Co-firing of coal & biomass waste in a conventional PF fired power station-issues & challenges

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ABSTRACT

Co-firing is defined as supplementing a primary fuel with a secondary fuel. Biomass can serve as a supplement for coal combustion and has been successfully employed by various electric utility companies.

There has been considerable interest in co-firing both biomass and waste fuels in coal-fired power plants in recent years. This is principally due to concerns regarding the emissions of greenhouse gases from these plants. Biomass and some waste fuels can be considered to be renewable and not to produce net CO2 emissions when combusted hence co-firing in a coal fired plant reduces overall greenhouse gas emissions.

Currently the most popular option for co-firing applications is direct co-firing, where biomass and coal are utilized together in the same boiler. This is mainly due to relatively low investment cost of turning an existing coal power plant into a co-firing plant. There are many successful co-firing systems, however there are various constraints that may be encountered. Most of them originate from fuel properties**.**

In the 1990s, many power plants demonstrated this option in Europe, Japan and United States, and then proceeded to use it commercially. In recent years with the need to reduce greenhouse gas emissions and meet Kyoto requirements in some countries, there is renewed interest in biomass cofiring on the basis that biomass is “CO2-neutral”.

Biomass may include switchgrass, sawdust, wood wastes, municipal solid wastes and other waste fuels. In most cases, biomass is limited to a maximum of 15 percent of the total plant input. The boilers could be designed specifically to accommodate biomass combustion or existing boilers could be modified; the industry has experience with both.

The aim of this paper is to give an overview of the process & constraints associated with co-firing systems.

1. INTRODUCTION

Energy production in coal-fired power plants by partial substitution of coal, as the main fuel, with biomass feedstock is called co-firing. This paper is devoted to biomass co-combustion, which is an accepted and viable use of biomass that can applied in existing power station infrastructure where one combusts a fraction (3 to 20% of total fuel weight or energy) of biomass in a coal or gas fired power station. Biomass co-firing offers renewable energy generation with the smallest capital cost, taking advantage of the high electrical efficiencies of today’s coal or gas power stations. In today’s political climate, fears over carbon emissions (among others) have raised people's attention to the opportunity to replace up to 20% of the coal fuel with biomass. This represents a substantial volume of avoided CO2 emissions. In addition biomass contains fewer traces of sulphur or metal compounds than coal and due to special interactions between biomass and coal during combustion SO2 emissions are further avoided, further legitimizing its use for co-firing.

There have been around 100 co-firing units in Europe. The graph below gives an impression of the extent of co-firing plants in Europe. Many of the plants are in trials or demonstrations, for example in the UK and USA. On the other hand, the co-firing plants in the Netherlands, Denmark, Finland and Sweden are mostly operating on a commercial basis.

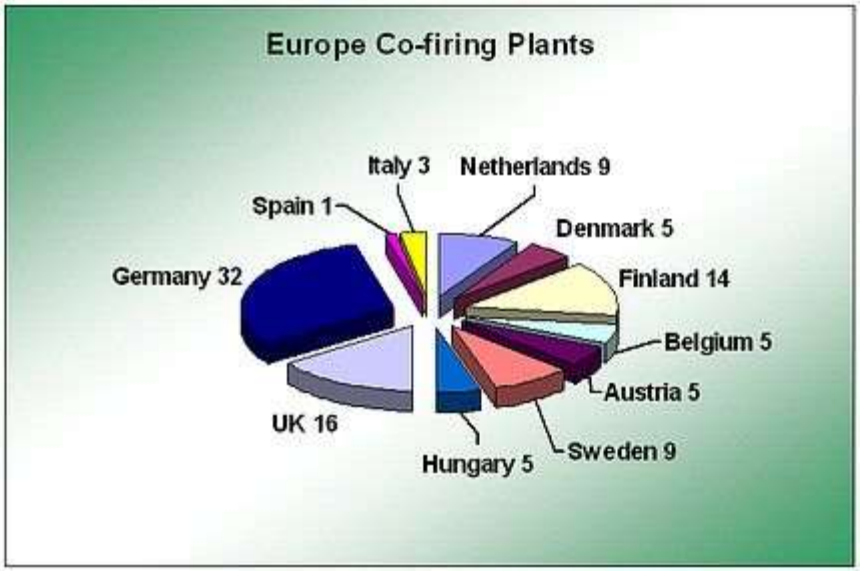

Fig. 1. Co-firing plants in Europe.

