer materials as straw, sawdust etc, when only slight increases of gas volumes, if at all, have been noticed.

The behaviour of the boiler and the burner after biomass co-firing is considered to be one of the main obstacles for broader implementation of biomass co-firing, due to the varying types of technical problems occurring while operation. Slagging, fouling and corrosion problems in the boiler are generally considered as very important problems in co-firing (SEC Biomass 2006). Chlorine-based corrosion in boiler deposits from biomass, especially in the case when high biomass shares of materials as straw and wood are used, is thought to consist one of the main concerns for biomass co-firing. However, it has been reported that after good mixing between coal and biomass in the combustion process, alkali chlorides will be converted to silicates (depending on the Cl/S ratio) and sulphates and therefore minimise corrosion damage (Baxter 2005). Therefore, both biomass and coal selection with regard to low chloride concentrations are important factors determining the optimum fuel blend for lower corrosion negative effects. Increasing fouling in the boiler walls and slagging can also occur while co-firing biomass (wood, straw) due to formation of potassium sulphate. To avoid this, the biomass share should be reduced and soot blowing should be increased. Risk of erosion and deposits in the burner can also be a consequent of high biomass amounts used, especially with wood biomass and straw as co-fuels. For an amelioration of such negative effects, the use of special material for coating to protect the boiler and wall surfaces can be proposed. Furthermore, adjustments of circulation patterns and velocities in the boiler, as well as changes in the maintenance requirements could diminish problems of erosion and deposits in the burner. A similar to the above-mentioned problem when fluid bed combustion technologies are used can be considered sintering in the boiler due to hot spots in the freeboard or bed agglomeration when straw and sewage sludge are co-fired (Peksa 2006). Furthermore, in case of demolition wood used as biomass material, melted metals (e.g. Zn, Al) are reported to be found on the boiler surface, after inadequate biomass screening. All problems related to slagging, corrosion and fouling are increasing with increasing amounts of biomass used in the fuel mixture. Better on-line monitoring technologies help to identify such problems in an early stage and would lead to fast and proper adjustments for taking precaution measures in time. However, there is a lack of implementation of such technologies in many existing co-firing plants due to old operation technology used.

In general, when biomass is used as a fuel in fluidised bed boilers, the need to increase steam temperature in order to improve combustion efficiency is essential. However, the low melting point of many biomass ashes and/or corrosive elements pose hinders. More in detail, and especially in new supercritical fb-boilers, steam temperature and pressure are very high and increase of condensation, chlorine corrosion and deposits on the heat exchangers and on superheaters have been reported due to higher content in fine materials (SEC Biomass 2006). In circulating fluidised bed combustion, freeboard combustion and final combustion of unburned gases in the hot cyclone are likely to be affected. Furthermore, insufficient residence time due to the content of fine materials can cause high temperatures before the superheater. To solve the above mentioned problems, new superheater materials need to be developed and used, as well as additional installations of steam heated pre-heaters are necessary (Rösch 1999). It is reported that new developments in this sector are under way in Thermie USC project (Kalf 2006).

Some of the above-mentioned constraints are considered major technical challenges related to the success of co-firing of biomass. Corrosion in the boiler, but also in the superheater, reheater, air preheater etc. is due to the alkaline and chloride content of biomass material and

restrains the use of higher amounts in percentage of biomass in relation to coal (Sami et al 2001). Despite the proposed technical solutions mentioned above, which add to the costs of a co-firing plant, in general maintenance costs are also becoming higher after use of biomass as a fuel in existing coal fired plants, leading to lower economic value of biomass co-firing, but this has to be put in the right perspective. For instance, increased maintenance costs is reported due to faster wearing of hammer mills compared to coal mills are reported when co-firing biomass. However, this cost is low after comparisons and evaluations of biomass and coal pricing; therefore integrated approaches where all aspects of biomass co-firing will be taken into account are needed. Extensive research efforts are currently conducted to evaluate hazards from such problems, and tests with different fuel mixtures in boilers potentially used for co-combustion are taking place as a way of identifying “site-specific” best practices.

2.4. Barriers related to flue gas clean-up system

As mentioned in previous parts of the report, co-firing of wet biomass in power plants increases the amount of flue gas volume. There are also recorded increases, not only of the volume, but also of the temperature in the flue gas path. Therefore, problems in the flue gas clean-up systems in terms of control of e.g. NO_x and SO_x emissions can occur when using biomass as a fuel (Meijer et al 2006). The consequent concentrations of hazardous contaminant emissions above the legal limits must be avoided and therefore technical modifications might be necessary in co-firing plants. A series of technical barriers and constraints related to the flue gas clean-up system are mentioned in the text below.

