Addressing the Constraints for Successful Replication of Demonstrated Technologies for Co-combustion of Biomass/Waste

(Part of the EU-DG XVII Thermie B project DIS/1743/98-NL)

Report of the final seminar

held at

1st World Conference and Exhibition on Biomass for Energy and Industry

Sevilla

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Organized by NOVEM and TNO-MEP on behalf of EU-DG XVII Thermie B project DIS/1743/98-NL, IEA Bioenergy Task 19 and IEA Clean Combustion Sciences

Project partners in the EU-DG XVII Thermie B project:

- Novem B.V. (the Netherlands) (project coordination)
- University of Stuttgart-IER (Germany)
- Imatra Voima Oy-IVO (Finland)
- Vattenvall AB (Sweden)
- Verbund Austrian Hydropower AG / Österreichische Draukraftwerke AG (Austria).

VATTENFALL IER Novem Verbund Fortum

Summary

The final seminar of the EU Thermie B project *"Addressing the constraints for successful replication of demonstrated technologies for co-combustion of biomass/waste"* was held at the *1st World Conference and Exhibition on Biomass for Energy and Industry* and was supported by the IEA Coal Combustion Science Group and the IEA Bioenergy Task 19: Biomass Combustion. Over 130 participants attended the seminar which incorporated both the results of the two workshops held earlier in the EU-project as well as co-firing experiences and research activities in the USA.

The final seminar was chaired by Gerard Smakman (project coordinator, NOVEM, NL) together with Philip Goldberg (DOE, USA and active in IEA CCS). Presentations were given by Pia Salokoski (Fortum, Finland) and Frans van Dijen (EPON, Netherlands) on the situation for co-combustion in Scandinavia and central Europe. Claus Greil (Lurgi, Germany) focused on the practical concepts for parallel firing, pre-gasification and gas cleaning with particular emphasis on CFB gasification. The technical barriers related to co-firing which were identified during the first project workshop were listed by Christine Rösch (IER, Germany), while the non-technical barriers identified at the second project workshop were listed by Harry Schreurs (NOVEM, Netherlands). The meeting was closed with experiences with cofiring from the USA. Regretfully, there was no-one from the EU present to elaborate on future EU policies and support to cofiring initiatives under the 5th Framework Programme.

Co-combustion is practised with different types and amounts of biomass wastes in different combustion and gasification technologies, configurations and plant sizes. Currently, direct cofiring is the most commonly applied configuration. The typical configuration applied in Finland is a fluidised bed combustion installation within the range of about 20 to 310 MW where different biomass wastes from forest industries are directly cofired, eventually with REF, RDF, coal or oil. Here, installations need to be fuel flexible, one reason for this is that the sparsely populated countries make specialized mass burning installations uneconomical. In Sweden, there are a large number of grate fired boilers in the range 1-30 MW which are operated for district heating (mostly firing "biomass" only, but it often means co-combustion of different types of residues). In paper and pulp industries, there are both fluidised and grate furnaces that burn mixtures of bark, sludges, wood residues, oil and some coal. A couple of PF boilers in Sweden are converted to fire pulverised biomass and/or a mixture of biomass/coal, biomass/peat or biomass/oil (80-300 MW th). A major factor is the taxation system, which makes heat generation more attractive by using biomass and electricity production more attractive by using fossil fuels. For this reason, it is attractive for operators of a cogeneration facility to cofire a share of biomass in the fuel mix according to the heat demand.

In Austria, co-combustion is accomplished mainly in the pulp and paper industries, using their own residues and wastes (e.g. black liquor) in small industrial boilers and in two large scale demonstration units of Verbund AG. In the Netherlands and Germany, biomass wastes (i.e. sewage sludge, demolition wood) are co-combusted at relatively small percentages in coal-fired power stations. In the USA, many test programs have been carried out with co-combustion of biomass and waste with coal. In the USA, the generation capacity for cofiring biomass and wastes in existing coal-fired plants could theoretically reach 2 GW by 2005 and 5 GW by the year 2010. Current government support measures (tax incentives etc) however need to be modified to realize such growth rates. The current experience in the USA is almost limited to non-commercial tests.

Indirect cofiring by pre-gasification is applied in a number of demonstration plants in Austria (Zeltweg), Finland (Lahti) and the Netherlands (Geertruidenberg). One of the major advantages is that ashes of the main fuel and the co-combusted fuel are kept separate. In parallel firing installations such as applied at a combination of a MSWI and gas fired combined cycle power plant in Moerdijk (Netherlands), a fully separate combustion installation is used for the biomass/waste and the steam produced is fed to the main installation where it is upgraded to higher conditions. Though the investment in indirect cofiring and parallel firing installations is significantly higher than in direct co-combustion installations, advantages such as the possibility to use relatively difficult fuels with high alkali and chlorine contents and the separation of the ashes are reasons why this can be justifiable.

Technical barriers related to the receiving, handling, storage, pre-processing, conveying and feeding of biomass waste in a co-combustion installation are mainly related to the type and consistence of the biomass waste used as co-combustion fuel. For example, the receiving, handling and storage of fresh wood chips or other wet fuels may cause odour or spore emissions. The technical constraints affecting the combustion system, the emission control

and the usability depend on the plant process and technology as well as on the properties of the biofuels used for co-combustion.

Most of the problems occurred have been solved partially or completely. The major technical constraints remaining are erosion and chlorine-induced corrosion. Other technical constraints which have not always been overcome satisfactory are the functionality of the boiler cleaning systems and the resistance of the heat exchanger materials and the reduction of NO_x emissions. SCR catalyst manufacturers often do not provide guarantees for operation with biomass fuels because of the negative influence of alkalis in the fuel on the catalyst. The higher content of unburned ashes in the bottom and fly ashes can also be a problem, depending on the burn-out efficiency of the plant and the use of the ashes. As stated before, indirect co-combustion is one way to avoid operational problems in the main boiler.

The amount of flue gases per unit of energy resulting from biomass combustion is much larger than that of coal. When co-firing biomass, this implies that flow patterns of combustion gases through the boiler can be dramatically modified. This limits the percentage of biomass that can be co-fired.

Several non-technical barriers are identified with co-combustion. Future government support, such as tax incentives, is uncertain for the lifetime of a co-combustion plant. In a liberalising European energy market where cost cutting is crucial for survival, the country policies on emissions, subsidies, taxes etc. still vary significantly. Since local authorities can impose even more stringent emissions limits in the permits, geographical differences in flue gas cleaning and water cleaning requirements may occur for the companies throughout the country. The presence of a European level playing field with uniform policies is therefore essential. Further, the draft emission legislation for co-combustion installations is (at least for non-clean biomass) more stringent than for stand-alone installations. Related to this is the uncertainty in more stringent emission standards for co-combustion installations, directly affecting the feasibility through additional gas cleaning equipment required.

Especially for larger installations, there is only limited experience with fuel handling, logistics, sampling, and trading. Since future availability and prices of fuel are uncertain in a growing bioenergy market, long term fuel supply contracts are made with a higher than usual fuel price. The different company culture of traditional biomass traders and the power companies may result in differences in opinion and conflicts. The NIMBY effect needs to be avoided by creating awareness with local municipalities, communicating plans and improvement of the local image.

A major barrier is the marketability of fly-ash in installations where biomass is co-combusted with coal. Although the quality of fly-ash from such processes as ingredient in cement or concrete should not necessarily be worse than that of pure coal firing, current building material standards restrict the use of fly ash to that of coal only.

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17:15 coffee break
17:30 Overview of technical barriers related to co-firing (Christine Rösch, IER, Germany)
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18:30 Overview of experiences with co-firing in the US (Larry Baxter, Sandia, USA)
19:00 Discussion

Chairman: Gerard Smakman, NOVEM, Netherlands
Co-Chairman: Philip Goldberg, DOE, USA

2 Report of the final seminar

The European Commission, through the Thermie B program, has provided financial support for the project "Addressing the constraints for successful replication of demonstrated technologies for co-combustion of biomass/waste", which is aimed at addressing the technical and non-technical constraints in the market introduction of demonstrated technologies for co-combustion of biomass/waste and fossil fuels. Project co-ordinator is Novem B.V. (the Netherlands). Partners in the project are University of Stuttgart-IER (Germany), Imatra Voima Oy-IVO (Finland), Vattenvall AB (Sweden) and Verbund Austrian Hydropower AG / Österreichische Draukraftwerke AG (Austria).

At the kick-off meeting of the EU-project, it was decided that the project would be confined to renewable (non-plastic) fuels and co-combustion in larger to medium scale plants in partner countries that produce electricity. A questionnaire has been sent out to plant owners in the participating countries to be able to identify essential constraints. In two separate workshops on the technical and non-technical constraints, additional issues have been highlighted through the consultation of power plant owners, technology experts, policy makers and research organisations. Both of these workshops were attended by about 30 representatives from power plants, technology suppliers and research organisations.

The co-firing workshop at the *1st World Conference and Exhibition on Biomass for Energy and Industry* served as the final seminar for the EU Thermie B project *"Addressing the constraints for successful replication of demonstrated technologies for co-combustion of biomass/waste"*, and was supported by the IEA Coal Combustion Science Group and the IEA Bioenergy Task 19: Biomass Combustion. As a result, the workshop incorporated the results of the mentioned EU-project as well as co-firing experiences from IEA member countries such as the USA. This report summarizes the presentations held during this final seminar.

Though participation in the conference workshop was open for all visitors to the 1st World Conference and Exhibition on Biomass for Energy and Industry, power plant owners have particularly been invited. The workshop was attended by at least 130 participants, of whom 100 have left their address in order to receive this report. This is significantly larger than the 60 participants previously anticipated at the project initiation. Around 15 of the participants were power plant owners. See page 11 for a list of participants.

2.1 Opening, Chairman

Gerard Smakman (project coordinator, NOVEM, NL) was chairing the session together with Philip Goldberg (DOE, USA and active in IEA CCS). He started the seminar by overviewing the goal, organisation and achievements sofar in the EU Thermie B project in the identification of technical and non-technical barriers for co-combustion. Philip Goldberg is involved with several DOE initiatives on co-combustion in the USA that are implemented under the BIOPOWER programme. The results gained with over 10 co-firing sites are largely positive. In the USA, cofiring is mainly done for economical reasons.

This workshop functions as the closing seminar for the EU-project. Though it was initially meant to be implemented as a separate seminar with invited participants, it was later decided to make it a joint activity with IEA Bioenergy Task 19: "Biomass combustion and cofiring" and the IEA Clean Combustion Sciences group. It is appreciated that as a result of this, additional experiences from non-EU member countries could be presented as well. The organisation of the workshop has been done jointly by TNO (Task leader of IEA Bioenergy Task 19) and NOVEM.

Through the presentations, the workshop presents an overview of experiences with fluidised bed based power plants in Scandinavia, coal power plants in central Europe and power plants in the USA. Both the technical and non-technical problems experienced with co-firing world-wide are presented, while Mr. Greil (Lurgi) elaborates on technical solutions for fuel handling, pre-gasification, raw gas cleaning etc. Mr. Smakman mentioned that the EU is supporting cofiring initiatives in various ways through policies and financial support, mainly through the 5th framework programme. Regretfully, no EU-delegate was present to elaborate on this.

2.2 Co- combustion in Scandinavia using fluidised bed furnaces (Pia Salokoski, Fortum, Finland)

In Scandinavia, fluidised bed combustion (FBC) is the most commonly applied technology for co-combustion. Currently there are about 150 fluidised bed boilers installed in Scandinavia. In various installations ranging from around 1 MW fixed bed boilers in sawmills up to 310 MW fluidised bed boilers in the pulp and paper industries, secondary fuels such as sawdust, wood chips, forest residues, sludges from forest industries, REF (source separated fuels) and RDF (Residue Derived Fuels that are sorted in a separate plant) are cofired with main fuels such as peat, wood, bark or coal. Fortum is one of the technology suppliers.

A major reason for the widespread market introduction of FBC installations is its large fuel flexibility in particle size, density, moisture and ash content, which enables fuel diversification. This is a great advantage for a sparsely populated country as Finland where mass burning facilities for wastes are not economical and a lot of biomass is available. Other important reasons for the widespread introduction of FBC technology are the low combustion temperature in the bed, which results in low NO_x emissions, as well as the option to directly inject limestone in the bed to remove sulphur cost-effectively.

Although the combustion bed is flexible to fuel specifications, it is not always possible to use the existing feeding installation for feeding biomass by premixing the fuels (this is the cheapest option). In cases where the feeding characteristics of the cofired fuel vary too much from the primary fuel, a separate feeder needs to be installed. Other problems that may occur when cofiring in FBC installations are related to the modified vertical temperature profile in Bubbling Fluidised Bed (BFB) installations, slagging and fouling on boiler walls and tubes when burning fuels with high alkaline content, bed agglomeration when burning fuels with high alkaline or aluminium content and Cl-corrosion on heat transfer surfaces (e.g. superheater tubes). The REF and RDF fuels are available in various classes with varying contents of pollutants, produced with highly sophisticated recycling and separation systems under tight quality control mechanisms. In some installations, Cl and heavy metals contained in these refuse derived fuels may cause emissions and corrosion related problems in the installation. For such cases, effective flue gas cleaning technologies can be supplied.

For reasons of cost reduction, there is now a general trend in Finland and Sweden to minimize operating staff at power plants. For co-combustion installations however, this reductions of staff is less easy since more fuels are handled.

FBC combustion is now a proven technology. For example, the LIEKSA biomass CHP plant has a high plant availability of over 98%. The environmental performance of FBC installations is good, with low emissions of CO (<50 mg/Nm3), NO_x (< 70 mg/MJ after the boiler, eventually reduced to less than 10 mg/MJ when using SCR) and high boiler efficiencies (about 90%).

2.3 Co-combustion in coal power plants in Central Europe (Frans van Dijen, EPON, Netherlands)

In central Europe, the interest in co-combustion in coal-fired power plants is increasing for economical reasons using opportunity fuels (such as Tyre Derived Fuels (TDF), Residue Derived Fuels (RDF) or petroleum coke) or for environmental reasons, producing green electricity using biomass fuels. By cofiring such fuels in existing coal power plants, the investment costs are reduced and no new generation capacity is added. Many power plants in central Europe use pulverised coal. Another option for cofiring is in the cement industries, where both the calorific value and the ash may contribute to the process.

In contrast to many other European countries, the Netherlands does not avail of large quantities of construction materials. For this reason, fly-ash and gypsum produced are valuable products of which the quality may not be affecting when cofiring secondary fuels.

One can distinguish direct and indirect co-combustion and parallel firing. For direct co-combustion, all components of the secondary fuel enter the boiler together with the primary fuel since both fuels enter the boiler (eventually in a separate feeder). At the Gelderland power plant for example, waste wood is pulverised and directly cofired in the pulverised coal furnace using a separate burner. Even sludge-types of biomass can be directly cofired, using an oil lance.

For indirect installations the ashes can be kept separate from one another since the thermal conversion is partially done in a separate installation. An example of indirect firing is the Amer9 power plant, where biomass is gasified, and the gas is cooled down and cleaned before it enters the main coal furnace.

For parallel firing, a fully separate combustion installation is used for the biomass/waste and the steam produced is fed to the main installation where it is upgraded to higher conditions. An example of parallel firing is the supply of steam from the Municipal Solid Waste Incinerator (MSWI) in Moerdijk (Netherlands) to a neighbouring natural gas fired combined cycle power plant.

The environmental impact assessment required to obtain a permit for operating a cofiring facility forms an important part of the preparatory work. In order to obtain such a permit, it is important that power companies communicate with issuing authorities on the goals and issues of the project from an early stage. As a result, these issuing authorities will deviate from requesting very detailed Life Cycle Analysis (LCA)-studies to more rational studies based on clear criteria such as usability of residues, fuel conversion efficiency and emissions.

In an open market for energy and fuels there needs to be a level playing field for different types of installations. In the area of emissions however, stand-alone installations are privileged over co-combustion installations since the new EU and national emission limits will be set at 11% O_2 for stand-alone installations instead of 6% O_2 for co-combustion installations. Further, it is debatable what cost-effectiveness is acceptable when reducing emissions under the ALARA[1] principle.