At the present time, experience is being generated with various options for co-firing. Three basic types of technological configurations for biomass co-firing in power plants can be identified: direct co-firing, parallel co-firing, and indirect co-firing.

Direct co-firing is the cheapest option, most straightforward and commonly applied approach. The biomass is directly fed to the boiler furnace after being passed through the same mills - crushers, bunkers and pulverisers - as the coal. The biomass can be mixed with the coal in the fuel yard or can be fed to the combustion chamber separately. Multi-fuel fluidised bed boilers achieve efficiencies over 90% while flue gas emissions are lower than for conventional grate combustion due to lower combustion temperatures.
In ***parallel co-firing*** the biomass is burnt in a separate boiler for steam generation. The steam is used in a power plant together with the main fuel. Parallel co-firing is most popular with the pulp and paper industries as dedicated biomass boilers are used for the utilisation of bark and waste wood. These industries economize and increase their energy efficiency by using the bio-residues and by-products from their main focus, the production of paper.
In ***indirect co-firing*** biomass is first gasified and the fuel gas is then co-fired in the main boiler. Sometimes the gas has to be cooled and cleaned, which is more challenging and implies higher operation costs. However, this approach offers a high degree of fuel flexibility. This system has been applied in a few stations, for example, Zeltweg plant in Austria, the Lahti plant in Finland and the AMER-8 plant in the Netherlands. Since the gasification takes place separately the ashes from the coal and biomass are kept apart. A wider variety of biomass fuels can be used as the potential problems from different biomass such as differing chemical composition and physical properties are dealt with before the fuel gas enters the main combustion chamber thus boiler efficiency in maintained.

The aim of this paper is to give an overview of the process & constraints associated with co-firing systems. The quantitative data on the problems encountered in co-firing systems is either not available or very general and limited.
The analysis is based exclusively on data and information sources publicly accessible or available through paid subscription, and has mainly qualitative character.

2. REVIEW OF RESEARCH PAPERS ON CO-FIRING OF COAL WITH BIOMASS

Van den Broek *et al.* [1] presented overview of the biomass combustion in boiler technologies and quoted the efficiency of 37% for a 4.5% biomass co-fired pulverised coal boiler.

Pedersen *et al*. [2] carried out full-scale measurements on a 250 MW, pulverized coal fired unit using l0-20% straw (thermal basis). With an increased fraction of straw in the fuel, a net decrease in NO, and SO2 emissions were measured. The SO2 emission decreased partly due to the lower sulfur content of the fuel per MJ, but also due to higher sulfur retention in the ash. The NO emission decreased solely due to lower conversion of fuel-N. An increased fraction of straw in the fuel blend resulted in a higher potassium content, but no significant increase in slagging or fouling was observed. Only small amounts of deposit at the lower part of the radiant super heater and little slagging at the furnace walls were observed as a result of co-firing straw and coal.

Boylan [3] reported the tests conducted in June 1992 at Georgia Power Company's plant Hammond Unit I to evaluate the impact of co-firing wood waste with pulverized coal on plant performance. Hammond 1 is a 100 MW Babcock and Wilcox (B & W) unit fuelled by pulverized coal. Over a three day period, 11 full load performance tests were conducted, five with coal and six with wood/coal mixture. A total of 125 tonnes (as received, 19% moisture) was burned, the wood waste a mixture of sawdust and ground tree trimming waste. Wood percentage in the fuel ranged between 9.7 and 13.5%, with an average for the co-fire tests of 11.5% (all percentages by weight). At medium and high O2 levels, boiler efficiency with wood co-firing was within 0.2-0.4% of boiler efficiency with coal alone.