The higher content of alkaline when biomass is co-fired can cause ageing and deactivation of the catalytic NO_x emission abatement equipment (e.g. selective Catalytic NO_x reduction, SCR). The reasons for this deactivation is in many cases not fully understood, but laboratory analyses confirm that alkali and alkaline earth metals are poisons to vanadium-based catalysts, which is included in all commercial SCR systems (Baxter 2005). The content of alkali and heavy metal compounds are completely dependent on the type of biomass used (Kalf 2006). Although no definite solution is advised to avoid the poisoning of SRCs (since the mechanism of the deactivation and poisoning is not fully understood yet), it is believed that methods as testing with combinations of different mixing of coal and biomass in the combustion, use of biomass with lower alkaline content, use of catalysts that can operate under biomass co-firing circumstances, and/or the removal of the catalyst poisons in the flue gas might be able to offer solutions in the future. Other reports suggest that the use of advanced primary NO_x techniques as the Two-Stage Combustion (TSC) might pose risks of increased slagging and of corrosion of furnace wall tubes when biomass is used as a fuel (Rösch 1999).

Technical problems related to desulphurisation of flue gas while co-firing biomass in fluidised bed have also occurred. As an attempt to minimise this problem, limestone addition for desulphurisation can be proposed, but it might proved to be difficult to achieve a satisfactory solution due to the variations in the ash composition of biomass. Another solution to minimise such problems could be the use of as homogenous as possible biomass and/or the installation of more advanced desulphurisation systems. Co-firing of high alkali biofuels like straw in high mixing rates increases the amount of wastewater from wet limestone-gypsum flue gas desulphurisation (FGD) due to the higher chlorine load. This is only critical if wastewater discharge is limited and one solution would be to reduce the biomass share. Finally, the emissions of heavy metals might also exceed the limit values set for the EU mixing rule when co-firing occurs. This barrier can be diminished if the biomass material used contains small

amounts of heavy metals. By avoiding the use of materials as demolition wood, which contains high amounts of heavy metals, such problems can be solved. Therefore, careful selection of biomass material is required to avoid increased heavy metal emissions from the plant. The installation of an additional flue gas cleaning unit might be also advisable in cases where the input with heavy metals via the biofuel is inevitable. However, this solution might be expensive to implement.

In many cases, technical constraints and solutions for solving problems related to flue gas clean-up system under biomass co-firing are largely still under investigation. Research is being conducted to reduce the amounts of emissions from co-firing plants with testing of different mixtures of coal-biomass and use of other than “conventional” catalysts. The emission control when co-firing of biomass with coal occurs is of high importance for a sustainable power plant operation, since public acceptance of such operations adds to their value. Furthermore, the limits set by national and international law (especially in Europe) are usually very stringent and a great amount of investments is required to control the emissions. In many cases while co-firing biomass, the behaviour and composition of flue gas is different due to the differing biomass materials used and the type of combustion. Therefore, systematic tests are important to standardise the procedures to avoid high emissions of hazardous compounds. Increase of the percentage of biomass might cause problems and therefore the mixing effects need to be thoroughly investigated with full-scale testing.

2.5. Barriers related to by-product use

The quality standards of fly ash produced after co-firing of biomass in coal power plants and its future usability is one of the main challenges for biomass co-firing operations, since the further use of by-products would involve an increased value of the whole co-firing operation. Differences in the mineral content of fly ashes from coal and biomass combustion imply different possibilities for appropriate future uses of those by-products. On 2003, of the total amounts of coal fly ash produced in EU countries, ca. 47% were further used in construction industry and in underground mining, from which ca. 37% of fly ash from coal combustion were used in cement industry (as raw material or blends), ca. 34% in concrete industry, ca. 33% for road construction and the rest for underground mining, adding to the value of coal firing operations (ECOBA 2003). On the other hand, ash from pure wood combustion is not considered suitable for the above-mentioned uses due to increased content of unburned carbon and of alkaline and other inorganic compounds that affect concrete properties, and can be used as forest or agricultural fertilisers (demonstration and research efforts have been/are conducted under a number of EU projects, e.g. the RecAsh project). When co-firing coal with biomass, an ideal situation would imply complete separation of the different ashes coming from the different fuels. This is not possible when direct co-firing occurs, and it is costly in cases of indirect co-firing. From the above, it is obvious that mixing of ashes coming from coal and biomass co-firing can result in differences in quality and consequently deterioration of chances for its future use.

Until recently, one of the main reasons and reservations for not implementing direct biomass co-firing in power plants with coal was the restrictions by law for using fly ash from co-firing as a by-product in the concrete industry. In the old EN 450 (European fly ash standards for use of fly ash in concrete), fly ash from co-combustion was excluded and no use of ash in concrete industry was possible. Only in some countries ash from co-combustion could be used in concrete on the basis of specific national technical approvals (von Berg and Feuerborn