The LCA methods on which permit decisions are based are at present not very transparent and often do not include the full life cycle of a product. It is therefore advisable to employ a transparent methodology with clear results. In this perspective, external logistics such as fuel supply and distribution of heat are determining factors as well.

In principle one can derive the acceptance criteria for contaminants in secondary fuels (in terms of g/GJ fuel) can be derived from the emission limits set and the quality of the thermal process and the flue gas cleaning. It is proposed to use these acceptance criteria for new cofiring installations in the Netherlands. The high costs involved with the sampling and analysis of cofired fuels as stated in the imposed fuel acceptance procedures may be reduced for bulk deliveries of large supplies with little variation in characteristics if government bodies allow for statistically acceptable reduction of sampling/analysis.

Mr. van Dijen foresees that because of the growing importance of fuel flexibility for cofiring installations, CFB gasification and CFB combustion will gain market share. Since the combustion quality in CFBC installations is very good, the need for keeping a minimum of 6% oxygen in the dry flue gases as required in EU regulations for non-dangerous wastes may be dropped to reduce costs and increase energy efficiency.

Currently, the quality and use of residues and products is often regulated by quality standards (DIN, ASTM, ISO) that only allow secondary use if the ash is derived from coal. Such quality standards negatively influence the penetration of direct co-combustion installations that have a significantly lower investment cost than indirectly fired installations. It is thus required to formulate criteria for these secondary products based on the physical consequences for their application in concrete.

There is a serious risk that government policies on taxation for sustainable energy will vary during the long lifetime of a coal power plant. Since this forms a serious risk for plant owners that operate the plant, it is advisable that long-term covenants are signed between power producers and the government.

[1] As Low As Reasonably Achievable

2.4 Practical concepts for parallel firing, pre- gasification and gas cleaning (Claus Greil, Lurgi, Germany)

CFB gasification is a mature and very flexible pre-treatment technology that can be applied to biomass co-firing. Nowadays, CFB gasifiers from Lurgi are in operation at a scale between about 10-100 MW_{th}. The CFB technology has been applied commercially for calcination (since 1960), combustion (since 1972) and gasification (since 1987). All CFB installations are characterized by identical flow patterns and design, where the fluidisation speed is increased until all solids and bed materials go 'over the top' of the furnace into a cyclone where gases can escape and solids and bed material are fed back into the bed. Through the intensive mixing of solids and gases and a high heat and mass transfer, this yields a highly uniform temperature through the reactor. The high thermal inertia of the bed material (around 10-12 tons of sand in a 100 MW_{th} gasifier) also contributes to this.

CFB gasification has been applied to a wide variety of applications and fuels, such as coal, lignite, wood, bark, miscanthus, RDF, rubber waste and sewage sludge. Typical applications for the fuel gas are

- Supplementary firing in a cement kiln without gas cleaning.
- Supplementary firing in an existing boiler plant, eventually with removal of dust, HCl, NH_3, H_2S.
- A gas turbine power plant (e.g. IGCC), with fuel drying, gas cleanup and gas compression

Knowledge has been gained on the gas composition as a function of fuel composition and process conditions. For example, it is now known that CaO in sewage sludge acts as a catalyser for PH reduction, resulting in relatively low CH_4 concentrations in the fuel gas. Also, through different combustion behaviour, sewage sludge results in more bottom ash as compared to what is obtained with wood. Such knowledge is important to design downstream processes such as gas coolers.

Since the chain length of resulting tars is relatively short, no condensation takes place above 230°C. This enables the use of a fabric filter to reduce dust concentrations to a level below 5 mg/Nm^3, if required. Eventually, catalyser can be added to the bed material to modify the fuel gas properties. If necessary, scrubbing the NH_3 containing fuel gas can prohibit NO_x formation. Even for pressurized CFB installations, feeding mechanisms for various types of biomass are now available.

An example of a CFB gasifier is the 85 MW_{th} ACFB wood gasification installation at the AMER9 power plant in the Netherlands. Here, 150 kton/y of waste wood will replace 70 kton/y of coal. After gasification, the gas is cooled to 200°C, dedusted to 5 mg/Nm^3 and stripped of ammonia before it is fed to the main coal boiler.

2.5 Overview of technical barriers related to co-firing (Christine Rösch, IER, Germany)

In the EU, cofiring biomass with coal is considered as an effective option for increasing the share of renewable energy in fuel consumption and reducing the anthropogenic CO_2-emissions, because of the lower capital and operating cost, higher electrical efficiencies and increased fuel flexibility. Another driving force of gaining importance is the ban to dump combustible wastes.

In most of the co-combustion installations currently in operation, biomass is directly combusted together with fossil fuels. In the pulverised coal fired installations such as operating in central Europe, the percentage of biomass that is cofired is relatively small as compared to the fluidised bed installations operating in Scandinavia.

- In Austria, the majority of the biomass fuels are by-products from production processes, e.g. black liquor, bark and sewage sludge in the pulp and paper industries, which are co-fired with coal, oil and gas. These installations are relatively small. Cofiring demonstration plants are in operation in St. Andrä (grate firing) and Zeltweg (pre-gasification).
- In Denmark, a lot of experience exists with co-firing straw, wood and other biomass with coal in various PC and BFB installations.
- In Finland, large quantities of biomass wastes from forest industries are used as the main fuel in grate-fired, BFB or CFB combustion plants within the range of 5 to 20 MW. In Lahti, LCV gas is cofired in the main coal boiler.
- In Germany and the Netherlands, the situation is similar. In both countries, waste wood and sewage sludge are directly cofired in exisiting PC installations. At the AMER9 power plant in the Netherlands, waste wood is gasified in a CFB installation before it is fed into the main coal boiler.

- In FBC installations installed in district heating or power plants in Sweden, forest residues, sawdust, demolition wood, fibre and paper sludge are often burned together with coal or oil.

Besides a great number of technical and economical advantages, there are also technical constraints related with the co-combustion of biomass waste with fossil fuels at different steps of the process. These were identified during the first project workshop, held in Zeltweg, Austria.

The technical constraints connected with receiving, handling, storage, pre-processing, conveying and feeding the biomass waste are mainly related to the type and consistence of the biomass waste used as co-combustion fuel. For example, the receiving, handling and storage of fresh wood chips or other wet fuels may cause odour or spore emissions. The technical constraints affecting the combustion system, the emission control and the usability depend on the plant process and technology as well as on the properties of the biofuels used for co-combustion.

Most of the problems occurred have been solved partially or completely. The major technical constraints remaining are wear (erosion) and chlorine-induced corrosion. Other technical constraints which have not always been overcome satisfactory are the functionality of the boiler cleaning systems and the resistance of the heat exchanger materials and the reduction of NO_x emissions. The higher content of unburned ashes in the bottom and fly ashes can also be a problem, depending on the burn-out efficiency of the plant and the use of the ashes.

Co-combustion with biomass pre-gasification is one way to avoid operational problems in the main boiler. This also increases the fuel flexibility and unexpected problems with the biomass waste fuel only affect operation of the gasifier. Another important advantage of pre-gasification is that the ashes are completely kept separately. This is already applied in a number of demonstration plants in Austria (Zeltweg), Finland (Lahti) and the Netherlands (Geertruidenberg).

2.6 Overview of non-technical barriers related to co-firing (Harry Schreurs, NOVEM, Netherlands)

Several non-technical barriers for co-combustion were identified during the second project workshop held at the Amer power plant, the Netherlands. Of course, these parameters vary from one country to another. The main subjects are listed below.

In a situation where it is uncertain what government support (such as tax exemptions) can be expected over the long lifetime of a co-firing plant, plant owners are confronted with a high perceived risk which translates into a high premium for risk insurance. On the other hand, plant owners are confronted with a liberalising energy market where cost cutting is crucial for survival. Although the market for energy and fuels opens up in Europe, the country policies on emissions, subsidies, taxes etc. still vary significantly. There is therefore a great need for a European level playing field by implementing uniform policies. The high perceived risk also results in high costs of capital that is obtained from financial markets.

The problems experienced with fuel contracting and handling are directly related to the size of the systems. While in Germany and the Netherlands the emphasis is on large-scale systems, in other countries such as Austria smaller scale systems are more common. The size of the installation also has consequences for the handling of residues and may necessitate an environmental impact assessment in order to obtain a permit.

Co-combustion is only done if it is financially attractive for a power plant owner. The financial feasibility is however influenced by unstable biomass prices and insecure supply. Especially when a new biomass conversion unit is built or when additional flue gas cleaning is necessary, the investments are relatively high. Guaranteed supply of sufficient biomass for acceptable prices is then a necessary prerequisite. Traditionally, the company culture of fuel suppliers is different from that of the power plants, which may lead to differences in opinion and conflicts. To guarantee long term supply of biomass for the lifetime of the installation, fuel suppliers will translate the risk of increasing market prices of the fuel into a higher-than-usual price for a long-term contract. The investment risks may be reduced through subsidies.

Changing legislation and more stringent emission limits make co-combustion of biomass or waste more difficult. Investments are needed to reduce emissions. When the fly ashes, bottom ashes and gypsum cannot be used as building materials but need to be landfilled, the extra costs involved may make it unfeasible to realize cofiring.

Hands-on experience needs to be developed with the plant operators and managers in relation to the fuel handling and contracting. Awareness needs to be created and plans need to be communicated with local municipalities to improve the local image and avoid the NIMBY effect.

2.7 Overview of experiences with co-firing in USA (Larry Baxter, Sandia, USA)

In the USA, a lot of experience has already been gained with co-combustion of biomass and waste with coal. For the near term, co-firing is considered the most cost-effective method for biomass power generation. Large coal-fired plants are more efficient (around 35%) than the smaller dedicated biomass plants (typically 20%). Currently, six power plants in the U.S. are cofiring coal and wood residue products on a commercial basis, and a seventh plant recently ceased cofiring after more than 10 years of continuous operation. Another ten plants have successfully tested cofiring over the last decade, and at least six more plants are now planning tests.

In the USA, about 1 billion tons of coal are burned annually. At most, 15% of this (around 5 EJ) could be substituted by biomass. According to recent reports prepared for the Department of Energy, the generation capacity for cofiring in existing coal-fired plants could reach 2 GW by 2005 and 5 GW by the year 2010. Though such action would have a substantial impact on the national CO_2-emission, much more reduction would be needed to achieve the reduction levels required for the USA in the Kyoto protocol. Apart from CO_2, cofiring biomass and waste with coal may as well have a positive impact on NO_x and SO_2 emissions and form an appropriate waste processing option.

In anticipation of fiscal or financial incentives to co-fire biomass, existing coal plants are making co-combustion trials with various forms of biomass or waste. Since cofiring is usually not financially attractive in the absence of such incentives however, cofiring is usually not continued after such combustion trials.

The public perception towards bioenergy as a renewable form of energy is not very positive in the USA. In fact, this even counts for all energy forms involving a flame, while biomass preferably has to originate directly from forests or farm grown lands to qualify as renewable fuel.

Problems with co-firing are related to the very different characteristics of biomass and coal. Biomass may contain up to 72% of volatiles, while coal is almost pure carbon. Biomass particles may therefore be much larger than coal particles. The amount of flue gases per unit of energy result from biomass is also much larger than that of coal. When cofiring biomass, this implies that flow patterns of combustion gases through the boiler can be dramatically modified. This limits the percentage of biomass that can be co-fired in existing installations.

Other problems may occur due to the alkali contents of many biomass fuels, such as straw. Due to the significantly lower ash melting point of biomass ash, slagging and fouling may occur. Chloride contained in straw may cause severe corrosion on boiler tubes, however it has been found that this problem is less for biomass with high alkali contents. Also, when slag is formed on the superheater tubes in a controlled manner, a protective layer of slag may be formed that actually protect the metal for Cl-corrosion. Such knowledge is applied in the latest straw combustion installations recently installed in Denmark. Sulphur contained in coal also has a positive influence on chloride corrosion. Further, inorganic constituents in biomass may heavily speed up the devolatilisation rates of biomass. Of such mechanisms however, little understanding is yet available. Although the deposition rates increase significantly when cofiring straw, cofiring wood or switchgrass may lead to a reduced deposition rate.

There is a different mechanism applicable for the formation of NO_x from biomass. Almost 100% of the NH_3 formed from nitrogen contained in the fuel is converted to NO_x, while NO_x from coal combustion is mostly formed through HCN. With regard to the removal of NO_x, SCR catalyst manufacturers often do not provide guarantees for operation with biomass fuels with high alkali contents because alkalis may deactivate the catalyst.

Another major barrier for more widespread introduction of co-combustion installations is related to the marketability of residues. The existing standards for the use of fly ash in cement and concrete exclusively allow for fly ash originating from coal to be used. It has however been shown that concrete produced from a cofiring installation does not necessarily have to be of less quality than normal concrete. Further research is needed on how ash composition influences concrete strength as it has been shown that fly ash originating from herbaceous fuels <u>does</u> influence the characteristics of concrete. It is advisable that existing norms for use of fly ash in concrete are modified to acceptation criteria regarding the constituents instead of prescribing that it has to originate from coal. In the USA, this is jointly done with utility partners.

Annex A: List of participants

Chairmen, speakers, partners:

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Annex B: Co- combustion in Scandinavia using fluidised bed furnaces (Pia Salokoski, Fortum, Finland)

Fortum

Co-combustion in Scandinavia using fluid bed furnaces

Pia Salokoski 15.6.2000 1

Co-combustion in Scandinavia using fluid bed furnaces

- There are about 150 fluidised bed boilers in Scandinavia
- Size range from 1 to 310 MWth
- Most of the FBC boilers are co-fired
- Main fuels: peat, wood based biomass (bark, wood chips), coal
- Co-firing fuels: saw dust, wood chips, forest residue, sludges from forest industry, REF, RDF

Pia Salokoski 15.6.2000 2

Why Fluidised Bed Combustion

- To increase the scope of fuels used in existing power plants
- Maximized combustion efficiency even with low-grade fuels
- Uniform combustion of fuels with varying size, density, moisture and ash contents, and heating value
- Possibility to burn fuels with high ash and moisture contents
- Low NO_x emissions
- SO_2 reduction feasible without expensive FGD equipment

Special Areas for Concern

- Fuel storage, preparation and feeding
- Vertical temperature profile in BFBC
- Slagging and fouling when burning fuels with high alkaline content
- Bed agglomeration due to high bed temperatures, high alkaline and/or aluminium content of the fuel
- Corrosion of heat transfer surfaces and superheater tubes if the Cl content of the fuel is very high
- Minimization of the number of operating persinnel in small biomass-fired FBC boilers

Kauttua Multifuel CHP

- Multifuel CFBC utilising coal, peat, biomass and recycled fuels
- 19 MW electricity, 7 MW district heat and 50 MW steam

Uimaharju - Industrial Multifuel CHP

- Biomass-fired CHP located at Enocell pulp mill
- 90 MW electricity and 230 MW steam
- Bark boiler retrofit 1992 (old recovery boiler → BFB)
- Co-firing of bark and sludge
- Excess biofuel to electricity
  - 50 MW green electricity outside of the mill

BFB Boiler in Arvika, Sweden

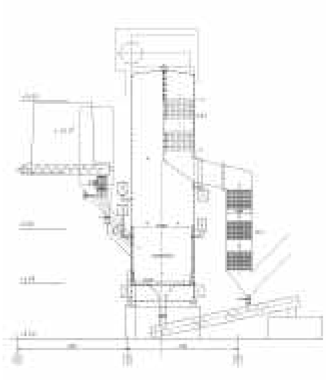
•FUELS:
- WOOD CHIPS
- FOREST RESIDUES
- BARK
- WOOD WASTE

•FUEL INPUT
- 18.2 MW

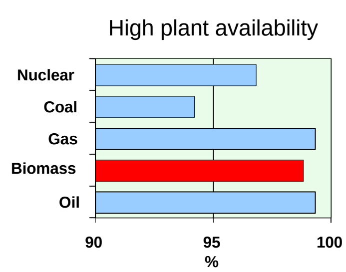
•DISTRICT HEATING OUTPUT
- 16 MW

•BOILER PRESSURE
- 10 BAR

•EMISSIONS
- NOx 63 mg/MJ
- CO 180 mg/MJ



Lieksa Biomass CHP Plant, Finland



Lieksa Biomass CHP Plant, Finland

Fortum Biomass Power Plants

- Bubbling fluidized bed boiler plant based on the FORTUM BFB technology
- FUEL FLEXIBILITY :
  - Peat
  - Wood biomass (wood chips, bark, saw dust, short rotation biomass)
  - Agricultural biomass (prunings, sansa...)
  - Sludges
  - Recycled fuels (rdf/ref)
- BOILER RANGE:
  - Heat only boiler 15-40 MWth
  - Small scale steam boiler 25-80 MWth
  - Large scale steam boiler 70-200 MWth

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Good Environmental Performance

- Low CO emissions 50 mg/m3n
- Low unburnt carbon in ash < 5 %
- Low NOx emissions
  - optimal air staging < 70 mg/MJ
  - SNCR < 40 mg/MJ
  - SCR < 10 mg/MJ
- High thermal effieciency
  - Boiler efficiency 90 %
  - Power generating efficiency with INTERHEATER + 2 %-units
- Effective flue gas cleaning for HCl, SO2 and heavy metals

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Conclusions

- Many FBC boiler manufactures in Finland and Sweden
- A lot of wood based biomass available
- Sparsely inhabited countries → mass burning facilities for waste not economical → co-firing
- Highly sophisticated waste recycling and separation system
- Tight quality control for refuse derived fuels

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Annex C: Co- combustion in coal power plants in Central Europe (F. van Dijen, EPON, Netherlands)

EXPERIENCES GAINED WITH DIRECT AND INDIRECT CO-COMBUSTION

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Contents

1. Summary

In this paper direct and indirect co-combustion are discussed. Factors of influence such as the quality of the product or residues, corrosion, fouling and emissions are reviewed. Problems met during the environmental assessment study and the procedures for obtaining permits are presented. Based on our experiences points of criticism as well as suggestions for improvement are discussed. Suggestion of improvement are amongst others: more uniform and simple emission regulations, not using the principles of BAT and ALARA (Best Available Technology and As Low As Reasonably Achievable), a better Life Cycle Analysis, a uniform acceptance procedure and acceptance criteria for the 'fuel' based on regulations concerning emissions into the atmosphere. The advantages of co-combustion are presented. At last the bright outlook of CFB-gasification and combustion as well as necessary developments for the future are discussed.

