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Quantifying the Benefits of Using Flue Gas Desulfurization Gypsum in Sustainable Wallboard Production

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ABSTRACT

Electric utilities produce more than 11.2 Mt of flue gas desulfurization (FGD) gypsum annually. Approximately 7.5 Mt is used in wallboard production. This article examines the environmental and cost benefits associated with replacement of natural gypsum in wallboard with FGD gypsum. A life-cycle analysis program was used to quantify the benefits of using FGD gypsum from electric power production in wallboard construction. Comparisons were made between energy consumption, water use, and greenhouse gas (GHG) emissions associated with obtaining and processing virgin gypsum material and those with FGD gypsum. The added impact of disposing of the unused FGD gypsum in landfills was also considered using life-cycle inventory for data generated from construction, operation, and maintenance costs for Subtitle D (nonhazardous municipal solid waste) landfills. Based on 2007 consumption data, the use of FGD gypsum in wallboard manufacture and concomitant avoided landfilling of unused FGD gypsum reduced energy consumption by 1200 TJ, water consumption by 18 GL, GHG emissions by 83 kt CO_2e, and had a cost savings of $49 to $64 million dollars. The 2007 reduction in energy consumption from using FGD gypsum in wallboard is commensurate with the annual energy use of 11,800 homes, 58% of the annual domestic water use in Nevada, and the removal of 11,400 automobiles from the roadway.

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1. Introduction

With growing concern over global climate change, many efforts have been made to reduce emissions of greenhouse gases (GHGs). The construction industry is one of the most material-intensive areas; massive quantities of energy are consumed and greenhouse gases are produced as a consequence of the process of construction material production. According to the U.S. Environmental Protection Agency (USEPA, 2009a), CO_2 emissions produced by the construction industry account for approximately 1.7% of total emissions in the United States, which places the construction industry as one of the top CO_2 emitters.

Coal combustion generated approximately 33% of the total energy (megajoules) produced in the United States (Energy Information Administration [EIA], 2009) in 2007. Furthermore, coal combustion is responsible for 50% of the electrical power–generating capacity of the United States (EIA, 2009). In 2007, 119 Mt (1 Mt = 1.1 million tons) of coal combustion products (CCPs) were produced as a result of energy production using coal (American Coal Ash Association [ACAA], 2008), and over 12% (11.2 Mt) of the CCPs consisted of gypsum from flue gas desulfurization (FGD). The desulfurization process uses wet scrubbers and forced oxidation to reduce SO_2 emissions, and the gypsum produced is mineralogically identical to natural gypsum ($CaSO_4 \cdot 2H_2O$), making FGD gypsum an ideal replacement for the mined gypsum used to manufacture wallboard. The ACAA reported that in 2007, 75% of FGD gypsum produced was beneficially used,

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90% of which was used to produce wallboard. If FGD gypsum cannot be beneficially used, environmental and financial consequences will arise due to the energy expenditure and GHG emissions related to obtaining virgin materials. Additionally, environmental and financial expenses will be accrued relating to disposal of the unused FGD gypsum.

There have been few efforts to quantify the significance of the beneficial use of FGD gypsum in mitigating CO_2 emissions, energy use, and water consumption. This study used life-cycle assessment to quantify the energy use, greenhouse gas emissions, and water use associated with producing wallboard with FGD gypsum and virgin gypsum. The comparison was made between using virgin gypsum and FGD gypsum in wallboard production in order to determine the savings associated with beneficial use of FGD gypsum.

