

Global operational status on cofiring biomass and waste with coal

Experience with different cofiring concepts and fuels

Jaap Koppejan¹, Larry Baxter²,

¹ Project manager Bioenergy systems, TNO-MEP, PO Box 342, 7300 AH Apeldoorn, Netherlands, phone +31 55 5493167, fax +31 55 5493287, email J.Koppejan@mep.tno.nl

² Professor Chemical Engineering, Brigham Young University, Provo, UT 84601, USA, phone: +1 (801) 422-8616, fax: +1 (801) 422-0151, email larry_baxter@byu.edu

1. Primary motivations for biomass-coal cofiring

One means of reducing the environmental impacts of fossil fuel combustion is to increase the fraction of renewable and sustainable energy in the national energy supply. Renewable energy technologies have, however, struggled to compete in open electricity supply markets with fossil energy, due to their low efficiencies, high costs, and the high technical and financial risks. The result is that they usually require the introduction of subsidies or other financial instruments to support their implementation.

The co-firing of biomass with the coal in traditional coal-fired boilers makes use of the large investment and extensive infrastructure associated with the existing fossil-fuel-based power systems, while requiring only a relatively modest capital investment, typically up to \$50-\$300 per kW of biomass capacity. [i]. These costs compare very favorably with any other available renewable energy option¹.

Worldwide, each percent of coal that is substituted with biomass in all coal fired power plants results in a biomass capacity of 8 GW_e, and a reduction of approx. 60 Mton of CO₂. At a typical cofiring ratio of 5% on energy basis, this would correspond with a global potential of approx. 40 GW, leading to an emission reduction of around 300 Mton CO₂/year.

Power plant operating costs are, in most cases, higher for biomass than for coal, due to the higher delivered cost of the fuel, particularly if energy crops are used. Even when the biomass is nominally free at the point of production, for instance in the case of some of the dry agricultural residues, the costs associated with collection, transportation, preparation, and on-site handling can increase the cost per unit heat input to the boiler to a point where it rivals, and often exceeds, the cost of coal. When compared to alternative renewable energy sources, however, biomass co-firing is normally significantly cheaper, and co-firing has the advantage that it can be implemented relatively quickly.

For most coal-fired power plants, the conversion efficiencies are commonly in the range 30-38% (higher heating value basis). These efficiency levels are much higher than those associated with smaller, conventional, dedicated biomass power-only systems, and rival or exceed the estimated

efficiencies of most of the proposed, advanced biomass-based power systems². The addition of biomass to a coal-fired boiler has only a modest impact on the overall generation efficiency of the power plant, depending principally on the moisture content of the biomass. [ii]

Biomass co-firing results in a direct reduction of the CO₂ emissions in proportion to the co-firing ratio. When proper choices of biomass, coal, boiler design, and boiler operation are made, traditional pollutants (SO_x, NO_x, etc.) and net greenhouse gas (CO₂, CH₄, etc.) emissions decrease. SO_x generally decreases in proportion to the sulfur in the fuel, which is low for many (but not all) biomass fuels. The NO_x chemistry of biomass shows the same, complex but conceptually well understood behavior as NO_x chemistry during coal combustion with the exception that biomass appears to produce much higher NH₃ content and a lower HCN content as a nitrogen -laden product gas compared to coal. Some of the commercially most mature biomass fuels, notably wood, contain relatively little fuel nitrogen and cofiring with such fuels tends to decrease total NO_x. Biomass fuels also commonly contain more moisture than coal, decreasing peak temperatures and leading to commensurate decreases in NO_x.

Most biomass materials have lower ash contents than steam coals, and there is a corresponding reduction in the quantities of solid residues from the plant.

Ancillary benefits of co-firing may also include a reduced dependency on imported fossil fuels, and there may be the potential to develop local biofuel supply chains, which can benefit local rural economies.

It is clear, therefore, that biomass co-firing technologies offer one of the best short and long-term means of reducing greenhouse gas emissions from power generation, but are only applicable where coal firing plays a significant role in the electricity supply. The development of small, dedicated biomass-to energy technologies will also be required, for application where co-firing is not an option.

2. Operational experience

There has been remarkably rapid progress over the past 5-10 years in the development of the co-utilisation of biomass materials in coal-fired boiler plants. Several plants have been retrofitted for demonstration purposes, or are involved in the commercial co-firing of biomass. New coal-fired boiler plants are already being designed with an in-built biomass co-firing capability.

² In case biomass is used in decentralized energy systems, waste heat that is produced as a result of the power cycle can typically more easily be utilized, which leads to higher overall efficiencies than large scale power-only systems. However, fossil fuel based decentralized energy systems share this benefit as well.

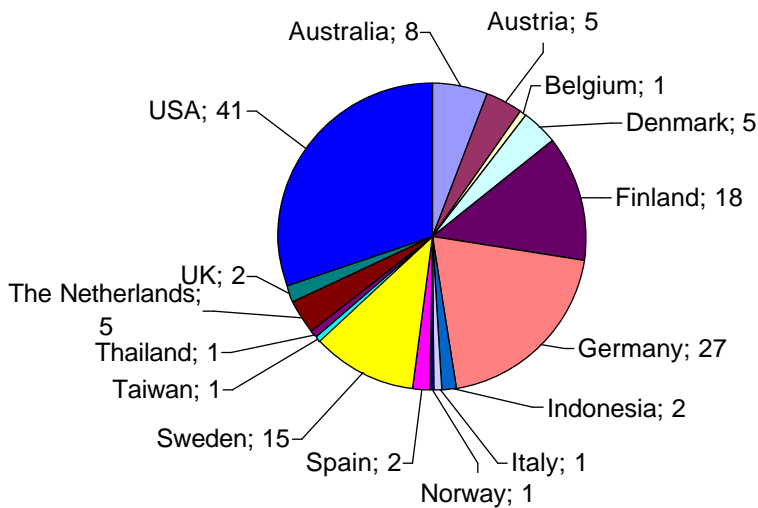


Figure 1 Geographic distribution of power plants that have experience with cofiring biomass with coal [iii].