2. Introduction

The interest for co-combustion as well as co-combustion itself is increasing. Co-combustion itself is not new. The basis for co-combustion is an economic one. Either inexpensive fuels are used, so called opportunity fuels such as old tires, Refuse Derived Fuel (RDF) and petroleum coke or so called 'green' or 'sustainable' heat and power are produced by using biomass as fuel. This green or sustainable heat and power yield higher prices per GJth or kWhe, compared to heat and power produced from fossil fuels or nuclear energy.

By using existing infrastructure such as existing power plants, the investment costs are reduced and no new generation capacity is added. The co-combustion of biomass in a coal-fired power plant makes this power plant more 'green'. In central Europe many coal and lignite-fired power plants are of the pulverised type.

Also cement kilns show a growing interest for co-combustion or even transferring to 100% opportunity fuel fired. Generally speaking, in the end cement kilns may process about 10% of the waste produced in Europe!

The term direct co-combustion indicates that all the components of the fuel enter the boiler, gas turbine or cement kiln. The term indirect co-combustion indicates that not all of the components of the fuel enter the boiler, gas turbine or the cement kiln.

3. Limitations for direct co-combustion

Direct co-combustion may be restricted due to:
- Corrosion, for instance of the boiler or the deNOx-catalyst by chlorine;
- Fouling, for instance of the boiler by lowering the melting point of the ashes;
- Emissions and
- The quality of the residues (gypsum, fly ash and slag) or product (cement). In the Netherlands all the residues from a coal-fired power plant are sold in the market and this must be remained.

When the fuel used in co-combustion is very wet, this will usually reduce the performance of kiln or power plant. In this case the use of energy efficient drying of the fuel is necessary. Especially when new solid fuel fired power plants are constructed drying the fuel is also economically attractive.
Examples of direct co-combustion are:
- A gasifier, according to the Lahti- and Rüdersdorf-concept;
- Mixing with coal and milling, using the coal mills and
- Milling in a separate milling plant, according to the Gelderland-concept.

When a gasifier is used, the bottom ash is a component, which does not enter the boiler or the cement kiln! However, this technology is considered as direct co-combustion.

4. Indirect co-combustion

When problems are met with direct co-combustion indirect co-combustion may solve these problems. In general, the concepts for indirect co-combustion are much more expensive, compared to direct co-combustion. Examples of indirect co-combustion are:
- Combustion in a separate plant, with adequate flue gas purification and with supply of steam to the power plant, according to the Moerdijk-concept;
- Gasification, gas cooling, gas purification and the supply of purified gas to the power plant or the cement plant, according to the Amer-concept.

With indirect co-combustion ash, chlorine, fluorine, heavy metals, volatile heavy metals and/or sulphur from the fuel can be prevented from entering the boiler, gas turbine or cement kiln.

5. Permits and environmental impact studies

For the co-combustion permits are usually needed. In order to obtain the permits environmental impact studies usually have to be made. The need for an environmental impact study seems justified, when the amount of 'secondary fuel' processed is considered. This amount may be as high as about 500,000 tons of RDF per year for a cement kiln and up to about 1,000,000 tons of biomass per year as dry matter for a 600 MW pulverised coal fired power plant replacing 40% of the coal by biomass. Imagine these masses being transported by trucks only!

The costs for permits and environmental impact studies may vary between about 100,000 and 250,000 EURO. The costs will be especially high when laws and regulations are not clear, when life cycle analyses have to be made and when know how is limited. In the past permits were based on very detailed information. In more recent years permits are based on the most relevant aspects such as emissions, safety, noise and dimensions.

The time needed from the start of the environmental impact study to the reception of the permits will be between 1 and 3 years. The time needed is especially high when laws and regulations are not clear, when life cycle analyses have to be made and when know how is limited (again).

It is strongly advised to agree in advance with the civil servants involved on the main goals and issues of the project, the environmental impact study and the permits. It is also strongly advised to establish a good working relation with the civil servants involved. This not only speeds up the process but also enhances the quality of the project, at least to our experience. Besides, the process for obtaining permits becomes more agreeable to all parties involved.

Although co-combustion itself is not new, the request for permits and the environmental impact studies on this technology are. In this way, the process is lengthy, but we are learning a lot, which speeds up future requests for permits and environmental impact studies.

People involved with environmental issues in The Netherlands have presented a paper in which they describe according to which criteria they judge projects such as co-combustion (1). Their main criteria are:
- The residues must be sold in the market;

- The fuel efficiency must be high;
- The emissions must be low.

Although these criteria are since long state of the art for power producing companies in The Netherlands like EPON for coal fired power plants, not all the projects realised in The Netherlands in recent years meet these criteria! The same holds for some projects that are in progress.

According to EPON another criterion will be added:
- Transport to a suitable site by ship or train, not by trucks, when the fuel is not produced in the region.

5.1 Emissions

The emissions from co-combustion must meet many laws and regulations:
1. Of the EU (in progress);
2. National (in progress, usually more stringent);
3. Local (usually even more stringent);
4. Use of the Best Available Technology (BAT);
5. Use of the ALARA-principle (As Low As Reasonably Achievable).

Here is it surprising, that the emission limitations for co-combustion in coal fired power plants are much more severe than for stand alone plants, when waste and non-pure biomass are used as a fuel. Emission limitations of co-combustion are based on dry flue'gas with 6% oxygen, whereas those for stand-alone plants are based on dry flue gas with 11% oxygen. As the EU will set these emission limitations, they must be obeyed on the national and local levels.

The EU and Dutch proposals are presented in table 1 (2).

Table 1. Limits for emissions in The Netherlands for biomass and waste as proposed, for 'dirty' fuels

Component	Unity	Stand alone, EU	Co-combustion, EU	Stand alone, NL	Co-combustion, NL
Nm^3 flue gas	Dry, 11% O_2	11	6	11	6
CO	Mg/Nm^3	50	50	50	50
VOS	Mg/Nm^3	10	10	10	10
Dust	Mg/Nm^3	10	10	10	10
Nox	Mg/Nm^3	200	200	70	70
SO2	Mg/Nm^3	50	50	50	50
Cl	Mg/Nm^3	10	10	10	10
F	Mg/Nm^3	1	1	1	1
Hg	Mg/Nm^3	0.05	0.05	0.02	0.0075
Cd + Tl	Mg/Nm^3	0.05	0.05	0.05	0.05
Sum heavy metals	Mg/Nm^3	0.5	0.5	0.5	0.5
Dioxins and furans	ng/Nm^3 TEQ	0.1	0.1	0.1	0.1

Note that the proposal of the EU is based on the German 17. BImSchV.

EPON feels that a level playing field is important in a liberalised and competitive market. With this many laws and regulations concerning emissions, EPON feels that the civil servants expect companies like EPON to be a better catholic than the pope himself! Besides, even lawyers specialised in this subject discuss about the right interpretation and execution of the laws and regulations.

We suggest:
- Simple emission limits, for instance the German 17. BImSchV for all installations. This means independent of the capacity, the type of fuel or waste, the technology, etceteras.
- Emission limits based on protection of the environment only. This means, that the use of the BAT and the ALARA-principle becomes irrelevant.
- No local emission limits.

Our objections against use of the BAT beyond sound emission limits set by laws and regulations are that at present emissions can be reduced drastically, as the technology is available. However, usually the costs for further (flue) gas purification are drastically increased. This money is better spent on other items, which may even be related to the environment, such as wild life protection, preservation of natural habitats, etceteras. Our objections against the use of the ALARA-principle are similar. Here the discussion concentrates on the interpretation of the term reasonably.

5.2 Life cycle analysis

One or more Life Cycle Analyses are often requested as part of the environmental impact study. This LCA is often limited to comparing different types of waste disposal or the use of different type of fuels. In this sense LCA does not study the life cycle of a product. So, the use of the term LCA is often not correct.

The production of a LCA can be based on different methods. According to our experience, not all methods are good, some are very poor indeed. The way a computer program calculates and what data is used is often a company secret. The way information is presented is sometimes not suited for presentation at all. In this way the information obtained cannot be communicated towards the public and the authorities. We suggest an LCA which:

- Produces results which can be presented to a broad public and
- Uses a clear process from data input to information obtained.

A poor example in The Netherlands is the method from bureau De Roever, although this method is advised and used by the authorities. A fine example in The Netherlands is the CMLmethod, using the software SimaPro, version 4.0, as used by KEMA. EPON and other power producers in The Netherlands often use KEMA as a consultant.

5.3 External logistics

One item discussed more and more is the external logistics or the transport of solid and/or liquid fuel to the power plant and of the residues from the power plant. Usually and preferably coal fired power plants are either located near the sea or a large river. AS an alternative power plants are also located next to the mining operations for coal or lignite. External logistics in the last case are often by belt conveyer. In the first case external logistics uses ships. The use of ships is accepted as a sound solution.

Trucks often transport 'fuels' like waste wood, RDF and others. In this way external logistics becomes a problem. Preferably these 'fuels' should be treated locally in order to reduce truck transports. Most of the polluting emissions come from these truck transports and not from the power plant. The same holds for the noise produced. A large city may produce about 1,000,000 tons of combustible waste per year. When transported by trucks as loads of 20 tons each, this means a lot of rides per year (2 x 50.000).

Naturally, the 'fuel' can also be transported by train. This is considered as an intermediate solution between transport by ship and by truck.

The experience obtained from large coal fired power plants (and steel mills) shows that a location near a water way (sea, lake or river) and transport of solid fuels and residues by ship is a sound solution from the environmental point of view and to gain acceptance by the public. However, the owner of the ‘fuel' may have a different view!

Cogeneration is often a financially interesting option, especially for conventional MSWI. For cogeneration transport of heat in form of steam or hot water using pipelines is necessary. The presence of customers nearby, preferably a large heat consuming industry such as a paper mill, is obligatory. Transport of heat outside of the power plant is also considered as external logistics.

5.4 Acceptance criteria for the 'fuel'

The acceptance of the 'fuel' by the plant is usually described as a procedure, may be part of a contract between a supplier and the plant and will be of interest for the permits.

According to EPON 1 GJ (LHV) of fuel produces 550 Nm^3 of flue gas, dry and at 11% oxygen and 370 Nm^3 of flue gas, dry and at 6% oxygen. From these values, the quality of the thermal process, the quality of the (flue) gas purification and the chemical composition of the fuel the emissions can be predicted. As these emissions must meet laws and regulations, it is possible to follow the opposite way: from the emission limitations set and the quality of the thermal process and of the (flue) gas purification, the chemical composition allowed of the fuel can be calculated. This results in acceptance criteria of the fuel expressed in g or mg per GJ. These acceptance criteria may become stricter due to other restrictions mentioned above: quality of the product or residues, corrosion and fouling.

The acceptance criteria as proposed for fuel for direct co-combustion in the EPON coal fired power plant are given in table 2. The same holds for fuel suited for indirect co-combustion by gasification in the EPON gas fired power plant.

Table 2. Acceptance criteria for fuel based on the German 17. BImSchV from 1998

Component	Unit	Pulverised coal power plant, direct co-combustion	Natural gas fired power plant, indirect co-combustion
Cl	g/GJ	110	1,400
S	g/GJ	140	2,000
F	g/GJ	3.8	100
Cd + Tl	g/GJ	2.8	1.8
Hg	g/GJ	0.11	1.8
Sum heavy metals	g/GJ	1280	900

5.5 Acceptance Procedure for the 'fuel'

The authorities usually suggest to analyse the fuel before acceptance and, more important, before co-combustion. When the fuel does not meet the acceptance criteria it must be sent back to the supplier. Literature on acceptance procedures is already available (3).

It is suggested that the fuel must be sampled three times: at the supplier, at the gate of the plant and just before co-combustion. Naturally many of the samples must be analysed. The supplier must guarantee the chemical composition of the fuel and sent the fuel to the plant with a declaration and a chemical analysis.

This whole procedure may become too costly due to the many sampling and analyses. So, the number of suppliers of a plant may be limited. By using statistics, sampling and analyses may be reduced, when a supplier has shown that the fuel always meets the criteria.

The suggestion of analysing first before firing may result in large stockpiles at the plant. Due to risks of heating and fire this seems not a good solution. Besides, large stockpiles are costly.

6. Advantages of co-combustion

Co-combustion in combination with large power plants may result in following advantages:

- Lower investment costs
- Higher electrical efficiency
- No new generating capacity of electricity added
- Fuel flexibility
- Savings of fossil fuel

Co-combustion in combination with cement kilns may result in following advantages:

- Low investment costs
- High fuel efficiency
- Savings of fossil fuels
- Savings of raw materials

Co-combustion in cement kilns is often more competitive compared to co-combustion in power plants, especially for 'fuels' like RDF. Both are competitive compared to waste incineration.

7. Speculations about the future

In the future CFB-gasification and CFB-combustion will become important technologies for stand-alone plants and co-combustion of biomass and waste. These technologies are highly flexible in relation to the fuels used. Co-combustion by itself will continue to grow. At the end, cement kilns will be fired with 'recovered fuels'. Biomass and RDF will also become important fuels for power plants. They will be converted with a high electrical efficiency.

However, important items have to be developed further:

- The quality and use of residues and products must be established from a technological point of view and in the markets.
- The acceptance procedures for the 'secondary fuels' must be developed with and accepted by the authorities. The same holds for acceptance criteria.

- The production of high quality LCA's, that can be communicated with normal people, must be established as well.
- Emission limits should be made more simple and uniform.
- The sustainability of fiscal stimulation and other regulations by governments must be discussed.

When large investments are involved with thermal conversion of waste and biomass, the risks must be limited and so, fiscal stimulation and other regulations must be predictable, which means sustainable. For instance, they must be granted to a project over a period of at least 15 years.