Hunt *et al*. [4] presented the results for Unit 2 and Unit 3. Unit 2 is a 138 MWe (gross) wall-fired pulverized coal boiler equipped with ball and race mills, table feeders, and low-NOx burners. Unit 3 is a 190 MWe (gross) tangentially fired pulverized coal boiler equipped with bowl mills, paddle feeders, and low-NOx burners. Firstly, the project tested the use of blended bio fuels in boilers equipped with low NOx burners. Additionally, three types of bio fuels were tested: (1) mill waste sawdust, (2) utility right of- way trimmings, and (3) harvested hybrid poplar. For both units, the 3 weight percent bio fuel blends behaved like wet coal. Three percent wood co-firing produced significant negative impacts in the pulverizing systems, leading to significant boiler capacity reductions in both a wall-fired PC boiler and a tangentially fired PC boiler. They recommended separate injection of wood to avoid the negative impacts experienced during the testing.

Ekmann *et al.* [5] discussed the status of co-firing coal with biomass and other wastes in the light of International Survey of co-firing coal with biomass. They reported co-firing of waste tyres, municipal solid waste, and wood waste up to 10% in units designed for pulverised coal.

In year 2000, Tillman [6] wrote an editorial in a journal titled “Biomass and Bio energy” in which he stated “Every tonne of biomass co-fired directly reduces fossil CO2 emissions by over 1 tonne. Co-firing is in its infancy today. If we can not make co-firing work as commercial technology for electricity generations, it is doubtful that we can make the more far-reaching technologies a commercial reality”. He strongly advocated co-firing as low cost, low risk, renewable strategy.

Tillman [7] reviewed the co-firing experience of various organisations in USA like Electric Power Research Institute (EPRI), TVA,GPU Genco, Northern Indiana Public Service Company

(NIPSCO), Central and South West Utilities (C&SW), Southern Company, Madison Gas & Electric (MG&E), New York State Electric and Gas (NYSEG). These companies blended 5-20% of the wood waste with coal. He advocated for co-firing due to environmental benefits of reduced NOx, SO2, and CO2 for electricity generation despite the reduction in boiler efficiency reported at various stations.

Sami et al. [8] reviewed the state of knowledge on burning of pulverised coal and biomass. In their review, they anticipated that blending biomass with higher quality coal would reduce flame stability problems as well as corrosion effects. They suggested that synergetic effects of blending coal and biomass may also lead to reduction in other emissions like NOx, SOx and CO2. Authors quoted name of the 32 full scale utility boilers where co-firing tests performed using waste wood, sander dust, saw dust, plastic waste, willow, grass crop and forest debris as biomasses Most of the utilities used wood. They concluded that fundamental combustion studies must be performed, particularly for pre-mixed coal and biomass fuel blends, in order to determine combustion behaviour characteristics in controlled laboratory settings. They described coal biomass combustion a promising technology for electric utility despite of all the issues and concerns.

Savolainen [9] reported the results of co-firing tests with sawdust and coal that were carried out at FORTUM's Naantali-3 CHP power plant (315 MW fuel). The Naantali-3 plant is a tangentially-fired pulverised-coal unit with a Sulzer once-through boiler that produces 79 MW electricity, 124 MW district heat and 70 MW steam. Naantali-3 is equipped with roller coal mills (Loesche), modern low-NOx burners (IVO RI-JET), over-fire air (OFA), electrostatic precipitator (ESP) and flue-gas desulphurization plant (FGD). Coal and sawdust were blended in the coal yard, and the mixture fed into the boiler through coal mills. Tests were carried out for three months during the April 1999 to April 2000 period with pine sawdust (50-65% moisture, as received). During the tests, sawdust proportions of 2.5–8% (from the fuel input) were examined. The co-firing tests were successful in many ways, but the behaviour of the coal mills caused some problems, and therefore the simultaneous feed will not be the solution in a long-term use. A separate bio fuel grinding system and bio- or bio-coal-burner were developed. By using this system, it is possible to utilize many kinds of bio fuels in PC-boilers as well as increase the share of bio fuels, compared to the simultaneous feed of bio fuel and coal.

