Waste and Materials-Flow Benchmark Sector Report:

Beneficial Use of Secondary Materials -

Coal Combustion Products

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EXECUTIVE SUMMARY

INTRODUCTION

The U.S. Environmental Protection Agency's Office of Solid Waste (EPA OSW) is currently developing methods to evaluate the environmental, human health, and economic outcomes of specific EPA programs. As an initial step, OSW is examining the extent to which the costs and benefits of source reduction, reuse, and recycling may be quantified for a range of materials targeted by the Resource Conservation Challenge (RCC).

Coal combustion products (CCPs) are among the materials targeted by EPA's Resource Conservation Challenge (RCC). The RCC is designed to facilitate changes in the economics and practice of waste generation, handling, and disposal (e.g., by promoting market opportunities for beneficial use). Under the RCC, EPA has established three goals for increased beneficial use of CCPs:

- Achieve a 50 percent beneficial use rate of CCPs by 2011;
- Increase the use of coal fly ash in concrete by 50 percent (from 12.4 million tons per year in 2001 to 18.6 million tons by 2011); and
- Reduce greenhouse gas emissions from concrete production by approximately 5 million metric tons CO_2 equivalent by 2010.[1]

CCPs are formed during coal-burning processes in power plants and industrial boilers. Coal combustion produces various forms of CCPs, which are categorized by the process in which they are generated. Common CCPs include: fly ash, bottom ash, Flue Gas Desulphurization (FGD) material, boiler slag, Fluidized Bed Combustion (FBC) ash, and cenospheres. CCPs may be beneficially used as a component of building materials or as a replacement for other virgin materials such as sand, gravel, or gypsum. Size, shape, and chemical composition determine the suitability of these materials for beneficial use. Higher value applications, such as use in cement or concrete products, require moderately stringent specifications (in terms of size, shape and chemical composition), whereas lower value uses, such as structural or mining fills, can accept more variable materials.

This report serves two purposes: (1) To provide an initial assessment of the market dynamics that affect the generation, disposal, recovery, and beneficial use of CCPs; and (2) to provide a preliminary life cycle analysis of the beneficial impacts of CCP use, including an initial estimate of the baseline beneficial use impacts with current (2005) CCP levels and, for some materials, the beneficial impacts associated with achieving the 2011 RCC goal.

CCP GENERATION AND MARKET DYNAMICS

The American Coal Ash Association (ACAA), a trade association whose purpose is to advance the beneficial use of CCPs, reports that the electric power industry generates approximately 123 million short tons of CCPs annually. Of these, the industry disposed of approximately 74 million short tons to landfills, while beneficially using approximately 50 million short tons in products.[2] Exhibit ES-1 summarizes results of the most recent (2005) ACAA survey of generators of CCPs, which indicates that

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[1] U.S. EPA, "About C2P2," accessed at http://www.epa.gov/epaoswer/osw/conserve/c2p2/about/about.htm.

[2] The ACAA survey is administered to both ACAA members and non-members. ACAA members account for approximately 40 percent of private power generation. Not all survey recipients complete the survey each year. ACAA extrapolates survey respondent data to the entire coal-fired electricity generation industry.

the most common beneficial use applications for CCPs are as a replacement for virgin materials in concrete and cement-making, structural fill, and gypsum wallboard.

EXHIBIT ES-1: ACAA SURVEY OF KEY BENEFICIAL USE APPLICATIONS FOR CCPS IN 2005 (MILLION SHORT TONS)

APPLICATION (INDUSTRY)	COAL FLY ASH	BOTTOM ASH	FGD GYPSUM	OTHER FGD WET MATERIAL	FGD DRY MATERIAL	BOILER SLAG	FBC ASH	TOTAL
Concrete[a] (Construction)	14.99	1.02	0.33	0	0.01	0	0	**16.35**
Structural fill[b] (Construction)	5.71	2.32	0	0	< 0.01	0.18	0.14	**8.35**
Wallboard[c] (Construction)	0	0	8.18	0	0	0	0	**8.18**
Raw feed for cement clinker[d] (Construction)	2.83	0.94	0.40	< 0.01	0	0.04	0	**4.22**
Waste stabilization[e] (Waste Mgmt)	2.66	0.04	0	0	0	0	0.14	**2.84**
Blasting Grit/Roofing Granules	0	0.89	0	0	0	1.54	0	**1.63**
Total - Key Uses	*26.19*	*4.41*	*8.90*	*< 0.01*	*0.02*	*1.76*	*0.28*	*41.57*
Total - Other Uses[f]	*2.93*	*3.13*	*0.36*	*0.69*	*0.014*	*0.13*	*0.66*	*8.04*
TOTAL - ALL USES	**29.12**	**7.54**	**9.27**	**0.69**	**0.16**	**1.89**	**0.94**	**49.61**
2005 QUANTITY GENERATED	**71.10**	**17.60**	**12.00**	**17.70**	**1.43**	**1.96**	**1.37**	**123.13**[g]
CCP UTILIZATION RATE[h]	**41%**	**43%**	**77%**	**4%**	**11%**	**97%**	**69%**	**40%**

Notes:

a. CCPs are frequently used as a replacement for a portion of portland cement in the manufacture of concrete.
b. Structural fill is an engineered material that is used to raise or change the surface contour of an area and to provide ground support beneath highway roadbeds, pavements and building foundations. It can also be used to form embankments.
c. FGD gypsum is used as a substitute for virgin gypsum in wallboard manufacturing.
d. CCPs can be blended with limestone or shale and fed into the cement kiln to make clinker, which is then ground into portland cement.
e. The chemical properties of CCPs make them effective stabilizers of biosolids (i.e., sludge from municipal waste water treatment).
f. Includes quantities beneficially used in minor applications not included in this exhibit, but listed in Appendix A.
g. Includes 115,596 tons of "Other FGD Material" not listed in this table because of the small quantities generated.
h. CCP utilization rates reflect all use applications, some of which are omitted from this table but are included in Appendix A. Utilization rates are calculated by dividing the total quantity used by the total quantity generated.

Note: Results from the 2006 CCP Production and Use Survey conducted by the ACAA indicate a total utilization rate of 43.43 percent, up from 40.29 percent reported for 2005. This reflects an ongoing upward trend in the CCP utilization rate over the past decade. The 2006 results were received too late for incorporation into this report.

Sources:

1. American Coal Ash Association. "2005 Coal Combustion Product (CCP) Production and Use Survey," accessed at: http://www.acaa-usa.org/PDF/20045_CCP_Production_and_Use_Figures_Released_by_ACAA.pdf.
2. Western Region Ash Group, "Applications and Competing Materials, Coal Combustion Byproducts," accessed at: http://www.wrashg.org/compmat.htm.

The CCP beneficial use market is composed of three primary segments. These are:

- **Generators:** Approximately 400 to 500 coal-fired electric utilities currently operate in the United States. Since the coal power industry consumes approximately 92% of all U.S. coal, it is responsible for producing the vast majority of CCPs in the country. Other industries that use coal as a fuel source in commercial or industrial boilers (e.g., mineral and grain processors) also produce small quantities of CCPs. Several factors influence a generator's decision to either dispose or seek beneficial use options for spent CCPs. Key considerations include the costs of landfill disposal, transport, processing, storage, and marketing.
- **Intermediaries:** Some coal-fired utilities market CCPs for beneficial use through a third-party instead of selling directly to users. In these cases, a utility perceives an efficiency in outsourcing the marketing of its CCPs. Marketers typically accept all of a generator's CCPs as a service to the company, sell the marketable portion, and dispose of the portion that is not salable. The marketer typically bears the cost of hauling CCPs from the utility and the liability associated with moving or storing the materials.
- **End-Users:** Several economic factors determine an end-user's decision to use CCPs in its product. These factors include: the price of CCPs relative to the price of virgin materials for specific uses; the technical fit between CCPs and the use application; access to sufficient quantities of CCPs; and federal and state policies associated with CCP use.

Impacts of Current Policy Setting on Market Dynamics

While states play a primary role in establishing industrial waste regulations and guidance, EPA has an opportunity to provide coordination and assistance at the national and regional level to help achieve a shift in waste management policy. EPA is currently engaged in several partnerships to facilitate and increase beneficial use of CCPs. Efforts within these partnerships include: promoting the beneficial use of CCPs through the development of web resources; developing technical guidance on the best practices for the beneficial use of CCPs; holding educational workshops and outreach support for CCP users; and providing recognition for the innovative beneficial use of CCPs. Key partners in these efforts include the American Coal Ash Association (ACAA), Utility Solid Waste Group (USWAG), the U.S. Department of Energy (DOE), and the Federal Highway Administration (FHWA).

ESTIMATING THE IMPACTS OF THE BENEFICIAL USE OF CCPS

To quantify the environmental impacts of increased beneficial use of CCPs in various applications, we use a life cycle analysis approach, as both a first step in an economic analysis, and, where economic analysis is not practical, as a meaningful proxy.

To estimate beneficial impacts of CCP use, we first develop preliminary estimates of the incremental impacts associated with using a specific quantity (e.g., one ton) of CCPs in different applications. These impacts can then be extrapolated in specific scenarios designed to address program-level outcomes. To fully capture the beneficial impacts of EPA program achievements, it is necessary to model each beneficial use application of all CCPs targeted by the RCC. However, the time, data, and resources required to perform this task are beyond the scope of this report. For this preliminary analysis, therefore, we have selected two common CCPs, fly ash and FGD gypsum, whose beneficial use applications are well understood, and for which life cycle models and existing data are available.

We conduct separate analyses to evaluate the incremental environmental impacts associated with beneficially using a specific quantity (e.g., one ton) of fly ash and FGD gypsum. We selected two life cycle modeling applications, Building for Environmental and Economic Sustainability (BEES) and SimaPro, to conduct the analyses. Both models have been peer-reviewed and evaluate a large suite of environmental metrics. We employ the BEES model to investigate the beneficial impacts of using one ton of fly ash as a substitute for finished portland cement in concrete, and SimaPro to evaluate the use of one ton of FGD gypsum as a substitute for virgin gypsum in wallboard. Both analyses assume that the beneficial use material (fly ash or FGD gypsum) substitutes for virgin material (finished portland cement or virgin gypsum) on a one-to-one, mass-based basis. Exhibit ES-2 presents the results of the BEES and SimaPro analysis.

EXHIBIT ES-2: INCREMENTAL BENEFICIAL IMPACTS OF USING FLY ASH IN PORTLAND CEMENT AND FGD GYPSUM IN WALLBOARD

AVOIDED IMPACTS	PER 1 TON FLY ASH AS PORTLAND CEMENT SUBSTITUTE IN CONCRETE	PER 1 TON FGD GYPSUM IN WALLBOARD
ENERGY USE		
NONRENEWABLE ENERGY (MJ)[a]	4,214.18	12,568.97
RENEWABLE ENERGY (MJ)[b]	43.55	13.69
TOTAL PRIMARY ENERGY (MJ)	4,259.29	12,582.66
TOTAL PRIMARY ENERGY (US$)[c]	119.26	352.31
WATER USE		
TOTAL WATER USE (L)	341.56	14,214.60
TOTAL WATER USE (US$)[d]	0.22	9.01
GREENHOUSE GAS EMISSIONS		
CO_2 (G)	636,170.21	77,754.24
METHANE (G)	539.49	175.51
AIR EMISSIONS		
CO (G)	593.45	39.06
NOX (G)	1,932.48	168.02
SOX (G)	1,518.21	139.14
PARTICULATES GREATER THAN PM_{10} (G)	0.00	1,194.25
PARTICULATES LESS THAN OR EQUAL TO PM_{10} (G)	0.01	520.93
PARTICULATES UNSPECIFIED (G)	1,745.25	17.11
MERCURY (G)	0.04	0.00
LEAD (G)	0.03	0.03
WATERBORNE WASTES		
SUSPENDED MATTER (G)	13.96	23.60
BIOLOGICAL OXYGEN DEMAND (G)	3.07	21.87

AVOIDED IMPACTS	PER 1 TON FLY ASH AS PORTLAND CEMENT SUBSTITUTE IN CONCRETE	PER 1 TON FGD GYPSUM IN WALLBOARD
CHEMICAL OXYGEN DEMAND (G)	26.00	24.71
COPPER (G)	0.00	0.02
MERCURY (G)	0.00	0.00
LEAD (G)	0.00	0.01
SELENIUM (G)	0.00	0.00
NONHAZARDOUS WASTE (KG)[e]	0.00	3.12

Notes:

a. Nonrenewable energy refers to energy derived from fossil fuels such as coal, natural gas and oil.

b. Renewable energy refers to energy derived from renewable sources, but BEES does not specify what sources these include.

c. In addition to reporting energy impacts in megajoules (MJ), we monetize impacts by multiplying model outputs in MJ by the average cost of electricity in 2006 ($0.0275/MJ), converted to 2007 dollars ($0.0280/MJ). The 2006 cost of energy is taken from the Federal Register, February 27, 2006, accessed at: http://www.npga.org/14a/pages/index.cfm?pageid=914. The cost was converted to 2007 dollars using NASA's Gross Domestic Product Deflator Inflation Calculator, accessed at: http://cost.jsc.nasa.gov/inflateGDP.html.

d. In addition to reporting water impacts in gallons, we monetize impacts by converting model outputs from liters to gallons and multiplying by the average cost per gallon of water between July 2004 and July 2005 ($0.0023/gal), converted to 2007 dollars ($0.0024/gal). The 2005 cost of water is taken from NUS Consulting Group, accessed at: https://www.energyvortex.com/files/NUS_quick_click.pdf. The cost was converted to 2007 dollars using NASA's Gross Domestic Product Deflator Inflation Calculator, accessed at: http://cost.jsc.nasa.gov/inflateGDP.html.

e. BEES reports waste as “end of life waste.” In contrast, SimaPro reports “solid waste.” It is not clear if these waste metrics are directly comparable as SimaPro does not specify whether “solid waste” refers to manufacturing waste, end-of-life waste, or both.

The results of the fly ash and FGD gypsum analyses suggest many positive environmental impacts from beneficial use. For most metrics, there is a significant difference between the unit impact value for fly ash and FGD gypsum. The difference in unit impact values reflects different avoided processes when fly ash is used to offset portland cement versus when FGD gypsum is used to offset virgin gypsum. For example, the primary driver of benefits when fly ash is used in concrete is avoided raw materials extraction and avoided portland cement production.[3] In comparison, the primary driver of benefits when FGD gypsum is used in wallboard is avoided virgin gypsum extraction and the processing of virgin gypsum into stucco. Portland cement production generates relatively high greenhouse gas emissions. Thus, the avoided CO_2 and methane emissions are greater for fly ash than for FGD gypsum in this analysis. In contrast, gypsum mining requires comparatively higher quantities of water, so the water savings are greater for FGD gypsum in this analysis than for portland cement. In addition, the difference in unit impacts likely reflects minor differences in the system boundaries in each analysis and the data sets utilized by each model.

ESTIMATING PROGRAM LEVEL IMPACTS

In order to extrapolate the beneficial impacts presented in Exhibit ES-2 to evaluate EPA’s program level efforts, two critical steps are necessary.

- Development of defensible beneficial use scenarios that accurately identify the extent to which different beneficial uses are likely to increase; and

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[3] It is unclear from the documentation provided for BEES what impacts (e.g. virgin materials extraction, plant infrastructure, etc.) are modeled for portland cement production. For this reason, it is not possible to explain the differences in unit impact results between the FGD gypsum and fly ash analysis.

- Implementation of a well-supported attribution protocol for assigning beneficial use impacts to specific EPA programs.

At this time, the data necessary to develop accurate beneficial use scenarios and to support a clear attribution of impacts are not sufficient to inform a detailed program analysis. In the absence of such data, we present a preliminary analysis of the total impacts associated with current (baseline) beneficial use patterns. While these impacts do not strictly reflect RCC program achievements, they represent the best available information on the environmental benefits of beneficially using certain CCPs, and reflect the impacts of all EPA, state, and industry efforts to increase CCP use to its 2005 level. The beneficial use impacts of current fly ash and FGD gypsum use are calculated by extrapolating the impacts identified in Exhibit ES-3 to the current quantity of each material beneficially used in each application. For fly ash, we also extrapolate the beneficial impacts associated with achieving the 2011 RCC goal—a 50% increase in fly ash use in concrete. Exhibit ES-3 presents the key impacts of the beneficial use of CCPs extrapolated to current use quantities. Note that the impacts presented in Exhibit ES-3 represent only a partial estimate of the total impacts of beneficially using CCPs. Beneficial use of fly ash as a substitute for finished portland cement in concrete and FGD gypsum in wallboard accounts for only 47% (23.2 million tons) of all beneficially used CCPs in 2005.

EXHIBIT ES-3: EXTRAPOLATED IMPACTS OF THE BENEFICIAL USE OF CCPs

AVOIDED IMPACTS	FLY ASH IN CONCRETE EXTRAPOLATED TO RCC GOAL (18.6 MILLION TONS)[a]	FLY ASH IN CONCRETE EXTRAPOLATED TO CURRENT USE (15.0 MILLION TONS)[b]	FGD GYPSUM IN WALLBAORD EXTAPOLATED TO CURRENT USE (8.2 MILLION TONS)[c]	PARTIAL SUM OF CURRENT USE BENEFICIAL IMPACTS[d]
ENERGY USE				
NONRENEWABLE ENERGY (MJ)[e]	78.4 billion	63.2 billion	102.8 billion	166.0 billion
RENEWABLE ENERGY (MJ)[f]	810.0 million	652.8 million	111.9 million	764.7 million
TOTAL PRIMARY ENERGY (MJ)	79.2 billion	63.8 billion	102.9 billion	166.7 billion
TOTAL PRIMARY ENERGY (US$)[g]	$2.2 billion	$1.8 billion	$2.9 billion	$4.7 billion
WATER USE				
TOTAL WATER USE (LITERS)	6.3 billion	5.2 billion	116.2 billion	121.4 billion
TOTAL WATER USE (US$)[h]	$4.0 million	$3.2 million	$73.7 million	$77.9 million
GREENHOUSE GAS EMISSIONS				
CO_2 (G)	11.8 trillion	9.5 trillion	0.6 trillion	10.2 trillion
METHANE (G)	10.0 billion	8.1 billion	1.4 billion	9.5 billion
TONS CO_2 EQUIVALANT[i]	13.2 million	10.6 million	0.7 million	11.5 million
AIR EMISSIONS				
CO (G)	11.0 billion	8.9 billion	0.3 billion	9.2 billion
NOx (G)	35.9 billion	29.0 billion	1.4 billion	30.3 billion
SOx (G)	28.2 billion	22.8 billion	1.1 billion	23.9 billion

AVOIDED IMPACTS	FLY ASH IN CONCRETE EXTRAPOLATED TO RCC GOAL (18.6 MILLION TONS)[a]	FLY ASH IN CONCRETE EXTRAPOLATED TO CURRENT USE (15.0 MILLION TONS)[b]	FGD GYPSUM IN WALLBAORD EXTAPOLATED TO CURRENT USE (8.2 MILLION TONS)[c]	PARTIAL SUM OF CURRENT USE BENEFICIAL IMPACTS[d]
PARTICULATES GREATER THAN PM_{10} (G)	0	0	9.7 billion	9.7 billion
PARTICULATES LESS THAN OR EQUAL TO PM_{10} (G)	0.2 million	.02 million	4.3 million	4.3 million
PARTICULATES UNSPECIFIED (G)	32.5 billion	26.1 billion	0.1 billion	26.3 billion
MERCURY (G)	714,000	576,000	8,000	584,000
LEAD (G)	523,000	421,000	235,000	656,000
WATERBORNE WASTES				
SUSPENDED MATTER (G)	259.6 million	209.2 million	193.0 million	402.2 million
BIOLOGICAL OXYGEN DEMAND (G)	57.1 million	46.1 million	178.8 million	1224.9 million
CHEMICAL OXYGEN DEMAND (G)	483.6 million	389.7 million	202.1 million	591.8 million
COPPER (G)	0	0	194,000	194,000
MERCURY (G)	1	0	3,000	3,000
LEAD (G)	0	0	65,000	65,000
SELENIUM (G)	3	2	2,000	2,000
NON-HAZARDOUS WASTE (KG)[j]	0	0	25.4 million	25.4 million