A recent inventory of the application of co-firing worldwide [iii] has indicated that more than 150 coal-fired power plants have experience with co-firing biomass or waste, at least on a trial basis. The power plants involved are in the range 50-700MW_e, although a number of very small plants have also been involved. The majority are pulverised coal boilers, including tangentially fired, wall fired, and cyclone fired units. Bubbling and circulating fluidised bed boilers, and stoker boilers have also been used. The co-firing activities have involved all of the commercially significant solid fossil fuels, including lignites, sub-bituminous coals, bituminous coals, anthracites, and petroleum coke. These fuels have been co-fired with a very wide range of biomass material, including herbaceous and woody materials, wet and dry agricultural residues and energy crops. As of 2004, there were approx. 40 pulverised coal fired power plants worldwide that cofired biomass on a commercial basis with on average 3% energy input, thereby substituting some 3.5 Mton of coal and reducing around 10 Mton of CO₂.

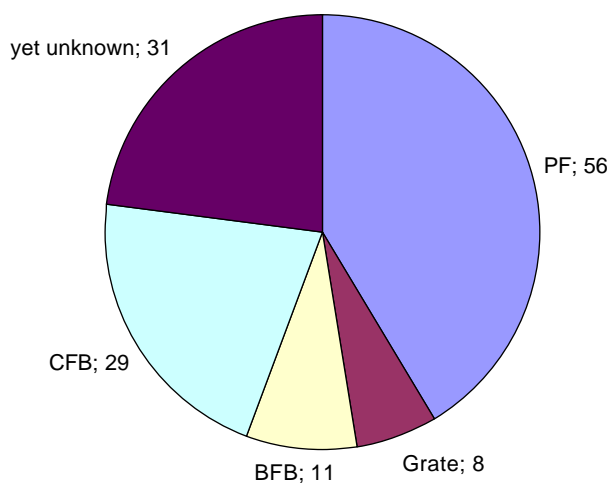


Figure 2 Distribution of firing systems with coal fired power plants that have experience with cofiring biomass [iii].

There are three basic co-firing options for biomass materials in coal-fired boilers, and all of these options have been demonstrated at industrial scale, viz:

- Direct co-firing is the least expensive, most straightforward, and most commonly applied approach. The biomass and the coal are burned in the coal boiler furnace, using the same or separate mills and burners, depending principally on the biomass fuel characteristics. This is by far the most commonly applied cofiring configuration as it enables cofiring percentages up to approx 3% on energy basis, without significant investment costs.
- It is possible to install a biomass gasifier to convert the solid biomass into a fuel gas, which can be burned in the coal boiler furnace. This approach can offer a high degree of fuel flexibility, and the fuel gas can be cleaned prior to combustion to minimise the impact of the products of combustion of the fuel gas on the performance and integrity of the boiler. This approach has been applied a few times sofar, for instance, in the Zeltweg plant in Austria, the Lahti plant in Finland and the AMERGAS project in the Netherlands.
- It is also possible to install a completely separate biomass boiler and utilise the steam produced in the coal power plant steam system. This approach has been applied in the Avedøre Unit 2 Project in Denmark.

3. R&D issues to be addressed for further application of co-firing technology

Although industrial experience with biomass co-firing is expanding rapidly, both in Australia, Europe and in North America, there are still a number of risk areas, which require further development work. The major technical and non-technical challenges associated with biomass co-firing include:

1. Extension of operational experience for other fuels and increased cofiring percentages,
2. The uncertainty associated with the long term impacts of co-firing on the performance of SCR systems
3. The development of fly ash utilization options,
4. The development of an improved understanding of ash deposition and boiler tube corrosion issues,
5. The development of biomass fuel specifications and standardized fuel characterization procedures, and pre-processing requirements for adequate conversion,
6. Formation of striated flows in boilers
7. Public awareness/image issues

These issues are being discussed briefly below. Previous Task 32 reports have focused on several of these issues, for a more detailed description reference is made to the Handbook of Biomass Combustion and Cofiring [iv].

3.1 *Extension of operational experience for other fuels and increased cofiring percentages*

Although around 150 coal fired power plants of different types do have experience with cofiring a wide variety of biomass fuels, most of these plants have shown correct operation for a limited period only in the order of a few weeks to a few months. Approx. 40 coal fired plants do cofire biomass on a commercial basis today, however this is typically done with relatively low percentages of biomass being cofired (average 3% on energy input) and for relatively clean types of (woody) biomass.

To broaden the market potential for biomass cofiring with coal, new techniques are currently being developed that should enable increasing biomass co-firing ratios, introduce a greater degree of fuel flexibility into co-firing systems, and reduce the costs of co-firing systems. Increased insights are

being derived from recent R&D programs into the below issues that affect plant reliability and how these could be mitigated, need to be demonstrated in practice through long term operational experience for a wide variety of fuels, coals and power plant configurations.

3.2 Impacts on SCR Systems

There is evidence from cofiring demonstrations conducted in European SCR-equipped boilers that cofiring biomass with coal results in significant deactivation of SCR catalysts. The reasons for this deactivation are not definitive, but laboratory analyses confirm that alkali and alkaline earth metals are significant poisons to vanadium-based catalysts (which would include all commercial SCR systems) when the metals are in intimate association with the catalyst. Essentially all biomass fuels contain high amounts of either alkali or alkaline earth metals or both as a percentage of ash. Some biomass fuels, however, have remarkably low ash contents, clean heartwood such as sawdust being a classical example. It is possible that the commercially observed SCR deactivation arises from such poisoning or from catalyst fouling, which is also associated with such poisoning.