In several countries of the EU regulations concerning the combustion of non-dangerous waste have to be met, such as:

- A temperature of more than 850°C
- A residence time of more than 2 seconds
- A maximum CO concentration of 50 mg/Nm^3, dry and at 11% oxygen and
- At least 6% oxygen in the dry flue gases

The goal of these regulations is to establish a good combustion/oxidation of the waste. When fluidised bed or circulating fluidised bed technology is used, instead of Stoker technology, these 4 rules seem overdone. The fluidised bed and CFB technologies usually result in excellent combustion of the waste. Dropping the rule of more than 6% oxygen in the flue gases would allow for both substantial increases in fuel efficiency and lower project cost. The remaining three rules are sufficient to establish an excellent combustion, at least for the FB and CFB technology.

8. Conclusions

Co-combustion is developing. Not everything has been invented yet. In this way it is an interesting field to work in. One day, co-combustion will be established as an efficient, environmentally sound and relatively cheap way of waste disposal and of using biomass as a fuel.

9. Literature

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Annex D: Practical concepts for parallel firing, pre- gasification and gas cleaning (Claus Greil, Lurgi, Germany)

(Overhead sheets presented)

mg engineering
Lurgi

Fuel Gas from Biomass
Practical Concepts for Parallel Firing, Pre-gasification and Gas Cleaning

C. Greil, H. Vierrath
Lurgi Envirotherm GmbH,
Frankfurt/Main

Co-firing Workshop
June 6, 2000
Sevilla, Spain

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mg engineering
Lurgi

CFB Gasification

Content

1. Development of CFB Gasification
- **CFB Pilot Plant 1 Gasification Principle**
- **Tested Fuels**

2. Test Results for Commercial Plant Design
- **Gas Composition (Biomass/Waste)**
- **Gasifier Operation**
- **Efficiencies**

3. Commercial CFB-Plants
- **Typical Plant Concepts/Reference Plants**

4. The Amer 9 Wood Gasification Installation
- **Description**
- **Technical Data**

CFB Gasification

1. Development of CFB Gasification

CFB Combustion → CFB Gasification: identical design, flow pattern

CFB reactors for calcining: since 1960

CFB reactors for combustion: since 1972

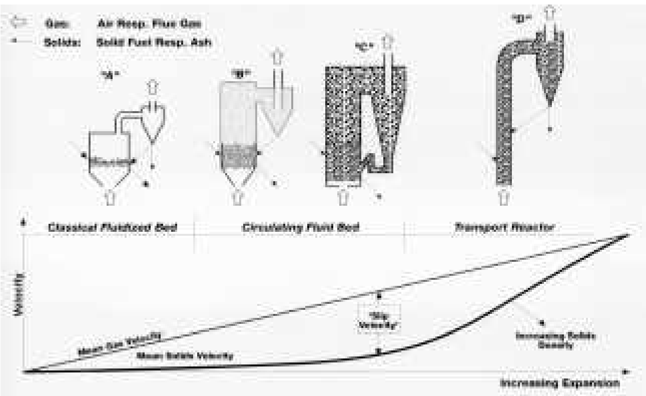
1st CFB power plant Duisburg 100 MWe in operation since 1985
largest unit Gardanne 250 MWe in operation since 1995

CFB Gasification:
Pilot plant 1.7 MWth since 1983
1987 1st commercial CFB gasifier in operation, 27 MWth
1996 worldwide largest CFB gasifier in operation, 100 MWth

CFB Gasification

1. Development of CFB Gasification

CFB Gasification principle



CFB Gasification

1. Development of CFB Gasification

Process Features

- Intensive mixing of gas and solids
- High heat and mass transfer
- Gasification reactions start virtually immediately
- Uniform temperatures through the reactor
- Advantages because of high slip velocity (between classical bubbling bed and pneumatic transport reactor)
- Internal and external circulation

→ Low tar production

CFB Gasification

1. Development of CFB Gasification

Various fuels have been tested in the pilot plant since 1983:

- Petcoke, hard coal, lignite
- Wood, miscanthus, sorghum, tree bark
- Contaminated wood, RDF, sewage sludge
- Paper, plastic rejects, rubber waste
- Carbon containing lignite ash

CFB Gasification

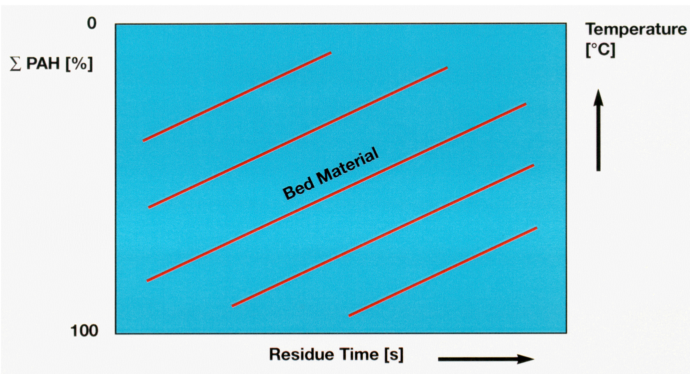
2. Test results for Commercial Plant Design

Test fuels: Wood, Waste Wood, Sewage Sludge, RDF

CFB Gasifier	:	Overall design confirmed Modifications: - ash discharge for fuels with high metal contents
Tar Cracker	:	Not required
Gas Cooler	:	Design according to fly ash content in fuel gas Fly ash content and particle size depend on fuel type
Dry Dust Removal	:	Fabric filter design confirmed
Wet Gas Scrubbing	:	HCl, NH3 removal as required-wash water circulation, temperature to be adjusted according to chlorine, nitrogen content of feedstock
Type of Bed Material	:	Addition of catalytic material depends on fuel gas consumer type

CFB Gasification

2. Test results for Commercial Plant Design



3. Commercial CFB Plants

Typical Plant Concept

- **Fuel gas production for supplemental firing in a rotary kiln e.g. No fuel gas treatment (cooling, cleaning) required**
- **Fuel gas production for supplemental firing in @in existing boiler plant. Fuel gas treatment may be required for removal of fine dust, HCl, NH3 and H2S, however depending on type of flue gas treatment already installed (Desox, Denox)**
- **Fuel gas production for use in a gas/steam turbine power plant. In addition to the fuel gas treatment a fuel drying unit upstream of the gasifier and a gas compressor upstream of the gas turbine is required.**

3. Commercial CFB Plants

Reference plants

Location	Capacity	Plant Description	Fuel	Start up
Pöls Austria	27 MWth	dryer, gasifier air preheater	tree bark	1987
Rüdersdorf, Germany	100 MWth	gasifier	wood, rejects, CCLA	1996
Bioelettrica, Pisa, Italy	12 MWe	dryer, gasifier gas cooling/cleaning/ compression, water treatment, combined cycle	SRF, wood	2000
N.V. EPZ Geertruidenberg The Netherlands	85 MWth	gasifier gas cooling/cleaning water treatment	waste wood	2000

4. The Amer 9 Wood Gasification Installation

N.V. EPZ Project, Geertruidenberg, NL

Existing power station : Amercentrale Unit 9, 600 MWe

Fuel : pulverised coal

150 000 t/y waste wood to replace 70 000 t/y coal,

corresponding to a CO_2 reduction of 170 000 t/y

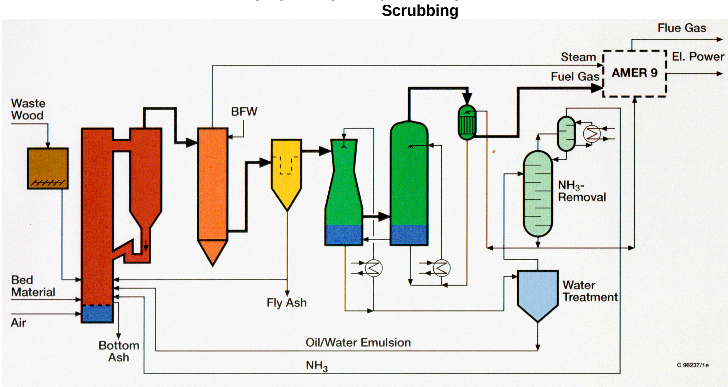
Gasifier Capacity : 85 MWth, air, atmos. CFB
→ 38 000 mn3/h fuel gas from 21.6 t/h wood

Fuel gas treatment	**gas cooling**	→	**55 bar 1 superheated**
	dedusting	→	**< 5 mg/mn3**
	NH_3 removal	→	**< 100 mg/mn3**

CFB Gasification

4. The Amer 9 Wood Gasification Installation

CFB Gasification | Gas Cooler | Dust Removal (baghouse) | Gas Cleaning by Multistage Scrubbing | Power Plant



CFB Gasification

5. Conclusion

Status:	**Lurgi CFB Technology commercially proven**
Application:	**Fuel gas production for**
	- supplemental firing
	- power generation
Feedstocks:	**Waste, Biomass, Coal**
Plant capacity:	**min. 10 MWth, units in operation up to 100 MWth**
Prospect:	**Commercial demonstration of Integrated Gasification Combined Cycle plants and Co-gasification plants**

Fuel Gas from Biomass
Practical Concepts for Parallel Firing, Pre-gasification and Gas Cleaning

C. Greil, H. Vierrath; Lurgi Envirotherm GmbH;
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1 Introduction

This paper presents an overview on the Lurgi-Circulating Fluidized Bed technology (CFB). CFB units are state of the art and have proven their capability of converting biomass, waste or coal into power and/or steam.

CFB reactors are in commercial operation for reduction processes and for combustion and gasification of solid fuels. In this paper reduction processes are not considered. The fact, that world-wide over 80 CFB combustion plants using Lurgi technology are commercially operating proves that this technology is well accepted. Lurgi's CFB gasification technology is at present applied in two industrial plants. It is the key process for our advanced biomass or waste utilisation plants. The subject paper will focus on CFB fuel gas production for combined cycle plants (IGCC) and for co-firing into existing boiler plants.

2 CFB Gasification

The atmospheric CFB gasification is suitable for feedstocks like biomass, coal or wastes. The Lurgi CFB gasifier operates at near atmospheric pressure and is therefore well suited for smaller capacities (i.e. up to around 30 t/hr of feedstock). The CFB gasification unit consists of a vertical, cylindrical, refractory lined vessel with recycle cyclone, bottom ash cooling, and if required, dry fly ash removal and wet gas scrubbing systems. The CFB gasifier operates in a mode between the classical bubbling bed and the pneumatic transport reactor. Under those conditions the slip velocity between solids and gas (or the velocity differential) is highest, leading to maximum heat and mass transfer between gas and solids, requiring the smallest reactor diameter of all fluidized bed principles. Biomass, coal, wastes or other solid fuels are introduced into the reactor near its bottom.

Gasification agents - depending on product gas specification - air, oxygen and steam, or oxygen and carbon dioxide are introduced through a nozzle grate in the lower part of the reactor. Ash is partly withdrawn through the reactor's grate (bottom ash) and partly recovered from the product gas (fly ash).

Gasification reactions are starting close to the bottom of the reactor at the fuel feeding point. Reaction temperature typically ranges from 800 - 1050°C, depending on the type of feedstock. The dust laden product gas leaves the reactor at its top and passes through a cyclone. The major portion of the dust is removed from the gas and recycled to the gasifier bottom through a stand pipe with seal pot, leading to high carbon conversion. The product gas is then cooled, dedusted and purified depending on the requirements of its further use. Commercial gasification plants are in operation with capacities of up to 100 MW_{th} [1, 2].

3 Application of the Atmospheric CFB Gasification Process

Since 1983 the CFB reactor in the Lurgi AG Research and Development Centre has been operated in the gasification mode more than 6000 hours during test runs. The gasifier has a thermal capacity of 1.7 MW_{th}.

Various feedstocks have been tested such as:

- petcoke, hard coal, lignite
- wood, miscanthus, sorghum, tree bark
- contaminated wood, RDF
- sewage sludge
- paper, rubber waste
- fine and coarse rejects (plastic waste)
- carbon containing lignite ash

The tested feedstocks are suitable for the atmospheric CFB gasification process. Therefore, CFB gasification can be efficiently used as a front end process in the following applications.

Production of Electric Power

- CFB gasification attached to Power Plant Boiler:
  Gas from biomass is used as substitute fuel in existing coal or heavy oil fired power plants.
- CFB gas for Combined Power Cycle:
  CFB gas from biomass is cleaned and conditioned for combined cycle power generation or utilisation in a gas motor. [4]

Fuel Gas for Cement Kiln Firing

CFB gas from biomass is used as substitute fuel for precalciners and/or main burners (partial substitution) of cement kilns.

Fuel Gas for Lime Kiln Firing

CFB gas from tree bark / wood waste / paper sludge is used for lime kiln firing for instance in pulp mills. [3]

4 Experience with CFB Gasification

Based on the test runs with various feedstocks the gasifier design has been optimised, i.e. the CFB gasification technology is commercially available since 1985.

Design Features and Technical Advantages of Lurgi CFB Gasification are:

- Commercially proven process

- Robust system with simple operation
- Proven hardware design of gasifier associated components
- Unique process features
  - Intensive mixing of gas and solids
  - High heat and mass transfer
  - Gasification reactions start virtually immediately
  - Uniform temperatures through the reactor → no hot spots
  - Advantages because of high slip velocity (between classical bubbling bed and pneumatic transport reactor)
  - Internal and external circulation
  - Low tar/oil production

Experience and Market Implementation

Location	Capacity	Plant Description	Fuel	Start up
Pöls, Austria	27 MW_{th}	dryer, gasifier air preheater	tree bark	1987
Rüdersdorf, Germany	100 MW_{th}	gasifier	wood, rejects, CCLA	1996
Bioelettrica, Pisa, Italy	12 Mw_e	dryer, gasifier gas cooling/cleaning compression, water treatment	SRF, wood	2000
N.V. EPZ Geertruidenberg, The Netherlands	85 MW_{th}	gasifier gas cooling/cleaning water treatment	waste wood	2000

5 Description of Current Projects

Increasing interest in the utilisation of biomass for the production of energy since the early nineties created several projects, part of them are currently materialising.

The most advanced projects are the Bioelettrica Project in Pisa, Italy and the EPZ Project in Geertruidenberg, The Netherlands.

The Bioelettrica Project will demonstrate the feasibility of power-generation from biomass through the *Integrated Gasification / Combined-Cycle* (IGCC) concept. It is expected that the construction of the plant will be completed in early 2000, and that it will be commissioned by the end of that year.

With the EPZ Project the cleaned fuel gas will be directly fired to an existing boiler plant to replace coal and thus reduce the CO_2 emissions. Commissioning will be in early 2000.

5.1 The Bioelettrica Project

Within the framework of the THERMIE Programme 1994 of the European Union (EU), a group of European organisations constituted by USF/Smogless S.p.A., (a subsidiary of US Filter), EDP-Electricidade de Portugal S.A., Energia Verde S.p.A., Lurgi Umwelt GmbH and Fumagalli S.p.A. is implementing the THERMIE Energy Farm (TEF) Project aimed at the demonstration of the technical and economic feasibility of power generation from biomass, using the Integrated Gasification Combined-Cycle concept.

At a site close to Pisa (Italy), a plant with a net power output of approximately 12 MW_e will be erected; it features an atmospheric, air blown, circulating fluidised bed (CFB) gasifier integrated with a 10.9 MW_e, single-shaft, heavy duty gas turbine, suited to burn the low-calorific value fuel gas produced by the gasifier, and a heat recovery steam generator (HRSG), which provides steam to a 5 MW_e condensing steam turbine. The plant's net thermal efficiency amounts to about 32 per cent.

The gasification and gas turbine islands are supplied by respectively Lurgi and Nuovo Pignone; the Architect Engineer activities including the design of the overall plant are provided by a consortium of ENEL-SIN and EDP-PROET, which are the engineering departments of ENEL and EDP.

Wet wood is shredded to chips, mixed with the agricultural residues and fed to a dryer. Here, flue gases from the HRSG are used to dry the fuel to the desired moisture content. The dried fuel is gasified in a CFB reactor to produce a fuel gas. This fuel gas is cooled in two stages during which the gasification air is preheated and steam is produced in a gas-cooler (GC). Then, it is washed in a wet scrubber and compressed in several intercooled stages before it is delivered to the gas turbine model PGT10 B/1. The gas turbine adopts a newly developed high efficiency air compressor and its special, dual fuel HRSG. The steam turbine is fed by the steam produced in the HRSG and the GC located in the gasification island.

