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Results of fly ash quality for disposal options from high thermal shares up to pure biomass combustion in a pilot-scale and large scale pulverized fuel power plants

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ABSTRACT

This work evaluated fly ash quality from combustion of high thermal shares of biomass fuels. Woody biomass was (co)combusted in an industrial scale pulverized fuel power plant, and a herbaceous biomass was co-combusted in a pilot-scale test facility. Ashes from the electrostatic precipitator were collected and evaluated for chemical compounds, leaching behavior, and mechanical properties. Results from the large-scale industrial pulverized fuel showed the ashes still had good reactivity and mechanical properties according to EN450-1, which is a good unexpected occurrence regarding strength development. Results from the pilot-scale test facility showed that a herbaceous biomass co-fired up to 50% thermal share does not seem to have any negative impact on existing fly ash utilization routes. It is concluded that co-firing clean woody biomass at a very high thermal share and co-firing a high thermal share of a herbaceous biomass with lignite would not change current utilization practices. In practice ashes from high thermal shares are not used due to safeguards in standards form a lack of experience from enough performance testing. Thus, the findings can lead to support for standards that incorporate other assessment methods for biomass fly ash utilization requirements.

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1. Introduction

Depleting natural resources and damage to the natural environment necessitates alternatives to utilizing fossil fuels. The increase in environmental awareness worldwide over the recent decades has resulted in countries shifting energy policies to include renewable energy sources in their energy mix to produce heat and electricity. Estimations show that after 2042 the only fossil fuel with significant remaining reserves is coal [1]. Thus, coal combustion, the traditionally essential energy supply system, will continue to play a role, either as an indigenous source or as an imported raw material, in the European energy mix and its diversification [2], as the energy demand is likely to continue to increase. Out of concern for the environment, the European Commission has a binding target to increase the level of renewable energy sources in the EU's overall energy mix to 20% by 2020 [3]. Those renewable energy sources include, but are not limited to, biomass fuels. Noted is the potential of biomass to make a significant contribution to an increasing sustainable energy production globally [4]. Biomass is a renewable and CO_2-neutral energy source, which continues to gain increasing importance worldwide, aiding to the diversification of renewable energy sources as a fuel for energy production, leading to various reduced emissions besides CO_2 [3–5]. Atmospheric concentrations of CO_2 have increased from pre-industrial era levels to date [6], arguably contributing to higher global temperatures, the greenhouse effect, and ocean acidification. Thus, the increase in environmental awareness has led to the growth of environmental legislation, driven by a rising interest in environmental protection and sustainability.

It is noted that in Europe, most notably in Eastern Europe, both hard coal and lignite are available as indigenous sources, whereas in the future the Southern and Western European countries will

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have to continue to import coal or switch to other energy sources [2]. Among the renewable energy options considered for GHG emission mitigation, biomass is currently the most important, being the fourth largest energy source following coal, oil, and natural gas [7]. Biomass is considered to be the most promising source of renewable energy regarding the use of alternatives to using fossil fuels, with all countries having a trend of increasing their share of biomass in the process of industrial combustion. A reported goal of EU regulations is 14% of biomass in the process of coal combustion by the year of 2020 [8]. Biomass generally belongs to one of the six categories: woody and woody biomass, herbaceous and agricultural biomass, aquatic biomass, animal and human biomass wastes, contaminated biomass and industrial biomass wastes (semi-biomass), and biomass mixture [9]. Interest in biomass combustion has increased during the last decades, as one of the major renewable energy sources [10–12]. Biomass has the potential to make a large contribution to an increase in sustainable energy production globally [4]. The majority of the energetic uses of biomass are in the heating sector, but the production of electricity from biomass is rapidly growing. Dedicated biomass power plants are a technological option; however, their typical conversion efficiency is quite low, near 25% [13]. Biomass co-firing in existing coal-fired power plants is another technological alternative, which combines the high efficiencies of coal power plants (at least 43% for the newest facilities [14]) with installation costs lower than dedicated biomass combustion facilities and comparable or lower to other renewable energy sources options [15]. Many biomass fuels, such as residues, energy crops, herbaceous, and woody biomasses have been co-fired in pulverized fuel, stoker, and cyclone boilers, ranging in proportions from (1 to 20) % [3]. In most cases, the quick adoption of co-firing relies on the availability of relatively high quality wood biomass fuels, often in the form of pellets or chips. In addition, the biomass thermal shares are typically below 20%. Competition with the heating sector, price increases, as well as the overall policy direction, lead to a push for a more extensive utilization of other biomass types, such as agricultural residues and dedicated energy crops [16]. Energy crops in particular are considered as very promising candidates for the production of solid biofuels due to their potential for high yields, which may pose a more attractive alternative to farmers in the frame of the EU Agricultural Policy and the challenges of the agricultural sector [17,18]. On the other hand, herbaceous biomass has higher amounts of constituents that negatively impacts slagging, fouling, corrosion and by-product quality. The use of forest residues, herbaceous and fruit biomass is the greatest potential to increase the share of biomass in energy production. Up to now, herbaceous and fruit biomass make up only 7% of the total biomass utilization and mainly straw is used [19]. Currently the EU only exploits 48% of the biomass potential for bioenergy production, with herbaceous and fruit biomass having the highest potential followed by forest residues [20]. Thus, the potential for biomass use for energy production in the EU27, whether imported or indigenous, remains a viable option as another energy source than coal.