Figure 3 illustrates results from surface composition analyses from a catalyst exposed to the slipstream of a combustor firing alkali- and alkaline-earth-rich fuels. These normalized compositions and detection limits show that this catalyst, which experienced significant deactivation, is enriched in sulfur and alkali and alkaline earth metals after exposure relative to the pre-exposure concentrations. By contrast, the surface vanadium content decreased (by dilution). These results are consistent with the general hypothesis that alkali and alkaline earth metals can cause catalyst deactivation, but they do not indicate by what mechanism such deactivation occurs.

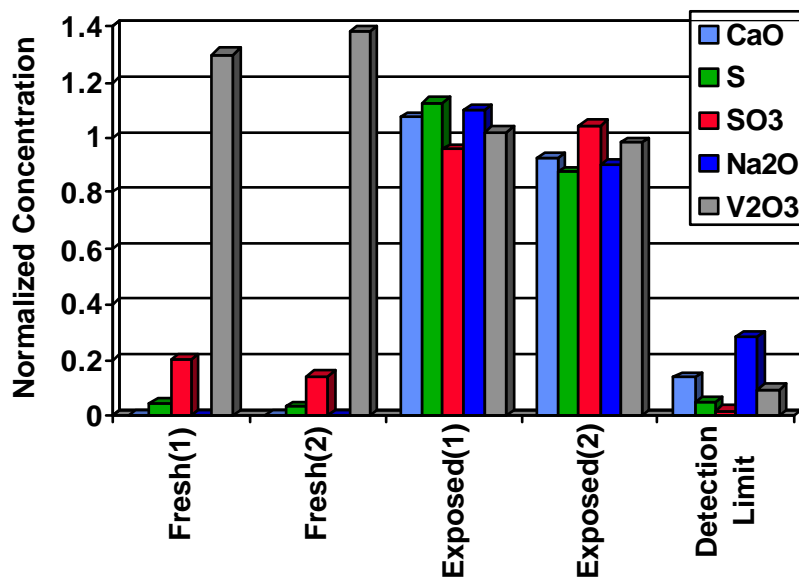


Figure 3 Concentrations of key elements (reported as oxides) in pre- and post-exposed catalyst from a slip-stream reactor.

This issue will become increasingly important as increased numbers of boilers install SCR system to comply with lower NO_x emission limits. Members of Task 32 are engaged in several investigations to more fully explore this phenomenon, including advanced laboratory and field tests.

3.3 Fly ash utilization options

The concrete market presents among the best fly ash utilization opportunities for coal-derived fly ash. However, the ASTM specification (ASTM Standard C618) for use of fly ash in concrete requires that the fly ash be derived entirely from coal combustion. Many processes in modern boilers result in coal fly ash mingled with other materials, including ammonia from pollutant control devices, sorbents or other injected materials from scrubbers, residual sulfur or other compounds from precipitator flue gas treatments, and fly ash from cofired fuels such as biomass. There is a broad, but not universal, recognition that the standard should be modified, but it is not clear what modifications should be made. Here some preliminary results regarding the impact of biomass-derived ash on concrete properties are presented.

This systematic investigation of the impact of biomass- and coal-derived fly ash on concrete involves both Class C (sub-bituminous) and Class F (bituminous) fly ash as well as similar fly ashes mingled with herbaceous and woody biomass fly ash. In all cases, 25% of the cement originally used in the concrete is displaced by fly ash, with the fly ash containing 0-40% biomass-derived material. Tests of concrete air entrainment, flexural strength, compressive strength, set time, freeze thaw behavior, and chlorine permeability determine the extent of the biomass impact. Only selected results are presented here and, as the tests require up to a year to conduct, all results are preliminary. The focus is on the herbaceous biomasses, since many woody fuels contain so little ash that practical cofiring is not likely to have a measurable impact on fly ash properties.

Figure 4 illustrates the impact of fly ash on the required amount of aerating agent to establish ASTM-compliant air entrainment levels in concrete. Air entrainment in concrete is essential to prevent failure during freeze-thaw cycles. As is apparent, the amount of aerating agent increases with increasing herbaceous biomass content. This dependence arises from the effect of water soluble components (higher in herbaceous biomass than in coal fly ash) tying up the aerating agent (generally surfactants), preventing them from forming films that support bubble growth. The impact illustrated is of minor economic concern but is of major process concern. That is, if fly ashes from cofired units were treated the same way as fly ashes from coal, the resulting concrete would likely fail under freeze thaw cycles. Increasing the surfactant to an acceptable level is of little economic impact, but failure to recognize the need to adjust it is of major impact.

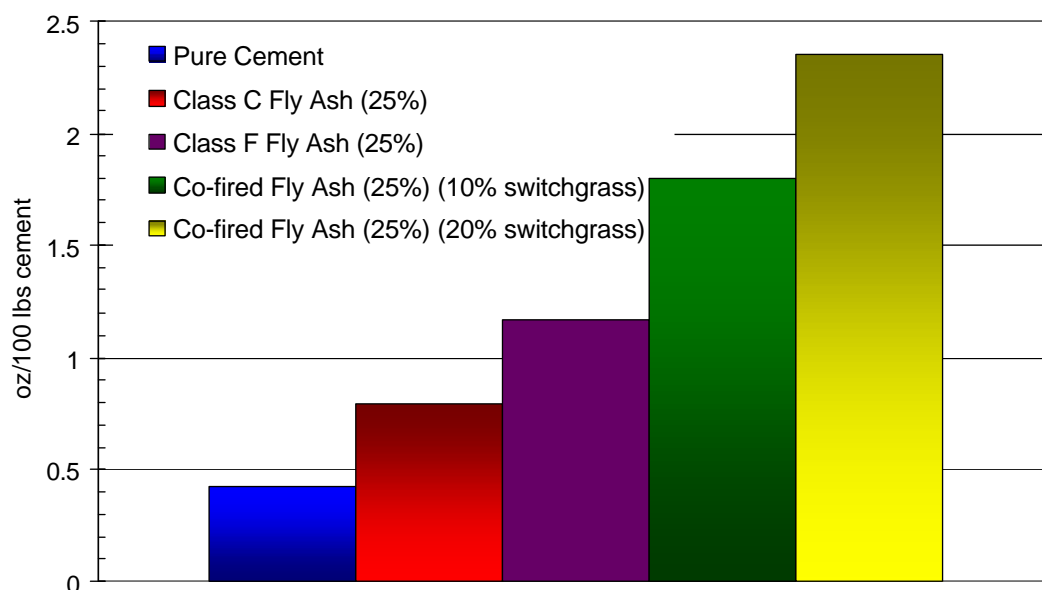


Figure 4 Required amount of aerating agent required to generate air entrainment within ASTM specifications for a variety of fly ash compositions.