Notes:

a. We extrapolate the incremental impacts (i.e., impacts associated with use of 1 ton fly ash) to estimate impacts of attaining the RCC goal for the use of fly ash in concrete (18.6 million tons by 2011). To extrapolate, we multiply each of the incremental impacts calculated by the BEES model by 18.6 million.

b. We extrapolate the incremental impacts (i.e., impacts associated with use of 1 ton fly ash) to estimate the impacts of current beneficial use of fly ash in concrete (15.0 million tons). The current quantity of fly ash that is beneficially used as a substitute for finished portland cement in concrete is reported by ACAA's 2005 CCP Survey. We multiply each of the incremental impacts calculated by BEES by 15.0 million tons to extrapolate these impacts to reflect current use.

c. We extrapolate the incremental impacts (i.e., impacts associated with use of 1 ton FGD gypsum) to estimate the impacts of current beneficial use of FGD gypsum in wallboard (8.2 million tons). The current quantity of FGD gypsum that is beneficially used as a substitute for finished portland cement in concrete is reported by ACAA's 2005 CCP Survey. We multiply each of the incremental impacts calculated by SimaPro by 8.2 million to extrapolate these impacts to reflect current use.

d. Calculated as the sum of the fly ash and FGD gypsum current use extrapolations.

e. Nonrenewable energy refers to energy derived from fossil fuels such as coal, natural gas and oil.

f. Renewable energy refers to energy derived from renewable sources, but BEES does not specify what sources these include.

g. In addition to reporting energy impacts in megajoules (MJ), we monetize impacts by multiplying model outputs in MJ by the average cost of electricity in 2006 ($0.0275/MJ), converted to 2007 dollars ($0.0280/MJ). The 2006 cost of energy is taken from the Federal Register, February 27, 2006, accessed at: http://www.npga.org/14a/pages/index.cfm?pageid=914. The cost was converted to 2007 dollars using NASA's Gross Domestic Product Deflator Inflation Calculator, accessed at: http://cost.jsc.nasa.gov/inflateGDP.html.

h. In addition to reporting water impacts in gallons, we monetize impacts by converting model outputs from liters to gallons and multiplying by the average cost per gallon of water between July 2004 and July 2005 ($0.0023/gal), converted to 2007 dollars ($0.0024/gal). The 2005 cost of water is taken from NUS Consulting Group, accessed at: https://www.energyvortex.com/files/NUS_quick_click.pdf. The cost was converted to 2007 dollars using NASA's Gross Domestic Product Deflator Inflation Calculator, accessed at: http://cost.jsc.nasa.gov/inflateGDP.html.

i. Greenhouse gas emissions have been converted to tons of CO_2 equivalent using U.S. Climate Technology Cooperation Gateway's Greenhouse Gas Equivalencies Calculator accessed at: http://www.usctcgateway.net/tool/. This calculation only includes CO_2 and methane.

j. BEES reports waste as "end of life waste." In contrast, SimaPro reports "solid waste." It is not clear if these waste metrics are directly comparable as SimaPro does not specify whether "solid waste" refers to manufacturing waste, end-of-life waste, or both.

The results show that current beneficial use of fly ash in concrete and FGD gypsum in wallboard results in positive environmental impacts. The most significant impacts include energy savings and water use reductions. Energy savings associated with the use of fly ash and FGD gypsum totals approximately 167 billion megajoules of energy (or approximately $4.7 billion in 2007 energy prices). Based on the average monthly consumption of residential electricity customers, this is enough energy to power over 4 million homes for an entire year. Avoided water use totals approximately 121 billion liters or approximately $76.9 million in 2007 water prices).[4] This is roughly equivalent to the annual water consumption of 61,000 Americans.[5] The extrapolated beneficial impacts also include key impacts such as avoided greenhouse gas (11.5 million tons of avoided CO_2 equivalent), and avoided air emissions (30.3 million kilograms of avoided NOx, and 23.9 million kilograms of SOx).

This report also presents a distributional screening analysis using the EIO-LCA model that indicates significant avoided environmental impacts from reductions in the demand for cement or virgin gypsum that are distributed across several economic sectors. From the perspective of energy and air emissions, cement manufacturing leads to large impacts, and is in general the largest source of emissions across the supply chain. Reducing the amount of cement produced by beneficially reusing products can lead to large supply chain-wide reductions of emissions. Comparatively, the impact of the substitution of FGD gypsum for virgin gypsum in wallboard manufacturing is less clear, as the model was not able to adequately represent the wallboard sector.[6]

The preliminary results of this initial analysis suggest that a more detailed evaluation of the beneficial impacts of the beneficial use of CCPs could assist EPA in the more specific estimation of the achievements of the RCC program. A more detailed analysis would require:

- The development of realistic and effective beneficial use scenarios that incorporate more detailed descriptions of markets, beneficial uses, and policies. Realistic scenarios should reflect key market dynamics and limits such as distance to markets and virgin material prices, and be able to assess the impacts of these dynamics on the growth potential for specific beneficial uses.
- The development of a methodology to attribute beneficial use impacts to specific EPA/RCC efforts and programs. A phased approach may be employed that initially assumes all impacts result from EPA actions. This assumption could then be refined to reflect specific strategies, policies, and other efforts, and link these, where possible, to specific changes in beneficial use practices and markets.
- The expansion of the assessment to include additional CCPs and beneficial use applications. This analysis only examines the beneficial impacts of substituting using fly ash for finished portland cement in concrete and substituting FGD gypsum for virgin gypsum in wallboard manufacturing. The two processes represent less than 50% of the total beneficial use of CCPs. Additional high volume applications that EPA may wish to analyze include: the use of fly ash as a raw feed in cement clinker; the use of boiler slag as blasting grit; and the use of various CCPs in structural fill and waste stabilization. In addition, the Agency may investigate the beneficial impacts of lower volume applications to identify those that may have potentially high incremental impacts.

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[4] Based on the assumption that an average residential customer uses 938 kilowatt-hours per month. Department of Energy, Energy Information Administration, "Energy Basics 101," http://www.eia.doe.gov/basics/energybasics101.html, accessed August 30, 2007.

[5] Based on 2000 USGS per capita water use estimate of 1,430 gallons per day. Lumia et al., United States Department of the Interior, United States Geological Survey, Summary of Water Use in the United States, 2000.

[6] EIO-LCA models impacts at the sector level using NAICS codes but an individual NAICS code does not exist for the wallboard manufacturing sector.

CHAPTER 1: INTRODUCTION

The U.S. Environmental Protection Agency's Office of Solid Waste (EPA OSW) is currently considering the strategic direction of solid and hazardous waste policy. As part of this effort, OSW is developing methods to evaluate the environmental, human health, and economic outcomes of specific EPA programs to support strategic planning and program evaluation. Three important areas of focus in this transition are:

- Measurement of materials flow and life cycle impacts related to waste minimization and materials recovery and reuse, including an emphasis on "upstream" resource conservation beneficial impacts;
- Documentation of the impacts of voluntary programs, including the various efforts and materials targeted by EPA's Resource Conservation Challenge (RCC);[7] and
- Development of data and approaches that can support annual performance reporting under the Government Performance and Results Act (GPRA) and OMB's Performance Assessment Rating Tool (PART) evaluations.

As an initial step in the development of methods to assess the beneficial impacts of program benefits for both voluntary programs and PART, OSW is examining the extent to which the costs and benefits of source reduction, reuse, and recycling may be quantified for a range of materials targeted by the RCC.

This report examines one of the materials targeted under the RCC: coal combustion products (CCPs). CCPs are produced during coal-burning process at electric utilities and in industrial boilers. Beneficial use of CCPs refers to the use or substitution of CCPs for other products based on performance criteria. Under the RCC, EPA has established three goals for increased beneficial use of CCPs:

- Achieve a 50 percent beneficial use rate of CCPs by 2011;
- Increase the use of coal fly ash in concrete by 50 percent (from 12.4 million tons per year in 2001 to 18.6 million tons by 2011); and
- Reduce greenhouse gas emissions from concrete production by approximately 5 million metric tons CO_2 equivalent by 2010.[8]

Additionally, to support efforts to increase the beneficial use of CCPs, EPA has established partnerships with several industry groups and government agencies, including the American Coal Ash Association (ACAA), Utility Solid Waste Group (USWAG), the U.S. Department of Energy (DOE), and the Federal Highway Administration (FHWA). Efforts within these partnerships include: promoting the beneficial use of CCPs through the development of web resources; developing technical guidance on the best practices for the beneficial use of CCPs; holding educational workshops and outreach support for CCP users; and providing recognition for the innovative beneficial use of CCPs.

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[7] The RCC is an EPA initiative that seeks to identify and encourage innovative, flexible, and protective ways to conserve natural resources and energy. Specifically, the RCC is a cross-Office program that assists in developing voluntary programs that promote the source reduction, reuse, and recycling of materials.

[8] U.S. EPA, "About C2P2," accessed at http://www.epa.gov/epaoswer/osw/conserve/c2p2/about/about.htm.

OVERVIEW OF REPORT

This report serves two purposes: (1) To provide an initial assessment of the market dynamics that affect the generation, disposal, recovery, and beneficial use of CCPs; and (2) to provide a preliminary life cycle analysis of beneficial impacts of CCP use, including an initial estimate of the baseline beneficial use impacts with current (2005) CCP levels and, for some materials, the beneficial impacts associated with achieving the 2011 RCC goal. Ultimately, in combination with specific information about explicit RCC efforts, this report can be used to support the development and implementation of measures of program efficiency.

Organization of Report

The report proceeds in four chapters following this introduction. To provide market context, the second chapter characterizes the current generation and management of CCPs. The third chapter summarizes the current market structure for CCPs and outlines specific EPA efforts to increase their beneficial use. The fourth chapter uses baseline and Agency goal information, and available LCA tools to provide a preliminary life cycle analysis of the impacts of beneficial use of FGD gypsum and fly ash. The final chapter discusses the potential to extrapolate these beneficial use impacts and attribute them to EPA program efforts.

CHAPTER 2: BASELINE CHARACTERIZATION OF CCP GENERATION AND BENEFICIAL USE

The coal-fired power industry is the largest generator of CCPs. Other industries, such as commercial boilers and mineral and grain processors that use coal as a fuel source also produce small quantities of CCPs. Because these other industries generate such small quantities of CCPs relative to the coal-fired electric power industry, this report focuses solely on the coal-fired electric power industry.[9]

CCPs are categorized by the process in which they are generated, which varies by plant. CCPs include the following materials:

- **Fly ash.** Exhaust gases leaving the combustion chamber of a power plant entrain fly ash particles during the coal combustion process. To prevent fly ash from entering the atmosphere, power plants use various collection devices to remove it from the gases that are leaving the stack. Fly ash is the finest of coal ash particles. The American Society for Testing and Material (ASTM) identifies two classes of fly ash suitable for beneficial use based on chemical composition. Class F fly ash results from the burning of anthracite or bituminous coal, while Class C fly ash results from the burning of lignite or subbituminous coal.

- **Bottom ash.** With grain sizes ranging from fine sand to fine gravel, bottom ash is coarser than fly ash. Utilities collect bottom ash from the floor of coal burning furnaces used in the generation of steam, the production of electric power, or both. The physical characteristics of the product generated depend on the characteristics of the furnace.

- **Flue Gas Desulphurization (FGD) material.** FGD material results from the flue gas desulphurization scrubbing process that transforms gaseous SO_2, released during coal combustion, to sulfur compounds. Coal-fired power plants employ either a wet or dry scrubbing method to remove SO_2 from their emissions. The final by-product of wet scrubbing is primarily FGD gypsum, although small amounts of other materials (e.g., ash, metals) are also produced.[10] In this report, we refer to these other materials as "other FGD wet material." The dry method produces by-products that consist of mainly calcium sulfite, fly ash, portlandite, and calcite. Collectively, we refer to these materials as "FGD dry material."[11] All three materials, FGD gypsum, other FGD wet scrubber material, and FGD dry scrubber material, can be used in a growing number of beneficial use applications.

- **Boiler Slag.** Boiler slag consists of molten ash collected at the base of cyclone boilers. Facilities cool boiler slag with water, which then shatters into black, angular pieces that have a smooth appearance.

- **Fluidized Bed Combustion (FBC) ash** (not pictured in Exhibit 2-1)**.** A fluidized bed combustion boiler, a type of coal boiler that combines the coal combustion and flue gas

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[9] As of the writing of this report, we were unable to locate data estimating the quantities of CCPs attributable only to the electric power industry; however, since the coal power industry consumes approximately 92 percent of all U.S. coal, it is reasonable to assume that significant majority of CCPs result from the burning of coal at coal-fired power plants. Department of Energy, Energy Information Administration, "U.S. Coal Consumption by End-Use Sector," http://www.eia.doe.gov/cneaf/coal/quarterly/html/t28p01p1.html, June 2007.

[10] FGD gypsum has the same chemical structure as naturally occurring gypsum (calcium sulfate dehydrate).

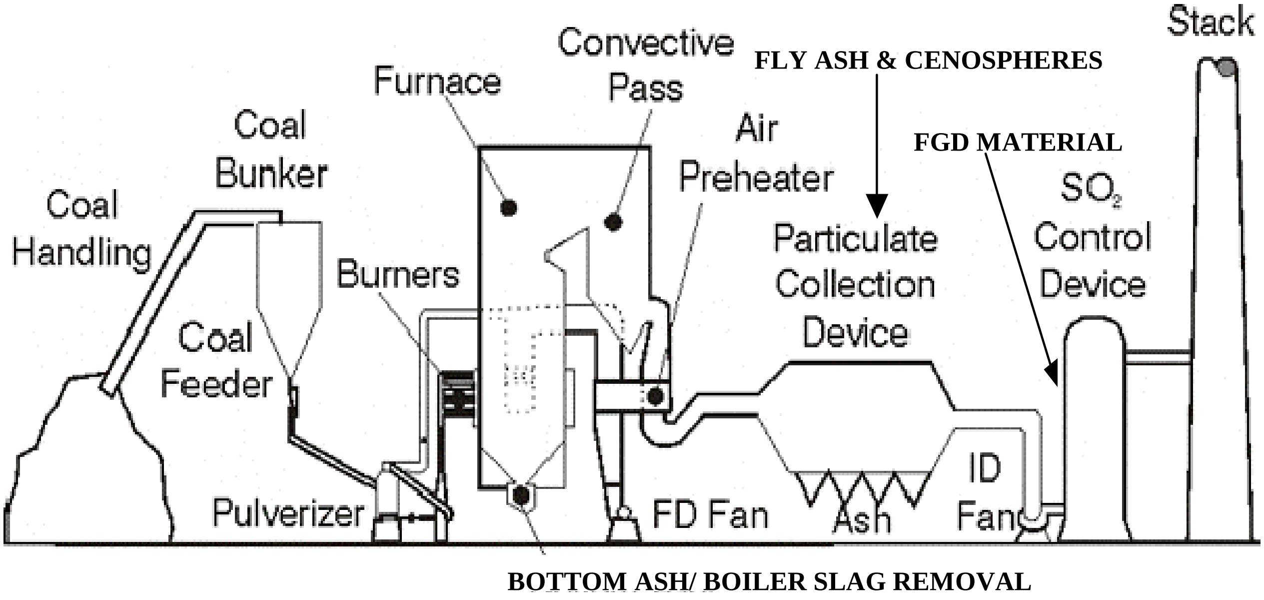
[11] Electric Power Research Institute. 1999. Environmental Focus: Flue Gas Desulfurization By-Products. BR-114239

desulphurization processes within a single furnace, generates FBC ash. FBC ash is rich in lime and sulfur.

- **Cenospheres.** Generated as a component of fly ash in high temperature coal combustion, cenospheres consist of extremely small, lightweight, inert, hollow spheres comprised largely of silica and alumina that are filled with low-pressure gases.[12] When fly ash is disposed in settlement lagoons, cenospheres can be collected on the surface where they can be skimmed for use in manufacturing processes.

At a typical coal-fired power plant, coal combustion generates CCPs during several phases of the process. Exhibit 2-1 illustrates the collection of several types of CCPs. As depicted below, facilities remove bottom ash and boiler slag from the base of the furnace. Fly ash accumulates in the particulate collection device, while FGD material collects in the SO_2 control device.

EXHIBIT 2-1: COAL COMBUSTION PROCESS AT A COAL-FIRED POWER PLANT



Source: Energy Information Administration, accessed at: www.eia.doe.gov.

CURRENT QUANTITIES OF CCPS GENERATED AND MANAGED

In 2005, the coal-fueled electric power industry generated approximately 123 million short tons of CCPs. Of these, the industry disposed of approximately 74 million short tons to landfills, while beneficially using approximately 50 million short tons in products. Exhibit 2-2, below, presents the current quantities of CCPs generated and managed, in the context of other materials targeted by the RCC. Except for construction and demolition material, the U.S. generates larger quantities of CCPs than other industrial and municipal solid waste (MSW).

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[12] Cenospheres range in size from 20 to 5000 microns.

EXHIBIT 2-2: RCC MATERIALS BY QUANTITIY

MATERIAL[a]	QUANTITY GENERATED (MILLION SHORT TONS)	QUANTITY RECOVERED/ BENEFICIALLY USED[b] (MILLION SHORT TONS)	QUANTITY DISPOSED (MILLION SHORT TONS)	YEAR
C&D Material[1]	331	214[c]	118	2003
CCPs[2]	**123**	**50**	**74**	**2005**
Paper and Paperboard[3]	83	40	43	2003
Packaging[3]	74	29	45	2003
Organics[3]	56	17	39	2003
Foundry Sand[4, d]	9.2	2.6	6.6	2005
Chemicals[5]	0.04	NA	NA	2003

Notes:

a. Under the RCC 2005 Action Plan, increases in the rate of MSW recovery and reduction of priority and toxic chemicals are also targeted. We have included these material streams in this exhibit even though they are not targeted specifically for beneficial use.
b. The figures shown for paper and paperboard, packaging, and organics are the quantities recovered from the MSW stream. The figures shown for C&D debris, CCPs, and foundry sand are quantities that are beneficially used.
c. A Construction Materials Recycling Association member survey estimates that approximately 270 million tons of C&D material including asphalt and concrete from roads, bridge-related infrastructure, and land clearing debris was recovered in 2004.
d. The foundry sand quantity generated is uncertain, but estimates fall within the range of 6 to 10 million tons/year. Due to the lack of precise data on annual quantities generated and managed, the quantity disposed may include foundry sand that is being beneficially used as daily landfill cover.

Sources:

1. US EPA, "Characterization of Building-Related Construction and Demolition Debris in the United States" and "Characterization of Road-related Construction and Demolition Debris in the United States," 2005. (Note that these documents are preliminary and are currently undergoing peer-review).
2. American Coal Ash Association (ACAA), "2005 Coal Combustion Product (CCP) Production and Use Survey," accessed on October 29, 2006 at: http://www.acaa-usa.org/PDF/2005_CCP_Production_and_Use_Figures_Released_by_ACAA.pdf.
3. US EPA, "Municipal Solid Waste in the United States: 2003 Data Tables," Table 1, accessed on October 26, 2006 at: <http://www.epa.gov/epaoswer/non-hw/muncpl/pubs/03data.pdf>.
4. American Foundry Society (AFS). "Foundry Industry Benchmarking Survey," August 2007.
5. US EPA, "Draft National Priority Trends Report (1999-2003) Fall 2005," as reported in the NPEP GPRA 2008 database of TRI data from 1998-2003.

The American Coal Ash Association (ACAA), a trade association whose purpose is to advance the beneficial use of CCPs, conducts an annual survey of coal-fired electric plants to collect data on the production, disposal, and use of CCPs in the U.S.[13] Exhibit 2-3 summarizes the 2005 survey on generation, disposal, and beneficial use of various CCP categories.