Baxter [10] highlighted the benefits of biomass and coal co-combustion as low risk, low cost, sustainable, renewable energy option that promises reduction in net CO2, SOx and NOx emissions along with several societal benefits. He also mentioned challenges associated like supply, handling, storage, potential increase in corrosion, fly ash utilisation etc. He concluded that issues associated biomass combustion are manageable but require careful consideration of fuels, boiler operating conditions and boiler design.

Demirbas [11] while describing biomass coal co-firing in boilers revealed that biomass like spruce wood, beech wood, hazelnut shell, wheat straw and tea waste have higher volatile matter yield than coals: the biomass fuels have VM/FC ratio typically>4:1 as compared to VM/FC of coal of virtually always<1:0. He found that greater is the VM/FC ratio greater is the reduction in NOx. A laboratory scale bubbling fluidised bed combustor was used for experiments. He endorsed the co-combustionof biomass with coal as an effective method to reduce NOx, SO2 and ash volume for coal fired power plants.

Lu *et al*. [12] reported little effect of the amount of biomass addition on flame stability provided that the addition is less than 20%.

Zhang *et al*. [13] presented an overview of recent advances in thermo-chemical conversion of biomass. They dicussed the principles, reactions, and applications of four fundamental thermo-chemical processes (combustion, pyrolysis, gasification and liquefaction) for bioenergy production, as well as recent developments in these technologies. They have also discussed advanced thermo-chemical processes, including co-firing/co-combustion of biomass with coal or natural gas, fast pyrolysis, plasma gasification and supercritical water gasification. While discussing advantages and disadvantages, potential for future applications and challenges of these processes, ***they concluded that the co-firing of biomass and coal is the easiest and most economical approach for the generation of bio-energy on a large-sale because of the few modifications that are required to upgrade the original coal based power plants.***

3. CONSTRAINTS RELATED TO CO-FIRING OF COAL WITH BIOMASS

Co-combustion of biomass and coal may face many challenges, which, among others, include fuel preparation, handling, storage issues, milling, feeding, different combustion behavior, possible changes in overall efficiency, deposit formation (slagging and fouling), agglomeration and sintering, corrosion and/or erosion and consequently changes in life-time of equipment, ash utilization issues and overall economics The above listed problems need not to be encountered in every system. In systems with proper combination of technology, biomass, and coal they are likely not to be an issue, as is usually the case in systems co-firing clean biomass at low ratios. However the importance of these challenges increases with trends to raise the biomass/coal ratio, and utilize low quality biomass, especially in direct co--firing systems.

Different types of difficulties (challenges) can be faced depending on:
- Co-firing configuration - e.g. in direct co-firing systems, the milling of biomass can become a problematic issue, for a number of reasons. Existing coal mills have certain capacity while the calorific values of biomass are on average half of that of coal. This can create the limitation to the amount of biomass that can be co-milled with coal in existing mills, and consequently co-fired. Moreover, coal mills or pulverizers cannot process certain types of biomass, due to its fibrous nature. These problems are not likely to be often faced in indirect or parallel co-firing configurations, as the biomass is milled and delivered to the boiler by an independent line (such dedicated line could also be introduced to direct co-firing system), however other issues are challenging there.