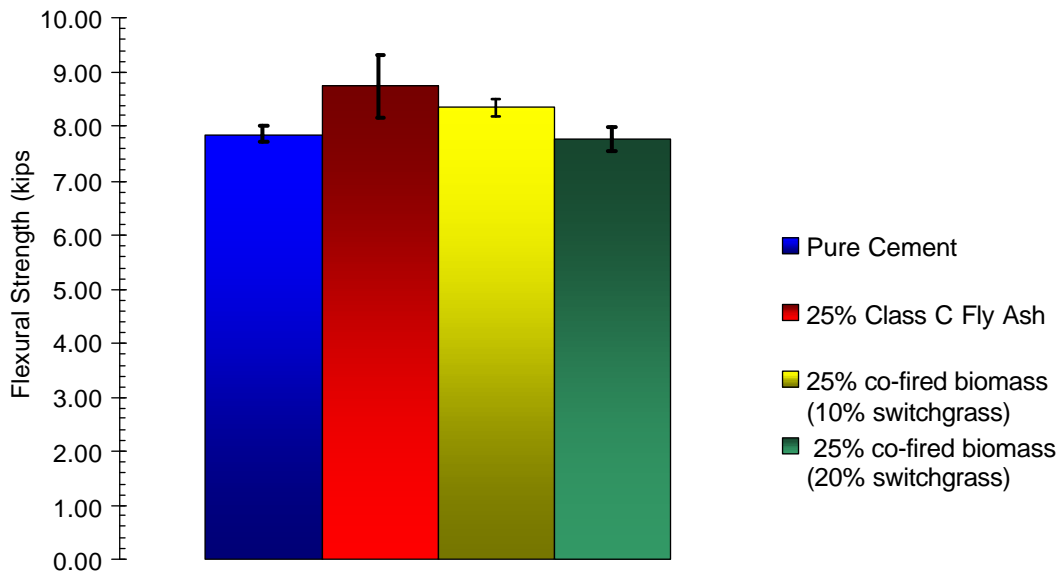


Figure 5 Flexural strength and its dependence on fly ash composition.

Figure 5 illustrates the impact of biomass-coal commingled fly ash on flexural strength. In these tests little significant difference is seen among the various samples. Additional data on set time and compressive strength indicate that all fly ashes delay set time by 2-4 hours compared to concrete made from cement only but the biomass-containing fly ash does not delay set times significantly more than the non-biomass containing fly ash. Early compressive strength (in the first month or so) is compromised by all fly ashes, again with the biomass-containing fly ash similar to coal fly ashes. However, late strength (longer than 2 months or so) is enhanced by the presence of all fly ashes.

In conclusion, there appear to be only manageable impacts of biomass-containing fly ash on concrete properties based on these preliminary data, with amount of aerating agent being an example of one issue that requires monitoring. Otherwise, biomass-containing fly ash behaves qualitatively similar to coal fly ash with no biomass in terms of structural and performance properties when incorporated into concrete.

3.4 Ash deposition and boiler tube corrosion

Although the ash contents of both wood and straw materials are significantly lower than those of most power station coals, the ash chemistry and mineralogy are very different. In general terms, biomass ashes have relatively low ash fusion temperatures, with deformation temperatures commonly in the range of 750 to 1000°C, compared to values in excess of 1000°C for most coal ashes. Even at modest cofiring ratios, the co-firing of biomass materials can have a major impact on the ash fusion behavior. The rate and extent of coal ash slag formation on surfaces in the boiler furnace tends to increase, due principally to the decrease in the fusion temperatures of the mixed biomass-coal ashes, since fused or partially fused slag deposits tend to be more receptive to oncoming particles and grow more rapidly. The impact of co-firing on slag deposition depends largely on the chemistry and the fusion behavior of the coal ash and the co-firing ratio.