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[13] The ACAA survey is administered to both ACAA members and non-members. ACAA members account for approximately 40 percent of private power generation. Not all survey recipients complete the survey each year. ACAA extrapolates survey respondent data to the entire coal-fired electricity generation industry. To the extent that other coal-burning industries are not represented in the ACAA sample, the survey may underestimate the quantity of CCPs generated and/or beneficially used.

EXHIBIT 2-3: SUMMARY OF CCP GENERATION AND MANAGEMENT IN 2005

PRODUCT	CCPS GENERATED (MILLION SHORT TONS)	BENEFICIALLY USED (MILLION SHORT TONS)	PERCENT USED	QUANTITY DISPOSED (MILLION SHORT TONS)[a]	PERCENT DISPOSED
Fly Ash	71.10	29.12	41%	41.98	59%
Flue Gas Desulfurization (FGD) Material	31.10	10.12	33%	20.99	67%
Other FGD Wet Material	*17.70*	*0.69*	*4%*	*17.01*	*96%*
FGD Gypsum	*11.98*	*9.30*	*77%*	*2.71*	*23%*
FGD Dry Material	*1.43*	*0.16*	*11%*	*1.27*	*89%*
Bottom Ash	17.60	7.52	43%	10.06	57%
Boiler Slag	1.96	1.90	97%	0.07	3%
Fluidized Bed Combustion (FBC) Ash	1.37	0.94	69%	0.42	31%
Cenospheres[b]	Not available	0.08 [c]	Not available	Not available	Not available
Total CCPs	**123.13**	**49.61**	**40%** (see note 2)	**73.51**	**60%**

Notes:

a. Calculated by subtracting quantity beneficially used from quantity generated.

b. The ACAA's "CCP Production and Use Survey" does not report total generation or disposal quantities for cenospheres, only sales.

c. Follow-up communication with D. Goss on 11-10-07 indicated that this figure may be misreported in the 2005 CCP Survey. The actual figure is likely to be an order of magnitude less, or approximately 0.008 million short tons.

Note 2: Results from the 2006 CCP Production and Use Survey conducted by the ACAA indicate a total utilization rate of 43.43 percent, up from 40.29 percent reported for 2005. This reflects an ongoing upward trend in the CCP utilization rate over the past decade. The 2006 results were received too late for incorporation into the benefits analysis.

Source:

American Coal Ash Association. "2005 Coal Combustion Product (CCP) Production and Use Survey," accessed at: http://www.acaa-usa.org/PDF/2005_CCP_Production_and_Use_Figures_Released_by_ACAA.pdf.

Exhibit 2-3 illustrates several important aspects of the generation, beneficial use, and disposal of CPPs:

- Of reported materials, fly ash constitutes the largest proportion (58 percent) of CCP materials generated in 2005. FGD material follows at 26 percent.[14] Bottom ash, boiler slag and FBC ash collectively comprise the remaining 17 percent of CCPs generated in 2005.
- Boiler slag and FGD gypsum have the highest percentage of beneficial use of the six coal combustion products.
- Fly ash, FGD material (other than FGD gypsum), and bottom ash have the highest disposal rates.

In addition to quantities of fly ash reported in the ACAA survey, stockpiles may provide another potential source of fly ash for certain beneficial uses. Industry sources estimate that between 100 million and 500

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[14] The quantity of cenospheres generated is not reported by ACAA so the 58 percent estimate could be higher if cenospheres were included.

million tons of fly ash have accumulated in U.S. landfills since the 1920s, when disposal of fly ash in landfills began.[15, 16]

Beneficial Use Options

The chemical and physical properties of CCPs allow for their use in a wide range of products. CCPs may be used as a component of various building materials (i.e., as a replacement for portland cement in concrete) or as a direct replacement for other virgin materials such as sand, gravel, or gypsum. The physical properties of CCPs make them especially useful for construction and industrial materials. Size, shape, and chemical composition determine the suitability of specific material flows for beneficial use. Higher value applications, such as use in cement or concrete products, require comparatively stringent specifications (in terms of size, shape and chemical composition), whereas lower value uses, such as structural or mining fills, can accept more variable materials. For this reason, EPA has found that lower technology applications that require large volumes of CCPs may present the greatest potential for expanded beneficial use.[17]

Exhibit 2-4 summarizes the most common beneficial uses for each CCP. As shown, this table excludes cenospheres and FBC ash as data on the primary beneficial uses of these materials are not available.

EXHIBIT 2-4: COMMON BENEFICIAL USES FOR CCPS

CCP	BENEFICIAL USE
Fly Ash	**Concrete:** Concrete consists of a mixture of approximately 25% fine aggregate (sand), 45% gravel, 15% portland cement, and 15% water. Class C and class F fly ash can replace a percentage of the portland cement component of concrete. Fly ash contributes to enhanced concrete strength and durability, and is typically less expensive than portland cement.
	Cement clinker: Clinker is an intermediary product of the portland cement manufacturing process. Clinker is formed when a raw mix consisting of limestone, clay, bauxite, iron ore and quartz are heated in a kilm at higher temperatures. Fly ash can be blended with limestone or shale and fed into the cement kiln to make clinker, which is then ground into portland cement.
	Structural fill: Structural fill is an engineered material used to raise or change the surface contour of an area and to provide ground support beneath building foundations. It can also be used to form embankments. Depending on the soil type, fly ash can replace a percentage (generally 50 percent) of virgin rock, dirt, sand or gravel in structural fill.
	Waste stabilization: Fly ash can be used in place of portland cement, cement kiln dust, or lime to solidify and harden wet or liquid waste before it is landfilled. Class C fly ash hardens by itself in contact with moisture, but class F fly ash must be mixed with another hardening agent, such as portland cement, in order to be used in waste stabilization.

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[15] Personal communications with Dave Goss, ACAA and Tom Janson, WE Energies, November 27, 2006.

[16] The quantity of stockpiled fly ash that is available for beneficial use is unclear. The chemical composition of fly ash varies depending on the type of coal used, and only two types of fly ash--class C fly ash and class F fly ash—meet the ASTM technical requirements for concrete. It is unclear how much of the estimated 100-500 million tons of stockpiled fly ash falls into one of these classes. In addition, exposure to moisture or contamination in the stockpiles can limit the beneficial use options of Class C ash, though, this is not a concern with Class F ash. Information on these standards can be found at http://www.astm.org.

[17] EPA. 1999. "Report to Congress: Wastes from the Combustion of Fossil Fuels." Vol. II. EPA-530-R-99-010, March 1999.

CCP	BENEFICIAL USE
FGD Gypsum	**Wallboard:** Gypsum wallboard (or drywall) is used as an interior finish in the construction of homes and building. Wallboard is comprised of a layer of gypsum stucco sandwiched between two sheets of heavy paper. FGD gypsum can replace 100 percent of virgin gypsum in wallboard after the excess moisture has been removed.
	Agricultural soil amendment: FGD gypsum can be used to replace liming agents as an agricultural soil amendment for specific soil and crop types.
	Cement additive: In the production of portland cement, clinker is blended with a small amount of gypsum prior to grinding into finished portland cement. FGD gypsum can be used to offset virgin gypsum in cement manufacture.
Bottom Ash	**Structural fill:** Structural fill is an engineered material used to raise or change the surface contour of an area and to provide ground support beneath building foundations. It can also be used to form embankments. Bottom ash can be used to offset virgin sand and gravel in structural fill.
	Road base: A road base is a foundation layer underlying a pavement and overlaying a subgrade of natural soil or embankment fill material. It protects the underlying soil from the detrimental effects of weather conditions and from the stresses and strains induced by traffic loads. Bottom ash can be used to offset virgin sand or gravel in road base.
	Concrete: Bottom ash can be used as a coarse aggregate for concrete blocks, with its porous nature often qualifying the product for lightweight classification.
Boiler Slag	**Blasting Grit:** Blasting grit is an industrial abrasive used to shape, cut, sharpen, or finish a variety of other surfaces and materials. Boiler slag can be used as a replacement for other slags or virgin sand as blasting grit.
	Structural fill: Structural fill is an engineered material used to raise or change the surface contour of an area and to provide ground support beneath building foundations. It can also be used to form embankments. Boiler slag is occasionally used to offset virgin sand and gravel in structural fill.

Exhibit 2-5, below, illustrates the quantities of CCPs being used in the most common beneficial use applications. The applications highlighted in the exhibit represent approximately 80% of the current use of CCPs.[18] We include an expanded version of this table, which details a more inclusive set of CCP beneficial use applications, in Appendix A.

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[18] Relatively minor applications comprise the remaining 20 percent of CCP beneficial uses. These applications include use such as soil stabilizers, mineral filler in asphalt, and mine reclamation.

EXHIBIT 2-5: KEY BENEFICIAL USES FOR CCPS IN 2005 (MILLION SHORT TONS)

APPLICATION (INDUSTRY)	COAL FLY ASH	BOTTOM ASH	FGD GYPSUM	OTHER FGD WET MATERIAL	FGD DRY MATERIAL	BOILER SLAG	FBC ASH	TOTAL
Concrete[a] (Construction)	14.99	1.02	0.33	0	0.01	0	0	**16.35**
Structural fill[b] (Construction)	5.71	2.32	0	0	< 0.01	0.18	0.14	**8.35**
Wallboard[c] (Construction)	0	0	8.18	0	0	0	0	**8.18**
Raw feed for cement clinker[d] (Construction)	2.83	0.94	0.40	< 0.01	0	0.04	0	**4.22**
Waste stabilization[e] (Waste Mgmt)	2.66	0.04	0	0	0	0	0.14	**2.84**
Blasting Grit/Roofing Granules	0	0.89	0	0	0	1.54	0	**1.63**
Total - Key Uses	*26.19*	*4.41*	*8.90*	*< 0.01*	*0.02*	*1.76*	*0.28*	*41.57*
Total - Other Uses[f]	*2.93*	*3.13*	*0.36*	*0.69*	*0.014*	*0.13*	*0.66*	*8.04*
TOTAL - ALL USES	**29.12**	**7.54**	**9.27**	**0.69**	**0.16**	**1.89**	**0.94**	**49.61**
2005 QUANTITY GENERATED	**71.10**	**17.60**	**12.00**	**17.70**	**1.43**	**1.96**	**1.37**	**123.13[g]**
CCP UTILIZATION RATE[h]	**41%**	**43%**	**77%**	**4%**	**11%**	**97%**	**69%**	**40%** (see note 2)

Notes:

a. CCPs are frequently used as a replacement for a portion of portland cement in the manufacture of concrete.

b. Structural fill is an engineered material that is used to raise or change the surface contour of an area and to provide ground support beneath highway roadbeds, pavements and building foundations. It can also be used to form embankments.

c. FGD gypsum is used as a substitute for virgin gypsum in wallboard manufacturing.

d. CCPs can be blended with limestone or shale and fed into the cement kiln to make clinker, which is then ground into portland cement.

e. The chemical properties of CCPs make them effective stabilizers of biosolids (i.e., sludge from municipal waste water treatment).

f. Includes quantities beneficially used in minor applications not included in this exhibit, but listed in Appendix A.

g. Includes 115,596 tons of "Other FGD Material" not listed in this table because of the small quantities generated.

h. CCP utilization rates reflect all use applications, some of which are omitted from this table but are included in Appendix A. Utilization rates are calculated by dividing the total quantity used by the total quantity generated.

Note 2: Results from the 2006 CCP Production and Use Survey conducted by the ACAA indicate a total utilization rate of 43.43 percent, up from 40.29 percent reported for 2005. This reflects an ongoing upward trend in the CCP utilization rate over the past decade. The 2006 results were received too late for incorporation into the benefits analysis.

Sources:

1. American Coal Ash Association. "2005 Coal Combustion Product (CCP) Production and Use Survey," accessed at: http://www.acaa-usa.org/PDF/20045_CCP_Production_and_Use_Figures_Released_by_ACAA.pdf.
2. Western Region Ash Group, "Applications and Competing Materials, Coal Combustion Byproducts," accessed at: http://www.wrashg.org/compmat.htm.

Exhibit 2-5 illustrates several important aspects regarding the beneficial use options for CCPs:

- Concrete, wallboard, structural fill, cement, and waste stabilization comprise the highest volume beneficial uses of CCPs.
- The use of fly ash as a pozzolanic binder in concrete represents the largest single beneficial use application of a CCP material.[19] Fly ash can substitute for finished portland cement in concrete and can be a valuable additive to concrete mixtures that enhances the strength, durability, and workability of the concrete product.[20]
- FGD gypsum serves as a substitute for virgin gypsum in wallboard construction. This high value use represents the second largest use of CCPs, by volume, and second highest utilization rate at 77 percent.
- Although one of the smaller material streams, facilities beneficially use boiler slag in blasting grit, structural fill and waste stabilization, at the highest percentage of all CCPs. Boiler slag possesses two key properties that make it ideal for beneficial use: (1) the highly uniform quality of boiler slag increases its acceptance among potential end-users; and (2) boiler slag's unique abrasive properties make and excellent material for blasting grit and asphalt shingles.[21]

In comparison to the same ACAA survey conducted in 2004, total CCP utilization from 2004 to 2005 has increased slightly (0.21 percent). However, it is important to note that both the generation and beneficial use of CCPs increased during this time period. Both bottom ash and wet FGD material saw modest decreases in beneficial use rates (4% and 3%, respectively). The greatest increase in utilization rates over this time period was in boiler slag, with an increase of seven percent.[22, 23]

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[19] Fly ash is technically a pozzolanic, not a cementitious material. A cementitious material, such as portland cement, is one that hardens when mixed with water. A pozzolanic material will also harden with water but only after activation with an alkaline substance such as lime. The combination of portland cement and water in concrete mixtures creates two products: a durable binder that "glues" concrete aggregates together and free lime. Fly ash reacts with this free lime to create more of the desirable binder.

[20] Personal communication with Tom Pyle, Caltrans, November 2006.

[21] EPA. "Boiler Slag," accessed at: http://www.epa.gov/epaoswer/osw/conserve/c2p2/about/about.htm.

[22] American Coal Ash Association. "2005 Coal Combustion Product (CCP) Production and Use Survey," accessed at: http://www.acaa-usa.org/PDF/20045_CCP_Production_and_Use_Figures_Released_by_ACAA.pdf. and "2004 Coal Combustion Product (CCP) Production and Use Survey," accessed at: http://www.acaa-usa.org/PDF/2004_CCP_Survey(9-9-05).pdf.

[23] More efficient furnace types that use pulverized coal are replacing the cyclone and slag-tap furnaces that typically produce boiler slag. The replacement of these boiler types is decreasing the available supply of boiler slag. EPA. "Boiler Slag," accessed at: http://www.epa.gov/epaoswer/osw/conserve/c2p2/about/about.htm.

CHAPTER 3: MARKET STRUCTURE OF BENEFICIAL USE FOR CCPs

Understanding the factors that affect beneficial use of CCPs requires consideration of the underlying markets affecting its generation and management. The CCP market includes three market segments: (1) coal-fired utilities, (2) intermediaries: CCP marketers and consultants, and (3) end-users. In addition, state regulators determine the extent to which CCPs can be beneficially used by defining the regulatory context in which these actors operate. This chapter considers the factors affecting beneficial use decisions among these groups participating in the marketplace. We then present a discussion of opportunities for growth in the general CCP markets, along with a more specific illustration using three common beneficial applications. Finally, we discuss our efforts to improve market conditions for CCPs.

Three main challenges exist in developing the beneficial use market for CCPs. First, because CCPs are a heavy material to transport, the distance between the location of the coal-fired utility generating the CCPs and the potential end-user is a driving factor in determining whether the CCPs will be beneficially used in a project. Another difficulty in developing the beneficial use market is the capacity for individual coal-fired utilities to provide a quantity of high quality CCPs sufficient to meet the end-users' demands. The ability of end-users to obtain enough CCPs for their purposes is an important consideration in driving demand for CCPs. Finally, as noted above, the variability in use options across states poses a challenge to both coal-burning plants and end-users in trying to determine applicable beneficial use options for CCPs.

COAL-FIRED UTILITY PRACTICES: CCP SUPPLY

The coal-fired power industry is the largest generator of CCPs in the United States. As noted previously, other industries that use coal as a fuel source in commercial or industrial boilers (e.g., mineral and grain processors) also produce small quantities of CCPs. Coal-generated electricity supplies approximately 50% of the electricity consumed in the United States.[24] Since electricity demand is projected to increase by 40% by 2020 and coal will continue to be an important fuel source, it is likely that the quantity of CCPs produced and available for beneficial use will also increase.[25, 26]

Approximately 400 to 500 coal-fired electric utilities currently operate in the U.S.[27] Exhibit 3-1 shows the geographic distribution of coal consumption by electric power plants across the U.S. Coal consumption by power plants is greatest in the East North Central region of the U.S., but consumption remains relatively high throughout the entire Central and Southern United States. Coal consumption is low in the contiguous and noncontiguous Pacific regions of the U.S. and in New England. CCP generation closely approximates the geographic distribution of coal consumption across the U.S., but CCP generation is not directly proportional to coal consumption. The composition of coal varies regionally in the U.S. For example, the non-combustible portion (commonly referred to as "ash") of Western bituminous coal is higher than that of Western sub-bituminous coal (approximately 10% to15% and 4% to 6% ash, respectively). Coal with a higher non-combustible ash content will yield greater quantities of CCPs when combusted.

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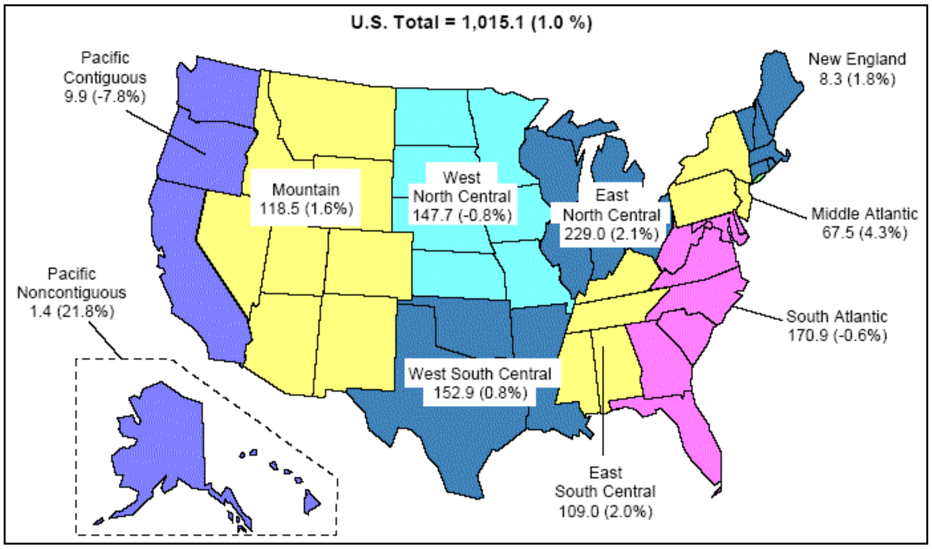
[24] American Coal Foundation, "All About Coal: Fast Facts About Coal," accessed at: http://www.teachcoal.org/aboutcoal/articles/fastfacts.html.

[25] Center for Energy and Economic Development, "Growing Demand," accessed at: http://www.ceednet.org/ceed/index.cfm?cid=7500,7582.

[26] American Coal Foundation, "Coal's Past Present and Future," accessed at: http://www/teachcoal.org/aboutcoal/asrticles/coalppf.html.

[27] Personal communication with Dave Goss, American Coal Ash Association, April 2006.

EXHIBIT 3-1: ELECTRIC POWER SECTOR CONSUMPTION OF COAL IN 2004, BY CENSUS REGION (MILLION SHORT TONS AND PERCENT CHANGE FROM 2003)



Source: Energy Information Administration, accessed at: www.eia.doe.gov.