Grindability and co-milling – In general, coal mills break up coal by a brittle fracture mechanism, and most biomass materials have poor grinding properties and therefore, some larger biomass particles tend to be retained within the mill, and this can act to limit the co-firing ratio that is achievable in this way . In vertical spindle coal mills, the power consumption might increase with increasing biomass co-firing ratio (the power required to size biomass is higher than for coal due to non-friable character of biomass) and this may represent a limiting factor as well. In most conventional coal mills, where hot air is applied to dry the coal in the mill, safety might be an issue, as biomass materials tend to release combustible volatile matter into the mill body at temperatures significantly lower than those that apply when milling bituminous coals. As a consequence, it may be necessary to modify the mill operating procedures to minimize the risks of overheating the coal-wood mixture.
Despite these potential difficulties and limitations, co-milling of a number of chipped, granular and pelletized biomass materials through most of common designs of conventional coal mills has been carried out successfully on a fully commercial basis in a number of power plants in Europe.
The milling of wood pellets in coal mills, and the firing of the mill product through the existing pipework and burners, is done at a small number of power stations in Europe, including Hasselby in Sweden. The coal mills are very robust, and have high availability/low maintenance requirements. At best, the coal mill breaks the pellets back to the original dust size distribution. The mill has to be modified to operate with cold primary air. There are generally no requirements for modifications to the grinding elements. The maximum heat input from the mill group is significantly derated, commonly to around 50-70% of that with coal.
The more popular option, involves **the pneumatic injection of the pre-milled biomass into the pulverised coal firing system downstream of the coal mills**, i.e. into the pulverised coal pipework or directly into the burners. In both cases, additional air and fuel are introduced to the mill group of burners, and the mill primary air and coal flow rates have to be reduced accordingly, to maintain both the coal mills and burners within their normal operating envelopes. This option has proved to be relatively inexpensive and simple to implement, however there are significant

interfaces with the mill and combustion control system, which have to be carefully managed. The options for the location of the biomass injection point are:

· Directly into the burner.

· Into the pulverised coal pipework, just upstream of the burner, and

· Into the mill outlet pipework local to the mill outlet,

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

4. TECHNICAL ISSUES RELATED TO CO-FIRING OF COAL WITH BIOMASS

Boiler capacity and performance - Biomass may contain around 70% of volatiles, while coal is almost pure carbon. The amount of flue gases per unit of energy resulting from biomass is much larger than that of coal, which implies that flow patterns of combustion gases through the boiler can be changed and limit the percentage of biomass that can be co-fired in existing installations.

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

In general, if there are no large biomass particles, (> 2-5 mm), passing to the burners, the combustion behaviour of the blended fuel is acceptable. Biomass materials are more reactive in combustion systems than most coals and in general the unburned carbon levels in bottom and fly ashes are similar, or less than when firing coal alone.

Addition of biomass to a coal-fired boiler does not significantly impact, or at worst slightly decreases the overall boiler efficiency of coal-fired power plant.

Ash deposition in the near-burner zone can negatively impact the co-firing efficiency or combustion conditions, eventually leading to unburned carbon levels in the ash.

Co-combustion of biomass and coal may face various challenges, which include fuel preparation, handling, storage issues, milling, feeding, different combustion behavior, possible changes in overall efficiency, deposit formation (slagging and fouling), agglomeration and sintering, corrosion and/or erosion, ash utilization issues and overall economics.

The degree of the difficulties associated with co-firing systems depends on the quality and percentage of biomass in the fuel blend, type of combustion and/or gasification used the co-firing configuration of the system, properties of coal and others. In low co-firing ratios, those issues might be of low significance, due to high buffering capacity of coal in the system. In general the operating and maintenance costs of co-firing systems (vs. coal based systems) increase with higher biomass/coal ratio, and lower quality of biomass used.

Most of the problems encountered in co-firing systems originate from biomass properties. Certain problems could be reduced or even avoided with appropriate fuel blend control. Other way of dealing with these are the downstream solutions (change of corroded equipment, cleaning of deposits, addition of chemicals to the process etc.) as well as the upstream solutions (tailoring biomass properties by pre-treatment, installation of separate equipment dedicated to biomass, investing in more advanced configuration of co-firing system). Biomass pre-treatment is an interesting option, because by modifying biomass properties, it addresses the source of problems, rather than their consequences

5. ECONOMICS OF BIOMASS CO-FIRING SYSTEM

In general, the energy systems which co-fire biomass with coal are more expensive than dedicated coal systems. ***Therefore, reasons for co-firing are primarily connected with environmental benefits rather than cost-savings.*** Thus a more appropriate approach is a comparison of the costs of co-firing systems with other renewable energy options, among which co-firing is usually the cheapest, in most situations where biomass resources and coal-based power plant are available in the same region .