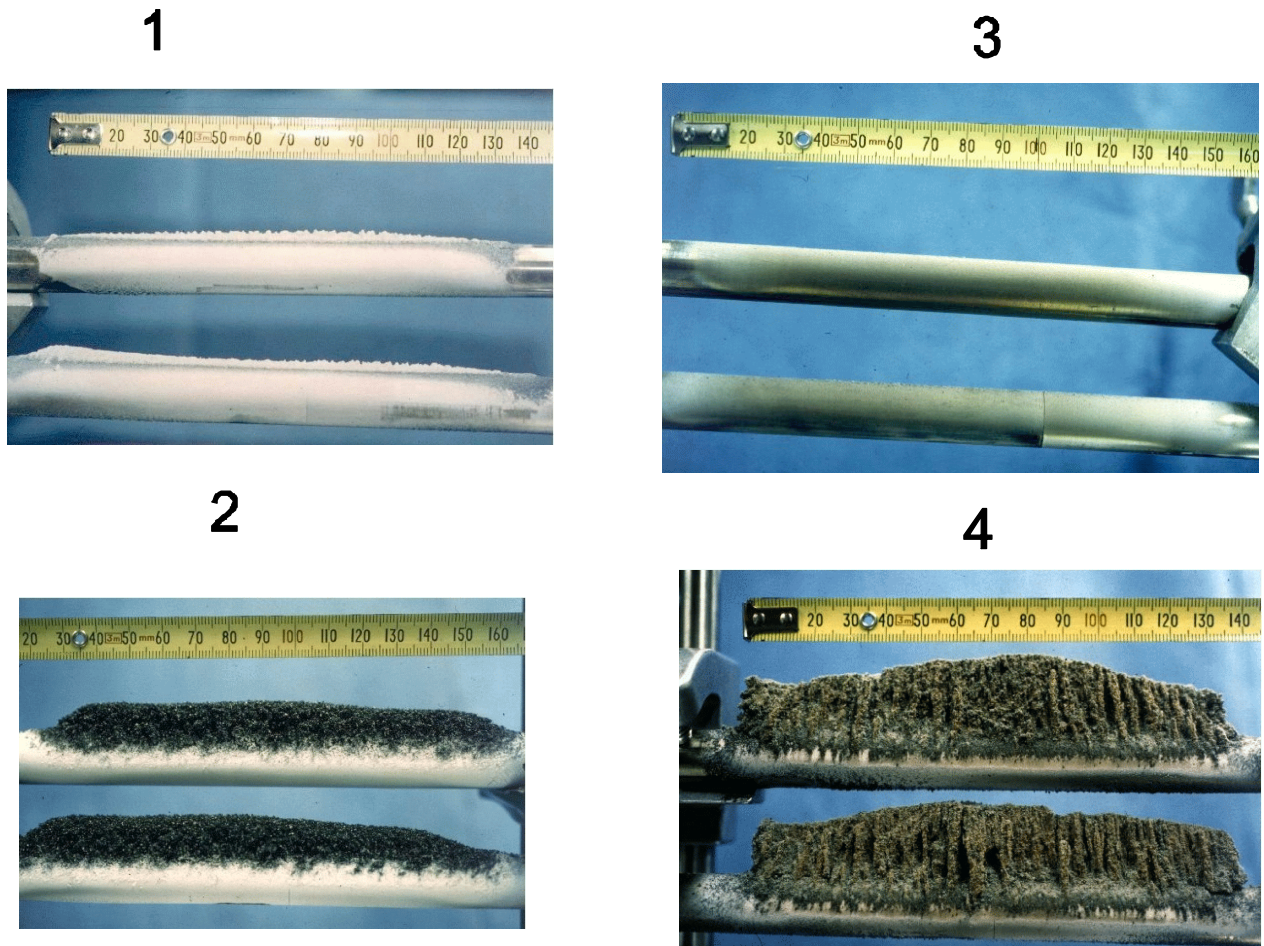


Figure 6 Ash deposition of different types of fuels under practical conditions. 1 is Red Oak Wood, 2 is Danish Wheat Straw, 3 is Pittsburgh No. 8 coal and 4 is a blend of 15% Imperial Straw and 85% Pittsburgh #8 Coal [v].

A simple index has been developed [vi], which can be used to assess the fouling propensity of a fuel or mixed fuel ash. The index is based on the mass in kg of alkali metal oxides ($K_2O + Na_2O$) introduced into the system per GJ heat input to the furnace. At index values above 0.17 kg per GJ, significant fouling of the boiler convective section is probable. At index values in excess of 0.34 kg per GJ, severe fouling is to be anticipated. Most biomass materials, and particularly those from fast-growing plants, will have index values in excess of 1 kg per GJ, whereas most coals have relatively low values, generally less than 0.1 kg per GJ.

Figure 7 and Figure 8 indicate previously reported results [vii,viii,ix] illustrating how sulfur from coal helps mitigate chlorine-based corrosion in boiler deposits from biomass. The principal result is that alkali chlorides that sometimes condense from chlorine-laden biomass fuel flue gases react with SO_2 , generated primarily from coal, to form alkali sulfates, which are significantly less corrosive.

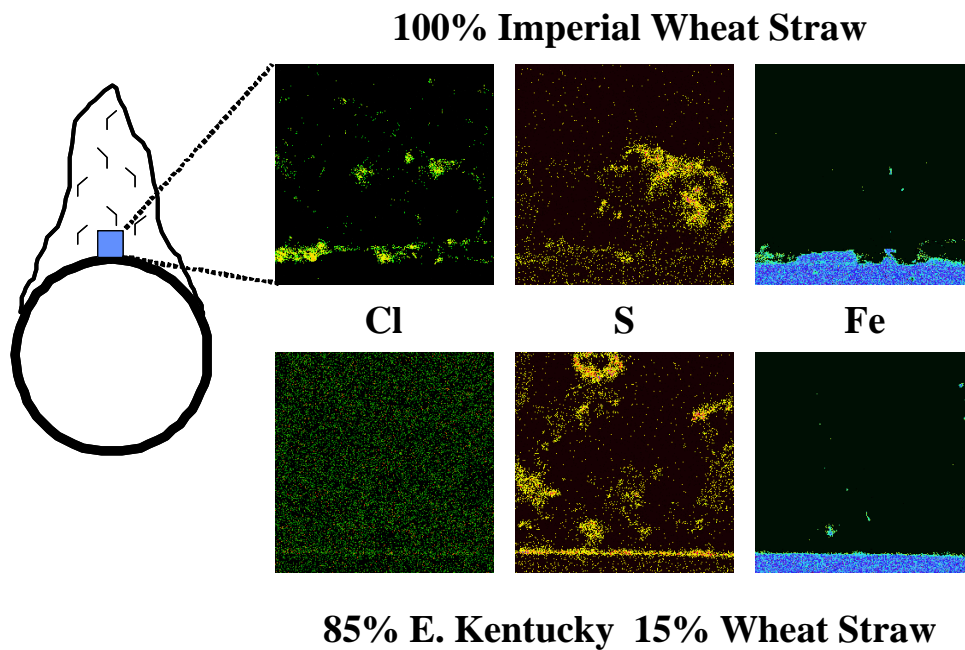


Figure 7 SEM images illustrating formation of chlorine layers on simulated boiler tubes and the effect of coal-derived sulfur during cofiring in eliminating the chlorine layers [vii, viii, ix].