Several factors influence a utility's decision to supply CCPs for beneficial use. Economic factors are the primary consideration and include:

- **Landfill disposal costs.** For many utilities, the sale of CCPs for beneficial use is a means of reducing operating costs through avoidance of landfill tipping fees. In order for beneficial use of CCPs to be competitive, the cost of reselling CCPs, minus revenue from the sale, must be less than the cost of landfill disposal. Landfill tipping fees vary regionally but range from $5 per ton to $45 per ton.[28] Avoiding landfill disposal costs may be a significant incentive for a utility to engage in beneficial use.
- **Revenue from sale.** Depending on the type of CCP, an electric utility may or may not receive revenue for its ash. For some CCP types, marketers will accept ash as a service to the plant (allowing the plant to avoid disposal costs) but do not pay for the ash. For other CCP types, especially fly ash, boiler slag and cenospheres, the revenue received can be a significant incentive for a utility to market its ash.[29]
- **Transport costs.** CCPs are heavy materials, which makes transport over long distances expensive. Transport distance between the utility and the nearest landfill or end-user is a significant determinant in the management of CCPs.
- **Processing costs.** Approximately 90% to 95% of CCPs do not require processing prior to beneficial use. However, higher value applications that require specialized CCP products may require processing to meet material specifications.

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[28] Personal communication with Dave Goss, American Coal Ash Association, April 2006.

[29] Personal communication with Dave Goss, American Coal Ash Association, May 2006.

- **Storage costs.** In many parts of the country, the production of coal ash is high during both the coldest and hottest months of the year when people are heating and cooling their homes, offices and schools. However, the winter season is often the slowest period for construction and other applications that beneficially use the fly ash. As a result, it is necessary to store CCPs until they can be utilized. Typically, domes are inflated adjacent to boilers for the CCP collection. The cost of storing fly ash or other CCPs during the winter months may be a deterrent to beneficial use by a utility.
- **Marketing costs.** In order to attract buyers of CCPs, a marketer must devote financial resources to marketing their CCP product(s) for beneficial use. Some utilities market their CCPs directly to end-users, but others pay a third party marketer or broker to negotiate CCP sales.

In the end, a generator's decision to make CCPs available for beneficial use rather than disposal is a result of a confluence of all the above factors, as well as non-economic factors such as access to information about permissible applications and availability of technical assistance. Depending on the circumstances, a coal-fired utility may weigh certain factors more heavily than others. For example, since off-site disposal and transport to a marketer or end-user both require hauling, total transport distance to the off-site facility is an important consideration. If the off-site disposal facility is closer, then a generator may opt to send its CCPs to the landfill instead of to the marketer or end-user. However, if the avoided disposal costs from the marketing arrangement are higher than the cost of offsite disposal, then avoided costs may be enough to offset the additional cost to transport the materials to the marketer or end-user. In addition, a coal-fired utility may be more willing to absorb higher costs (of transport, marketing, etc.) for higher-value materials and uses for which it can charge a higher premium (e.g. fly ash as a portland cement substitute in concrete).[30]

INTERMEDIARIES

Many coal-fired electric generators market their CCPs through a third-party marketer instead of selling directly to the end-user. In these cases, a utility perceives an efficiency in outsourcing the marketing of its CCPs. Marketers typically accept all of a generator's CCPs as a service to the company, sell the marketable portion, and dispose of the portion that is not salable. The marketer typically bears the cost of hauling CCPs from the utility and incorporates this cost into the sale price.

END-USERS AND PURCHASERS: CCP DEMAND

Several factors influence an end-user's decision to use CCPs in their product. Such considerations include:

- **Price of CCPs relative to the price of virgin materials.[31]** If the price of a virgin material is less than the price of CCPs (which will reflect cost factors such as transport distance, processing and storage costs), end-users will generally purchase virgin materials. In areas where virgin materials are abundant and inexpensive, CCPs may not be economically viable. Exhibit 3-2 shows the typical price ranges for CCPs used in various applications relative to the virgin materials they replaces.

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[30] Note that the transfer of CCPs from generators to users may lead to potential cost savings for the generators. It may be possible for generators to shift liability (and related costs) associated with CCPs to users of the product. The law on this matter is not well-defined and needs to be clarified to determine the magnitude of any potential cost savings.

[31] Note that the "price" of CCPs represents how much an end-user would pay for the product.

EXHIBIT 3-2: SAMPLE CCP AND VIRGIN MATERIAL PRICES FOR CCP APPLICATIONS

VIRGIN MATERIAL	2005 AVG PRICE, (PER TON, FREE ON BOARD)[a,b]	CCP SUBSTITUTE	2005 AVG PRICE, (PER TON, FREE ON BOARD)[a]
Portland cement	$80	Concrete quality fly ash	$0 to $45
		Boiler slag	Not available
Virgin aggregate for fill	$3	Fly ash for flowable fill	$1
Virgin aggregate for road base	$5	Bottom ash or fly ash for road base	$4 to $8
Lime for soil stabilization (Hydrated lime)	$83	Fly ash for soil stabilization	$10 to $20
Lime for waste stabilization (Quicklime)	$66	Fly ash for waste stabilization	$15 to $25
Virgin aggregate for snow and ice control	$5	Bottom ash for snow and ice control	$3 to $6
Gypsum for wallboard interior	$4.50 - $12.0	FGD Gypsum	$0 - $8.00

Notes:

a. Virgin material prices are reported by USGS while CCP prices are provided by ACAA. This price data represents the best available information, and should be cross-compared with caution, as the data may not capture all factors driving price variability.

b. "Free on Board" is a shipping term, which indicates that the supplier pays the shipping costs (and usually the insurance costs) from the point of manufacture to a specified destination, at which point the buyer takes responsibility.

Sources:

1. USGS, "Mineral Commodities Summary 2006: Cement," accessed at: http://minerals.usgs.gov/minerals/pubs/commodity/cement/cemenmcs06.pdf
2. USGS, "Mineral Commodities Summary 2004: Construction Sand and Gravel," accessed at: http://minerals.usgs.gov/minerals/pubs/commodity/sand_&_gravel_construction/sandgmyb04.pdf
3. USGS, "Mineral Commodities Summary 2005: Lime," accessed at: http://minerals.usgs.gov/minerals/pubs/commodity/lime/lime_myb05.pdf
4. USGS, "Mineral Commodities Summary 2006: Gypsum," accessed at: http://minerals.usgs.gov/minerals/pubs/commodity/gypsum/gypsumcs06.pdf
5. American Coal Ash Association, "Frequently Asked Questions," accessed at: www.acaa-usa.org
6. Miller, Cheri . Gypsum Parameters. Presentation at WOCA Short Course: "Strategies for Development of FGD Gypsum Resources."

- **Technical fit between CCPs and use application.** CCPs have varying physical and chemical characteristics due to differences in coal types, combustion processes, air pollution control technologies, and CCP management practices at individual power plants. To be beneficially used in a particular application, the chemical and physical properties of the CCP must align with the engineering requirements of that application. For example, high carbon content or the presence of air emission additives may render some CCPs unsuitable for some use applications.

- **Sufficient quantities of CCPs.** Some beneficial use applications require larger volumes of CCPs than are typically produced at a single power plant. Where demand for CCPs is greater than the supply generated by a single plant, the end-user may need to purchase CCPs from multiple suppliers; this can increase transaction costs.

- **State Regulations.** Regulations governing beneficial use of CCPs vary by state. In many states, beneficial use of CCPs must be approved on a project-by-project basis. Currently, public and environmental health considerations drive state regulatory decisions concerning beneficial use of CCPs in end-use applications.[32,33]

- **Incomplete science.** In absence of definitive data on health risks associated with the beneficial use of CCPs, some states have chosen to limit the use of CCPs in building materials. For example, EPA research has found that CCPs may release small quantities of mercury to the ambient air during use in certain industrial processes.[34] Noting this research, States have questioned the safety of using fly ash in cement to be used in schools.[35]

MARKET DYNAMICS OF SPECIFIC USE APPLICATIONS

The beneficial use markets for CCPs depend on the physical properties of the materials, the demand for their particular uses, and the supply of materials available for use. Exhibit 3-3, below, summarizes the current state of the beneficial use markets for the suite of CCPs, along with an analysis of the potential for growth in the beneficial use market for each material. An established market contains four key elements, all of which are interconnected:

- Generators producing a consistent supply of materials;
- End-users with the demand to use the product;
- Well-known, accepted beneficial use applications; and
- A distribution system to transport materials from generators to users.

Limited markets may have a subset of these key elements, but likely need a shift in technology, demand, or price to increase beneficial use of the product. Emerging markets are typically unorganized and the connections between the elements are not fully formed.

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[32] Energy & Environmental Research Center, University of North Dakota, "Review of Florida Regulations, Standards, and Practices Related to the Use of Coal Combustion Products: Final Report," April 2006, accessed at: http://www.undeerc.org/carrc/Assets/TB-FLStateReviewFinal.pdf.

[33] Some states, such as Wisconsin, have set up regulatory schemes designed to speed up the approval process for products using beneficial use materials such as CCPs. Currently, Wisconsin requires initial leachate testing of the material to be beneficially used, which leads to a specific rating. Materials that fall into a standard rating class are automatically approved for specific uses. For example, material found to meet drinking water standards can be used in any application, whereas material found to have a moderate level of contamination, may only be approved for encapsulated uses. Users are also required to submit annual reports demonstrating testing of CCPs. Personal communication with Bizhan Sheikholeslami, Wisconsin Department of Natural Resources, November 2006.

[34] Hassett, David J., Debra F. Pflughoeft-Hassett, Dennis L. Laudal, and John H. Pavlish. 1999. Mercury Release from Coal Combustion ByProducts to the Environment.

[35] Personal Communication with Antoinette Stein, State of California Department of Health Services, June 2006.

EXHIBIT 3-3: CCP BENEFICIAL USE MARKETS

CCP	STATE OF BENEFICIAL USE MARKET	POTENTIAL FOR MARKET GROWTH
Fly Ash	Established markets	The markets for fly ash have the potential to continue to grow. Generators produce fly ash in large quantities and there are several well-known, high-value uses. Currently, only 41% of fly ash is beneficially used.
FGD Gypsum	Established markets	The FGD gypsum market has room for moderate growth. FDG gypsum wallboard is an accepted alternative to virgin gypsum wallbaord with users often directly connected to generators. Currently, 77% of FDG gypsum is beneficially used. Other uses are emerging but are currently limited, and data on market opportunities are limited.
Dry FGD Material	Limited market	The current market for dry FDG material appears to have only limited potential for growth. Uses for the material appear to be limited to relatively low-value uses, such mine reclamation. Currently, only four percent of this material is beneficially used. Data on the market opportunities for this material are limited.
Other Wet FGD Material	Limited market	The current market for other FDG wet material appears to have only limited potential for growth. Uses for the material appear to be limited to relatively low-value uses, such mine reclamation. Currently, only 11% of this material is beneficially used. Data on the market opportunities for this material are limited.
Bottom Ash	Established markets	The markets for bottom ash have the potential to continue to grow. Generators produce bottom ash in large quantities and there are several well-known, high-value uses. Currently, only 43% of bottom ash is beneficially used.
Boiler Slag	Established markets	The markets for boiler slag are mature and have limited opportunity for growth. Since approximately 97% of boiler slag is beneficially used (primarily as blasting grit), supply is currently roughly equivalent to demand.
FBC Ash	Established markets	The markets for FBC ash have potential for moderate growth, although mainly for low-value uses. Currently nearly 70% of FBC ash is beneficially used.
Cenospheres	Emerging market	The markets for cenospheres have the potential for growth as information on their uses becomes more widely available. However, information regarding potential uses is limited at this time. Currently the beneficial use rate for cenospheres is unknown.

Aside from the boiler slag market, the markets for the various CCPs generally have room for growth. EPA programs that aim to increase growth in the markets for CCPs by targeting beneficial use applications that are well-accepted practices in the industry may have significant success in helping expand these markets by overcoming targeted technical, administrative and technical and informational hurdles. The economic viability of the top three beneficial uses (by volume) is considered individually below. Concrete, gypsum wallboard, and structural fill are all long-standing, widely accepted uses for CCPs.

Concrete

Certain performance benefits can be attained through the use of coal fly ash in concrete, including greater workability, higher strength, and increased longevity in the finished concrete product.[36] Fly ash substitutes directly for portland cement in the concrete mixing process. This beneficial use represents one of the highest value applications for CCPs, and has the potential to increase as a result of the current high demand for portland cement in the U.S.[37,38]

Industry representatives and some state agencies have stated that there are possible emerging issues related to regulatory programs for the control of nitrogen oxides (NOx) and mercury in power plant flue gases. These issues relate to the potential for negative impacts on coal fly ash quality and available quantities due to the potential for increased mercury contamination in the ash, or unacceptably high levels of carbon content. There are technology choices that would minimize these impacts on the beneficial use of coal fly ash. However, the selection of equipment for control of nitrogen oxides and mercury, and corresponding technologies potentially necessary to minimize quality impacts on coal fly ash is very complex, resulting in industry solutions that would be unit-specific. Losses of anywhere between $40/ton and $80/ton of coal fly ash[39] are possible if industry is unable to sell high carbon fly ash as a supplementary cementitious material in the manufacture of concrete. This estimate also includes the additional costs associated with the need to dispose of a formerly marketable material.

State of Florida officials noted that installation of air emission controls at coal-fired power plants might result in increased mercury associated with coal fly ash. Since coal fly ash is used in portland cement manufacturing, electric utilities and portland cement manufacturers have expressed concern that the Florida Department of Environmental Protection's (FDEP) New Source Review (NSR) might limit or even eliminate the use of CCPs for this purpose. Officials also noted that similar impacts might occur for coal fly ash containing higher levels of unburned carbon or other components resulting from changes in operations, fuel, or emission controls.[40] This may have the potential of jeopardizing the recycling of many tons of CCPs that are currently reused.

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[36] Personal communication with Tom Pyle, Caltrans, November 2006.

[37] Strong demand for cement in the U.S. is a result of both increased domestic construction activity and strong demand by growing foreign economies (especially China).

[38] Portland Cement Association. "FAQ: Cement Supply Shortage," accessed at: http://www.cement.org/pca/shortageQA.asp. We contacted two industry experts, Dave Goss of the American Coal Ash Association and Barry Deschenaux of Holcim Cement, to elaborate on this trend (increased use of coal ash in cement due to domestic and foreign demand), but neither was able to provide more detailed information on the extent to which this might occur in the future.

[39] Mercury-CCP dialogue meeting summary document, Final Draft, 1/14/08

[40] Energy and Environment Research Center (EERC), April 2006. Review of Florida Regulations, Standards, and Practices Related to the Use of Coal Combustion Products. 2006-EERC-04-03. University of North Dakota, Grand Forks, ND.

The Texas CCP review also notes that emissions control in the electric utility industry has had a subsequent impact on the type, quantity, and quality of the solid materials produced at a specific power plant[41]. Officials indicate that the reduced supply of high quality coal fly ash already poses a threat to coal fly ash use in TX DOT projects, where high volumes of consistent quality coal fly ash are needed over the duration of large, long-term projects.

Overall, technology options are available to the industry, specifically for the application of NOx controls, which would minimize any impacts on the quality of fly ash. Furthermore, technology solutions are currently being developed and deployed in the industry to minimize or avoid any such impacts from the use of mercury controls as well.

Gypsum Wallboard

FGD gypsum is a product derived from the wet FGD process. Utilization of FGD gypsum in wallboard manufacture is a well-established market. Because the quality of FGD gypsum produced by power plants is generally consistent, new wallboard facilities often locate adjacent to power plants to allow FGD gypsum to be delivered directly to the wallboard plants. In some cases, wet FGD gypsum is piped directly to the adjacent wallboard facility, a step that significantly reduces transport and handling costs. Given these developments, the demand for FGD gypsum will likely remain high, and may increase as new wallboard manufacturing facilities are being constructed to accommodate FGD gypsum in wallboard production.[42]

Structural Fill

Structural fill is an engineered material used to raise or change the surface contour of an area and to provide ground support beneath highway roadbeds, pavements, embankments and building foundations. The quality and engineering standards for use of CCPs in structural fill are less stringent than the standards for structural applications such as concrete. Consequently, CCPs destined for use in structural fill generally do not require processing, which keeps costs low.

Demand for CCPs in structural fill applications is variable and generally occurs on a project-by-project basis. One large construction project using CCPs in fill can create a spike in demand for CCPs, but this may be followed by a lull in demand until another sizeable project can be identified.[43] Because CCPs are generated continuously, the generator's or marketer's capacity to store and accumulate the material between projects is a significant determinant in the use of CCPs in structural fill.

IMPACTS OF CURRENT POLICY SETTING ON MARKET DYNAMICS

While states play a primary role in establishing industrial waste regulations and guidance, EPA has an opportunity to provide coordination and assistance at the national and regional levels to help achieve a shift in waste management policy. EPA is currently engaged in several long-term efforts to increase beneficial use of CCPs.

Under the RCC, EPA established goals for beneficial use of CCPs (as enumerated in the introduction) and established the Coal Combustion Products Partnership (C^2P^2) to help reach these goals. C^2P^2 is a cooperative effort among EPA, ACAA, the Utility Solid Waste Activities Group (USWAG), the U.S.

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[41] Energy and Environment Research Center (EERC), January 2005. Review of Texas Regulations, Standards, and Practices Related to the Use of Coal Combustion Products. 2005-EERC-01-01. University of North Dakota, Grand Forks, ND.

[42] Electric Power Research Institute, "Environmental Focus: Flue Gas Desulfurization By-Products," 1999.

[43] Personal communication with David Goss, American Coal Ash Association, March 2006.

Department of Energy (DOE), the U.S. Federal Highway Administration (FHWA), the Agricultural Research Service of USDA, and the Electric Power Research Institute (EPRI). Through C^2P^2, EPA and its co-sponsors work with all levels of government, as well as industry organizations, to identify and address regulatory, institutional, economic, and other limiting factors to the beneficial use of CCPs. One important overarching barrier addressed by C^2P^2 is the lack of information about beneficial use opportunities. Specifically, the program includes the following initiatives and activities:

- **The C^2P^2 Challenge:** Under the C^2P^2 challenge, partners are eligible for awards recognizing activities such as documented increases in CCP use and successes in CCP promotion and utilization.
- **Barrier Breaking Activities:** C^2P^2 addresses limiting factors to increased CCP utilization through activities such as developing booklets and web resources on the benefits and impacts of using CCPs in highway and building construction applications; publishing case studies on successful beneficial use of CCPs; supporting Green Highways; and updating a manual for highway engineers on the use of fly ash in highway applications.
- **Technical Assistance:** C^2P^2 has conducted a series of workshops with FHWA, EPA, DOE, ACAA and other partners to provide technical assistance and outreach to support the use of CCPs in concrete highway construction. These workshops present the technical feasibility of using CCPs and the economic and environmental benefits that result from their use.

CHAPTER 4: IMPACTS ASSOCIATED WITH BENEFICIAL USE OF CCPs

To evaluate EPA's efforts to improve the beneficial use of CCPs, it is essential to quantify the important environmental and human health impacts of increased use of these materials in various beneficial use applications. An initial step in this process is describing the incremental environmental impacts associated with using a specific quantity (e.g., one ton) of CCPs in different applications. These impacts can then be extrapolated in specific scenarios designed to address program-level outcomes. Life cycle analysis (LCA) represents a proven methodology for describing the impacts of beneficial use of specific quantities of material, and can also inform a broader evaluation of program achievements.

This chapter first provides a brief overview of the use of LCA in the assessment of environmental impacts of beneficial use, and also discusses the relationship between LCA and the economic analysis of net social benefits. Next, the chapter identifies several available LCA tools that can be used to provide insights into the impacts of beneficial use of CCPs in different applications, and presents an initial life cycle analysis of the potential impacts associated with the use of one ton of fly ash and FGD gypsum in concrete and wallboard manufacture, respectively. Finally, we note key limitations of this initial assessment and identify areas for additional research.