The growing use of biomass in the energy production sector will continue to influence the by-product quality, affecting its potential utilization routes. To ensure the sustainable use of biomass fuels in power plants for heat and electricity, one must maintain the quality of the fly ash, among other coal combustion by-products, for valuable end-use market applications.

Fly ash is a fine powder of mainly spherical, glassy particles, derived from burning of pulverized coal, with or without co-combustion materials, which has pozzolanic properties and consists essentially of SiO_2 and Al_2O_3; electrostatic or mechanical precipitation of dust-like particles from the flue gases of the power stations obtains the fly ash in bottom hoppers [21]. Coal combustion products, to include fly ash, are mainly utilized in the building material industry, civil engineering, road construction, construction work in underground coal mining, and recultivation and restoration purposes in open cast mines, with the majority produced to meet requirements of standards or specifications for utilization in a certain area [22]. EU or EU member states' national standard regulations of fly ash utilizations in the EU27 are for various applications. EN 450-1 defines the use of fly ash in concrete, allowing co-firing shares of biomass up to 40% on a mass fraction percent for selected secondary streams, as well as up to 50% on a mass fraction percent for untreated clean wood [21]. EN 197-1 that defines the use of fly ash in producing common cements [23]. EN 12620 defines fly ash for use in aggregates for concrete [24]. EN 14227 [25] and EN 13282 [26] define fly ash use for road construction, and EN 13055-1 for use in lightweight aggregates [27]. National regulations by EU member states mainly consist of requirements for the environmental compatibility of fly ashes, which are regulated by EU member states national laws. National standards and regulations by the various EU member state are noted to be required to be followed for uses in concrete blocks, infill-filling of voids, mine shafts and subsurface mine workings-, production of bricks, earthworks and landscaping, production of mortar, floor screed and plasters, and mining mortars/civil engineering products [28]. A further fly ash use included in the national regulations is for soil amerolient. Fly ash is noted to improve the texture of soils, improve soil aeration, percolation and water retention; it reduces crust formation and consumption of other soil amelioration agents such as fertilizers; it can decrease the mobility and availability of material in the soil [29,30]. Drawbacks are the reduction in bioavailability of some nutrients in soil due to alkaline fly ash and excess salinity and a high phytotoxic elements [30]. For example, in Germany those parameters and their limits are established in a document known as the LAGA Assessments – Guidelines from the German-Federal/State Working Group on Waste [31], in the Netherlands it is the Dutch Decree on Soil Quality [32].

Meanwhile, it is noted there are many applications were the fly ash meet performance requirements that are not regulated by EU standards or EU member states' national standards; thus, these utilization options are not widely practiced. Those include, among others, absorbents, metal recovery, ceramics and glass, geopolymers, cenospheres recovery, carbon recovery [30], stabilization, solidification, and encapsulation [33] and waste water treatment [34]. Reported in Ref. [35] is utilization of fly ash for metal recovery from waste to energy plant residues. While most fly ash utilization applications evolved from fly ash obtained from coal combustion, the increase use of biomass in thermal conversion technologies leads to a change in the constituents of fly ash due to biomass generally having higher amounts of alkalis, magnesium, phosphorous, and chlorine along with lower amounts of alumina, silica, and iron. Therefore, the requirements for the use of biomass ashes would likely need other assessment criteria to evaluate thoroughly its performance for a given application in order to identify the best utilization route from any changes in the fly ash chemical composition, morphology, physical properties, and mechanical properties, which affect its quality.

As biomass fly ashes are likely not to conform to chemical requirements in some standards, but may still be able to perform for a given end use application, a process to evaluate its performance for end use market applications appears to be a more valuable assessment. The non-conformity of biomass fly ashes is likely an expectation, as biomass ashes differ according to the following three groups: agricultural residues – high in silica and potassium, low in calcium; wood-based fuels – low in silica and potassium, high in calcium; and manure – high in calcium and phosphorus [9]. Furthermore, the inorganic matter in biomass is composed mostly

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