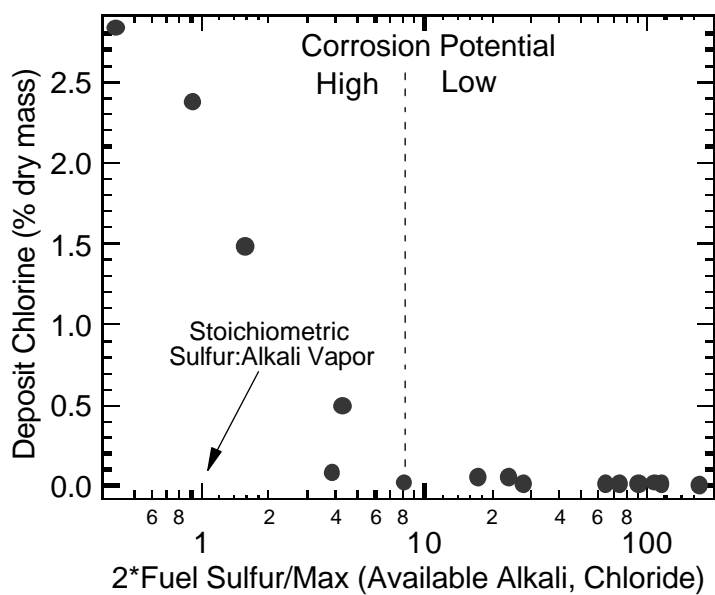


Figure 8 Results from systematic variation of fuel chlorine to sulfur ratios and the resulting chlorine content of deposits under standardized testing conditions [vii, viii, ix].

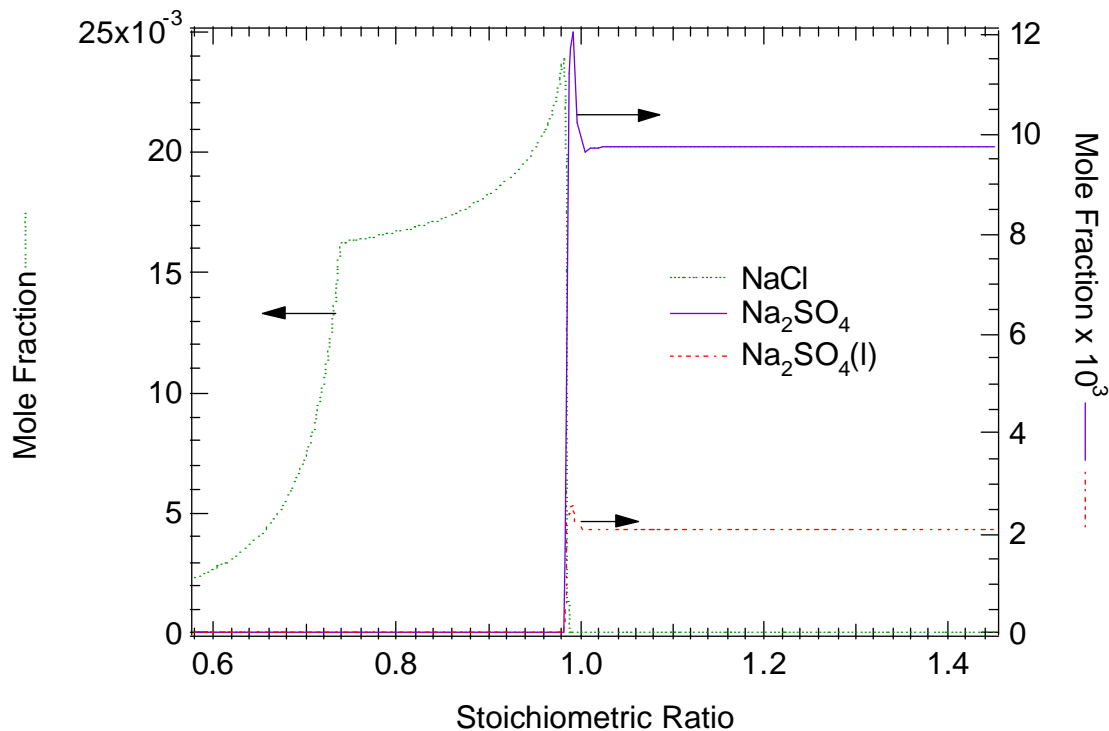


Figure 9 Illustration of predicted stoichiometric dependence of chlorine concentration in deposits.

Figure 9 illustrates theoretical (equilibrium) predictions that illustrate that this only occurs under oxidizing conditions. Under reducing conditions, chlorides, not sulfates, and the stable form of alkali species under typical boiler heat transfer conditions. Therefore, the ameliorating effects of coal-derived sulfur on corrosion during cofiring do not occur in regions of boilers where deposits are exposed to reducing conditions. Further experimental data indicates that even under oxidizing conditions, chlorine deposits may persist for many hours if deposit temperatures are very cool, reducing the kinetic rates of conversion to sulfates.

3.5 Fuel preparation, storage, delivery for adequate conversion

The preparation, storage, and handling properties of biomass impact are different from coal. Biomass has low bulk energy density, is generally moist and strongly hydrophilic, and is non-friable. Biomass heating values generally are slightly over half that of coal, particle densities are about half that of coal, and bulk densities are about one fifth that of coal. This results in an overall fuel density roughly one tenth that of coal. Consequently, cofiring biomass at a 10% heat input rate results in volumetric coal and biomass flow rates of comparable magnitudes. Consequently, biomass demands shipping, storage, and on-site fuel handling technologies disproportionately high compared to its heat contribution.