LIFE CYCLE ANALYSIS AND RCC PROGRAM OUTCOMES

Life cycle analysis depicts the production of materials as a system of complex physical outcomes, and can predict the incremental physical consequences of a change in material inputs, technology, waste management practices, or price incentives. In LCA, as in reality, one change in the physical system, such as the substitution of fly ash for virgin portland cement, leads to a corresponding cascade of economy-wide impacts and shifts. As inputs are substituted, technologies, physical outputs, and exposure pathways change. Using a range of modeling platforms and life cycle inventories to calculate the outputs associated with each intermediate change, LCA calculates the net result of all of these interactions, capturing the total incremental effect of a change in operations on physical environmental impacts such as air emissions, and energy and water use. Life cycle analysis can be an effective performance assessment tool, and because it is a systems approach to assessment, it represents an improvement over less comprehensive techniques.

The RCC is designed to help facilitate changes in the economics and practice of waste generation, handling, and disposal (e.g., by promoting market opportunities for beneficial use). The outcomes of the program, therefore, can be described as the changes in total environmental impacts that result from changes in beneficial use. Many of these impacts likely come from avoiding the production of virgin materials that would be used in the absence of industrial materials. In some cases, changes in materials use may also lead to (positive and negative) changes in processing, product performance, and disposal approaches. LCA can, given appropriate data and modeling scenarios, describe the net impacts of all of these changes, and can, therefore, provide an assessment of program results.

Life Cycle Analysis and Economic Benefit Assessment

As a tool for measuring physical impacts of system changes, LCA is a natural starting point in the assessment of the economic benefits of a program, but it is important to distinguish between LCA and economic benefits analysis. LCA is useful in the context of benefits analysis because it reflects a systems approach, allows measurement of changes to baseline conditions, identifies tradeoffs, and yields concrete, measurable metrics that can be evaluated both in isolation and comparatively, across programs and activities.

However, while it can provide a clear assessment of beneficial (and other) program *impacts*, LCA does not itself measure the social *benefits* and costs of changes in practice, for two reasons. First, LCA provides a *static* examination of impacts based on a one-time change to a system, and does not attempt to measure net impacts over time, adjusting for long-term market responses (e.g., changes in price and behavior) that can, in turn, affect the long-term system operation.[44] Beneficial use of large-volume CCP materials, such as fly ash and FGD gypsum, is already well-established. Therefore, gradual increases in use of these materials may have some impact on the large cement and gypsum markets in the U.S., but this analysis assumes that dramatic near-term changes in the market are unlikely. Therefore, the impacts estimated by LCA are reasonable representations of total market impacts. However, if **sudden**, large-scale changes in production of raw materials occur as a result of RCC efforts, then a net economic impact analysis using methods like partial equilibrium analysis might be necessary.

Second, a complete assessment of the net economic benefits of a program requires the application of economic valuation techniques to the physical outputs of LCA analysis, in order to describe, in economic terms, what the physical outcomes imply for human well-being. For example, an LCA can describe changes in the quantity of water used or waste generated in a process, but is not designed to identify the effect of these impacts on well-being.[45] Economic valuation of these changes depends upon the specific location, timing, and quality of the water that is consumed or waste disposal that occurs. The value of that water depends on how it would otherwise be used (e.g., for human consumption, industrial uses, habitat support, irrigation) and the "value" of the waste depends on the health risks it poses, release scenarios, and the people exposed.[46]

Ideally, LCA would be incorporated into a full-scale analysis of net program benefits that would account for market responses and would value specific environmental impacts such as decreased releases of pollutants. Unfortunately, the translation of physical changes into economic outcomes is typically costly, difficult, and often controversial when applied to human health or environmental outcomes. It frequently requires location-specific data on releases and exposures, as well as well-documented links between these exposures and health or environmental impacts. Assigning an economic value to even a small set of physical impacts can be a significant and expensive undertaking.[47]

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[44] For example, a beneficial use that has a significant impact on raw material demand (e.g., for virgin aggregate) and on electricity demand may ultimately affect the local prices of both energy and raw materials as demand for these commodities drops. The price changes could, in turn, result in other changes in practice (e.g., decisions on the part of other purchasers to buy more aggregate or changes in use patterns of electricity). These impacts would likely have some impact on the net change in environmental impacts measured in the LCA.

[45] Life cycle analysis can incorporate impact assessments using a range of different methods that can, at a minimum, provide comparative descriptions of the types of damage likely associated (or avoided by) the system change. However, valuation of specific impacts (e.g., health impacts from air releases) requires modeling of specific exposure scenarios; LCA is designed specifically to address systems without requiring unique location-specific information.

[46] Hendrickson, Lave, and Matthews (2006) notes the limitation of LCA outputs that are not linked to specific locations and exposures - "A typical [Life Cycle Inventory] of air pollution results in estimates of conventional, hazardous, toxic, and greenhouse gas emissions to the air. Even focused on this small subset of environmental effects, it is unclear how to make sense of the multiple outputs and further how to make a judgment as to tradeoffs or substitutions of pollutants among alternative designs."

[47] In the ecological realm, these kinds of translations are underdeveloped. The agency is aware of this ongoing limitation. For example, this conclusion has been drawn from several recent SAB reports, including EPA-SAB. 2003. "Underground Storage Tanks (UST) Cleanup & Resource Conservation & Recovery Act (RCRA) Subtitle C Program Benefits, Costs, & Impacts (BCI) Assessments: An SAB Advisory." (EPA-SAB-EC-ADV-03-001) and "Advisory on EPA's Superfund Benefits Analysis." (EPA-SAB-ADV-06-002). In addition, the SAB Committee on Valuing the Protection of Ecological Systems and Services is currently examining methods for addressing these limitations.

Accordingly, LCA can represent not only a necessary ingredient, but also a practical initial alternative to a complete economic benefit assessment. While net economic benefits are often the target performance measure, it is necessary in many cases to rely on simpler proxies to facilitate management and performance assessment. As proxies, LCA outputs can represent a legitimate and defensible measure of program impacts. Therefore, we use LCA to investigate the measurable *beneficial impacts* associated with RCC program achievements, using available LCA tools. A more detailed discussion of the role of LCA in economic benefits assessment is provided in Appendix B.

ASSESSMENT OF BENEFICIAL IMPACTS OF CCP USE

To fully capture the beneficial impacts of C^2P^2 program achievements, it would be necessary to model each beneficial use application of all CCPs targeted by the RCC. However, the time, data, and resources required to perform this task are beyond the scope of this report. For this preliminary analysis, we have selected two common CCPs, fly ash and FGD gypsum, which have well-understood beneficial use applications and processes, and for which life cycle models and existing data are available.

We conducted a comprehensive review of available data sources and tools for assessing life cycle benefits of beneficial use of these materials across all possible use applications. We identified four models that support specific evaluation of the environmental impacts of avoided virgin materials extraction in processes where CCPs are beneficially used in place of virgin materials:

- **Building for Environmental and Economic Sustainability (BEES)** was developed by the National Institute of Standards and Technology (NIST) with support from the U.S. EPA to allow designers, builders, and product manufacturers to compare the life cycle environmental, and economic performance of alternative building products.[48] The BEES methodology measures environmental performance using an LCA approach, following guidance in the International Standards Organization 14040 series of standards for LCA. Thus, all stages in the life of the product are analyzed: raw material acquisition, manufacture, transportation, installation, use, and recycling and waste management. The BEES model is implemented in publicly available decision-support software, complete with actual environmental and economic performance data for a number of building products.
- **SimaPro** was developed by the Dutch company Pré Consultants and can be used to perform detailed lifecycle analyses of complex products and processes. SimaPro provides a high degree of modeling flexibility in that it provides data profiles representing thousands of materials production, transport, energy production, product use and waste management processes that can be combined to model very specific systems. Thus, SimaPro relies on the user's understanding of the various lifecycle stages and processes in the system being modeled. Results can be displayed as lifecycle inventory flows (e.g. energy use, water use and pollutant emissions (for a variety of pollutants including the criteria pollutants). In addition, one of several impact assessment methods can be applied to characterize the environmental damages (e.g., global warming, eutrophication, etc.) associated with these flows.
- **Pavement Life Cycle Assessment Tool for Environmental and Economic Effects (PaLATE)** is an Excel-based tool developed by the Consortium for Green Design and Manufacturing at U.C. Berkeley for life cycle analysis of environmental and economic performance of pavements and

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[48] The BEES model and supporting documentation are accessible at: http://www.bfrl.nist.gov/oae/software/bees.html.

roads. The model was developed for pavement designers and engineers, transportation agency decision-makers, civil engineers, and researchers. PaLATE can evaluate the relative impacts of using different virgin and secondary materials in the construction and maintenance of roads. Based on user-specified data on the type and quantity of initial construction materials, road construction equipment (e.g., asphalt paver), material transportation distances and modes, maintenance materials and processes, and off-site processing equipment (e.g., rock crusher), PaLATE calculates twelve life cycle inventory flows including water and energy use, conventional air emissions (NOx, SO_2, CO_2, PM_{10}, and CO), toxic air emissions (Pb and Hg), RCRA hazardous waste generation; and cancer and non-cancer Human Toxicity Potentials.[49]

- The **WAste Reduction Model (WARM)** was created by EPA to help solid waste planners and organizations estimate greenhouse gas (GHG) emission reductions from several different waste management practices. WARM calculates GHG emissions for baseline and alternative waste management practices, including source reduction, recycling, combustion, composting, and landfilling. The user can construct various scenarios by entering data on the amount of waste handled by material type and by management practice. WARM then automatically applies material-specific emission factors for each management practice to calculate the GHG emissions and energy savings of each scenario. In addition, the model will convert these outputs to equivalent metrics including the equivalent number of cars removed from the road in one year, the equivalent number of avoided barrels of oil burned, and the equivalent number of avoided gallons of gasoline consumed.

All four models support life cycle analysis of various CCPs. PaLATE, BEES and WARM all include life cycle data to evaluate use of fly ash as a substitute for finished portland cement in concrete, and SimaPro supports evaluation of use of FGD gypsum in wallboard. We select BEES and SimaPro to evaluate fly ash and FGD gypsum beneficial use because these models have been peer-reviewed and evaluate a large suite of environmental metrics.[50] In contrast, PaLATE has not undergone a formal peer review process, and WARM evaluates only greenhouse gas metrics. For comparative purposes, however, we present the results of a WARM analysis of the use of fly ash in concrete in Appendix C.[51]

In addition to BEES and SimaPro, the U.S. Economic Input-Output Life Cycle Assessment (EIO-LCA) model provides an alternative approach for measuring the avoided upstream impacts of recycling. EIO-LCA was developed at Carnegie Mellon University and provides the capacity to evaluate economic and environmental effects across the supply chain for any of 491 industry sectors in the U.S. economy. EIO-LCA also can represent the supply chain use of inputs and resulting environmental outputs across the supply chain by using publicly available data sources from the U.S. government. By integrating economic data on the existing flow of commerce between commodity sectors with environmental data on releases and material flows generated by each sector, it is possible to estimate the additional environmental emissions caused by an increase in production within a particular sector, accounting for

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[49] PaLATE does not allow for life cycle assessment of the inventory results, but in other life cycle models, impact assessment methods can be applied to inventory results to estimate environmental damages.

[50] BEES has reliable data for the use of fly ash in concrete, but it does not evaluate use of FGD gypsum in wallboard. SimaPro does allow evaluation of both fly ash and FGD gypsum but we prefer the U.S.-based data in BEES to conduct the fly ash analysis. For this reason, we do not use the same model for both analyses.

[51] The PaLATE model was used to evaluate beneficial use of fly ash in previous iterations of this report, but we omit the PaLATE analysis from this version in order to avoid comparisons of peer reviewed model findings to non-peer reviewed model findings for CCPs. It is important to note, however, that PaLATE relies on much of the same LCI data as the EIO-LCA model, which is presented in Appendix C.

changes in the supply chain. This approach can be used to provide insight into the sectors of the economy that drive the environmental impacts of a given process, and shed light on the specific impacts of particular policy efforts. While it is very helpful in examining the distribution of impacts across economic sectors, the EIO-LCA is not optimal for a specific life cycle analysis of beneficial use of FGD gypsum in wallboard because the life cycle impacts are modeled at the sector level and do not provide the same process-level resolution that can be estimated for various use applications using SimaPro. EIO-LCA is more useful for modeling use of fly ash in concrete, as it includes data for a fairly homogenous cement sector. It is also important to note that EIO-LCA is a dollar-based model and thus, is not directly comparable to the BEES/SimaPro data that is presented in tons. Appendix C describes supply chain manufacturing impacts for cement and gypsum production modeled using EIO-LCA.

METHODOLOGY FOR EVALUATING UNIT IMPACTS OF BENEFICIAL USE

We conduct separate analyses to evaluate the incremental environmental impacts associated with beneficially using a specific quantity (i.e., one ton) of fly ash and FGD gypsum. We employ:

- BEES to investigate using one ton of fly ash as a substitute for finished portland cement in concrete; and
- SimaPro to investigate using one ton of FGD gypsum as substitute for virgin gypsum in wallboard.

The first step in evaluating the life cycle impacts of beneficial use of fly ash and FGD gypsum is development of environmental impact profiles for use of one ton of each material as a substitute for portland cement in concrete and for virgin gypsum in wallboard, respectively. One ton was selected as the unit-basis for these analyses because the impacts can then easily be extrapolated to current use quantities, which are reported by the American Coal Ash Association (ACAA) in tons. In addition, by developing life cycle benefits profiles for use of a consistent quantity of each material, the impact profiles of specific materials can be compared with each other.

The calculation of unit impact values for fly ash and FGD gypsum are described in greater detail below. To the extent possible, we attempt to use comparable assumptions and life cycle system boundaries in both analyses.

BEES Analysis of Use of Fly Ash in Concrete

BEES includes environmental performance data for a number of concrete products (e.g., concrete columns, beams, walls, and slab on grade). The user can compare the environmental performance data of each of these products using different pre-determined concrete mix-designs, some of which include fly ash. The BEES environmental performance data serve as quantified estimates of the energy and resource flows going into the product and the releases to the environment coming from the product, summed across all stages of the product life cycle for one cubic yard of concrete. BEES quantifies these flows for hundreds of environmental metrics, but to capture the general spectrum of impacts, we focus on the following:

- Total primary energy use (MJ);
- Renewable energy use (MJ);
- Nonrenewable energy use (MJ);
- Water use (liters);

- Atmospheric emissions (CO_2, methane, CO, NOx, SOx, particulates, Hg, Pb) (grams);
- Waterborne waste (suspended matter, biological oxygen demand, chemical oxygen demand, Hg, Pb, selenium; and
- Nonhazardous waste (kg).

As an example of the LCA approach, we assess the beneficial environmental impacts of using fly ash to offset virgin cement inputs in a concrete beam with a compressive strength of 4 KSI (4,000 psi) and a lifespan of 75 years. It is important to note that this concrete product was selected to represent use of fly ash in any generic concrete application; the unit impact values do not reflect any assumptions specific to the life cycle of a concrete beam in BEES.[52] Furthermore, any concrete building product data set could have been used without changing the unit impact value. For further details on the life cycle inventory data used in this analysis, refer to Appendix D.

The benefits of fly ash use are measured as the difference in environmental impacts between a baseline scenario and a beneficial use scenario. In the baseline scenario, a one cubic yard 4 KSI concrete beam is produced using 100% portland cement. In the beneficial use scenario, a one cubic yard 4 KSI concrete beam is produced using 15% coal fly ash and 85% portland cement.[53, 54] The difference in environmental impacts between the baseline and beneficial use scenarios represents the change in impacts from substituting 15% of the portland cement with fly ash in one cubic yard of 4 KSI concrete. We translate these impacts from a cubic yard concrete basis to a ton fly ash basis by dividing the impacts by the absolute quantity of fly ash in one cubic yard of the concrete product. For an illustration of this methodology, refer to Appendix D.

SimaPro Analysis of FGD Gypsum in Wallboard

We calculate the unit impacts of using FGD gypsum in place of virgin gypsum stucco in wallboard as the difference in impacts between wallboard made with 100% virgin gypsum and wallboard made with 100% FGD gypsum. We model these impacts as one ton of avoided “stucco” manufacture in SimaPro.[55] Stucco is the term used in SimaPro to describe the gypsum material used in wallboard. We selected the EcoInvent data set because it includes gypsum mining but also includes the processing of gypsum for use in wallboard (i.e., burning of gypsum and milling of stucco for use in gypsum wallboard). Thus, this dataset includes all the processes that would be avoided if an equivalent quantity of FGD gypsum were used in place of stucco in wallboard. The production of FGD gypsum from coal combustion is not modeled, as discussed in the following section on allocation of life cycle impacts to FGD gypsum. In addition, this analysis assumes that FGD gypsum dewatering occurs via holding ponds and that the environmental impacts of dewatering are negligible.[56] This analysis also does not model transport distance; we assume FGD gypsum would have the same transport distances to the construction site as

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[52] All concrete building product data in BEES (e.g., concrete columns, beams, walls, and slab on grade) use a 75-year lifespan assumption. Calculating unit impact values using data from any one of these products yields the same values. In addition to life cycle inventory data for concrete building products, BEES also includes data for a concrete parking lot pavement. The concrete parking lot data, however, use a 30-year lifespan assumption; calculating unit impact values using pavement data yields values that are approximately 2.5 times greater than the values calculated from building product data because the pavement data assume a 2.5 times shorter lifespan than building products.

[53] Fly ash replaces portland cement in concrete in a one to one ratio based on mass.

[54] Both the concrete beam made with and without blended cement assume a 60-mile round trip transport distance for portland cement and fly ash and a 50-mile round-trip transport distance for aggregate to the ready-mix concrete plant.

[55] We use the EcoInvent data set titled “Stucco, at plant/CH U” for this purpose.

[56] There may actually be emissions/dusting impacts associated with dewatering in a holding pond, but we have been unable to identify quantified estimates of these impacts. Alternatively, dewatering may be accomplished through mechanical processes but we were also unable to identify the energy impacts of mechanical dewatering.

virgin gypsum.[57] Thus, avoided gypsum mining and avoided processing of gypsum into stucco, as represented by the EcoInvent stucco manufacturing data set, are the only lifecycle stages modeled in SimaPro. Appendix D provides more information on the FGD gypsum analysis.

Allocation of Life Cycle Impacts to CCPs

As EPA programs evolve to emphasize both beneficial use of industrial materials and life cycle analysis approaches to evaluating these programs, it is important to consider upstream impacts of the processes that create beneficial use materials, including, in this case, the impacts of the electrical power generation industry that produces CCPs for beneficial use.

The beneficial use of CCPs has positive environmental and energy impacts relative to landfilling and virgin material production. Consideration of the negative upstream impacts of electricity production through "allocation" does not actually reduce the beneficial impacts of beneficial use, nor does it "create" negative impacts. Instead, it represents a quantitative way of recognizing that CCPs are associated with the generation of coal-fired power and not an environmentally “free” product.

Analysis of life cycle impacts is, in its simplest form, the calculation of all impacts associated with a single production system (e.g., the manufacture of paper, or the production of energy using coal). However, when one production system (or a set of linked production systems) makes two or more products with market value (i.e., co-products), it is accepted practice in life cycle analysis to recognize that these products are associated with environmental impacts, and to *allocate* the total life cycle production impacts across these products.[58] Several methods for allocation are possible, depending on the system(s), inputs, and the quantity and value of co-products. Simple methods include allocating impacts proportionately by total mass or by market value; more complex methods may be necessary when integrated systems use different types of inputs or produce a range of products with different features and environmental profiles.

Waste is not considered a co-product, and it is, therefore, generally unnecessary to allocate specific production impacts to materials that are destined for disposal (disposal impacts are allocated 100% to the producing industry). However, when an industrial material becomes a beneficial use material and ceases to be considered a waste, it reflects a market value. It is, therefore, a co-product, though typically a very low-value one when compared to the primary products of the industry (in this case, electricity). It is important to consider whether co-products of electricity generation (such as fly ash and FGD gypsum) that are beneficially used should have some portion of the production impacts associated with coal combustion (e.g., energy use, greenhouse gas equivalents, releases to air and water) attributed to them.[59]

In Appendix E, we provide an illustration of a potential approach for allocating the environmental and energy impacts from coal-fired power generation across electricity generation and CCPs. The analysis considers some hypothetical macro-level scenarios for coal-fired power generation, as well as macro-level flows of several key CCPs. The preliminary analysis in Appendix E is designed to assess the implications

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[57] We do not model a transport differential between virgin and FGD gypsum to be consistent with the transport assumptions used in the BEES fly ash analysis, which helps preserve the comparability of the fly ash and FGD gypsum unit impact values. It is important to note, however, that an increasing number of new gypsum wallboard plants are being constructed adjacent to coal-fired power plants, so the transport distance of FGD gypsum to the wallboard manufacturing facility may, in some cases, be less than the transport distance of virgin gypsum.