As a consequence of the changed agricultural market, in which the set aside policy has been greatly reduced in scope, while incentives for the traditional food production have been reintroduced, the fuel will consist not only of short rotation forestry (SRF) but also of forestry and agricultural residues. The wood species include poplar, black locust, willow and chestnut, whereas the agricultural residues comprise olive stones and grape-seed flour.

The financial viability of the project relies on the incentive provided by the Italian government with a premium price per kWh of electricity produced from renewables and on the financial contribution from the EU.

The implementation phase was started in May 1997, when three main supply-contracts were signed. The commissioning phase is envisaged to commence during autumn 2000 [5].

5.2 The EPZ Project

The first biomass to gas plant in The Netherlands has been initiated by the Dutch utility N.V. Elektriciteits-Produktiemaatschappij Zuid-Nederland (EPZ). Based on the global demand for CO_2 abatement a wood gasification plant configuration has been developed to produce specified fuel gas from construction and waste wood. The wood gasification plant will be located at the EPZ power station site in Geertruidenberg, NL. The fuel gas will be supplied to the Amercentrale unit 9 a 600 MW_e pulverised coal fired power station. The feed of clean fuel gas allows to save about 70,000 t/y coal corresponding to a CO_2 reduction of about 170,000t/y.

The thermal output of the gasifier is about 85 MW in accordance with a wood feed rate of 150,000 t/y. Chipped wood is delivered by ship and truck and stored in a silo. Since drying is not required the wood fuel is directly conveyed to the gasifier and gasified at a temperature of 850 °C. The raw gas leaving the gasifier is cooled in a gas cooler producing superheated steam at 55 bar. Downstream of the gas cooler is a bag-house filter installed dedusting the gas to a final dust content of less than 5 mg/m_n^3. The dedusted gas is then routed to a wet scrubbing stage where it is quenched and ammonia removed to the specified level. The clean gas is reheated and sent to the power station where it is combusted. The wash water is stripped of ammonia which is recycled to the gasifier. The stripped wash water is also sent to the boiler for combustion. The wood gasification plant is installed in a building requiring an area of approximately 700 m².

6 Conclusion

Lurgi CFB combustion and CFB gasification technologies are commercially available for a wide variety of feedstocks. Both technologies have proven their reliability. Results from continued operation concluded that use of CFB technology to burn or gasify biomass achieves high conversion efficiencies and the required low emission levels. The process of choice has to be selected case by case and depends on the client’s specific requirements.

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Annex E: Overview of technical barriers related to co-firing (Christine Rösch, IER, Germany)

(Overhead sheets presented)

Presentation at the Workshop "Biomass Co-firing" Related to the 1st World Conference and Exhibition on Biomass for Energy and Industry
6th June, Sevilla, Spain

Technical constraints related to co-firing of biomass - experiences made in Europe

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Structure of the lecture

1. Introduction
2. Overview co-firing in Europe (AT, DE, DK, FI, NL, SE)
3. Technical constraints related to
   - Biomass pre-processing
   - Biomass combustion
   - Flue gas clean-up system
   - Usability of by-products
4. Conclusions

1. Introduction

Political goals

→ Increase the share of renewable energy in fuel consumption
→ Reduce anthropogenic CO_2-emissions from fossil fuels

Why co-firing biomass?

→ Potential of biomass available as renewable energy source
→ Advantages compared to stand alone biomass power plants:
- Lower capital and operating costs
- Higher electrical efficiency
- Lower sensitivity feedstock supply and prices

2. Co-firing in Europe

Austria
→ Co-firing black liquor, bark, sewage sludge (up to 95%) with coal, oil, gas in bl, bfb, cfb boilers in pulp and paper industry
→ Demonstration of separate biomass grate firing (St. Andrä) and co-firing LCV gas (Zeltweg)

Denmark
→ Demonstration co-firing of straw (< 20 %) with coal in pc plants

Finland
→ Co-firing wood, paper and process wastes and sludges with coal or oil in fb furnaces
→ Demonstration co-firing LCV gas (Lahti)

2. Co-firing in Europe - II

Germany

→ Co-firing sewage sludge, demolition wood with lignite, coal in pc power plants (2-5 % (db); 10-20 % (st)

The Netherlands

→ Co-firing waste wood with coal in pc power plants

→ Demonstration of co-firing biogenic LCV gas after gas-cleaning (Geertruidenberg)

Sweden

→ Co-firing forest residues, sawdust, demolition wood or paper fibre sludges (<70-85 %) in grate firing, bfb, cfb, pc with oil or coal

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Technical constraints are influenced by

→ *Biomass feedstock*: characteristics and percentages of the main, supplementary, supporting fuels

→ *Combustion system and operation*: boiler type, design specification ranges, burner type/configuration, materials of furnace walls, superheater, reheater, economiser, live and reheat steam temperatures and pressures, boiler operation, type of flue gas clean-up system

→ *By-product use:* quality requirements for reuse or land filling of fly ash, bottom ash, gypsum

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3. Technical constraints related to

a. *Biomass fuel preparation*: Receiving, quality surveillance, pre-processing, storage, conditioning, blending, conveying, feeding

b. *Biomass fuel combustion*: Boiler/burner design, behaviour, surfaces of superheater, reheater, economiser,
superheated steam temperature, fly and bottom ash volume/quality

c. *Flue gas clean-up system:* DeNOx, ESP, FGD

d. *Usability of by-products*

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3a. Biomass fuel preparation

→ *Pre-processing*: No space, equipment available, emissions (e.g,. dust, spores, methane, odours)

→ *Storage*: Risk of bridging, decomposition, spores, explosions, fires

→ *Conditioning/fuel blending*: Increased wear and blockage in shredders/mills, negative effect to fuel homogeneity/grinding result, risk of self ignition, dust explosion

→ *Conveying/feeding* : Bridging, plugging, stickiness, tightness, blockages and damages in pumps, loading hoppers, conveyors, bins, feeders and ash outlets

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3b. Fuel combustion

→ *Boiler design*: Increase of gas and ash volume and gas water content

→ *Boiler and burner behaviour*:
- Deposits and erosion at burner
- Sintering, fouling and slagging in boiler and burner
- Corrosion, fouling, erosion, deposits at reheater, superheater, economiser, air preheater

→ *Composition of products*: lower superheated steam production (cfb), higher fly and bottom ash volumes with content of unburned carbon

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3c. Flue gas clean-up system

→ Increase of flue gas volume and temperature

→ Alkaline-induced aging or deactivation of catalysts

→ Lower efficiency of flue gas desulphurisation

→ Additional gas cleaning to comply with emission limit values

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3c. Usability of by-products

→ Increase of bottom and fly ash volumes

→ Different composition and quality of bottom and fly ashes and gypsum

→ Limited marketability of fly ash as additive in the cement and concrete industry (EN 450)

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4. Conclusions

→ A great number of technical constraints related to co-firing has been mastered successfully

→ Major technical challenges remaining are the risk of corrosion, erosion, deposits, slagging and fouling in the combustion system and the usability of by-products

→ Ways to overcome these technical constraints are e.g. to limit the amount of supplementary biomass or to co-fire LCV gas from a separate biomass gasifier directly or after gas cleaning in the fossil fuel fired boiler

(Paper to be included in the proceedings)

TECHNICAL CONSTRAINTS OF CO-FIRING IN EUROPE

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ABSTRACT. Besides the different technical, economical and environmental advantages, there are still some technical constraints related to co-firing of biomass with fossil fuels. These technical barriers connected to handling, storage, pre-processing, blending, conveying and feeding the supplementary biomass fuel are influenced by the share of co-firing and the type and specific physical, mechanical and chemical properties of the supplementary biomass feedstock. The technical constraints affecting boiler and burner, flue gas clean-up system and usability of the by-products and residues depend additionally on the requirements and design specification ranges of the combustion technology and process. Meanwhile, a great number of the technical challenges, which have appeared during the early stage of co-firing, has been mastered partially or completely. The major technical constraint remaining is the higher risk of wear, corrosion, erosion, slagging and fouling in the combustion system. Other technical challenges, which have not always been overcome satisfactorily, are the functionality of the boiler cleaning systems and the ageing or deactivation of catalysts. The higher content of the unburned ashes in the fly ashes can be a main barrier of co-firing, respectively if the fly ashes cannot be further used as valuable additives in the cement and concrete industry. Ways to overcome these constraints and to avoid operational problems in the boiler are for example to limit the share and types of supplementary biomass feedstock or to co-fire low calorific gas from separate biomass gasification directly or after gas cleaning in a fossil-fuel fired boiler. Pre-gasification of the biomass feedstock increases the fuel flexibility in choice of co-firing fuel and avoids that unexpected problems with the biomass affects plant operation in total. Besides that, the ashes resulting from biomass combustion can be kept completely separate from the fossil fuel ashes.

1 INTRODUCTION

Solid biofuels can contribute significantly to reach the political goals of the European Commission and the national governments in Europe to increase the share of renewable energy and to reduce CO_2 emissions from anthropogenic sources. Most of today's biomass power plants are based on stand alone combustion boiler and steam turbine technology. The average biomass plant size of below 20 MW_{el} is leading to high capital costs per kilowatt installed capacity and to high operating costs as only few kilowatt hours are produced per employer. These factors, combined with a low average biomass-to-electricity efficiency of around 20 %, which increase sensitivity to fluctuations in feedstock supply and price, have led to relatively high electricity costs.

Against this backdrop, co-firing of biomass in existing fossil-fuel fired energy conversion plants is a promising near term option to reduce high costs and efficiency disadvantages of existing biomass energy generation. And it offers a relatively inexpensive options for carbon mitigation by substituting biomass-based renewable carbon for fossil carbon.

Co-firing refers in practice of introducing biomass as a supplementary energy source in high efficiency boilers. The technique of co-firing has been practiced, tested or evaluated for a variety of biomass types and co-firing shares in combination with different combustion technologies and processes, including grate firing, fluidised bed combustion and pulverised combustion. Meanwhile, a great number of technical constraints related to co-firing has been mastered successfully. However, there are still some technical constraints remaining. The aim of the paper is to identify technical constraints of co-firing biomass (wastes) in existing fossil fuel-fired boilers and to point out ways to overcome these barriers. The results presented here are part of the EU-project "Addressing the technical constraints for successful replication of demonstrated technologies for co-combustion of biomass waste" supported by DG "Energy" of the European Commission.

2 CO-FIRING IN EUROPE

In Europe, co-firing is practised with various types of biomass (wastes) in different combustion technologies. In Finland, large quantities of biomass from forest industries are used as main fuel in grate-firing, bubbling fluidised bed (BFB) or circulating fluidised bed (CFB) boilers within the range of 5 to 20 MW_{th} (Salokoski, 1999). In Sweden, forest residues, sawdust, demolition wood and other waste wood, fibre and paper sludges is commonly used together with a smaller portion of coal or oil (15 to 30 %) in district heating or CHP plants using varying combustion technologies (grate firing, bfb, cfb and pulverised combustion (pc)) (Kallner, 1999). In Austria, co-firing is determined by small industrial boilers located mainly in the pulp and paper industry which generally use their own biomass wastes (i.e., black liquor, bark) (Hammerschmidt, 1999). In the Netherlands waste wood is the main supplementary biomass feedstock used in coal-fired pc power plants. In Germany, sewage sludge is the most important co-fired biomass in lignite or coal-fired pc power plants. However, the use of demolition wood and wood waste as additional feedstock is increasing. In dry bottom furnaces the percentage of sewage sludge is limited to 2 to 5 % of the total feedstock input. In slag tap furnaces the share of co-firing sewage sludges is within the range 10 to 20 % (Rösch, 1999). In

Denmark, co-firing of straw up to a share of 20 % in pc power plants has been demonstrated successfully (Overgaard, 1999)

Co-firing is defined as the simultaneous combustion of different fuels in the same boiler. Many coal- and oil-fired boilers at power stations have been retrofitted to permit multi-fuel flexibility. This flexibility can be increased by pre-gasifying biomass in a separate CFB biomass gasifier. The low calorific value (LCV) gas can be burned directly or after gas cleaning in the fossil-fuel fired boiler. Different technologies and processes of pre-gasification of the biomass feedstock have been or will be demonstrated with the support of the European Commission at distinct locations in Europe (e.g., Lathi, Finland; Zeltweg, Austria; Geertruidenberg, The Netherlands).

The remaining technical constraints of co-firing are related to the percentage and type of biomass used as supplementary feedstock but also to the combustion plant technology, design and process. In this paper, technical constraints of co-firing will be identified and analysed in these fields:

- Biomass feedstock pre-processing
- Combustion system and operation
- Flue gas clean-up system
- Usability of solid by-products and residues

3 BIOMASS FEEDSTOCK PRE-PROCESSING

The technical constraints connected with receiving, handling, storage, pre-processing, conveying and feeding the biomass waste are exclusively related to the type and consistence of the biomass used as supplementary fuel. Biomass is compared to fossil fuels characterised by a wide range of various fuels differing in physical and mechanical properties (e.g., moisture content, particle size) and chemical composition (e.g., content of nitrogen, sulphur and chlorine).

The process of receiving, handling, pre-processing, storage, conditioning, fuel blending, conveying and feeding the biomass fuel lead to the need of space and equipment designed specifically for handling and pre-processing of the biomass feedstock. The processes are associated with emissions (e.g., dust, fungi spores, methane, odours) and an increased risk of decomposition, dust explosions, self ignition and fires. During storage, fuel conditioning (e.g. with shredders, mills), conveying and feeding the process can be interrupted or stopped as a result of bridging, plugging, stickiness, tightness and blockages. Besides, wear and damages can occur. More detailed information about technical constraints related to biomass feedstock pre-processing and ways how to successfully overcome these constraints are given in Table 1.

4 COMBUSTION SYSTEM AND OPERATION

The technical constraints related to the combustion system and operation are determined by the plant process and technology, but also influenced by the physical/mechanical and chemical properties of the biomass feedstock used for co-firing. The superheated steam temperature can be reduced due to a lower CFB bed temperature while co-firing. The boiler design can become a technical barrier to co-firing if the increase of gas and ash volumes are not manageable.

Major technical challenges related to co-firing are the risk of slagging, fouling, sintering and high temperature chlorine induced corrosion in the boiler. These risks are increasing when herbaceous fuels (e.g. straw) with a high content of alkaline are co-fired. Corrosion and deposition can occur also on surfaces of superheater, reheater, economiser and air preheater. Table 3 gives an overview on the technical constraints of co-firing related to the combustion system and operation and on solutions.

5 FLUE GAS CLEAN-UP SYSTEM

Co-firing of biomass can be limited due to changes in the efficiency and maintenance of the flue gas clean-up systems (DeNOx, ESP, FGD). The increase of the flue gas volume and flue gas temperature can necessitate adjustments at the plant design and equipment. Accelerated aging and deactivation of the (high and low dust) SCR catalysts has been observed due to the higher content of alkaline (K, Na) which are catalyst poisoner. Flue gas desulphurisation can become a technical constraint because limestone addition is difficult to control due to the relatively great variations in the ash composition of different biomass feedstocks.

Emissions limit values are no problem in case of sulphur, because unlike coal, most types of biomass contain very small amounts of sulphur. The same is true for nitrogen if the biomass feedstock consists of low nitrogen and leads to high volatile yields (i. e. wood fuels). Then, generally NOx emissions can be reduced. However, emission limit values can become a major constraint for co-firing, especially if the co-firing plant has to comply with strict emissions limits for heavy metals (e.g. mercury). Table 3 point out ways to overcome technical constraints related to the flue gas clean-up system.

6 USABILITY OF SOLID BY-PRODUCTS

A major technical challenge associated with co-firing biomass is the potential for reduced fly ash marketability due to concerns that commingled biomass and coal ashes will not meet the existing EN 405 fly ash standards for concrete mixtures, a valuable fly ash market. If the biomass fuel is moderately dry and processed to small particle sizes and if the time required to completely combustion is sufficient, the risk of a high fly ash carbon content limiting their performance and value as a cement or concrete additive decreases. Strict interpretation of current standards for inclusion of fly ash in concrete preclude mixed ashes, excludes biomass-coal ashes. Table 4 includes measurements how to overcome the technical constraints related with the quantity and quality of fly and bottom ashes from co-firing.