Biomass produces a non-friable, fibrous material during comminution. It is generally unfeasible (and unnecessary) to reduce biomass to the same size or shape as coal. In many demonstration plants, biomass firing occurs with particles that pass through a 1/4" (6.4 mm) mesh, which measurements indicate results in a size distribution dominantly less than about 3 mm. Depending on the type of biomass and preparation technique, average aspect ratios of these particles range from three to seven, with many particles commonly having much higher aspect ratios. Such particles have very low packing densities and create challenges when pneumatically or otherwise transporting biomass fuels.

When biomass is milled together with coal, biomass particles tend to leave the mill as relatively large and non-spherical particles, which poses challenges for fuel conversion efficiency. Coal particles of

such size would not nearly burnout in a coal boiler, but there are compensating properties of biomass. Biomass yields a much higher fraction of its mass through devolatilization than does coal. Typically biomass of the size and under the heating rates typical of pc-cofiring yields 90-95% of its dry, inorganic-free mass during devolatilization, compared with 55-60% for most coals. Devolatilization occurs rapidly and is temperature driven, therefore most biomass fuels will yield at least this fraction of mass so long as they are entrained in the flue gases. Biomass particles too large or dense to be entrained sometimes enter the bottom ash stream with little or no conversion beyond drying. However, these are generally the exception for well-tuned fuel preparation systems. Secondly, the low particle densities help biomass particles oxidize at rates much higher than coal. However, excessive moisture or excessive size particles still may pose fuel conversion problems for biomass cofiring despite these mitigating effects.



Figure 10 Wood chips are metered directly on a coal conveyor before the mills at Wallerawang Power Station, Australia (Courtesy of Delta Electricity, Australia).

3.6 Formation of Striated Flows

Many boilers do not mix flue gases effectively in furnace sections, resulting in gas compositions near the boiler exit that reflect burner-to-burner variations in stoichiometry and other properties. The impact of such behavior during cofiring can be an issue if one is hoping, for example, that sulfur from coal will mix with biomass-derived flue gases to ameliorate corrosion. Biomass is commonly injected in only a few burners. If the gases do not mix thoroughly, many regions of the boiler will be exposed to much higher biomass cofiring percentages than suggested by the overall average.

Advanced computational fluid mechanics models illustrate the impact of striations on ash deposition. Figure 11 illustrates the deposition patterns predicted on superheater tubes under conditions where such striations exist. As illustrated, there are large local variations in the rate of deposit accumulation. These arise from lack of complete mixing and striation in gas composition, gas temperature, gas

velocity, particle loading, and other similar properties (not illustrated). Such results are highly system dependent but are believed to be a common feature of biomass-coal combustion as well as both dedicated coal and dedicated biomass combustors.

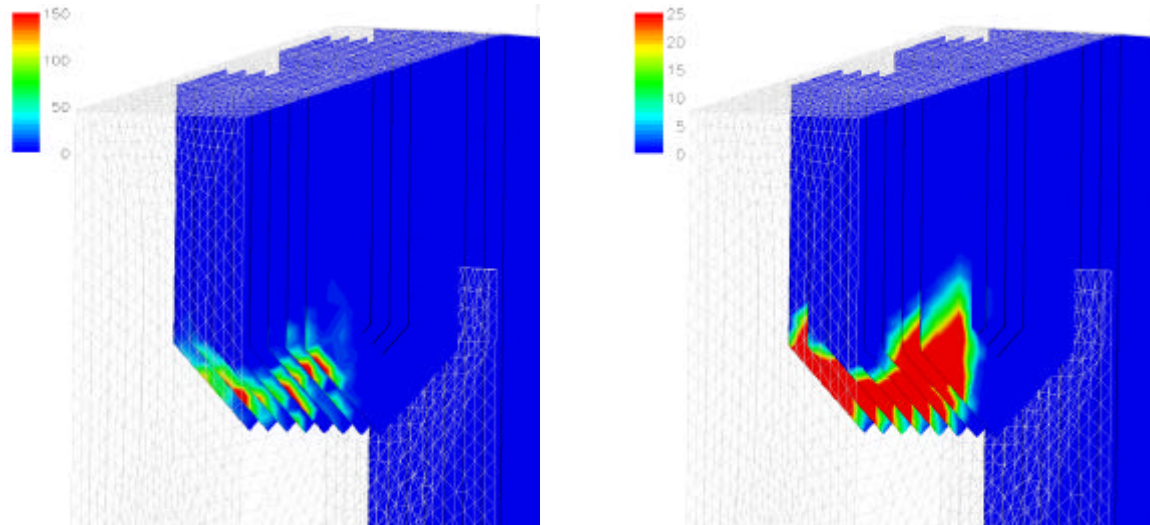


Figure 11 Impacted of temperature, velocity, and gas composition striations on two major classes of deposit formation mechanisms: impaction mechanisms (left) and boundary-layer mechanisms (right).

3.7 Public awareness/image issues

It is easy for many people to misunderstand the above mentioned benefits of biomass cofiring with coal, because it is associated with coal which often carries a negative connotation. Public support for cofiring however remains crucial for further development of the biomass to energy capacity. Several experiences exist where a negative public perception has threatened the financial feasibility of biomass cofiring (e.g. through lower prices of renewable energy certificates originating from the renewable energy component generated from the power plant), or even led to cancellation of a permit that was already issued.

Participations from NGO's and utilities in a workshop recently organized by IEA Bioenergy Task 32[x] on biomass cofiring with coal agreed on the following position

- Cofiring should preferably be done in existing coal power plants. New coal plants should never be justified solely on the basis that they can co-fire biomass, however other arguments may justify the construction of new coal fired power plants (such as a mismatch between demand for energy and availability of renewable energy including biomass, reliability of the electricity grid, cost of energy supply, dependency on import of fuels, etc.). In cases where it is decided that a new coal power plant is going to be constructed anyway because of such reasons, then it makes sense to seriously consider co-firing biomass right from the start as an environmental benefit.
- A number of environmental impact assessments (EIA's) have illustrated the negative environmental impacts associated with the growing phase of many annual energy crops that are grown in traditional agricultural systems, e.g. switchgrass. An important cause is related to the use of nutrients and surface water pollution, see for example Figure 12. For this reason, biomass residues that are already available are preferred over annual energy crops. It needs to be mentioned specifically that this observation does not include that perennial energy crops grown using extensive agricultural systems (such as willow), as this is associated with much less negative environmental impacts than annual energy crops.