2. Methods

The environmental and economic benefits of FGD gypsum use in wallboard were quantified by computing differences in energy expenditure, water consumption, and GHG emissions between wallboard generated with virgin gypsum and that produced with FGD gypsum. Unit benefits (the impact per ton of FGD gypsum used in manufacture per year) of using FGD gypsum as a substitute for conventional gypsum in wallboard manufacturing were obtained with the life-cycle assessment modeling software SimaPro, using the EcoInvent and U.S. life-cycle inventory (National Renewal Energy Laboratory [NREL], 2000) databases as inputs, the cumulative energy demand (CED; version 1.07, Ecoinvent Centre, 2003) assessment method for energy consumption, and the building for environmental and economic sustainability (BEES; version 4.02, National Institute of Standards and Technology, 2007) assessment method for water consumption and GHG emissions. The total annual benefits were obtained as the product of unit benefits for energy use, water consumption, or GHG emissions and the most recent annual FGD beneficial use quantity (in tons) provided by the ACAA (2008). Unit financial savings for energy and water consumption were generated using financial data given by the National Propane Gas Association (NPGA, 2006). The social carbon cost (SCC) was used to calculate the financial benefit of the reduction of greenhouse gases (CO_2 equivalents, CO_2e). The SCC incorporates social benefits of CO_2 reduction into a cost-benefit analysis of regulatory actions. The SCC was set at $5.20 or $68.00 per ton of carbon (2009 U.S. dollars) to reflect low- and high-cost scenarios based on recommendations by the Department of Energy (USDOE, 2010).

The SimaPro analysis for the replacement of virgin gypsum with FGD gypsum in wallboard manufacture considered wallboard produced with 100% natural gypsum or 100% FGD gypsum. The system boundary for production of stucco (processed gypsum for wallboard sheet filling) is shown in Figure 1 for virgin and FGD gypsum. Discussions with wallboard industry representatives indicated that the resources associated with predrying FGD gypsum at the wallboard plant are comparable to or lower than those associated with milling and predrying virgin gypsum. Therefore, the resource consumption associated with processing virgin and FGD gypsum at the wallboard plant is conservatively assumed to be equal. Consequently, gypsum mining was the only factor contributing to environmental differences between wallboard manufacturing using virgin gypsum and FGD gypsum (Figure 1).

SimaPro uses the EcoInvent database, which defaults to a Swiss electricity mix. To make the analysis more representative of U.S. conditions, the database was modified using a U.S. electricity mix (NREL, 2000). The modified energy network for gypsum mining is shown in Figure 2.

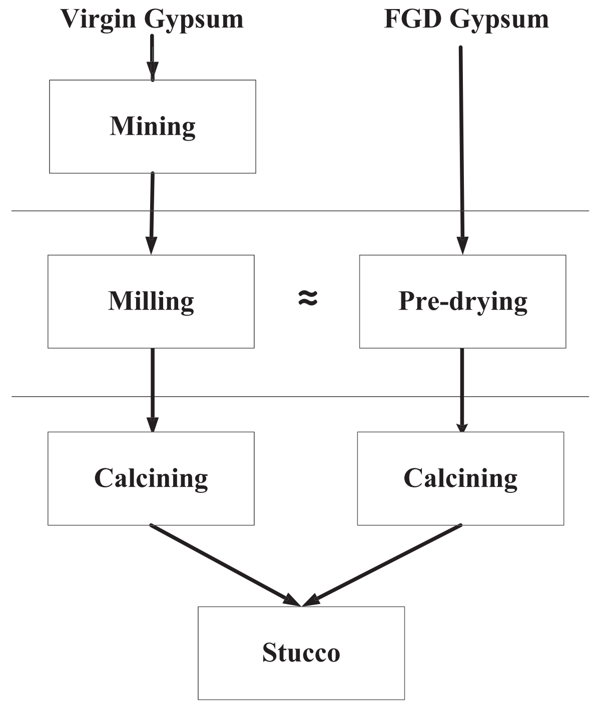

Fig. 1. System boundary for stucco production during wallboard manufacturing using virgin gypsum or flue gas desulfurization (FGD) gypsum.

