Reducing Environmental Impacts: Coal Combustion

Case Study

A Life Cycle Comparison of Disposal and Beneficial Use of Coal Combustion Products in Florida

Part 1: Methodology and Inventory of Materials, Energy, and Emissions*

Callie W. Babbitt and Angela S. Lindner**

Department of Environmental Engineering Sciences, University of Florida, P.O. Box 116450, Gainesville, FL 32611, USA

** Corresponding author (alind@eng.ufl.edu)

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Abstract

Background, Goal, and Scope. Currently, only 40%, or 44.5 million metric tons, of coal combustion products (CCPs) generated in the United States each year by electric utilities are diverted from disposal in landfills or surface impoundments and recycled. Despite promising economic and environmental savings, there has been scant attention devoted to assessing life cycle impacts of CCP disposal and beneficial use. The objective of this paper is to present a life cycle inventory considering two cases of CCP management, including the stages of coal mining and preparation, coal combustion, CCP disposal, and CCP beneficial use. Six beneficial uses were considered: concrete production, structural fills, soil amendments, road construction, blasting grit and roofing granules, and wallboard.

Methods. Primary data for raw material inputs and emissions of all stages considered were obtained from surveys and site visits of coal-burning utilities in Florida conducted in 2002, and secondary data were obtained from various published sources and from databases available in SimaPro 5.1 (PRé Consultants, Amersfoort, The Netherlands).

Results. Results revealed that 50 percent of all CCPs produced, or 108 kg per 1,000 kg of coal combusted, are diverted for application in a beneficial use; however, the relative amounts sold by each utility is dependent on the process operating parameters, air emission control devices, and resulting quality of CCP. Diversion of 50% of all CCPs to beneficial use applications yields a decrease in the total raw materials requirements (with the exception of gravel and iron) and most emissions to air, water, and land, as compared to 100% disposal.

Discussion. The greatest reduction of raw materials was attributed to replacing Portland cement with fly ash, using bottom ash as an aggregate in concrete production and road construction in place of natural materials, and substituting FGD gypsum for natural gypsum in wallboard. The use of fly ash as cementitious material in concrete also promised significant reductions in emissions, particularly the carbon dioxide that would be generated from Portland cement production. Beneficial uses of fly ash and gypsum showed reductions of emissions to water (particularly total dissolved solids) and emissions of metals to land, although these reductions were small compared to simply diverting 50% of all CCPs from landfills or surface impoundments.

Conclusions. This life cycle inventory (LCI) provides the foundation for assessing the impacts of CCP disposal and beneficial use. Beneficial use of CCPs is shown here to yield reductions in raw material requirements and various emissions to all environmental compartments, with potential tangible savings to human health and the environment.

Recommendations and Perspectives. Extension of this life cycle inventory to include impact assessment and sensitivity analysis will enable a determination of whether the savings in emissions reported here actually result in significant improvements in environmental and human health impacts.

Keywords: Coal combustion, beneficial use; coal combustion products (CCPs); disposal; emissions, coal combustion; Florida; Life Cycle Inventory (LCI)