Costs related to co-firing (adapting coal-based power plant to co-firing) can be divided into few groups:

1. **Capital costs** (capital, depreciation, interest costs) - Co-firing installations costs range from $50-$300/kW of biomass capacity and are so low, because they mostly make use of existing infrastructure of a power plant. These costs are usually lower than for any other renewable energy option, except for hydropower.
2. **Fuel costs** (fuel procurement, pre-treatment costs and the electricity demand for it) - One of the most sensitive factors in economics of co-firing is the cost of biomass fuel. Even in the case of residues, where the fuel is usually nominally free at the point of its generation, the costs of transportation, pre-treatment and handling increase its effective costs per unit of energy to the extent, that it sometimes exceeds that of coal. That is why the supply chain of biomass fuels deserves to be given attention, as by its optimization, the costs could be reduced.
3**. Operation-based costs (O&M)** (personnel costs, maintenance) - Operating costs are typically higher for biomass than for coal. This is mainly due to different biomass properties in comparison with coal, such as lower energy density, resulting in high volumes to be handled etc. The O&M costs usually remain constant irrespective of the actual amount of electricity generated, but some are dependent on it e.g. lubricants and chemicals used in the generation process.

In general, costs of biomass as a fuel for energy consist of two main parts: the purchase price and the costs of logistics (transport, storage, handling and pre-treatment). In general, the operation costs of biomass are higher compared to the fossil fuels due to a number of reasons e.g. lower energy density of biomass in comparison with fossil fuels, translating into higher transportation and storage costs per energy unit.
An issue, which could influence the economy of the plant, is related to challenges associated to co-firing of biomass with coal. It is not necessarily economical to use the cheapest fuel available, if the negative effects on the boiler operation or fuel operability are significant.

6. RELEVANCE OF BIOMASS CO-FIRING SYSTEM FOR INDIA

India is an energy deficient country. The per capita electricity consumption was 779 kWh in 2009–10 (as per CEA report). Over the same period, the world average per capita electricity consumption was about 2659 kWh, almost four times larger than that of India. Over one third of India's rural population lacked electricity, as did 6% of the urban population. Of those who did have access to electricity in India, the supply was intermittent and unreliable. India faces a power deficit of 10.3%.
At present, people are facing severe load shedding/blackout problems due to shortage of about 2 GW power supply. India relies on coal for two-thirds of its power generation, and will need even more for the additional capacity planned to tackle the power deficit. Indigenous reserves of oil and gas are limited and the country heavily depends on imported oil. The oil import bill is a serious strain on the country's economy.
India must develop indigenous environment friendly energy resources to meet its future electricity needs. India can overcome this energy crisis by co-utilizing its un-used agricultural residues and coal reserves. This strategy can solve the energy crises while producing clean energy, deposing off waste and increasing income of the rural population.
Co-combustion of agricultural residues in energy recovery schemes could significantly increase the income of the rural people in our country. Agricultural residues are a form of biomass that is renewable but largely not utilised in the energy recovery schemes.
Agricultural residues are non-edible plant parts that are left in the field after harvest. Co-firing of these abundantly available agricultural residues with coal can convert a negative value biomass in to a positive fuel along with environmental relief. If only 5% of coal energy could be replaced by biomass in all coal-fired power plants, this would result in an emission reduction of around 300 Mton CO_2/year [14].

Both issues of agricultural waste management and pollutant emissions from existing coal power plants can be resolved simultaneously by utilising co-firing potential of agricultural waste. Biomass as a fuel class is very much different from coals. They have high volatile matter, higher hydrogen content, generally low nitrogen content and little or zero sulphur.

7. INSTANCES OF CO-FIRING STUDIES/TRIALS IN INDIA

Co-firing is currently practiced in many countries around the world. A database [15] of power plants that use one of the co-firing technologies includes 243 units around the world. The database shows that co-firing is mainly practiced in Europe and North America. Hence, there is enough operational experience worldwide.
However, no record of any major power plant utilizing co-firing in India has been found. Following are some references available on co-firing studies/trials in India