7 CONCLUSIONS AND OUTLOOK

Besides a great number of technical, economical and environmental advantages, there are also technical constraints related to co-firing of biomass with fossil fuels. Most of the problems observed have been mastered successfully within recent years. The higher content of unburned ashes in the bottom and fly ashes can sometimes be a problem, depending on the burn-out efficiency of the plant and the designed utilisation of the ashes. The major technical constraints still existing are wear and chlorine-induced corrosion which have to be further investigated. Other technical constraints which are not always overcome satisfyingly are the efficiency of the boiler cleaning systems and the ageing or deactivation of catalysts. Co-firing with pre-gasification of the biomass wastes is one way to avoid operational problems in the main boiler. Besides, the fuel flexibility in choice of the co-fired fuel is greater and unexpected problems with the biomass waste fuel only affects the operation of the gasifier. Another important advantage is that there are no problems with mixing of ashes.

8 ACKNOWLEDGEMENTS

The results of this paper are based on the outcome of the EU project "Addressing the technical constraints for successful replication of demonstrated technologies for co-combustion of biomass waste”. The author wishes to thank DG XVII “Energy” for their financial support and the partners of the project for their valuable contributions to the research work.

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Table 1: Technical constraints of co-firing related to biomass feedstock pre-processing

TECHNICAL CONSTRAINT	HOW TO OVERCOME THE CONSTRAINT
Pre-processing of the biomass: No equipment and space at the power plant for pre-processing ***Receiving and handling of the biomass***: Emissions of dust, methane or odours during	Buy specified biomass from certified suppliers Do the receiving indoor with an increase of air exchange Protect your workers and take precautions against fires and explosions
Fuel quality assurance: Determination and surveillance of the quality of the received biofuels	Use standardised, certified and regularly analysed biomass Undertake visual inspection and regular sampling and testing in your own or independent laboratories Install screening equipment to control size distribution
Storage: Problems with bridging, risk of fires and dust or methane induced explosions in the silos	Compress bulk biomass to pellets or briquettes Install prevention measurements (water or nitrogen inertia)
Conditioning: Increased wear of shredder and mills, risk of spark ignition, explosion and fire	Use a stone and sand remover or trap and a metal separation system Install a security system with spark detection and water or nitrogen fire protection
Conveying: Problems with bridging, blockages, stickiness and back slipping of frozen biomass and emissions of odours, dust and dirt, methane	Mix fresh biomass with dried biomass material Screen the material to exclude oversized material which cause blockages Use proved belt and vertical conveyor systems or other reliable systems Cover the conveyor belts Avoid long transportation distances and junctions
Feeding: Tightness or blocking of the (duplex rotary) feeders	Use reliable feeding systems Install more than one feeding point Find the optimum for the location feeding point Adjust the feeding rates

Table 2: Technical constraints of co-firing related to combustion system and process

TECHNICAL CONSTRAINT	HOW TO OVERCOME THE CONSTRAINT
Boiler design: The gas volumes are increasing and also the water content in the gas	The increase is manageable by the existing boiler equipment if only a small amount (5 to 10 %) of biomass is co-fired

Boiler and burner behaviour: Melted metals (e.g. zinc, aluminia) found on the grate (if demolition wood is used as supplementary fuel) High temperature chlorine induced boiler corrosion due to reduced oxygen layer Sintering in the boiler due to hot spots in the freeboard Increased risk of slagging, fouling in the boiler (walls) Increasing risk of erosion and deposits at the burner	Special material coating with protection and deflection materials Add more feeding points to guarantee a good biofuel distribution Change circulation patterns and increase the central velocity Increased need for soot blowing Adjust the maintenance requirements
Burn-out problems due to the insufficient residence time for fine biofuel particles. In CFBC: Significant freeboard combustion and also final combustion of fines and unburned gases in the hot cyclone possible	Reduce share of fine materials
High temperature before the superheater due to the content of fine materials	
Surfaces of the heat exchanger (and air preheater), super-heater and economiser: Increase of condensation, chlorine induced corrosion and deposits	Special coating with protection and deflection materials Change materials, e.g. use martensitic and austenitic steels instead of ferritic steel Additional installations of a steam heated air pre-heater Sonic blowers to remove slag depositions
High-temperature corrosion of superheater tubes induced by the presence of chlorine on the tube surface	
Reduction of superheated steam production due to the lower CFB bed temperature	

Table 3: Technical constraints of co-firing related to the flue gas clean-up systems

TECHNICAL CONSTRAINT	HOW TO OVERCOME THE CONSTRAINT
Flue gas path: Flue gas volume and flue gas temperature are increasing	Substitute lignite with coal
Catalysts: Accelerated ageing and deactivation of the (high and low dust) SCR catalysts has been observed due to the higher content of alkaline which are catalyst poisons	Use biofuel with lower content of alkalises Regenerate the catalyst Use catalysts which can operate under these circumstances Remove the catalyst poisons in the flue gases
FGD: limestone addition for desulphurisation is difficult to control due to relatively great variations in the ash composition of biomass wastes (e.g. limestone, sulphur)	
Emission limit values for heavy metals	Use only small amount (and/or clean or only slightly contaminated) of biofuels to be able to keep the limits of the new EU mixing rule Add additional flue gas cleaning unit if necessary

Table 4: Technical constraints of co-firing related to the usability of solid by-products and residues of co-firing

TECHNICAL CONSTRAINT	HOW TO OVERCOME THE CONSTRAINT
Ashes: Increase of the bottom and fly ash volumes	Adjust your system and extend the fly ash handling system
Composition and quality of the bottom and fly ashes and the gypsum (chemical, physical and mineralogical ash properties) is changing (e.g. higher content of unburned carbon and of alkaline)	Adjust type and amount of biomass to ensure that the variation in the ash properties are within the range of coal ashes Limit the share of co-fired biomass in order to meet the quality requirements of the bottom and fly ashes (European Code EN 450 for fly ash use in concrete production) Reduce the content of alkaline and chlorine in the biomass Use separate pre-gasification system to separate ashes Increase the air supply at the burners or the residence time for the biomass particles in the boiler Clean the economiser and air pre-heater

Annex F: Overview of non-technical barriers related to co-firing (Harry Schreurs, NOVEM, Netherlands)

Constraints Co-Firing

Goal set:

Research, evaluate and disseminate constraints for market introduction of co-firing coal with biomass/waste

Constraints Co-Firing

Partners:

- Novem (co-ordination)
- Draukraftwerke (AUT)
- IER, Univ.Stuttgart (GER)
- Fortum (FIN)
- Vattenfall (SWE)

Subcontracts (AUT, NL)

2

Constraints Co-Firing

Project Milestones

- Workshop Technical Constraints
- Workshop Non-Technical Constraints
- Concluding Seminar

3

Constraints Co-Firing

Workshop 1:

- Overview participating countries + DMK
- Presentation main projects
- Discussion technical feasibility

4

Constraints Co-Firing

Workshop 2:

- Overview Non-Technical Constraints
- Review main Projects
- Discussion

5

Non-Technical Constraints

Acceptance & Support:

- Financing & Insurance
- Administrative Conditions
- Organisation & Infrastructure
- Knowledge & Information
- Perception & Acceptance

6

Non-Technical Constraints/1

Financing & Insurance:

- Changing Energy Market
- Governmental Support
- Tax Credits
- Private financing
- Risk insurance

7

Non-Technical Constraints/2

Administrative Conditions:

- Permissions (Site, etc.)
- Regulations (Emissions, etc.)
- Regulating Framework (Policies)

8

Non-Technical constraints/3

Organisation &

Infrastructure

- Culture Participants
  Large Differences in Opinions
- Logistics
  Organising in new fields
- Price Acceptance
  Higher Price as Usual

9

Non-Technical Constraints/4

Knowledge & Information

- Feedstock
  Availability, Behaviour
- Attitude
  Personal Skills, Awareness
- Management
  'Balancing on a rope'

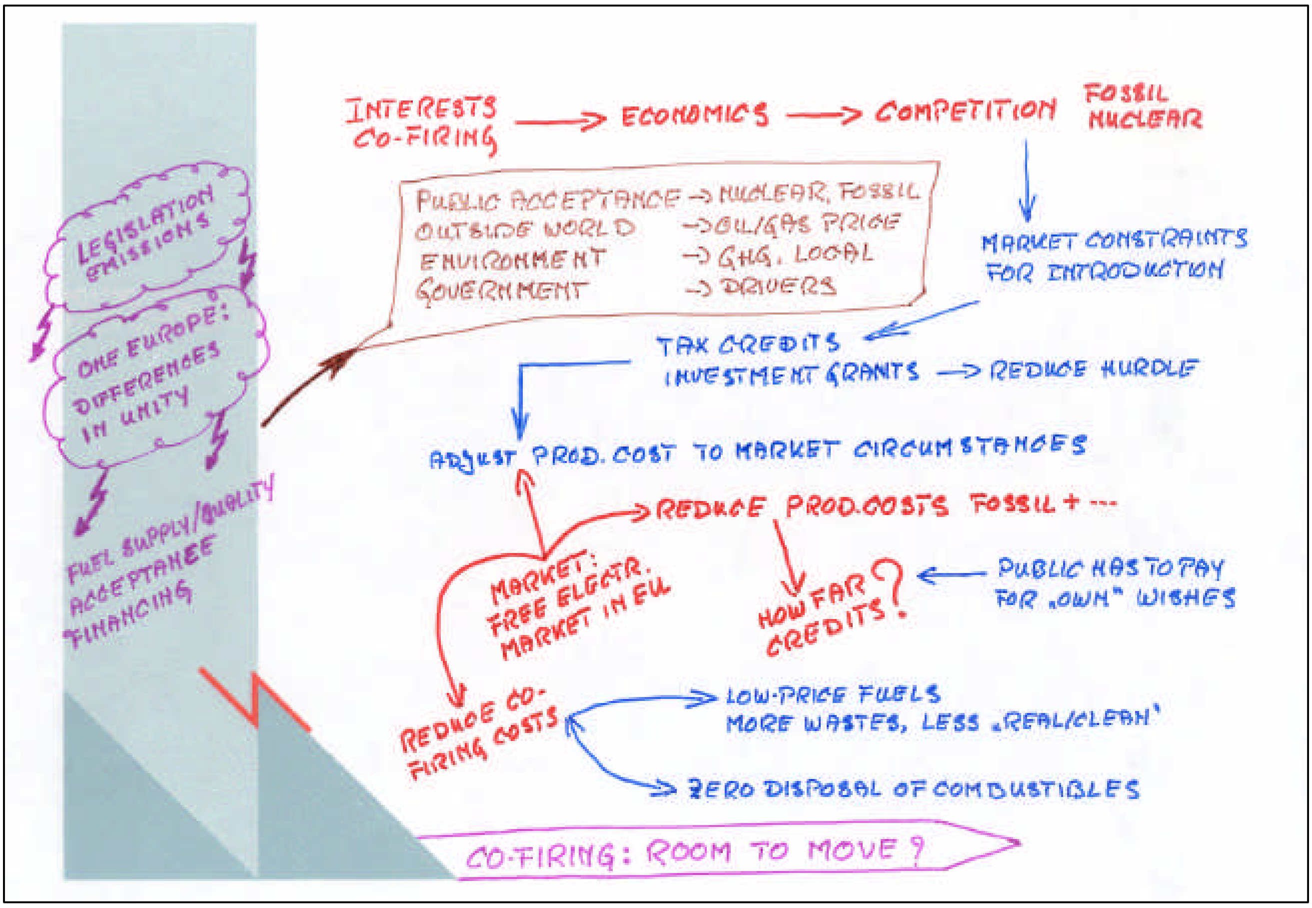
10

Non-Technical Constraints/5

Perception & Acceptance

- Green House Gas Emissions
  Reduction Fossil Fuel Use
- Uprated "Fuel"-Value
  Value (Organic) Residues
- NIMBY-Effect
  Local Image and Attractiveness

11


INTERESTS CO-FIRING
ECONOMICS
COMPETITION
FOSSIL NUCLEAR
PUBLIC ACCEPTANCE → NUCLEAR, FOSSIL
OUTSIDE WORLD → OIL/GAS PRICE
ENVIRONMENT → GHG, LOCAL
GOVERNMENT → DRIVERS
MARKET CONSTRAINTS FOR INTRODUCTION
TAX CREDITS
INVESTMENT GRANTS → REDUCE HURDLE
ADJUST PROD. COST TO MARKET CIRCUMSTANCES
REDUCE PROD. COSTS FOSSIL + ...
MARKET: FREE ELECTR. MARKET IN EU
HOW FAR CREDITS?
PUBLIC HAS TO PAY FOR „OWN" WISHES
REDUCE CO-FIRING COSTS
LOW-PRICE FUELS
MORE WASTES, LESS „REAL/CLEAN"
ZERO DISPOSAL OF COMBUSTIBLES
LEGISLATION EMISSIONS
ONE EUROPE: DIFFERENCES IN UNITY
FUEL SUPPLY/QUALITY ACCEPTANCE FINANCING
CO-FIRING: ROOM TO MOVE?

Annex G: Overview of experiences with co-firing in the US (Larry Baxter, Sandia, USA)

Biomass-Coal Cofiring in the US

Larry Baxter
Combustion Research Facility
Sandia National Laboratories
Livermore, CA

Presented at
IEA Task 19 Workshop
Sevilla, Spain

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  - **UG Students: Gretchen Streiter, Andrew Peronto, Candace Morey, April Brough, Hobart Lee, Jordan Brough, Hanne Lee**
  - **Industrial Visitors: Helle Junker, Scott Turn**
- **Cofunded Collaborators**
  - **Professors: Honghi Tran, Jim Frederick, Bryan Jenkins**
  - **Industrial Professionals: Rick Wessel, Jørn Roed, Richard DeSollar, Bob Roscoe, Martha Rollins, Doug Boylan, Jim Chaney, Bill Carlson**
- **Sandia Management**
  - **Don Hardesty (Deparment) and Bill McLean (Center)**

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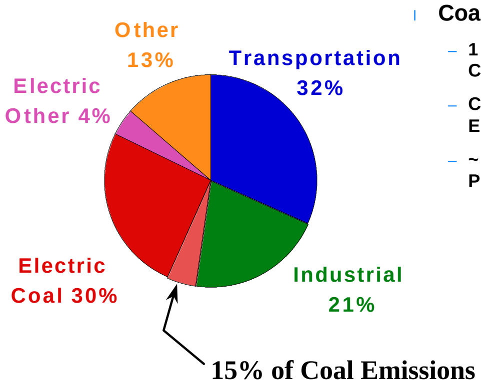
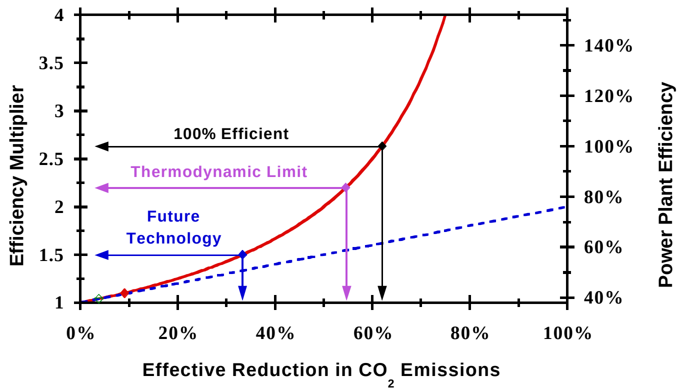
US CO_2 Emissions

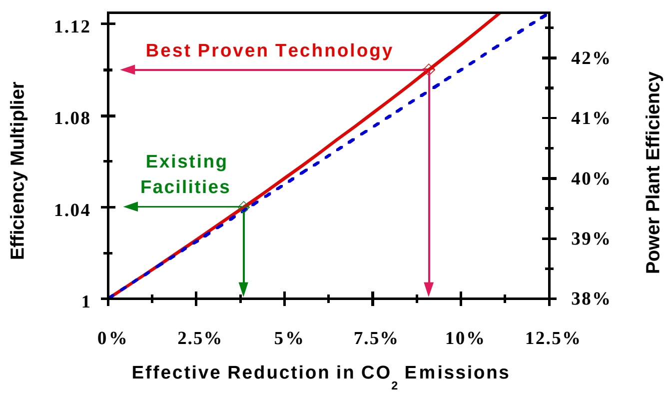


- Coal Facts and Figures:
  - 1 Billion Tons of Coal Consumed
  - Coal generates 54% of US Electricity
  - ~ 1200 Coal-Fired Power Plants