Transport of natural gypsum can require greater energy and result in increased GHG emissions compared with FGD gypsum, especially since wallboard manufacturing plants tend to be constructed adjacent to coal-fired power plants using wet scrubbers for FGD. This benefit is difficult to quantify and was not included in the analysis (i.e., transportation energies for virgin gypsum and FGD gypsum were assumed to be identical). This assumption resulted in additional conservatism in the analysis.

Unit benefits in terms of reduction in energy and water consumption and GHG emissions obtained by processing FGD gypsum in lieu of virgin gypsum for wallboard construction and the corresponding unit economic savings are shown in Table 1. These benefits are achieved by avoiding the water and energy consumption and GHG emissions associated with mining virgin gypsum.

Environmental impacts associated with disposing of 1 ton of unused FGD gypsum in landfills were also calculated using a life-cycle inventory (LCI) for construction, operation, and maintenance costs for Subtitle D (nonhazardous municipal solid waste) landfills developed by the Environmental Research and Education Foundation (EREF, 1999). Using Subtitle D LCI data can be considered conservative because if Subtitle C (hazardous waste) landfills are required for FGD disposal, there are additional restrictions on operations, waste acceptance, disposal, and containment design that increase environmental and energy costs. Inventory information specific to municipal solid waste and not applicable to FGD disposal was excluded (e.g., GHG emissions due to waste decomposition). A breakdown of the unit impacts for each phase of landfill development is shown in Table 2. The unit impacts associated with disposal are summarized in Table 3. The CO_2 equivalence reported in Table 3 combines CO_2 savings and