[58] A discussion of general principals for allocation is presented in the International Standard on Environmental Management—Life Cycle Assessment—Goal and scope definition and inventory analysis (ISO 14041:1(E)), pp.11-12, and Annex B.

[59] It is important to stress that allocated impacts are not actual impacts associated with the beneficial use of the materials; in most cases use is significantly more beneficial than disposal. Instead, allocation is a means of placing the beneficial use materials in the context of their original production and recognizing that the processes that produce these byproducts may incur environmental costs.

of allocating the environmental effects of power generation to both the energy product and the CCPs. Using both an economic and a mass-based approach, we find that the only small flows would be allocated to the CCPs relative to the impacts of electricity production (i.e. less than one percent in the case of mass-based allocation).

Because of the small environmental impacts allocation indicated by our preliminary analysis in Appendix E, and because of high uncertainty associated with fuel sources, prices of electricity generation, and CCP prices, we do not currently include either an economic or mass-based allocation of coal combustion impacts to fly ash or FGD gypsum into this analysis. However, to fully understand the potential impacts of beneficial use on coal combustion, and to fully characterize the benefits associated with beneficial use, it may be important to assess these impacts under various analytical scenarios as the program moves forward.

Typically, as with fly ash and FGD gypsum, the economic value of beneficial use materials is small in comparison to the value of primary products of the producing industries. However, it is conceivable that significant increases in the value of beneficial use materials could alter the economics of the producing industries. While it is unlikely that any industry would alter production to *increase* production of beneficial use materials, demand for these materials could improve the cost structure of certain industrial processes. For example, increased demand for CCPs could improve the cost structure for coal-fired power plants and improve their competitive position in energy markets.[60] As beneficial use and the economic value of various industrial materials increases, it becomes increasingly important to accurately account for the processes that produce the materials as well as the processes that use them.

RESULTS

For both the baseline and beneficial use scenarios, BEES and SimaPro generate quantitative estimates of impacts for a suite of environmental metrics. For each metric, environmental outputs under the baseline and beneficial use scenarios represent life cycle impacts of replacing virgin materials with CCPs. Where this difference is positive, the impact is an environmental benefit of using CCPs in place of virgin materials. Where the difference is negative, use of CCPs suggests a decline in environmental quality. Exhibit 4-1 presents the results of the analyses of use of fly ash in concrete and use of FGD gypsum in wallboard.

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[60] An example of a system in which dramatic changes in co-product value have driven production changes is the recent change in demand for ethanol, which has resulted in a significant increase in demand for agricultural by-products and has altered production decisions to meet this new demand.

EXHIBIT 4-1: LIFECYCLE ASSESSMENT OF POTENTIAL IMPACTS OF CCP BENEFICIAL USE

AVOIDED IMPACTS	PER 1 TON FLY ASH AS PORTLAND CEMENT IN CONCRETE	PER 1 TON FGD GYPSUM IN WALLBOARD
ENERGY USE		
NONRENEWABLE ENERGY (MJ)[a]	4,214.18	12,568.97
RENEWABLE ENERGY (MJ)[b]	43.55	13.69
TOTAL PRIMARY ENERGY (MJ)[c]	4,259.29	12,582.66
TOTAL PRIMARY ENERGY (US$)[d]	119.26	352.31
WATER USE		
TOTAL WATER USE (L)	341.56	14,214.60
TOTAL WATER USE (US$)[e]	0.22	9.01
GREENHOUSE GAS EMISSIONS		
CO_2 (G)	636,170.21	77,754.24
METHANE (G)	539.49	175.51
AIR EMISSIONS		
CO (G)	593.45	39.06
NOX (G)	1,932.48	168.02
SOX (G)	1,518.21	139.14
PARTICULATES GREATER THAN PM_{10} (G)	0.00	1,194.25
PARTICULATES LESS THAN OR EQUAL TO PM_{10} (G)	0.01	520.93
PARTICULATES UNSPECIFIED (G)	1,745.25	17.11
MERCURY (G)	0.04	0.00
LEAD (G)	0.03	0.03
WATERBORNE WASTES		
SUSPENDED MATTER (G)	13.96	23.60
BIOLOGICAL OXYGEN DEMAND (G)	3.07	21.87
CHEMICAL OXYGEN DEMAND (G)	26.00	24.71
COPPER (G)	0.00	0.02
MERCURY (G)	0.00	0.00
LEAD (G)	0.00	0.01
SELENIUM (G)	0.00	0.00
NONHAZARDOUS WASTE (KG)[f]	0.00	3.12

AVOIDED IMPACTS	PER 1 TON FLY ASH AS PORTLAND CEMENT IN CONCRETE	PER 1 TON FGD GYPSUM IN WALLBOARD

Notes:

a. Nonrenewable energy refers to energy derived from fossil fuels such as coal, natural gas and oil.

b. Renewable energy refers to energy derived from renewable sources, but BEES does not specify what sources these include.

c. Total primary energy refers to the sum of nonrenewable and renewable energy.

d. In addition to reporting energy impacts in megajoules (MJ), we monetize impacts by multiplying model outputs in MJ by the average cost of electricity in 2006 ($0.0275/MJ), converted to 2007 dollars ($0.0280/MJ). The 2006 cost of energy is taken from the Federal Register, February 27, 2006, accessed at: http://www.npga.org/14a/pages/index.cfm?pageid=914. The cost was converted to 2007 dollars using NASA's Gross Domestic Product Deflator Inflation Calculator, accessed at: http://cost.jsc.nasa.gov/inflateGDP.html.

e. In addition to reporting water impacts in gallons, we monetize impacts by converting model outputs from liters to gallons and multiplying by the average cost per gallon of water between July 2004 and July 2005 ($0.0023/gal), converted to 2007 dollars ($0.0024/gal). The 2005 cost of water is taken from NUS Consulting Group, accessed at: https://www.energyvortex.com/files/NUS_quick_click.pdf. The cost was converted to 2007 dollars using NASA's Gross Domestic Product Deflator Inflation Calculator, accessed at: http://cost.jsc.nasa.gov/inflateGDP.html.

f. BEES reports waste as “end of life waste.” In contrast, SimaPro reports “solid waste.” In is not clear if these waste metrics are directly comparable as SimaPro does not specify whether “solid waste” refers to manufacturing waste, end-of-life waste, or both.

As shown in Exhibit 4-1, the results of the fly ash and FGD gypsum analyses suggest many positive environmental impacts associated with beneficial use. For most metrics, there is a significant difference between the unit impact value for fly ash and FGD gypsum. The difference in unit impact values reflects different avoided processes when fly ash is used to offset portland cement versus when FGD gypsum is used to offset virgin gypsum. For example, the primary driver of benefits when fly ash is used in concrete is avoided raw materials extraction and avoided portland cement production.[61] In comparison, the primary driver of benefits when FGD gypsum is used in wallboard is avoided virgin gypsum extraction and the processing of virgin gypsum into stucco. Portland cement production generates relatively high greenhouse gas emissions. Thus, the avoided CO_2 and methane emissions are greater for fly ash than for FGD gypsum in this analysis. In contrast, gypsum mining requires comparatively higher quantities of water, so the water savings are greater for FGD gypsum in this analysis than for portland cement.

In addition, the difference in unit impacts may reflect differences in the assumed system boundaries between the two analyses. It is unclear how the BEES system boundaries compare to SimaPro. Thus, the total life cycle impacts calculated in BEES could be large or small in comparison to the system boundaries in the SimaPro FGD gypsum analysis.

LIMITATIONS AND ASSUMPTIONS

Although the BEES analysis provides a useful example of the benefits that can be achieved through beneficial use of fly ash in concrete, it is important to recognize some of the key limitations and assumptions of the work to date:

- The BEES model may over- or underestimate the national impacts of using fly ash in concrete construction projects because site-specific environmental conditions and proximity to sources of fly ash may affect the resulting benefits and influence the net effect of choosing fly ash over portland cement.

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[61] It is unclear from the documentation provided for BEES what impacts (e.g. virgin materials extraction, plant infrastructure, etc.) are modeled for portland cement production. For this reason, it is not possible to explain the differences in unit impact results between the FGD gypsum and fly ash analysis.

- BEES assumes round-trip distances for the transport of concrete raw materials to the ready-mix plant of 60 miles for portland cement and fly ash and 50 miles for aggregate. The user cannot adjust these transport distances. This analysis also assumes the minimum possible transport distances for the finished concrete products to the construction site. This transport distance for ready-mix concrete for a pavement application is 50 miles.
- BEES environmental results are reported in physical quantities (e.g., MJ energy, liters water, g CO, g NO, g Hg, etc.), not in monetized terms.
- In BEES, the calculation of each environmental impact is not fully transparent. BEES does disaggregate the total life cycle impact value for each environmental metric (e.g., energy use, CO_2 emissions, etc.) by lifecycle stage and by product component, but it is not possible to see exactly how each impact is derived. This limits the user's ability to compare the results of the BEES model with those of others models, such as SimaPro.
- The FGD gypsum analysis is based on a Swiss life cycle inventory data. While we substituted Swiss electricity data with the average U.S. energy mix, it is unclear whether the average U.S. energy mix is an accurate representation of the electricity mix used in wallboard manufacturing. Given the recent trend in new wallboard facilities being constructed adjacent to coal-fired powered plants, it is possible that these facilities use primarily coal-based electricity. With the exception of energy mix, it is unlikely that any other differences between European and U.S. gypsum extraction and stucco processing would result in meaningful differences in environmental impacts.
- The FGD gypsum analysis assumes that dewatering of FGD gypsum is accomplished through evaporation in holding ponds. To the extent that the predominant practice is to use mechanical dewatering processes, the analysis should be modified to reflect this. The assumption of dewatering via holding ponds likely overstates the energy and energy-related emissions impacts in this analysis, since the impacts of dewatering, which are subtracted from the avoided gypsum processing impacts, would be greater for mechanical dewatering than for holding pond evaporation.

CHAPTER 5: ESTIMATING PROGRAM LEVEL IMPACTS

This chapter provides an overview of an initial, life-cycle based approach to evaluating program level impacts associated with the RCC effort to increase beneficial use of CCPs. The chapter first outlines two critical steps necessary for a complete evaluation of specific program impacts:

- Development of defensible beneficial use scenarios that reflect likely market trends, policy efforts, and key limitations; and
- Implementation of a well-supported attribution protocol for assigning beneficial use impacts to specific EPA programs.

This discussion is followed by a preliminary analysis of the total impacts associated with current (baseline) beneficial use patterns, based on an extrapolation of the life cycle analysis impacts identified in Chapter 4. The purpose of this chapter is to present an initial estimate of the measurable impacts associated with current levels of beneficial use of CCPs, and to outline the steps necessary to provide a refined, program-specific analysis of EPA's efforts through the RCC to increase beneficial use of CCPs.

DEVELOPMENT OF DEFENSIBLE BENEFICIAL USE SCENARIOS

Life cycle inventories (LCI) and LCA provide comprehensive information on the impacts associated with given quantities of materials used in specified systems. The impacts measured by LCA models are typically linear; as the quantity of CCPs used in a particular application (e.g., concrete) is increased, the environmental impacts increase proportionately.

While LCA can provide insights into the potential magnitude of program benefits, in some cases existing market limitations and trends suggest that a linear extrapolation of current practices would be unrealistic. An effective assessment of true program impacts requires the development of defensible market scenarios that accurately identify the extent to which different beneficial uses are likely to increase, given the realities of the existing and emerging markets for beneficial use and the structure of RCC programs.

Current Market Dynamics: Factors Affecting Beneficial Use

Several market factors can limit the increased beneficial use of CCPs in various products. In some cases programs can be designed to address these factors effectively. Exhibit 5-1 outlines several of these factors and presents hypothetical actions that might address them. It is important to note that the actions described below are intended only to illustrate possible conditions for increasing the beneficial use of CCPs; they do not represent specific policy recommendations or existing program priorities.

EXHIBIT 5-1: LIMITING FACTORS TO INCREASED BENEFICIAL USE OF CCPs

FACTOR TYPE	FACTORS AFFECTING INCREASED BENEFICIAL USE	HYPOTHETICAL ACTIONS TO INCREASE BENEFICIAL USE
Economic	Transportation costs generally limit the shipment of CCPs to within about a 50 to 150 mile radius of power plants. In some cases, however, the cost of transport to the end user may be prohibitively expensive.	Implementation of strategic actions to create incentives to increase beneficial use by shifting the economic drivers (i.e., cost of materials) in favor of CCPs. Potential incentives could include tax credits for the use of CCPs, increased CCP landfill disposal tipping fees, or streamlining the permitting process for facilities that use CCPs near coal combustion plants (e.g., FGD gypsum plants).
	In some parts of the country and for certain use applications, the cost of virgin materials may be cheaper than CCPs.	

FACTOR TYPE	FACTORS AFFECTING INCREASED BENEFICIAL USE	HYPOTHETICAL ACTIONS TO INCREASE BENEFICIAL USE
	Inexpensive landfill disposal can limit incentive to sell rather than dispose of CCPs.	
Institutional	National standards organizations have promulgated specifications that limit or disallow the use of CCPs in some construction applications because of quality and performance concerns and perceptions.	State DOTs rely on consensus standards for guidance and generally accept the use of fly ash in concrete. DOT projects can be used to demonstrate the performance of CCPs in geotechnical applications.
	The implementation of the U.S. Clean Air Mercury Rule (CAMR) may result in altering the chemical properties of fly ash, rendering it unmarketable for beneficial use. Similar impacts may also occur for fly ash containing higher levels of unburned carbon or other components resulting from installation of low-NOx burners at coal-based power plants.	Establishment of a research and development infrastructure to address the technical limiting factors to CCP use. Provide technical and/or economic assistance to utilities using low-NOx burners to identify and implement cost-effective process modifications or new equipment to reduce the carbon content of fly ash.
Technical	Lack of consistency and quality in the production of fly ash has resulted in limited use in the high-value ready-mix concrete market. The priority at a coal-fired power plant will always be on producing electricity, not ash. A change in the combustion process, such as the type of coal burned, results in a change in ash quality, making it difficult to produce a consistent product.	Taking into account the power plant's priority of generating electricity, the program could facilitate formal training programs to teach plant operators about the co-product value of producing consistent-quality fly ash.
Educational	While quality and consistency of fly ash are legitimate concerns of end-users, in some cases, negative perceptions toward CCP use are unwarranted. Negative perceptions can often be attributed to a single experience using CCPs in a project that failed, even if CCPs were not the cause of the failure. For example, at one time, the Austin, TX concrete market almost turned to an all-cement market because of one misuse resulting from a lack of education about the material.	Dissemination of objective, scientific material to educate potential end users. (EPA is currently addressing this through C^2P^2 and other activities).

Sources:

1. U.S. Department of Energy, National Energy Technology Laboratory, "General Summary of State Regulations," accessed at: http://www.netl.doe.gov/E&WR/cub/states/select_state.html.
2. Energy and Environmental Research Center, "Barriers to the Increased Utilization of Coal Combustion/Desulfurization By-Products by Government and Commercial Sectors--Update 1998," EERC Topical Report DE-FC21-93MC-30097--79, July 1999.

American Coal Ash Association, "Frequently Asked Questions," accessed at: http://www.acaa-usa.org/FAQ.htm.

Schwartz, Karen D. "The Outlook for CCPs," *Electric Perspectives*, July/August 2003.

5. Energy & Environmental Research Center, University of North Dakota, "Review of Florida Regulations, Standards, and Practices Related to the Use of Coal Combustion Products: Final Report," April 2006, accessed at: http://www.undeerc.org/carrc/Assets/TB-FLStateReviewFinal.pdf.
6. Energy & Environmental Research Center, University of North Dakota, "Review of Texas Regulations, Standards, and Practices Related to the Use of Coal Combustion Products: Final Report," January 2005, accessed at: http://www.undeerc.org/carrc/Assets/TXStateReviewFinalReport.pdf.

Exhibit 5-1 outlines a number of economic and non-economic factors that may limit the increased beneficial use of CCPs. The economic factors primarily relate to transportation costs and the price of virgin materials; a critical limitation of the market for CCPs may be the regional nature of the coal-burning industry and the extent to which CCPs can find viable markets competing with virgin materials within an economically viable distance.

Several of the non-economic issues presented in Exhibit 5-1 may also limit the expansion of CCP beneficial use, if, for example, new uses and new markets require changes in state policies governing CCP use. In response, targeted efforts among states to harmonize policies regarding beneficial use of CCPs could result in expansion of certain uses of CCPs.

To effectively describe impacts associated with RCC programs and goals, it is important to develop scenarios that correctly identify the limits of existing markets, and calculate the quantitative impact on the use of CCPs in different applications. In addition, scenarios should incorporate RCC priorities, in order to better predict which uses and markets are likely to expand. At this time, data on market limitations and on program priorities and goals are not refined enough to inform a detailed program analysis. However, spatial information about coal-fired power plants and new data on emerging markets may be sufficient to support an analysis in the near future. The result could be a set of scenarios that pinpoints specific uses for CCPs that are likely to grow and notes regional and national limits for certain applications.

Structural Changes to the Market

In addition to changes related to market trends and program activities, beneficial use scenarios must, in some cases, reflect significant changes to the market, such as large-scale technology shifts that might affect demand for or production of CCPs. In addition, for materials frequently used in construction, unexpected events such as large storms or terrorist attacks may result in sudden, regional changes in demand if, for example, large quantities of materials are needed for reconstruction or if coal-fired power plant operations change significantly as a result of a regional event.

Since these events are by definition unpredictable, it is important to identify methods for analyzing impacts if and when they occur. In particular, analyses that clearly identify the current regional market conditions (e.g., oversupply, strong demand) would provide a useful starting point for analysis of unexpected market shifts.

ATTRIBUTION OF IMPACTS TO EPA PROGRAMS

The factors affecting increased beneficial use also link to the issue of attributing changes in beneficial use markets or behavior to specific EPA initiatives. The issue of attribution is complex, and in many cases the data necessary to support a clear attribution of impacts are not available. Particularly in the case of voluntary programs, it is often difficult to attribute changes in behavior (or a proportion of the change in behavior) to specific EPA activities. For example, changes in recycling or source reduction may be due to outside forces (i.e., market dynamics), multiple government programs, or a combination of both.

One starting point in addressing the attribution of benefits to EPA activities is an examination of existing information and methods describing the performance of target EPA programs and overall trends in beneficial use. Linking program activity with market trends can, on a qualitative basis, provide an indication of whether the program is having an effect. This initial scoping exercise can then be supplemented with the development of specific program scenarios that endeavor to quantify incremental beneficial use levels attributable to EPA's initiatives. In other cases, it may be necessary to start with the assumption that all costs and all benefits are related to EPA activities, and adjust that assumption as programs mature and data become available.

A full-scale, defensible approach to attribution of voluntary program impacts, however, requires a clear understanding of both the specific activities undertaken by the program and the differences between behavior of program participants and those who do not participate. This information can sometimes be obtained or identified through broadly collected data that includes both participants and non-participants (e.g., the Biennial Report or the Toxics Release Inventory). In other cases, behavioral research can help predict effective response rates to different types of programs. Exhibit 5-2 outlines the process for a full-scale assessment of attribution.

EXHIBIT 5-2: OUTLINE TO ATTRIBUTE VOLUNTARY PROGRAM IMPACTS

STEP 1: ASSESS THE MARKET FAILURE BEING ADDRESSED

- Identify and describe specific market failure of interest
  Example: material with market value being disposed as waste
- Evaluate size of market failure: evaluation of total quantity affected, current recovery and management, potential *economically feasible* recovery
- Identify key behavior changes necessary to address market failure
- Identify programs in place to address market failure, including Federal, State, local, and private efforts.