1) Laboratory scale studies on combustion of Indian coal and biomass blends have been reported [16]
2) Co-firing trials [17] have also been performed previously in an industrial scale cogeneration unit in India with an aim to optimize the biomass/coal blending ratio from an emissions point of view
3) Thermax biomass boilers have been used to fire both biomass (mainly bagasse) and coal mainly in cogeneration plants located in sugar mills [18]

8. CHALLENGES IN IMPLEMENTATION OF CO-FIRING IN INDIA & WAY FORWARD

India has an ideal situation where co-firing of coal and biomass should be in optimal use. However, it has not been the case. The big question that immediately arises is why this technology has been overlooked?
Has it been tried and tested enough to be ignored? A preliminary analysis on this issue points to the following factors:
1) Technical problems arising from the combustion of biomass (even if minor) in furnaces designed for coal combustion.
2) Further capital investment in the power plant to accommodate biomass storage, processing, and feeding.
3) Fluctuating availability of biomass and unpredictable prices.
4) Utilities' concern about issues arising from the use of biomass and their effect on the plant availability and power production.
5) Utilities' mindset to only adopt conventional pulverised coal technology that has proven to be successful over the years with indigenous coal and now with imported coal as well.
6) Lack of government and industry initiatives to study and test coal/biomass co-firing in Indian power plants.

As discussed earlier, co-firing of coal and various kinds of biomasses is now a mature technology and is currently being practiced all over the world successfully. The technology has advanced and many limitations associated with it have been mitigated. If a proper system is established, co-firing could be successfully implemented in Indian coal-based power plants. A few recommendations in this regard are as follows:

1) The government should present subsidies or tax reductions and take initiatives to study the coal/biomass co-firing technology options in detail. Pilot co-firing projects need to be funded by the government / banks / collaborative projects to gauge the techno-economic feasibility.
2) A process similar to the allocation of coal resources should be followed to allocate biomass resources to the power plants. A minimum of 5-10% of coal should be replaced by biomass during co-firing.
3) Biomass sector should be organised better to ensure constant supply of biomass to the power plants. The production of energy crops should be encouraged to aid in the regular supply of biomass to power plants

9. CONCLUSIONS

The aim of this work was to provide an overview of possible constraints that can be encountered in systems co-firing coal with biomass.
The main conclusions from the literature review performed in this report can be listed as follows:
1. There are many successful commercial co-firing installations, however various constraints can be encountered, especially in the direct co-firing mode (which is the most common among co-firing systems), and with tendency to increase biomass/coal ratio, and use low quality biomass. These constraints include handling, storage, milling and feeding problems, deposit formation (slagging and fouling), agglomeration, corrosion and/or erosion, and ash utilization issues.

2. The problems associated with co-firing systems can be addressed by various measures.
Application of downstream measures (e.g. cleaning of deposits by soot blowing or exchange of agglomerated bed material) is one possibility. Another option is addition of chemicals reducing corrosion and increasing the ash melting point in order to avoid agglomeration and deposit formation.
A commonly applied option is an introduction of dedicated biomass infrastructure (e.g. for feeding, milling, storage, conveying) to the existing coal system. A more expensive alternative (in terms of investment costs) is an introduction of more advanced co-firing mode such as parallel co-firing or indirect co-firing, where not only fuel preparation and feeding lines, but also conversion units for biomass and coal are independent.
3. Most of the co-firing challenges originate from biomass properties and could be reduced (as one of the possible options) by upstream measures such as biomass pre-treatment. Pre-treatment is an interesting option, as by modifying biomass properties, it addresses problems at their source.

4. The costs of biomass utilization in co-firing systems depend not only on its purchase price and pre-treatment costs, but also on the costs of operability of the fuel (handling, storage, transport) and operability of the boiler and combustion process. It might not necessarily be optimal to use the cheapest fuel available, if negative effects on boiler operation and fuel operability are significant.

5. The most advanced form of bio-feedstock currently used in co-firing on commercial scale is biomass pre-treated into pellets, and it is commonly used in the Netherlands and Denmark.