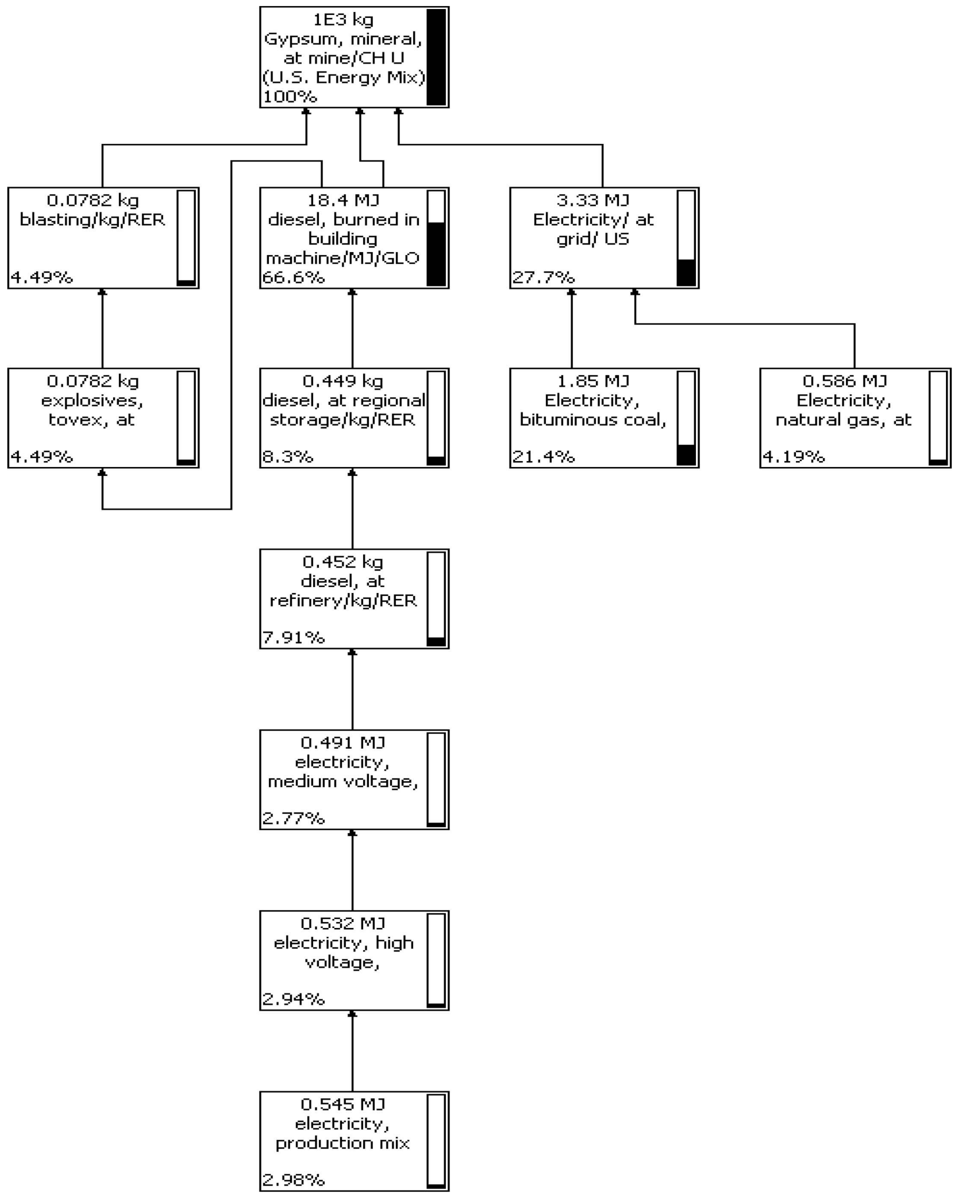

Fig. 2. SimaPro network diagram for mining virgin gypsum.

methane savings from Table 2 by converting methane to CO_2e using 1 t CH_4 = 23 t CO_2e.

3. Results and Discussion

Annual cumulative savings for energy expenditure, water consumption, GHG emissions, and financial expenses for replacing virgin gypsum with FGD gypsum in wallboard and avoided FGD disposal costs are summarized in Table 4. Using 7.5 Mt of FGD gypsum in wallboard manufacturing resulted in 1200 TJ of annual energy savings, 18 GL of annual savings in water consumption, and an annual reduction of 83 kt of CO_2e, with an additional cost savings of $49 to $64 million dollars.

The 2007 reduction in energy consumption is commensurate with the energy consumed by 11,800 homes (EIA, 2005), the water saved is equal to 58% of the annual domestic water use in Nevada,

Table 1
Unit benefits profile for processing flue gas desulfurization (FGD) gypsum instead of virgin gypsum for wallboard construction

Areas of impact		Savings/t FGD
Energy savings	Savings (MJ)	41.45
	Financial savings (US$)	1.20
Water savings	Savings (L)	2400
	Financial savings (US$)	1.59
CO_2 equivalent	Reductions (t)	0.003
	Financial savings (US$)	0.01–0.20

Table 2
Unit impact profile by landfill development phase

	Energy (MJ/t)	CO_2 (kg/t)	Methane (kg/t)
Construction	31.1	1.41	0.0008
Operation	56.6	3.82	0.002
Closure	29.0	1.68	0.0008
Postclosure	2.9	0.17	0.0001
Leachate	4.4	0.29	0.0005
Total	124	7.37	0.011

Table 3
Summary of unit benefits profile for avoided landfilling[1]

Benefits		Savings/t FGD
Energy	Savings (MJ)	124
	Financial savings (US$)	3.71
GHG emission	CO_2e (t)	0.008
	Financial savings (US$)	0.04–0.52

[1] FGD = flue gas desulfurization; GHG = greenhouse gas.

Table 4
National annual savings obtained by using flue gas desulfurization gypsum in sustainable wallboard manufacturing

Benefits	Annual savings
Energy (TJ)	1200
Water (GL)	18
CO_2e (t)	83,000
Financial (million US$)	49–64

and the reduction in GHG emissions is comparable to removing 11,400 automobiles from the roadway (USEPA, 2009b). These quantities indicate that the beneficial use of FGD contributes significantly to sustainability in the United States and should be nurtured and enhanced if possible.

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