STEP 2: DESCRIBE IN DETAIL EACH EPA PROGRAM WORKING ON THE "ISSUE"

- Summarize program goals, structure, policy leverage points using program evaluation methodologies.
- Identify, for each relevant program, current and intended participants, key resources available, actions taken by participants, timeline for behavioral change, and link between activities and behavioral change.

STEP 3: IDENTIFY AVAILABLE DATA ON EPA AND OTHER EFFORTS

- Quantitative estimates of recent trends in target behavior, specific estimates of recent changes in behavior among EPA program members and non-members, and research on response rates for similar programs, strategies.

STEP 4: ATTRIBUTION OF IMPACTS TO EPA PROGRAM(S)

- Refine analysis of data collected in Step 3 to identify: changes in behavior among EPA program participants and among non-members, expected leverage of EPA activities across federal, state, private programs (e.g., by expansion of recycling efforts from pilot programs or harmonization of state regulations as a result of EPA information development), and expected leverage of EPA activities over time.
- Identify and correct for independent, confounding market changes that may affect the issue, such as changes in virgin raw materials prices due to sudden shortage.

The result of this approach should yield a quantitative estimate of the total extent of changes that can be attributed to EPA. Where implementation and/or tracking data are not available, approaches can potentially include theoretical estimates reflecting literature on response rates for voluntary activities. As necessary, this effort can also provide information to effectively allocate total EPA impacts across multiple programs in cases where more than one program is focused on addressing the same market failure. In areas where the attribution of outcomes is not possible due to data and methodological limitations, program structure and purpose can be revisited with the intent of developing metrics (e.g., for PART analysis) that are meaningful in measuring change without attempting to achieve a simplistic success metric of "outcome/resources."

In the absence of specific information on behavior changes among participants and non-participants in RCC beneficial use activities, we focus below on total impacts associated with CCP beneficial use. This forms an upper bound estimate of the impact of EPA programs related to these materials, but may understate total beneficial impacts because not all materials are considered.

BENEFICIAL IMPACTS ASSOCIATED WITH CURRENT USE OF CCPs

In the absence of defensible beneficial use scenarios for CCPs or a well-supported allocation protocol for assigning beneficial use impacts to specific EPA programs, we present a preliminary analysis of the total impacts associated with current (baseline) beneficial use patterns. While these impacts do not strictly reflect RCC program achievements, they represent the best available information on the environmental benefits of beneficially using CCPs, and reflect the impacts of all EPA, state, and industry efforts to increase CCP use to its 2005 level.

We calculate the beneficial impacts of current beneficial use of CCPs by extrapolating the life cycle analysis impacts identified in Chapter 4 to the current quantity of CCPs beneficially used in each application as presented in ACAA's 2005 CCP Survey. We also calculate the beneficial impacts of achieving the RCC goal for beneficial use of fly ash (i.e., use of 18.6 million tons of fly ash in concrete by 2011). We are unable to similarly calculate RCC program achievements for increased use of FGD gypsum as a program goal has not been developed for FGD gypsum. Exhibit 5-3 presents the impacts of the beneficial use of fly ash and FGD gypsum extrapolated both to current use quantities and the RCC goal for use of fly ash in concrete.

EXHIBIT 5-3: EXTRAPOLATED IMPACTS OF THE BENEFICIAL USE OF CCPs

AVOIDED IMPACTS	FLY ASH IN CONCRETE EXTRAPOLATED TO RCC GOAL (18.6 MILLION TONS)[a]	FLY ASH IN CONCRETE EXTRAPOLATED TO CURRENT USE (15.0 MILLION TONS)[b]	FGD GYPSUM IN WALLBAORD EXTAPOLATED TO CURRENT USE (8.2 MILLION TONS)[c]	PARTIAL SUM OF CURRENT USE BENEFICIAL IMPACTS[d]
ENERGY USE				
NONRENEWABLE ENERGY (MJ)[e]	78.4 billion	63.2 billion	102.8 billion	166.0 billion
RENEWABLE ENERGY (MJ)[f]	810.0 million	652.8 million	111.9 million	764.7 million
TOTAL PRIMARY ENERGY (MJ)[g]	79.2 billion	63.8 billion	102.9 billion	166.7 billion
TOTAL PRIMARY ENERGY (BTU)	75 trillion	60 trillion	98 trillion	158 trillion
TOTAL PRIMARY ENERGY (US$)[h]	$2.2 billion	$1.8 billion	$2.9 billion	$4.7 billion
WATER USE				
TOTAL WATER USE (LITERS)	6.3 billion	5.2 billion	116.2 billion	121.4 billion
TOTAL WATER USE (US$)[i]	$4.0 million	$3.2 million	$73.7 million	$77.9 million
GREENHOUSE GAS EMISSIONS				
CO_2 (G)	11.8 trillion	9.5 trillion	0.6 trillion	10.2 trillion
METHANE (G)	10.0 billion	8.1 billion	1.4 billion	9.5 billion
TONS CO_2 EQUIVALENT[j]	13.2 million	10.6 million	0.7 million	11.5 million
METRIC TONS CARBON EQUIVALENT (MTCE)[k]	3.6 million	2.9 million	0.2 million	3.1 million
AIR EMISSIONS				
CO (G)	11.0 billion	8.9 billion	0.3 billion	9.2 billion
NOx (G)	35.9 billion	29.0 billion	1.4 billion	30.3 billion
SOx (G)	28.2 billion	22.8 billion	1.1 billion	23.9 billion
PARTICULATES GREATER THAN PM_{10} (G)	0	0	9.7 billion	9.7 billion
PARTICULATES LESS THAN OR EQUAL TO PM_{10} (G)	0.2 million	.02 million	4.3 million	4.3 million
PARTICULATES UNSPECIFIED (G)	32.5 billion	26.1 billion	0.1 billion	26.3 billion
MERCURY (G)	714,000	576,000	8,000	584,000
LEAD (G)	523,000	421,000	235,000	656,000
WATERBORNE WASTES				
SUSPENDED MATTER (G)	259.6 million	209.2 million	193.0 million	402.2 million

AVOIDED IMPACTS	FLY ASH IN CONCRETE EXTRAPOLATED TO RCC GOAL (18.6 MILLION TONS)[a]	FLY ASH IN CONCRETE EXTRAPOLATED TO CURRENT USE (15.0 MILLION TONS)[b]	FGD GYPSUM IN WALLBAORD EXTAPOLATED TO CURRENT USE (8.2 MILLION TONS)[c]	PARTIAL SUM OF CURRENT USE BENEFICIAL IMPACTS[d]
BIOLOGICAL OXYGEN DEMAND (G)	57.1 million	46.1 million	178.8 million	224.9 million
CHEMICAL OXYGEN DEMAND (G)	483.6 million	389.7 million	202.1 million	591.8 million
COPPER (G)	0	0	194,000	194,000
MERCURY (G)	1	0	3,000	3,000
LEAD (G)	0	0	65,000	65,000
SELENIUM (G)	3	2	2,000	2,000
NON-HAZARDOUS WASTE (KG)[k]	0	0	25.4 million	25.4 million

Notes:

a. We extrapolate the incremental impacts (i.e., impacts associated with use of 1 ton fly ash) to estimate impacts of attaining the RCC goal for the use of fly ash in concrete (18.6 million tons by 2011). To extrapolate, we multiply each of the incremental impacts calculated by the BEES model by 18.6 million.

b. We extrapolate the incremental impacts (i.e., impacts associated with use of 1 ton fly ash) to estimate the impacts of current beneficial use of fly ash in concrete (15.0 million tons). The current quantity of fly ash that is beneficially used as a substitute for finished portland cement in concrete is reported by ACAA's 2005 CCP Survey. We multiply each of the incremental impacts calculated by BEES by 15.0 million tons to extrapolate these impacts to reflect current use.

c. We extrapolate the incremental impacts (i.e., impacts associated with use of 1 ton FGD gypsum) to estimate the impacts of current beneficial use of FGD gypsum in wallboard (8.2 million tons). The current quantity of FGD gypsum that is beneficially used as a substitute for finished portland cement in concrete is reported by ACAA's 2005 CCP Survey. We multiply each of the incremental impacts calculated by SimaPro by 8.2 million to extrapolate these impacts to reflect current use.

d. Calculated as the sum of the fly ash and FGD gypsum current use extrapolations.

e. Nonrenewable energy refers to energy derived from fossil fuels such as coal, natural gas and oil.

f. Renewable energy refers to energy derived from renewable sources, but BEES does not specify what sources these include.

g.

h. In addition to reporting energy impacts in megajoules (MJ), we monetize impacts by multiplying model outputs in MJ by the average cost of electricity in 2006 ($0.0275/MJ), converted to 2007 dollars ($0.0280/MJ). The 2006 cost of energy is taken from the Federal Register, February 27, 2006, accessed at: http://www.npga.org/14a/pages/index.cfm?pageid=914. The cost was converted to 2007 dollars using NASA's Gross Domestic Product Deflator Inflation Calculator, accessed at: http://cost.jsc.nasa.gov/inflateGDP.html.

i. In addition to reporting water impacts in gallons, we monetize impacts by converting model outputs from liters to gallons and multiplying by the average cost per gallon of water between July 2004 and July 2005 ($0.0023/gal), converted to 2007 dollars ($0.0024/gal). The 2005 cost of water is taken from NUS Consulting Group, accessed at: https://www.energyvortex.com/files/NUS_quick_click.pdf. The cost was converted to 2007 dollars using NASA's Gross Domestic Product Deflator Inflation Calculator, accessed at: http://cost.jsc.nasa.gov/inflateGDP.html.

j. Greenhouse gas emissions have been converted to tons of CO_2 equivalent using U.S. Climate Technology Cooperation Gateway's Greenhouse Gas Equivalencies Calculator accessed at: http://www.usctcgateway.net/tool/. This calculation only includes CO_2 and methane.

k. Impacts in MTCE are calculated by dividing the impacts in MTCO2E by 44/12 (the ratio of the molecular weight of carbon dioxide to carbon). U.S. EPA, "A Climate Change Glossary," accessed at: http://www.globalwarming.org/node/91.

l. BEES reports waste as "end of life waste." In contrast, SimaPro reports "solid waste." In is not clear if these waste metrics are directly comparable as SimaPro does not specify whether "solid waste" refers to manufacturing waste, end-of-life waste, or both.

The results show that current beneficial use of fly ash in concrete and FGD gypsum in wallboard results in positive environmental impacts. The most significant impacts include energy savings and water use reductions. Energy savings associated with the use of fly ash and FGD gypsum totals approximately 167 billion megajoules of energy (or approximately $4.7 billion in 2007 energy prices). Based on the average monthly consumption of residential electricity customers, this is enough energy to power over 4 million homes for an entire year. Avoided water use totals approximately 121 billion liters or approximately $76.9 million in 2007 water prices).[62] This is roughly equivalent to the annual water consumption of 61,000 Americans.[63] The extrapolated beneficial impacts also include key impacts such avoided greenhouse gas (11.5 million tons of avoided CO_2 equivalent), and avoided air emissions (30.3 million kilograms of avoided NOx, and 23.9 million kilograms of SOx). Note that the impacts presented in Exhibit 5-3 represent only a partial estimate of the total impacts of beneficially using CCPs. Beneficial use of fly ash as a substitute for finished portland cement in concrete and FGD gypsum in wallboard accounts for only 47% (23.2 million tons) of all beneficially used CCPs in 2005.[64]

Economic Distribution of CCP Beneficial Use Impacts

In addition to an estimate of overall beneficial impacts associated with use of CCPs, we developed a screening analysis using the EIO-LCA model to provide insight into the distribution of impacts across economic sectors. We modeled the impacts associated with a hypothetical reduction of $1 million of demand from the cement manufacture and gypsum mining sectors. From the perspective of energy and air emissions, cement manufacturing leads to large impacts, and is in general the largest source of emissions across the supply chain. Reducing the amount of cement produced by beneficially reusing products can lead to large supply chain-wide reductions of emissions. Comparatively, the impact of the substitution of FGD gypsum for virgin gypsum in wallboard manufacturing is less clear, as the EIO-LCA model was not able to adequately represent the wallboard sector.

These results and others produced by the model do not affect the total estimate of beneficial impacts associated with changes in use of CCPs. However, they indicate the specific sectors, activities, and points in the supply chain that may be most important to consider in more detailed analyses of beneficial use scenarios. The EIO-LCA model may provide important insights into the success of policies and actions, because the model identifies the types of market changes that may result from specific changes in practice. EIO-LCA may, therefore, clarify the positive and negative impacts of specific, targeted programs and actions on different economic sectors. Appendix C provides a detailed discussion of the analysis.

CONCLUSIONS AND NEXT STEPS

This report provides a preliminary assessment of the baseline impacts associated with the beneficial use of fly ash and FGD gypsum in 2005. The analysis uses the life cycle-based BEES and SimaPro models, coupled with simple monetized estimates of energy and water savings, to estimate the impacts of replacing portland cement with fly ash in concrete and virgin gypsum with FGD gypsum in wallboard. The most significant impacts include energy savings and water use reductions. Energy savings associated with the use of fly ash and FGD gypsum totals approximately 167 billion megajoules of energy (or approximately $4.7 billion in 2007 energy prices). Based on the average monthly consumption of residential electricity customers, this is enough energy to power over 4 million homes for an entire year. Avoided water use totals approximately 121 billion liters or approximately $76.9 million in 2007 water

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[62] Based on the assumption that an average residential customer uses 938 kilowatt-hours per month. Department of Energy, Energy Information Administration, "Energy Basics 101," http://www.eia.doe.gov/basics/energybasics101.html, accessed August 30, 2007.

[63] Based on 2000 USGS per capita water use estimate of 1,430 gallons per day. Lumia et al., United States Department of the Interior, United States Geological Survey, Summary of Water Use in the United States, 2000.

[64] As shown in Exhibit 4, a total of 49.6 million tons of CCPs were beneficially used in 2005.

prices).[65] This is roughly equivalent to the annual water consumption of 61,000 Americans.[66] The extrapolated beneficial impacts also include key impacts such avoided greenhouse gas (11.5 million tons of avoided CO_2 equivalent), and avoided air emissions (30.3 million kilograms of avoided NOx, and 23.9 million kilograms of SOx).

This report also presents a distributional screening analysis using the EIO-LCA model that indicates significant avoided environmental impacts from reductions in the demand for cement or virgin gypsum that are distributed across several economic sectors. From the perspective of energy and air emissions, cement manufacturing leads to large impacts, and is in general the largest source of emissions across the supply chain. Reducing the amount of cement produced by beneficially reusing products can lead to large supply chain-wide reductions of emissions. Comparatively, the impact of the substitution of FGD gypsum for virgin gypsum in wallboard manufacturing is less clear.

The preliminary results of this initial analysis suggest that a more detailed evaluation of the beneficial use of CCPs could build on these results to assist the Agency in a more specific evaluation of the achievements of the RCC program. A more detailed analysis would require:

- The development of realistic and effective beneficial use scenarios that incorporate more detailed descriptions of markets, beneficial uses, and policies. Realistic scenarios should reflect key market dynamics and limits such as distance to markets and virgin material prices, and be able to assess the impacts of these dynamics on the growth potential for specific beneficial uses. For example, the limiting transportation distance for the beneficial use of CCPs in road construction may be far less then that of gypsum wallboard.
- The development of a methodology to attribute beneficial use impacts to specific EPA/RCC efforts and programs. A phased approach may be appropriate. Such an approach could initially employ the simple operating assumption that all impacts result from Agency actions. This assumption could then be refined to reflect specific Agency strategies, policies, and other efforts, and link these, where possible, to specific changes in beneficial use practices and markets.
- The expansion of the assessment to include additional CCPs and beneficial use applications. This analysis only examines the beneficial impacts of substituting fly ash for finished portland cement in concrete and substituting FGD gypsum for virgin gypsum in wallboard manufacturing. These two processes represent less than 50% of the total beneficial use of CCPs. Additional high volume applications that may be analyzed include: the use of fly ash as a raw feed in cement clinker; the use of boiler slag as blasting grit; and the use of various CCPs in structural fill and waste stabilization. In addition, the beneficial impacts of lower volume applications may be examined in order to identify those that may have potentially high incremental impacts.

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[65] Based on the assumption that an average residential customer uses 938 kilowatt-hours per month. Department of Energy, Energy Information Administration, "Energy Basics 101," http://www.eia.doe.gov/basics/energybasics101.html, accessed August 30, 2007.

[66] Based on 2000 USGS per capita water use estimate of 1,430 gallons per day. Lumia et al., United States Department of the Interior, United States Geological Survey, Summary of Water Use in the United States, 2000.

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APPENDIX A | KEY BENEFICIAL USE APPLICATIONS FOR CCPS

EXHIBIT A-1 KEY BENEFICIAL USE APPLICATIONS FOR CCPs (2005)

BENEFICIAL USE APPLICATION AND INDUSTRY	FLY ASH	BOTTOM ASH	FLUE GAS DESULFURIZATION GYPSUM	FLUE GAS DESULFURIZATION OTHER WET MATERIAL	FLUE GAS DESULFURIZATION DRY MATERIAL	BOILER SLAG	PRODUCT SUBSTITUTES
Concrete	14,989,958	1,020,659	328,752	0	13,965	0	Cement, Silica fume, Furnace slag
Cement additive	2,834,476	939,667	397,743	782	0	42,566	Clay, Soil, Shale, Gypsum
Flowable fill	88,549	0	0	0	9,673	0	Soil, Sand, Gravel, Cement
Structural fill	5,710,749	2,321,140	0	0	2,666	175,144	Sand, Gravel, Soil, Aggregate
Road base	205,032	1,056,660	0	0	0	300	Cement, Lime, Aggregate
Soil stabilizer	715,996	205,322	0	0	1,535	0	Cement, Lime, Aggregate
Mineral filler in asphalt	62,546	21,583	0	0	0	56,709	Sand
Snow and ice control	591	531,549	0	0	0	15,401	Sand
Blasting grit	0	89,109	0	0	0	1,544,298	Sand
Mine reclamation	626,428	46,604	0	245,471	112,100	31,540	Soil
Wallboard	0	0	8,178,079	0	0	0	Natural gypsum
Waste stabilization	2,657,046	42,353	0	0	0	0	Cement, Lime, Cement kiln dust
Agricultural soil amendment	23,856	7,670	361,644	3,312	19,259	0	Liming agents
Manufactured aggregate	180,275	692,501	0	0	0	0	Sand, gravel, aggregate
Miscellaneous/other	1,022,952	567,155	2,147	436,619	0	24,851	
CCP Category Use Totals	29,118,454	7,541,972	9,268,365	689,184	159,198	1,890,809	
CCP Utilization Rate	41%	43%	77%	4%	11%	97%	

Sources:

1. American Coal Ash Association. “2005 Coal Combustion Product (CCP) Production and Use Survey,” accessed at: http://www.acaa-usa.org/PDF/2005_CCP_Production_and_Use_Figures_Released_by_ACAA.pdf.
2. Western Region Ash Group, “Applications and Competing Materials, Coal Combustion Byproducts,” accessed at: http://www.wrashg.org/compmat.htm.

Note: Results from the 2006 CCP Production and Use Survey conducted by the ACAA indicate a total fly ash utilization rate of 44.78 percent, up from 40.95 percent (rounded to 41% above) reported for 2005. This reflects an ongoing upward trend in the CCP utilization rate over the past decade. The 2006 results were received too late for incorporation into the benefits analysis.

APPENDIX B | USE OF LIFE CYCLE ANALYSIS IN AN EVALUATION OF ECONOMIC BENEFITS

Life cycle assessment (LCA) inventory analyses of the type presented in this report deliver incremental changes in physical inputs, outputs, and energy arising from management or regulatory changes to an industrial production process. This discussion addresses the following issues: how does LCA relate to economic analysis of benefits, and how are economic impacts derived from changes in "physical inventory," such as energy use and alternative waste streams?

