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A review of biomass co-firing in North America

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ABSTRACT

Biomass fuels have long been accepted as useful renewable energy sources, especially in mitigating greenhouse gases (GHG), nitrogen oxides, and sulfur oxide emissions. Biomass fuel is carbon neutral and is usually low in both nitrogen and sulfur. For the past decade, various forms of biomass fuels have been co-combusted in existing coal-fired boilers and gas-fired power plants. Biomass is used as a supplemental fuel to substitute for up to 10% of the base fuel in most full commercial operations. There are several successful co-firing projects in many parts of the world, particularly in Europe and North America. However, despite remarkable commercial success in Europe, most of the biomass co-firing in North America is limited to demonstration levels. This review takes a detailed look at several aspects of biomass co-firing with a direct focus on North America. It also explores the benefits, such as the reduction of GHG emissions and its implications. This paper shows the results of our studies of the biomass resources available in North America that can be used in coal-fired boilers, their availability and transportation to the power plant, available co-firing levels and technologies, and various technological and environmental issues associated with biomass co-firing. Finally, the paper proffers solutions to help utility companies explore biomass co-firing as a transitional option towards a completely carbon-free power sector in North America.

Contents

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1. Introduction

Biomass is a renewable energy source that has the potential benefits of decreasing pollutant generation and being CO_2 neutral. One of the oldest sources of energy known to man, it is derived from organic matter such as agricultural crops, forest harvest residues, seaweed, herbaceous materials, and organic wastes [1–4]. Compared to other sources of energy, biomass offers some unique advantage with respect to the environment since it is "carbon neutral". Although the combustion of biomass generates as much carbon dioxide as do fossil fuels, the carbon dioxide released is removed when a new plant grows. This means the biomass expels the carbon (usually in the form of carbon dioxide) that it had originally taken in from the atmosphere, thereby reducing net carbon emissions significantly [5,6].

Biomass co-firing is regarded as one of the attractive short-term options for biomass in the power generation industry. It is defined as the simultaneous blending and combustion of biomass with other fuels such as coal and/or natural gas in a boiler in order to generate electricity [7–10]. Solid biomass co-firing is the combustion of solid biomass fuels like wood chips and pellets in coal-fired power plants [10]. Gas biomass co-firing is the simultaneous firing of gasified biomass with natural gas or pulverized coal in gas power plants in a technique usually referred to as indirect co-firing [11,12]. In both situations, whenever there is insufficient biomass feedstock, the primary fuel buffers the system until the biomass supply improves.

Co-firing biomass with fossil fuels like coal and natural gas offers several opportunities, especially to utility companies and customers, to protect the environment by minimizing GHGs [5]. It also creates opportunities in industries such as forestry, agriculture, construction, manufacturing, food processing, and transportation to better manage large quantities of combustible agricultural and wood wastes [1]. In addition, the cost of adapting an existing coal power plant to co-fire biomass is significantly lower than the cost of building new systems dedicated only to biomass power [13,14]. Even a dedicated biomass plant offers significant environmental benefits. However, relying solely on biomass is risky due to unpredictable feedstock supply because of the seasonal nature of biomass resources as well as poorly established supply infrastructure in many parts of the world [1,5]. Other constraints of generating power solely from biomass are the low heating values and the fuel's low bulk densities, which create the need transport large units of biomass [7]. Biomass co-firing for power generation provides an effective way to overcome these challenges.

This paper reviews biomass co-firing with a focus on North America. The specific objectives include: (1) a review of different biomass co-firing technologies, (2) a review of biomass co-firing in North America, (3) a review of possible approaches to improve biomass co-firing, (4) a comparative assessment of co-firing in North America and around the world and (5) a discussion on opportunities and the future of co-firing in North America due to policies.

2. Existing co-firing technologies

Biomass feedstock can be mixed with coal outside the boiler, or it can be added to the boiler separately. Co-firing technologies are usually implemented in existing coal-fired power plants. The most common type of co-firing facility is a large, coal-fired power plant, though related coal-burning facilities, like cement kilns, coal-fired heating plants, and industrial boilers can be used [9,15].

Al-Mansour and Zuwala [16] list three technological approaches of co-firing biomass with coal or natural gas in a power plant. The approaches differ in terms of the boiler system design as well as the percentage of biomass to be co-fired, and these are: direct co-firing, indirect co-firing, and parallel co-firing.

2.1. Direct co-firing

Direct co-firing is a simple approach and the most common and least expensive method of co-firing biomass with coal in a boiler, usually a pulverized coal (PC) boiler. As shown in Fig. 1, in direct co-firing technology biomass is fed directly into the furnace after either being milled together with the base fuel (Fig. 1a) or being milled separately (Fig. 1b) [17]. The fuel mixture is then burned in the burner. The co-firing rate is usually in the range of 3–5%. This rate may rise to 20% when cyclone boilers are used, although the best results are achieved with PC boilers [18,19].

Maciejewska et al. [15] notes that most direct co-firing issues are a result of high co-firing levels, poor biomass quality, and lack of dedicated infrastructure. Studies carried out by the Tennessee Valley Authority (TVA) show that blending biomass fuels like wood waste (for example sawdust) directly with coal in a PC boiler tend to have an unfavorable impact on the pulverizer and lead to unacceptable sieve analyses results as the co-firing percentages of the system starts to exceed 5% on a mass basis [20]. Depending on the type of biomass feedstock used, some challenges may be encountered when biomass is directly blended on the coal pile. For example, straws and switchgrass can plug the bunkers if they are milled to 25–50 mm (1–2 in.) in length. Also, bark may affect milling operations since it can be very stringy. When pulverizers are not used, cyclone boilers are recommended, although the coal should be crushed to a particle size of 6 mm × 0 mm (1/4 in. × 0 in.). However, there is a capacity limit that hinders the quantity of biomass that may be fired when cyclone boilers are used. This is based on the higher heating value of biomass feedstocks, which exceeds the design limits of most cyclone boilers (they would usually have a heating value of about 20 MJ/kg). Also, even though some experts specify an ash concentration level of approximately 5%, the ash concentration of different types of biomass fuels varies significantly from 0.44 in. white pine to 7.63 in. switchgrass, as shown in Table 2. The inherently high ash concentration levels of some biomass fuels like those from herbaceous materials might be a challenge in the boilers since there is a higher tendency of ash deposition problems like slagging and fouling as well as the corrosion of the boiler heat transfer surfaces [7,20,21].

2.2. Indirect co-firing

Indirect co-firing technology allows biomass to be co-fired in an oil- or gas-fired system. It exists in two forms, gasification-based co-firing and pyrolyzation-based co-firing. In gasification-based