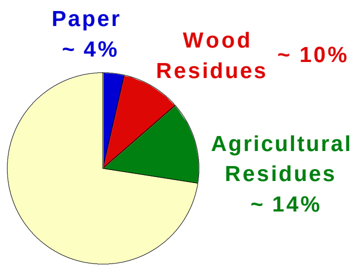
Cofiring Effectively Reduces Net CO_2 Emissions



Cofiring Effectively Reduces Net CO_2 Emissions



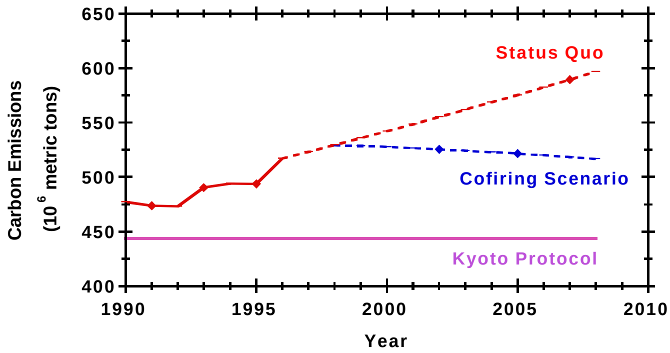
Biomass Available for Cofiring



18.7 Quads of Coal

- Wood waste: **logging residues, sawdust, nonrecyclable paper**
- Crop residues: **wheat/rice straw, bagasse, almond shells**
- Energy crops: **poplar, switchgrass, willow**

Cofiring Can Contribute to the Solution



Cofiring has Many Advantages

UTILIZES EXISTING FACILITIES

- **Biomass perspective:**
  - **Higher Efficiencies**
    - **Coal plants ~ 38%**
    - **Dedicated Biomass ~20%**
  - **Consistent Fuel Supply**

- Coal perspective:
  - Reduce CO_2
  - Reduce SO_2
  - Waste Reduction

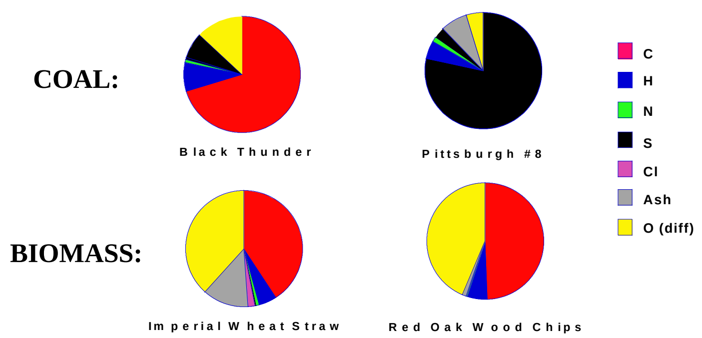
US Cofiring Work Spans Many Scales

- Large-scale Programs
  - Wood-derived Fuels
    - Investigated at lab and pilot scale
    - Demonstrated in cyclones and pc units
    - Major logistics issues
    - Few major fireside Issues
  - Energy Crops
    - Alfalfa, switchgrass (2), willow, poplar
    - Investigated at lab and pilot scale
    - Demonstrations scheduled for this fall
    - Potential major emissions, deposition, and corrosion issues.
- Laboratory research
  - Emissions (NOx, SOx)
    - Scale with fuel impurities
  - Deposition
    - Major issue for some fuels
  - Corrosion
    - Chlorine, alkali and sulfur
  - Carbon Conversion
  - Ash Utilization
  - SCR impacts
    - Potentially large

Wide Range of Field Work

Electric Utility	Generating Station	Boiler Type	Biomass Fired
TVA	Allen Fossil Plant	Cyclone	Sawdust and Chips
TVA	Colbert Fossil Plant	Wall-Fired PC	Sawdust
TVA	Kingston Fossil Plant	T-Fired PC	Sawdust
GPU Genco	Shawville Generating Station	Wall-Fired and T-Fired PC's	Sawdust
GPU Genco	Seward Generating Station	Wall-Fired PC	Sawdust
NIPSCO	Michigan City Generating Station	Cyclone	Urban Wood Waste and Sawdust
NIPSCO	Bailly Generating Station	Cyclone	Urban Wood Waste
Southern Company (Savannah Electric)	Plant Kraft	T-Fired PC	Sawdust
Southern Company (Georgia Power Co.)	Plant Hammond	Wall-Fired PC	Sawdust
Southern Company (Georgia Power Co.)	Planat Yates	T-Fired PC	Sawdust
Madison Gas & Electric	Blount St. Station	Wall-Fired PC	Switchgrass
New York State Electric and Gas	Greenidge Station	T-Fired PC	Wood Waste
Santee Cooper	Jeffries Station	Wall-Fired PC	Wood Waste
Kansas City Power & Light	LaCygne Generating Station	Cyclone	Railroad Ties
Tacoma Public Utilities	Steam Plant #2	Fluidized Bed	Wood Waste, RDF
Northern States Power	Black Dog	Fluidized Bed	Wood Waste

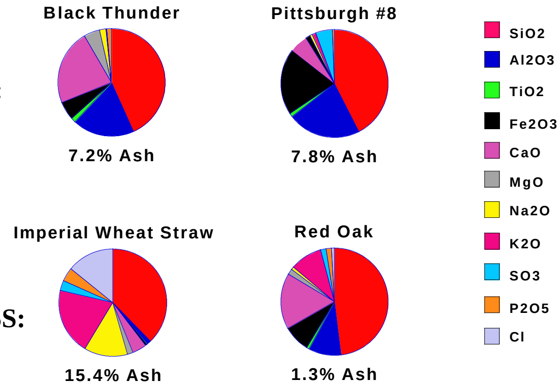
Coal and Biomass Elemental Compositions Differ



Coal and Biomass Ash Compositions Differ

COAL:

BIOMASS:



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Major Technical Cofiring Issues

- Fireside Issues
  - Pollutant Formation
  - Carbon Conversion
  - Ash Management
  - Corrosion
  - Downstream Processes
- Balance of Process Issues
  - Fuel Supply and Storage
  - Fuel Preparation
  - Ash Utilization

Recent work indicates there are no irresolvable issues, but there are poor combinations of fuel, boiler, and operation.

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Carbon Burnout

Pulverized Coal Particle
~ 100 μm

Biomass Particle
1 mm x 3 mm +

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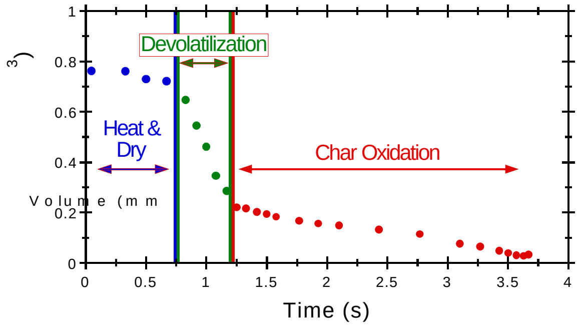
Combustion History of Wisconsin Switchgrass



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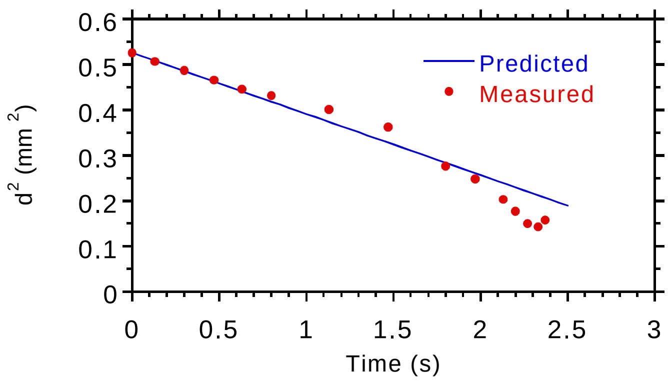
Experimental And Modeled Burning Rates of Switchgrass



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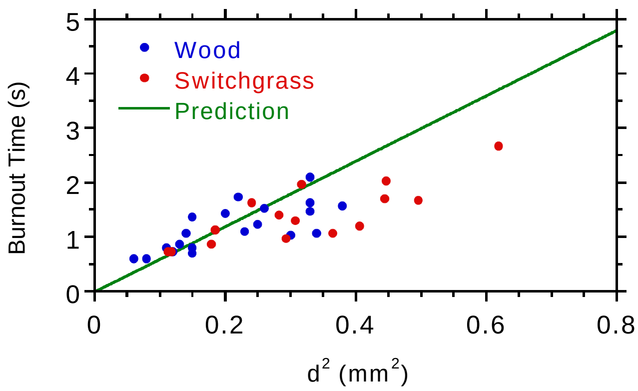
Burnout Times for Biomass Chars



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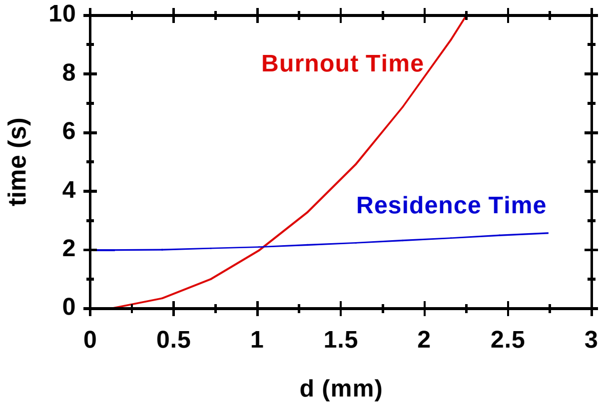
Biomass Char Residence and Burnout Times



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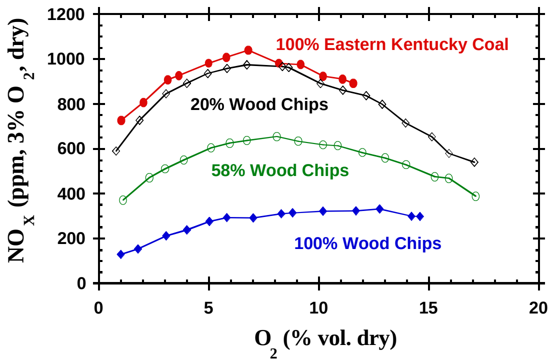
NO_x Emissions from Coal and Wood Chip Blends



Fuel Nitrogen
(lb N / MMBtu)

Coal	1.2
Wood	0.18

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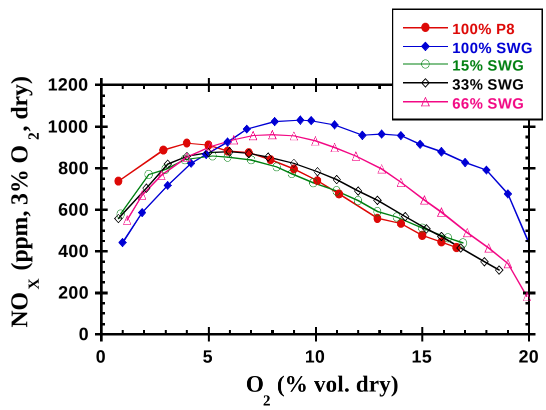
NO_x Emissions from Coal and Switchgrass Blends



Fuel Nitrogen
(lb N / MMBtu)

Coal	1.0
SWG	0.77

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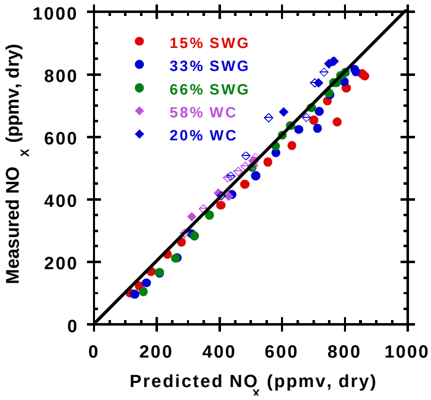
NO_x Emissions Scale With Blend Ratio



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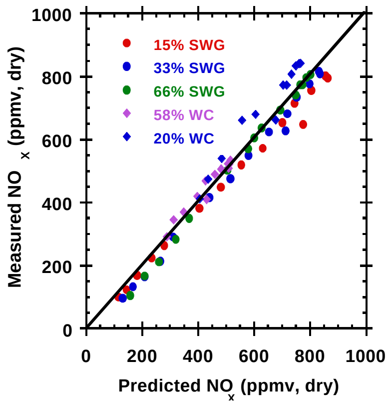
NO_x Can Decline During Cofiring

- Net NO_x production is not strongly affected by coal-biomass volatiles interactions.
- Large biomass volatile yields and change in flame temperature can affect NO_x concentrations.



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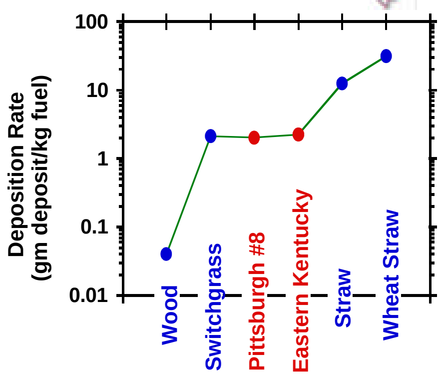
Deposition Rates Vary Widely

- Cofiring biomass can lead to either decrease or increase in deposition rates.
- Cofiring decreases deposition relative to neat fuels.



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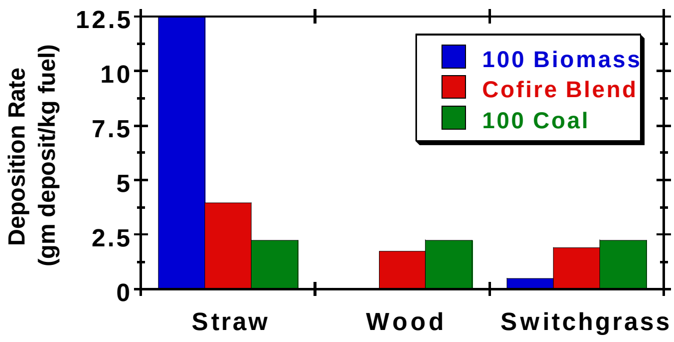
Effect of Cofiring on Ash Deposition Rates



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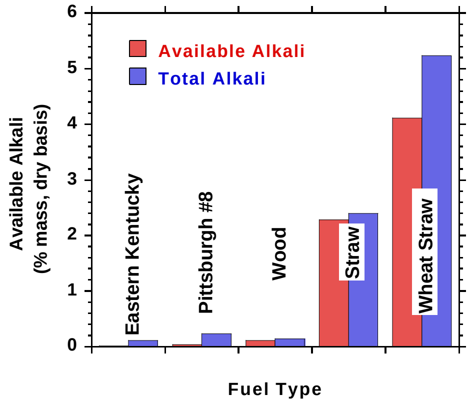
Herbaceous Biomass Contains Mobile Alkali



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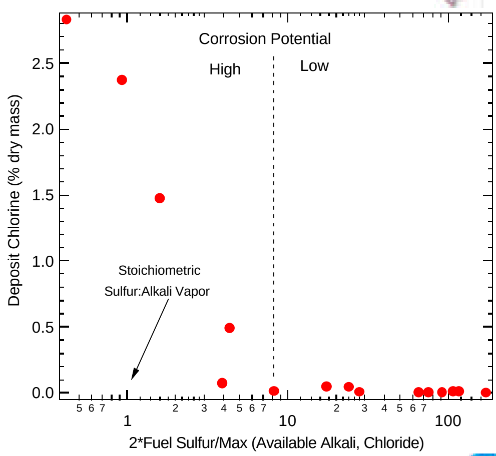
Chlorine-based Corrosion can be Controlled

- Deposit chlorine content near zero for most commercially relevant biomass-coal blends.
- Fuel-based index predicts deposit chlorine content.