2005). However, a new European Standard “Fly ash for concrete” has replaced the old one; from 2005, EN-450-1 has been adapted and implemented by the EU, and ash from co-firing of biomass can now be used in concrete. The former EN 450:1994 is now divided into two parts, EN 450-1 dealing with definitions, specifications and conformity criteria, whereas the new EN 450-2 covers the conformity evaluation of fly ash for concrete. In EN 450-1, fly ash obtained from co-combustion of specific co-combustion materials (vegetable material like wood chips, straw, olive shells and other vegetable fibres, green wood and cultivated biomass, animal meal, municipal sewage sludge, paper sludge, petroleum coke, virtually ash free liquid and gaseous fuels) can now be used in concrete if the percentage of co-combustion material does not exceed 20% by mass of the total fuel, and if the derived amount of ash from the co-combustion material shall not be greater than 10%. In the requirements is further stated that the suitability has to be proven by the power plant operators by testing fly ash when the highest intended amount of co-firing material is used. Furthermore, the environmental compatibility of fly ash has to be demonstrated before its use in concrete. In this line, e.g. the Danish Technological Institute conducted tests concerning ash from straw and coal co-firing of fresh and hardened concrete mixtures (Sander 2005). In total, the new EN 450-1 standards introduced for EU countries has resulted in tackling reservations and hinders of using different biomass fuel in co-firing plants, since a range of fly ashes can be used now in concrete.

The use of ash in cement industry is not regulated by EN 450 but by commercial agreements between the producer and the receiver of fly ash. However, it can be assumed that the new EN 450-2, which covers the conformity evaluation of fly ash for concrete with the various control criteria set, although not directly relevant to cement industry, was established to enable the use of the cementitious potential of the fly ash. This is due to the different control criteria demanded in EN 450-2, which is very similar to the certification system for cement. By this, it is demonstrated that fly ash is a produced building material as cement and not a waste, and can be used after proper controls and tests further in the cement industry as well. At this point, it should be explicitly mentioned that the use of fly ash as blending material with cement and the use of fly ash as a basic raw material for the production of clinker are under different regulations. For fly ash use in cement industry, EN 450 is relevant (as previously mentioned), but for the latter the requirements will differ per factory; Fly ash can be used as raw material in aluminium and (less) for silicium, and since a cement factory applies a certain material portfolio, the fly ash quality has to fit in with this portfolio. Thus, the fly ash requirements differ between factories, and the amounts of Al, Si, Ca, P, Na and K are important in terms of quality. Concentrations of the last three mentioned elements, and especially of P which is of critical importance, should not be high (Saraber and van den Berg 2006).

In some cases, it is not only the chemical character of the fly ash from biomass that can be problematic. Although ash deposition rates from wood biomass are typically lower than those of coal both for bottom and fly ashes, there are also cases (e.g. when only straw or only other herbaceous crops are used as a fuel) when generation of ashes is higher than when only coal is used. In general, the higher the chlorine and alkali parts are used in co-firing, the higher the possibility of having larger amounts of fly ash produced occurs (Van Loo and Koppejan 2003). That means that the volume of ashes can in some cases be higher in comparison to ash from only coal firing, and disposal costs can be proved higher due to higher volumes.

As a conclusion, depending on the percentage of biomass used as a fuel, deterioration of ash quality after co-firing of different biomass material with coal might affect drastically the marketing ability of final by-products. With the introduction of new standards accepted by EU

as the EN 450-1 and EN 450-2 for “Fly ash for concrete”, a range of biomass material is now included if the amount of biomass material does not exceed 20% of the total fuel. However, in cases where the amount of biomass is or is intended to be much higher than 20%, then the new standards cannot be applied. This case can be actual and quite used in countries like e.g. The Netherlands, Denmark etc, where in many cases percentage of biomass as a fuel in powder coal fired boilers (note that EN 450 is applied only for powder and not fluidised bed boilers) is higher than 20% (less in countries like Finland and Sweden where fluidised bed boilers are used more commonly). There, the problems mentioned in the NETBIOCOF preliminary report for technical barriers (D10) remain, and more research is needed to define good practices for further use of fly ash from such cases.

3. Conclusions

All the above mentioned technical barriers illustrate a general picture of the involved constraints and potential hazards co-firing of biomass with coal in existing coal firing power plants. There is a number of technical constraints that have been solved successfully or for which the suggested solutions are sufficient from a technical point of view. In most cases, investment costs involved for appropriate changes or additions are the limiting factor. The most severe technical challenges occurring while co-firing biomass seem to be the risks of corrosion, deposits, slagging and fouling in the combustion system and other parts of the plant and the reduced options for utilisation of by-products. Economically viable solutions remain to be found for the previously-mentioned problems. A way to overcome these technical constraints is in most cases to reduce the amount of mixed biomass, but the social and political will to increase the share of biomass for energy does not comply with such practices. Therefore other more advanced technical solutions must be introduced. The “site-specific” character of a co-firing method requires extensive tests for adaptation of best performance practices. In general, a good investigation will include the determination of which biomass type fits to the specific boiler, followed by economic calculations for possible extra costs/investments contra benefits after biomass co-firing practices. In many cases, the lack of exchanging information by commercial companies involved in such practices might lead to slow adaptation of new techniques for confronting potential technical constraints, but projects as NETBIOCOF might contribute to the exchange of knowledge on such matters.

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