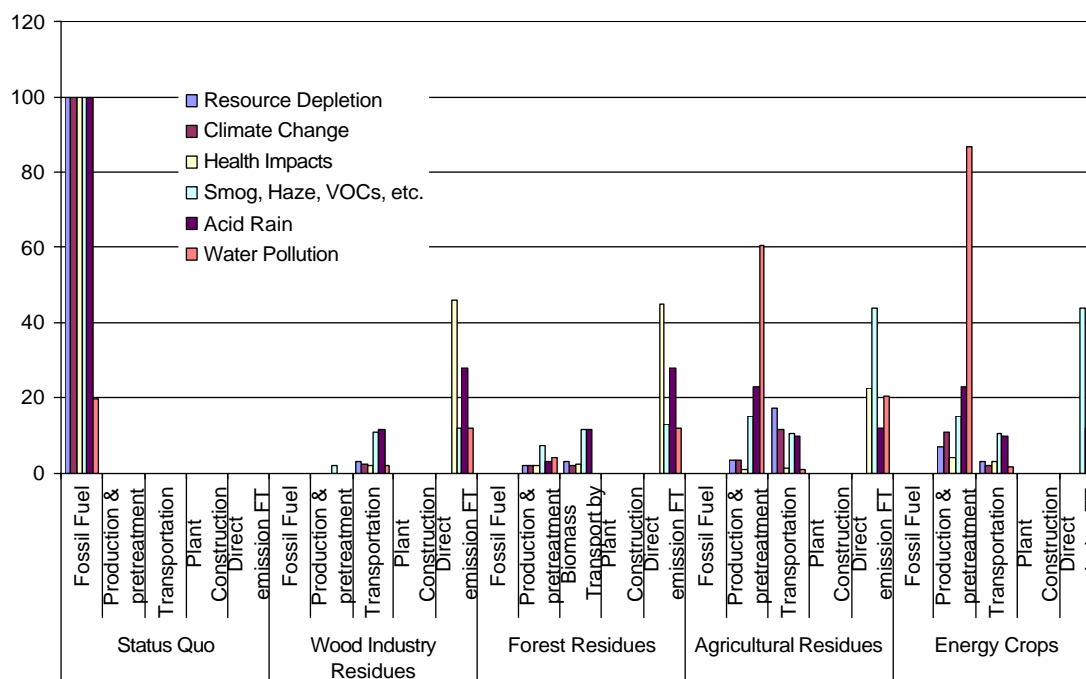


Figure 12 Result of an LCA on utilization of different fuels for biomass cofiring in USA. The graph includes switchgrass, an annual energy crop grown in a relatively intensive agricultural system. [xi].

IEA Bioenergy Task 32 is willing to cooperate with environmental NGO's and other organisations to provide objective and unbiased information about several aspects of biomass cofiring.

4. References

- i BAXTER, L. L., M. RUMMINGER, T. LIND, D. TILLMAN AND E. HUGHES (2000). Cofiring Biomass in Coal Boilers: Pilot- and Utility-scale Experiences. Biomass for Energy and Industry: 1st World Conference and Technology Exhibition, Seville, Spain
- ii TILLMAN, D. A., E. HUGHES AND B. A. GOLD (1994), Cofiring of biofuels in coal fired boilers: Results of case study analysis., 1st Biomass Conference of the Americas, Burlington, VT
- iii KOPPEJAN, J., 2004: Overview of experiences with cofiring biomass in coal power plants, IEA Bioenergy Task 32: Biomass Combustion and Cofiring, (2005)
- iv KOPPEJAN. J. , VAN LOO, S et al (2002) Handbook of Biomass Combustion and Cofiring, IEA Bioenergy Task 32: Biomass Combustion and Cofiring, Twente University Press, 2002
- v BAXTER, L.,2004, Biomass Cofiring Overview, presented at Second World Conference on Biomass for Energy, Industry, and World Climate Protection, May 10-14, Rome, Italy, 2004
- vi MILES, T.R., MILES, T.R. Jr., BAXTER, L.L., BRYERS, R.W., JENKINS, B.M. & ODEN, L.L.: Alkali deposits found in biomass power plant: a preliminary study of their extent and nature. National Renewable Energy Laboratory, Golden, CO, USA, 1995
- vii JUNKER, H., F. FOGH, L. BAXTER AND A. ROBINSON (1998). Co-firing Biomass and Coal: Experimental Investigations of Deposit Formation. 10th European Conference and Technology Exhibition, Würzburg, Germany.8-11 June 1998

-
- viii ROBINSON, A. L., H. JUNKER, S. G. BUCKLEY, G. SCLIPPA AND L. L. BAXTER (1998). Interactions between Coal and Biomass when Cofiring. Twenty-Seventh Symposium (International) on Combustion, Boulder, CO, Combustion Institute
- ix ROBINSON, A. L., H. JUNKER AND L. L. BAXTER (2002). "Pilot-scale investigation of the influence of coal-biomass cofiring on ash deposition." Energy & Fuels.
- x KOPPEJAN. J., VAN LOO, S. (2004) Workshop on Public Perception of Biomass Cofiring, Minutes of the meeting, IEA Bioenergy Agreement, Task 32, available on www.ieabcc.nl
- xi BAXTER, L. (2004) Cofiring biomass with Coal, presented at Workshop on Public Perception of Biomass Cofiring, IEA Bioenergy Agreement, Task 32.