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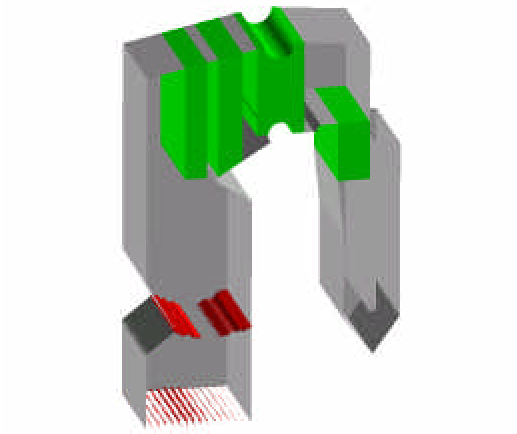
Outline of CFD model



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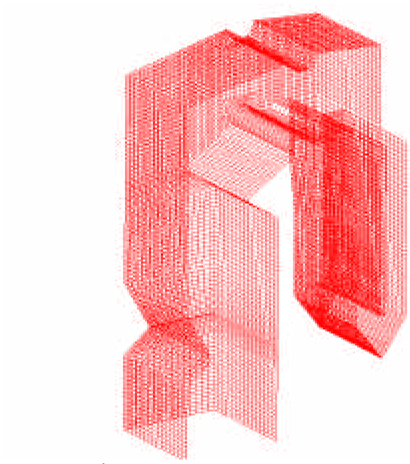
Computational mesh



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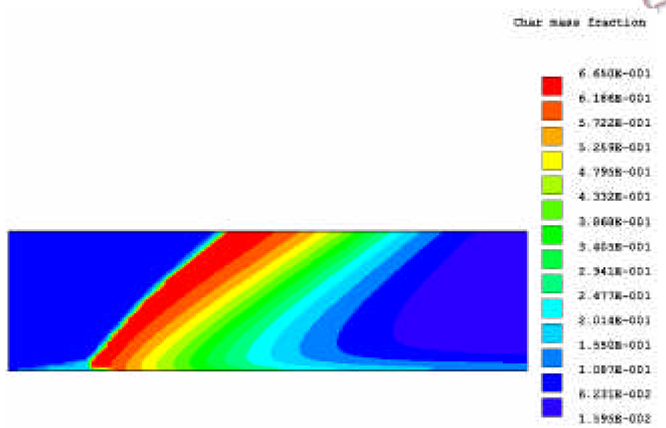
Bed fixed char content



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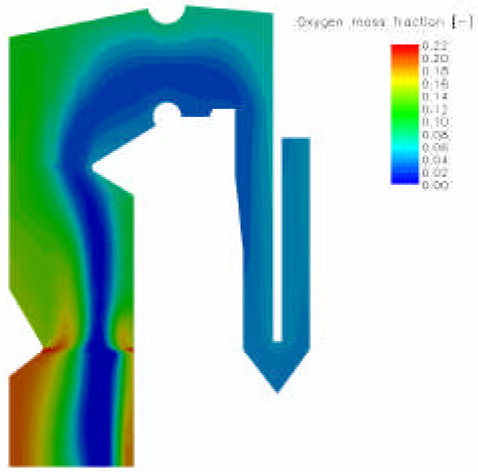
Gas oxygen mass fraction contours



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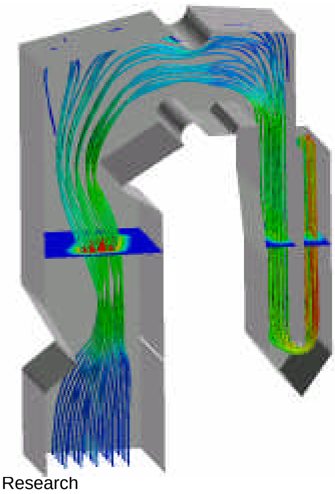
Particle transport



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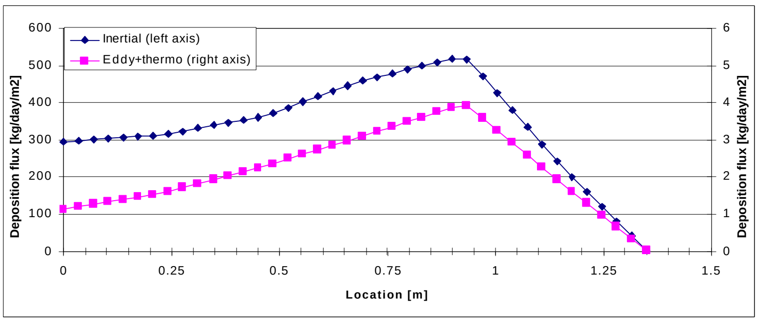
Integrated Deposition Rate: SH #2 (horiz)



$\rho_p = 2.2$

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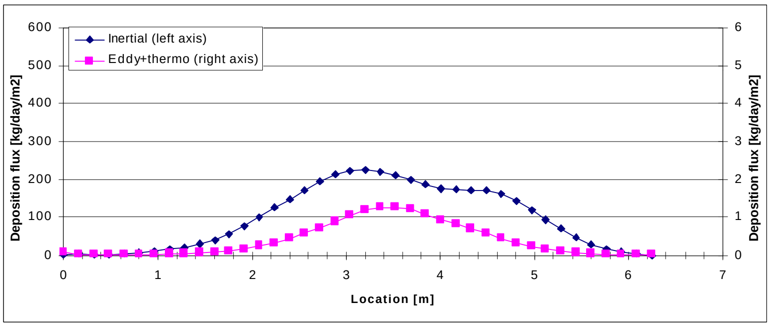
Integrated Deposition Rate: SH #1 (vert)



$\rho_p = 2.2$

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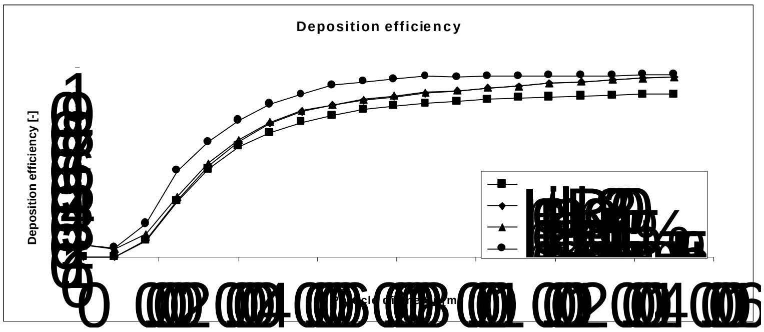
Cumulative deposition efficiencies



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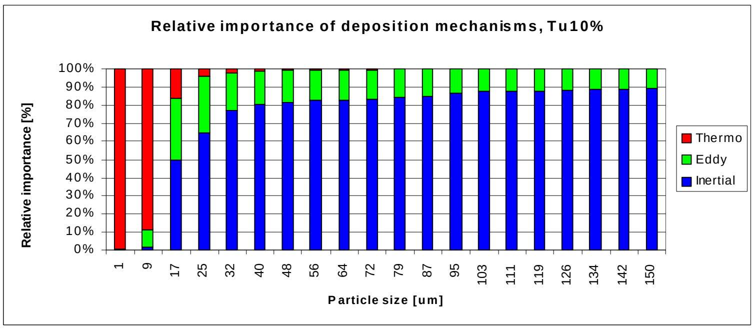
Size variation of mechanisms (con't)



$\rho_p = 2.2$

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Alkali and Alkaline Earth Metals & SCR

- Potential for alkali and alkaline earth metals to deactivate catalysts
  - physical masking
  - chemical poisoning
- No definitive field evidence of such deactivation
- Great deal of anectodal evidence of such deactivation
- Potentially serious obstacle to cofiring

Ash Utilization Issues

- Mingling biomass and coal ash compromises concrete market
- Standard is actively being revised
  - New standard
  - Modifications of old standard
- Meeting next week to discuss options

Conclusions

- Fuel Selection
  - Wood fuels are attractive
    - Potential for reduced NO_x emissions
    - Slight decrease ash deposition rates
  - Herbaceous fuels (straw) more problematic
    - Increased ash deposition rates
    - Interactions within the deposit
- Carbon Burnout
  - Predictions indicate big (> 1/4 inch) biomass particles may not burnout

Conclusions (cont')

- NO_x Formation
  - Usually reduction in NO_x when cofiring wood.
  - Herbaceous, fertilized fuels offer less reduction, possibly increase.
  - Volatile yield and aerodynamics offer potential additional NO_x reductions.
- Corrosion
  - Chlorine in deposits can be minimized by increasing gas sulfur content.

Conclusions (cont)

- Ash Deposition
  - Usually reduction in deposition when cofiring wood.
  - Potentially large increase in ash management problems when cofiring herbaceous fuels, especially those with high alkali, chlorine, and ash contents.
  - Deposit chemistry reflects interactions between coal and wood.

Future Plans

- Ash Utilization
  - Technically based specifications for cement and other high-value uses.
  - Cooperation with commercial and utility partners on standards.
- Modeling
  - Implementation of cofiring in pc-boiler simulation codes.
- Coordination with EPRI and other commercial tests
  - Jointly planning experiments at utility scale.
  - Developing objectives and hypotheses for pilot work.

Annex H: Additional sheets from Evan Hughes (not presented due to absence)

Biomass Energy Development and U.S. Cofiring Experience

Evan Hughes
Manager, Biomass Energy, EPRI
1-650-855-2179, ehughes@epri.com

Presentation material for
6 June 2000
(Larry Baxter at IEA workshop in Sevilla)

6/6/00 Hughes EPRI - 1

Technology Options

- Direct 100% combustion of clean wastes
- Cofiring with coal
- Advanced direct combustion: Whole Tree Energy, slagging combustor, FBC, etc.
- Gasification: low-pressure IGCC, high pressure IGCC, non-GT approaches (no biomass-gas through gas turbine)
- Biological, fuel-oriented, and other

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Critical Issue: Fuel Source

- The biomass must be from a **renewable** source. (In the US, forests are usually cut and grown in a renewable way.)
- Fuel supply and cost can make or break a biomass power project.
- Closed-loop, farm-grown is the hope and the challenge for biomass energy.

6/6/00 Hughes EPRI - 3

WHY BIOMASS COFIRING?

The path to major use of renewable, sustainable, CO_2-neutral biomass fuel/feedstock is via use of coal-fired generating capacity, coal science, coal-based combustion/gasification technology, and other coal-derived expertise.

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Cofiring Field Tests ~1997

Utility and Plant	MW, type	% h	Fuel, % m	MW bio
TVA Allen	272, C	10	sdust, 44	27
TVA Colbert	190, W	$1^1/_2$	sdust, 44	3
NYSEG Greenidge	108, T	10	wood, 30	11
GPU Seward	32, W	10	sdust, 44	3
MG&E Blount St.	50, W	10	swgrss, 10	5
NIPSCO Mich. City	425, C	$5^1/_2$	sdust, 30	23
				72

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U.S. Experience 1

No.	Name	Boiler/Technology	Fuel	NOx Sys.	Year	MW Size	% Heat	MWe Biomass
Pulverized Coal - Blended Feed:								
1.	Jeffries	Wall, Attrita mills	wood	none	1990	200 ?	4%	8
2.	Hammond	Wall, ball mills	wood	LNB	1992	100	6%	6
3.	Kingston	Corner, bowl mills	wood	none	1994	190	2%	3
4.	Colbert	Wall, ball mills	wood	LNB	1997	190	2%	3
5.	Yates	Wall, ball mills	wood	none	1994	150?	1%	2
6.	Greenidge	Corner, bowl mills	wood	none	1994	104	2%	2
7.	Shawville 3	Corner, bowl mills	wood	LNB, OFA	1995	190	1%	2
8.	Shawville 2	Wall, ball mills	wood	LNB, no OFA	1995	138	1%	2
9.	Gadsden	Corner, bowl mills	swgrss	none	2001	60	5%	3
10.	Ottumwa	Corner, bowl mills	swgrss	LNB, OFA	2001	700	5%	35
11.	Lee	Corner, bowl mills	railr tires	none	1996	200 ?	4%	8
							subtotal =	**74**

U.S. Experience 2

No.	Name	Boiler/Technology	Fuel	NOx Sys.	Year	MW Size	% Heat	MWe Biomass
Pulverized Coal - Separate Feed:								
12.	Kraft	Corner, bowl	wood	none	1993	55	40%	10
13.	Greenidge	Corner, bowl	wood	none	1995	108	7%	10
14.	Blount St.	Wall, ball, with grate	swgrss	none	1996-97	49	10%	5
15.	Seward 12	Wall, ball mills	wood	LNB	1997	32	10%	3
16.	Seward 15	Corner, bowl	wood	SNCR,SCR	1999	147	5%	7
17.	McIntosh	Wall, ball, with grate	wood	none	1998?	350	5% ?	N.A.
18.	Dunkirk	Wall, ball mills ?	wood	none	1999?	200 ?	5% ?	10
							subtotal =	**45**

U.S. Experience 3

No.	Name	Boiler/Technology	Fuel	NOx Sys.	Year	MW Size	% Heat	MWe Biomass
Cyclone - Blended Feed (except King):								
19.	King	Separate feed	wood	none	1987	500 ?	1%	5
20.	Big Stone	Blended	wood?	none	1992?	500 ?	4% ?	20
21.	Allen	Blended	wood	none	1994	272	9%	27
22.	Michigan Ci	Blended	wood	none	1997	469	5%	27
23.	Bailly	Blended	wood	none	1999	160	5%	8
24.	LaCygne	Blended	railr tires	none	1996	750	5% ?	15
25.	Gannon	Blended	wood	none	1997?	300?	5% ?	15
26.	England	Blended	wood	none	1998	300?	5% ?	15
							subtotal =	**132**
Fluidized Bed:								
27.	Tacoma	Separate	wood	none	1991	25	50%	13
28.	Black Dog	Separate	wood	none	1990?	160?	20% ?	32
							subtotal =	**45**
Stokers:								
29.	Jennison	Blended	wood	none	1991?	20?	25?	4
30.	Iron City	Blended	wood	none	1997	15	20	3
31.	BLM/NETL	Blended	wood	none	1999	15	20?	3
							subtotal =	**10**
							Total =	**306**

COFIRING AS CO2 REDUCTION

(<u>fossil</u> CO_2 "supply" or "mitigation" curve, USA)

- Categories: cyclone, PC low-%, PC mid-%
- Resource: 10 Mtons @ $0.53/MBtu, 20 Mtons@$0.96/MBtu
- Capital Cost: $50/kW blended feed, $200/kW sep. feed
- Payback: 3 years   Added Operators: only 1
- Result: 48 Mtonnes CO_2 for $210-320M
  (coal cost $1.40-$1.15/MBtu, marginal CO_2 @ $17-20/tonne CO_2)

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DOE/EPRI COFIRING RESULTS

- Seven confirming tests with results

—TVA	—GPU	—NIPSCO
—NYSEG	—Southern	—other?

—various assessments by FosterWheeler

- How small? Burnout calculations, experience, tests
- How dry? Burnout, per above, but also, NOx.
- At what cost? Two vs. one feed. How much milling.
- Why? Basis for our answers, also how certain.

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Issues for Other Technologies

- Gasification needs gas cleaning to protect gas turbine or a way to avoid the need to clean for GT while still getting needed cost/performance combination.
- Direct combustion needs enough size, or other economy of scale, and low enough fuel cost to overcome costs of being small (50 to 100, not 400 MWe) and biomass being low in energy density.

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Conclusions (1 of 2)

- View biomass as clean, renewable solar energy that has storage built in and is captured well in wet, cloudy climates.
- Direct combustion is here now and can be clean and renewable for green power.
- Technology advances are promising in all four areas: direct combustion, gasification, liquid fuels, and biological processes.

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Conclusions (2 of 2)

- Biomass cofiring in existing coal-fired power boilers is where the next major round of biomass power expansion can occur at low cost.
- And, it can be the entry point for clean and renewable green power from the industries with the assets and the expertise in coal fuel science, engineering and operations.

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USA Initiatives for biomass cofiring with coal

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							subtotal =	**10**
							Total =	**306**