Introduction

Approximately 110 million metric tons of coal combustion products (CCPs), categorized as fly ash, bottom ash, boiler slag, and flue gas desulfurization (FGD) material, are generated annually by electric utilities in the United States [1]. Fly ash is the ash and non-combustible minerals released during combustion that ‘fly’ out of the boiler with flue gases [2]. Bottom ash and boiler slag are heavy, non-combustible particles remaining in the bottom of the boilers [3]. FGD material is the residue of air emissions control devices that remove sulfur dioxide (SO₂) from the flue gas. The physical and chemical characteristics of CCPs enable their use in engineering and manufacturing markets, and, as a result, CCPs have become the third most abundant mineral resource in the United States [6]. It is estimated that 44.5 million metric tons, or 40 percent, of CCPs generated in the United States are diverted to beneficial uses, i.e., the replacement of virgin raw materials by CCPs in industrial applications. Examples of the most promising beneficial uses include substitution of fly ash for Portland cement in concrete production [4,6–9], bottom ash as lightweight aggregate, in structural fill, and in road bases and sub-bases [4,6,10–14], FGD gypsum for natural gypsum in wallboard manufacture [15–17], and boiler slag in blasting grit and asphalt roofing granules [6,18,19]. CCPs are also used as agricultural soil amendments and in material recovery and waste stabilization [1].
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The remaining 60 percent of CCPs generated are disposed of in landfills or surface impoundments located at the electric utility [1, 20]. Both disposal methods risk release of trace metals to the water and land and require burdensome permitting and extensive land mass [21]. A recent life cycle inventory (LCI) of coal used for electricity production in Florida reported that, for every 1000 kg of coal combusted, 216 kg of CCPs are produced, including fly ash (80 kg), bottom ash (9 kg), boiler slag (7 kg), and FGD gypsum (120 kg) [20]. This study identified CCP beneficial use as an opportunity to prevent or minimize emissions and potential environmental impacts resulting from CCP disposal [20]. Other benefits from CCP beneficial use may include decreased reliance on scarce and/or expensive natural resources, decreased energy requirements for processing or transporting the CCPs for disposal, and increased financial returns to the utilities and intermediate marketers from CCPs sales.

Most research on the potential environmental impacts of CCPs has centered on the effect that metals released from landfills or surface impoundments may have on human and ecosystem health [22–24]. A recent study addressed coal by-products from a life cycle perspective, but limited the analysis of CCPs to substitution of fly ash and bottom ash for cement in concrete and did not explicitly compare disposal and other beneficial use options [25]. Environmental and human health impacts resulting from diverting CCPs from disposal and replacing virgin raw materials are not well understood. To this end, the broad objective of this work was to use life cycle assessment (LCA) methods to expand the results of an LCI that focused on cradle-to-grave stages of coal used for electricity production in Florida by including CCP beneficial use. Here, Part 1 focuses on the LCI methodology and the comparative inventory of raw materials and emissions for beneficial use and disposal of CCPs in Florida. Whether these emission reductions result in significant improvements in environmental and human health impacts will be the focus of Part 2 of this series.

1 Methods

This LCA was performed following ISO 14040 series guidelines [26a–c]. Inventory calculations for Part 1 were based on primary data (collected directly from Florida utilities) and secondary data (collected from literature and regulatory agencies), and performed with SimaPro 5.1 (PRé Consultants, Amersfoort, The Netherlands). SimaPro 5.1 also contains inventory data for products and processes in databases created by ETH-ESU (Uster, Switzerland), Buwal 250 (Bern, Switzerland), and Franklin Associates (Prairie Village, Kansas, USA), among others [27].

1.1 Goal definition and scope of this study

The primary goals of this LCI were to inventory raw material requirements and pollutant emissions associated with common CCP beneficial uses and use these results to determine opportunities in the CCP life cycle for preventing or minimizing environmental or human health impacts. The ultimate objective was to aid regulators and CCPs generators in determining methods of CCP management that result in minimal impact to human and environmental health. The LCI scope included coal mining and preparation, coal combustion, CCP disposal, and CCP beneficial use. This assessment was limited to electric utilities during 2002 in the state of Florida, as this project was funded by the Florida Department of Environmental Protection (FDEP) and involved collaboration with the Florida Electric Power Coordinating Group (FCG), a consortium of electric utilities in Florida. Furthermore, this LCI specifically included coal processing and combustion technology that is currently used and well established. As shown in Fig. 1, two scenarios were considered: the baseline coal life cycle with 100% CCP disposal in onsite landfills and surface impoundments (Fig. 1A) and the CCP beneficial use scenario, with 50% of all CCPs diverted from disposal and used as raw material replacements in beneficial use within 50 miles of the utility (Fig. 1B).

![Fig. 1: Life cycle system boundaries. A: Baseline scenario – coal combustion with 100% CCP disposal. B: Baseline scenario – coal combustion with 50% CCP disposal and 50% CCP beneficial use within 50 miles](image-url)