The feasibility of using of biomass as a substitute fuel in coal fired power plants of NTPC should be given due attention. NTPC can utilize biomass as a low-cost, substitute fuel and an agent to control emission. The opportunity for the adoption of this technology is quite attractive due to benefits associated. NTPC plants are facing acute coal shortage & we have resorted to use of blended coal by using imported coal along with Indian coal. Use of this technology will reduce our coal consumption. ***Biomass co-firing with coal is proving to be the cheapest method for generating green power in utility plant demonstrations***.
Successful development of technology to use biomass as supplement fuel will create an environment-friendly, low cost fuel source for the power industry and provide means for an alternate method of disposal of biomass and a possible revenue source for farmers and feedlot operators.
Till date no such co-fired fossil based utility power plant using biomass exists in India. NTPC, market leader in Indian Power sector, through NETRA & CENPEEP can collaborate with national & international technology providers in this field for joint research & field demonstration through pilot study at one of its existing plants for technology validation & implementation.
Finally it is apt to conclude that burning renewable fuels such as biomass residues or energy crop-derived biomass fuels in conventional coal-fired utilities as a low-cost option for reducing greenhouse gas emissions.

REFERENCES:

[1] **Van den Brook, R., Faaij, A. and van Wijk**, **A.** 1996. Biomass combustion for power generation.
Biomass Bioenerg. 11:271-281.

[2] **Pedersen, L.S., Nielsen, H.P., Kiil, S., Hansen, L.A., Dam-Johansen, K., Kildsig, F. Christensen, J. and Jespersen, P.** 1996. Full-scale co-firing of straw and coal. *Fuel*. 75:1584-1590.

[3] **Boylan, D.M.** 1996. Southern company tests of wood/coal co-firing in pulverized coal units.
Biomass Bioenerg. 10:139-147.

[4] **Hunt, E.F., Prinzing, D.E., Battista, J.J. and Hughes, E.** 1997. The shawville coal/biomass Co-firing test: A coal/power industry cooperative test of direct fossil-fuel CO_2 mitigation.

[5] **Ekmann, J.M., Winslow, J.C., Smouse, S.M. and Ramezan, M.** 1998. International survey of Co-firing coal with biomass and other wastes. *Fuel Process. Technol*. 54:171-188.

[6] **Tillman, D.A.** 2000. Co-firing benefits for coal and biomass. *Biomass Bioenerg*. 19:363-364.

[7] **Tillman, D.A.** 2000. Biomass co-firing: the technology, the experience, the combustion consequences. *Biomass Bioenerg*. 19:365-384.
.
[8] **Sami, M., K. Annamalai and Wooldridge, M.** 2001. Co-firing of coal and biomass fuel blends.
Prog. Energ. Combust. 27:171-214.

[9] Savolainen, **K.** 2003. Co-firing of biomass in coal fired utility boilers. *Appl. Energ.* 74:369-381.

[10] **Baxter, L.** 2005. Biomass-coal co-combustion: opportunity for affordable renewable energy. *Fuel*.84:1295-1302.

[11] **Demirbas, A.** 2005. Biomass Co-Firing for Boilers Associated with Environmental Impacts. *Energ. Source.* 27:1385-1396.

[12] **Lu, G., Y. Yan, Cornwell, S., Whitehouse, M. and Riley, G.** 2008. Impact of co-firing coal and
biomass on flame characteristics and stability. *Fuel*. 87:1133-1140.

[13] **Zhang, L., Xu, C. and Champagne, P.** 2010. Overview of recent advances in thermo-chemical
conversion of biomass. *Energ. Convers. Manage*. 51:969-982.

[14] **IEA Bioenergy Task 32**, 2009. *Technical Status of Biomass co-firing*, Ed. Cremers, M.F.G. IEA. p.4,7,10.

[15] http:// www.ieabcc.nl/database/cofiring.php

[16] **K.V. Narayanan and E. Natarajan**, Experimental studies on cofiring of coal and biomass blends in India, Renewable Energy 32, (2007):2548–2558.

[17] http://www.thermaxindia.com/Fileuploader/Files/Biomass-Fired- Boilers.pdf

18. Report of the Group for Studying Range of Blending of Imported Coal with Domestic Coal, Central Electricity Authority, India, April 2012.