RELATIONSHIP BETWEEN LCA AND ECONOMIC ANALYSIS OF BENEFITS

LCA is a performance assessment tool – a method to depict physical outcomes that can be used to assess impacts and measure progress over time. And because LCA is a systems approach to assessment, it offers significant improvement over less comprehensive techniques. However, in economic terms, LCA is only one component of a true analysis of benefits – albeit a central component.

Consider the architecture of an economic benefit assessment. At the "front end" lies a set of economic drivers that determine technologies and practices employed by industry. These drivers include raw material prices, other input costs (including transport), competitive factors, regulation, technology, and taxes. EPA programs such as RCC work to facilitate changes in the economic drivers of waste generation, handling, and disposal (e.g., a change in tipping fees, tighter permit requirements on landfills, benefits to participation in beneficial use programs, etc.). Changes in these economic drivers can be expected to lead to changes in the physical system of production. In other words, the physical system and its outputs are properly thought of as the end product of a set of economic incentives (prices) and constraints (technology).

LCA depicts production as a *system* of sometimes reinforcing, sometimes counteracting physical outcomes. In particular, it allows the analyst to predict the *incremental* physical consequences of a change in disposal practices, technology, or price incentives. Any change in the physical system leads to a corresponding cascade of system changes – as inputs are substituted, exposure pathways are changed, and technology adapts. LCA produces the net result of these various changes and, thus, the true, incremental effect on physical outputs.[67]

Deriving an incremental physical effect from a complex system is difficult enough. As the agency seeks performance measures to satisfy its GPRA and PART requirements, LCA is a natural starting point. It demands systems thinking, properly views outcomes as changes to baseline conditions, identifies tradeoffs, and yields concrete, measurable metrics. LCA can tell us *who* and *what* will be affected by changes in industrial practice, and even *where* changes are likely to occur.

However, while LCA is a fundamental building block of benefit assessment, LCA does not itself yield the social benefits and costs of industrial change. To do that, we must apply economic valuation techniques to the physical outputs of LCA analysis.

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[67] For example, the PaLATE model generates incremental effects on physical outputs arising from changes in roadway materials.

Economic Assessment is desirable because we don't really care about physical outcomes, we care about what those outcomes imply for human well-being. Another way of putting this is, how do we compare the "apples" of one change to the "oranges" of another?[68] Also, how do we compare a given "small" physical gain in one waste to a "large" reduction in another. In physical terms, we might be tempted to say that the large gain outweighs the small loss. Of course, small physical changes can have large health and environmental consequences with large economic ramifications (think of the effect of radiation or toxics on health).

To understand how energy and raw materials use and emissions of different kinds affect well-being we must make a set of additional "translations." A physical change in lead concentrations leads, via ecological and epidemiological processes, to changes in human exposure. Changes in exposure lead to morbidity and mortality effects. Morbidity and mortality effects have social benefits and costs.[69] Those benefits and costs are the ultimate goal of our analysis. In another example, the effect of water consumption on well-being depends upon the location, timing, and quality of the water that is consumed. The value of that water depends on how it would otherwise be used – for human consumption, industrial uses, habitat support, irrigation, etc. LCA tells us little, if anything, about these relationships. Thus, LCA may tell us relatively little about the actual welfare effects of changes in industrial process.

Unfortunately, the translation of physical changes into economic outcomes is costly, difficult, and often controversial when applied to human health or environmental outcomes. As the report notes earlier, "with the exception of water and energy savings for which current price data are available, we do not calculate these benefits in dollar terms because monetizing involves complex valuation procedures." Putting economic value on even a small set of physical impacts can be a significant and expensive proposition.

Accordingly, LCA should be regarded, not only as a necessary ingredient, but also as a practical alternative to real benefit assessment. While economic benefits are the ultimate performance measure, businesses and governments routinely rely on simpler – though imperfect – proxies to facilitate management and performance assessment. As proxies, LCA outputs are a legitimate and defensible compromise.

INVENTORY CHANGES AND WELFARE: THE TRANSLATION OF LCA OUTPUTS TO ECONOMIC IMPACTS

There are two basic steps that must be employed to translate LCA-generated inventories into social benefits. The first is the translation of LCA inventories into "final economic goods." The second is the valuation of those final goods.

Mapping LCA inventories into final economic goods

In general, changes in LCA physical inventories will generate a set of corresponding changes in other physical conditions relevant to human well-being. Even before economic valuation occurs, these follow-on physical implications must be assessed. For instance, to value changes in

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[68] Hendrickson, Lave, and Matthews (2006) ("A typical [Life Cycle Inventory] of air pollution results in estimates of conventional, hazardous, toxic, and greenhouse gas emissions to the air. Even focused on this small subset of environmental effects, it is unclear how to make sense of the multiple outputs and further how to make a judgment as to tradeoffs or substitutions of pollutants among alternative designs."), 29.

[69] Some in the LCA community refer to this as an LCA impact analysis, as opposed to the preceding LCA inventory analysis. Inventory analyses are those most commonly referred to as LCA. See Graedel and Allenby (1995).

mercury releases, it is important to know how increased or decreased mercury emissions interact with exposure pathways to affect body burdens and human health. An LCA inventory does not address this issue; an analysis of epidemiology and exposure is required. Similarly, hydrological analysis is required to determine how a reduction in water usage translates into water availability in different locations and at different times. Further, ecological analysis must be deployed to answer questions such as "what is the effect of greater water availability on species and habitats?" The point is that benefit assessment requires synthetic systems thinking of an order at least as great as the original LCA analysis.[70]

The goal of these biophysical and epidemiological translations is to translate LCA inventory results to outcomes with *direct* human impact – health effects or the availability of water in a particular stream at a particular time.

In the human health realm, toxic wastes or air quality burdens must be evaluated in terms of fate, transport, and deposition models. Human health models then translate depositions into human health impacts via epidemiological analysis (e.g., dose-response relationships). EPA is relatively sophisticated in its use of such models, owing to decades of experience with air quality regulation and the analysis of economic effects arising from air quality-related health assessments.

In the ecological realm, these kinds of translations are underdeveloped. The agency is aware of this – the conclusion has been drawn from several recent SAB reports.[71] The analysis of ecological benefits is clarified by drawing distinctions between ecosystem processes and functions and the "final" outcomes of those processes (denoted here as "final ecosystem goods." Ecosystem processes and functions are the biological, chemical, and physical interactions associated with ecological features such as surface water flows, habitat types, and species populations. These functions are the things described by biology, atmospheric science, hydrology, and so on.

Final ecosystem goods arise from these components and functions but are different: they are the aspects of the ecosystem that are *directly* valued by people. The benefits of nature include many forms of recreation, aesthetic enjoyment, commercial and subsistence harvests, damage avoidance, human health, and the intangible categories mentioned earlier. Final ecosystem goods are the aspects of nature used by society in order to enjoy those benefits.

Part of the above definition is particularly important: namely, that ecosystem services are "final." Final goods are the things people actually make choices about. For an angler, these end products include a particular lake or stream and perhaps a particular species population in that water body. The choices involved include which lake, what kind of fish, what kind of boat (if any) and tackle to use, and how much time spent getting to and from the site. Valuation is about choices (is one thing better than another) and choices are the only thing economists can use to establish economic value. Environmental benefit assessment places values on the things people and households make actual choices about – the "final goods" of nature. It is very important to emphasize that many

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[70] For an example of a full social cost & benefit analysis see Krupnick and Burtraw (1997).

[71] For example, this conclusion has been drawn from several recent SAB reports, including EPA-SAB. 2003. "Underground Storage Tanks (UST) Cleanup & Resource Conservation & Recovery Act (RCRA) Subtitle C Program Benefits, Costs, & Impacts (BCI) Assessments: An SAB Advisory." (EPA-SAB-EC-ADV-03-001) and "Advisory on EPA's Superfund Benefits Analysis." (EPA-SAB-ADV-06-002). In addition, the SAB Committee on Valuing the Protection of Ecological Systems and Services is currently examining methods for addressing these limitations.

other aspects of nature are valuable, but not capable of being valued in an economic sense – because they are not subject to social or individual choices.

Ecosystem production functions are the relationships that translate LCA inventory changes into final ecosystem goods. One characteristic of these production functions is particularly worthy of note: ecological production functions are dependent upon space and landscape. Location- and scale-specificity are core characteristics of modern ecology. For example, the quality of a habitat asset can be highly dependent on the quality and spatial configuration of surrounding land uses. The ability of areas to serve as migratory pathways and forage areas typically depends on landscape conditions over an area larger than habitats relied upon directly by the migratory species. The contiguity of natural land cover patches has been shown for many species to be an indicator of habitat quality and potential species resilience. Hydrological analysis is yet another field that has long recognized the importance of relationships between landscape features. The nature of surface water flows, aquifer structures, and surface-groundwater interactions are dependent upon linked physical relationships across the landscape.

For OSW to move toward measurement of ecosystem impacts arising from beneficial use, or any other change in waste management practices, the ability to translate LCA inventory changes into final ecosystem good changes requires the development of spatial ecological modeling. Space and scale are important to the valuation of final ecosystem goods, as well.

Assigning value to changes in final ecological goods

The value of an ecosystem good is typically location-dependent. The value of a car is not closely related to whether it is located in California or New Jersey. This is not the case with ecological goods. The benefits of damage mitigation, aesthetic enjoyment, and recreational and health improvements depend on where—and when—ecosystem services arise relative to complementary inputs and substitutes. Also, the ecological asset interactions that enhance or degrade service flows are highly landscape-dependent. Accordingly, it is necessary to spatially define “service areas.” An unfortunate reality is that these will be different for every identified ecosystem service. Boundaries are needed to define the likely users of a service, areas in which access to a service is possible, and the area over which services might be scarce or have substitutes. This issue is well known in environmental economics (Smith and Kopp 1996). For example, a key methodological issue in any econometric recreational benefits study is the determination of the appropriate choice set facing recreators.

While market prices can be assumed to be largely constant within a single market, there is no arbitrage to ensure this condition for the implicit prices of environmental resources. Also, many ecological services are best thought of as differentiated goods with important place-based quality differences. As noted earlier, the biophysical characteristics of ecosystems are highly landscape-dependent. The same is true of ecological services’ social benefits. Accordingly, willingness to pay for ecological services is best represented by a hedonic price function, not a single price.

An intermediate step: benefit indicators as an alternative to full valuation

The spatial factors that affect ecosystem goods’ value create a problem for analysts. Benefit estimates from one study in one location cannot be transferred to other sites. In practical terms, this means that ecosystem valuation is expensive, time-consuming, and difficult. Problem-specific valuation will be impractical for most regulatory applications.

In this context, one alternative to full-scale valuation is the use of "benefit indicators" (Boyd 2004, Boyd and Wainger 2002). The benefits of a given ecosystem good are affected by the following: the ecosystem feature's scarcity, natural and built substitutes, complementary inputs, and the number of people in proximity to it. All of these can and should be measured spatially. Benefit indicators are map-able, countable landscape features that affect the value of a particular ecosystem good. Benefit indicators are an input to a wide variety of tradeoff analysis approaches, but do not themselves make or calculate the results of such tradeoffs. First, they can be used as ends in themselves as regulatory or planning performance measures. Second, they can be used as part of public processes designed to elicit public preferences over environmental and economic options – as in mediated modeling exercises or more informal political derivations. Benefit indicators are a potentially powerful complement to group decision processes. Third, they can be used as *inputs* to economic and econometric methods such as benefit transfer, or stated preference models. In the former, they can be used to calibrate the transfer function. In the latter case, they can be used to develop alternative choice scenarios.

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APPENDIX C | ANALYSIS OF BENEFITS USING ALTERNATE LIFE CYCLE MODELS

In the main body of this report, we present an analysis of the life cycle benefits of substituting fly ash for finished portland cement in concrete using BEES. For comparative purposes, this appendix illustrates the impacts associated with beneficial use of fly ash in concrete that can be calculated using two additional life cycle tools: the WARM and EIO-LCA models.

WARM MODEL ANALYSIS

The Waste Reduction Model (WARM) was created by EPA to help solid waste planners and organizations estimate greenhouse gas (GHG) emission reductions from several different waste management practices.[72] WARM calculates GHG emissions for baseline and alternative waste management practices, including source reduction, recycling, combustion, composting, and landfilling. The user can construct various scenarios by entering data on the amount of waste handled by material type and by management practice. WARM then automatically applies material-specific emissions factors for each management practice to calculate the GHG emissions and energy savings of each scenario. The model evaluates energy use and GHG emissions in three stages of the life cycle: (1) raw material acquisition, (2) manufacturing (fossil fuel energy emissions), and (3) waste management (carbon dioxide emissions associated with compost, non-biogenic carbon dioxide and nitrous oxide emissions from combustion, and methane emissions from landfills). At each of these points, the study also considers transportation-related energy use and GHG emissions.

The WARM model reports avoided lifecycle GHG emissions in either metric tons CO_2 equivalent ($MTCO_2E$) or metric tons CO equivalent (MTCOE), as well as energy use in BTUs. In addition, the model converts these outputs to equivalent metrics including the equivalent number of cars removed from the road in one year, the equivalent number of avoided barrels of oil burned, and the equivalent number of avoided gallons of gasoline consumed. Currently, the only CCP available for analysis using WARM is fly ash. WARM calculates GHG emissions and energy use associated with use of fly ash in concrete as an alternative to landfill disposal. We first use WARM to estimate the incremental impacts associated with beneficial use of one ton of fly ash in concrete, in comparison to disposing of that ton of fly ash in a landfill. Then, we extrapolate the results to estimate benefits associated with attainment of the 2011 RCC goal of beneficially using 18.6 million tons of fly ash in concrete.[73]

Results

Exhibit C-1 presents the results of the WARM model analysis for the beneficial use of fly ash.[74] The WARM model estimates that one ton of fly ash beneficially used in concrete results in avoidance of approximately 0.91 $MTCO_2E$ of GHG emissions and 5.29 million BTUs of energy use. Extrapolating these outcomes to the 2011 RCC goal of beneficially using 18.6 million tons of fly ash in concrete, results in savings of approximately 17 million $MTCO_2E$. According to the

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[72] WARM can be accessed at http://yosemite.epa.gov/oar/globalwarming.nsf/WARM?openform. Version 8 of the model was used for this analysis. Available information indicate that Version 8 was last updated in August of 2006.

[73] WARM allows the user to define key modeling assumptions, such as landfill gas recovery practices and transport distance to MSW facilities. For landfill gas (LFG) control, we select the "National Average" setting, which calculates emissions based on the anticipated proportion of landfills with LFG control in 2000. For transport distances, we use the default setting (20 miles).

[74] It is important to note that the results reported by WARM for avoided greenhouse gas emissions and avoided energy use may not be directly comparable to those reported by the BEES model or PALATE model due to differences in the methodologies (including life cycle system boundaries) employed by each model.

WARM model, this is equivalent to removing 3.7 million cars from the road. In addition, attaining the 18.6 million ton fly ash goal results in 98,394 BTUs (103.8 megajoules) of avoided energy use. This energy savings is equivalent to 17 million barrels of avoided oil consumption, 787 million gallons of avoided gasoline consumption, or a reduction in annual energy use by approximately half a million households.

EXHIBIT C-1: WARM RESULTS: IMPACTS OF BENEFICIAL USE OF FLY ASH IN CONCRETE

IMPACT	INCREMENTAL IMPACT OF USING 1 TON OF FLY ASH	TOTAL IMPACTS OF MEETING RCC GOAL (18,600,000 TONS)[a]
GHG EMISSIONS AVOIDED (MTCO$_2$E)	0.91	16.93 million
EQUIVALENT NUMBER OF PASSENGER CARS REMOVED FROM ROADWAYS	*0.20*	*3.72 million*
AVOIDED ENERGY USE (BTUs) [b]	5.29 million $135,424	98,394 billion $2,52 billion
EQUIVALENT AVOIDED OIL CONSUMPTION (BARRELS)	*0.91*	*16.93 million*
EQUIVALENT AVOIDED GASOLINE CONSUMPTION (GALLONS)	*42.33*	*787.34 million*
EQUIVALENT AVOIDED HOUSEHOLDS' ANNUAL ENERGY CONSUMPTION (HOUSEHOLDS)	*0.03*	*0.56 million*

Notes:

a. The total impacts of meeting RCC goal represent the difference between beneficially using 18.6 million tons of fly ash in concrete in comparison to disposal in a landfill.

b. In addition to reporting energy avoided energy use in BTUs, by the average retail price of electricity for all sectors in 2006 ($0.0874/KWh or $0.0256/1,000 Btu). (Source: Energy Information Administration, "Electric Power Monthly – Average Retail Price of Electricity to Ultimate Customers: Total by End-Use Sector," accessed on October 10, 2006 at: <http://www.eia.doe.gov/cneaf/electricity/epm/table5_3.html>.)

Sources:

1. US EPA, *Solid Waste Management and Greenhouse Gases, A Life cycle Assessment of Emissions and Sinks*, 2nd Edition, May 2002. (EPA530-R-02-006) (WARM Model)
2. US EPA, *Background Document for Life cycle Greenhouse Gas Emission Factors for Fly Ash Used as a Cement Replacement in Concrete,* November 2003. (EPA530-R-03-016)

Limitations and Assumptions

Although the WARM analysis provides a useful example of the energy use and GHG emissions benefits that can be achieved through the beneficial use of fly ash in concrete, it is important to recognize some of the key limitations of the work to date:

- Our analysis assumes a 20-mile transport distance from the point of collection to the landfill or concrete facility. In reality, transport distances may be greater or less than 20 miles. Adjusting transport distance would effect both GHG emissions and energy use.
- Emissions factors used in WARM reflect national averages. Our analysis may therefore over or under estimate impacts for a specific region or location. In addition, we use a

national average for landfill gas recovery that may also over or understate emissions for a specific landfill.

- WARM does not specifically calculate impacts on purchased energy. Purchased energy impacts may be incorporated into the avoided energy use metric, but this is not clear.
- WARM reports some environmental impacts in physical quantities (e.g., BTUs energy, lbs NOx, etc.), not in monetized dollar effects.

EIO-LCA ANALYSIS

The goal of this task was to do a preliminary assessment of what the baseline energy and air pollution effects are for existing cement production, such that any reduction of this demand in terms of beneficially used fly ash would lead to reduced impact.

To estimate baseline impacts of cement production, the Economic Input-Output Life Cycle Assessment (EIO-LCA) model was used. EIO-LCA was developed at Carnegie Mellon and provides the capacity to evaluate economic and environmental effects across the supply chain for any of 491 industry sectors in the U.S. economy. EIO-LCA also can represent the supply chain use of inputs and resulting environmental outputs across the supply chain by using publicly available data sources from the U.S. government. By integrating economic data on the existing flow of commerce between commodity sectors with environmental data on releases and material flows generated by each sector, it is possible to estimate the additional environmental emissions caused by an increase in production within a particular sector, accounting for the supply chain. This approach can be used to avoid some of the system boundary limitations of process LCA by drawing upon data for the entire economy. The EIO-LCA model includes a variety of such impacts for the entire US economy. For a closer look at the model, visit http://www.eiolca.net/ on the Internet.

Currently, the EIO-LCA model is in active use. Since 2000, the model has registered over 900,000 uses (or over 15,000 per month). Of identifiable access sites, educational users are most common, but there is substantial use by government agencies, non-profit organizations and companies. A surprising number of foreign users exist, suggesting that international comparisons are of considerable interest.

Cement Analysis

Specifically within EIO-LCA, industry “Sector #327310: Cement Manufacturing” was selected for analysis in the model. This industry comprises establishments primarily engaged in manufacturing portland, natural, masonry, pozzolanic, and other hydraulic cements. Cement manufacturing establishments may calcine earths or mine, quarry, manufacture, or purchase lime. Examples of activities in this sector:

- Cement (e.g., hydraulic, masonry, portland, pozzolana) manufacturing
- Cement clinker manufacturing
- Natural (i.e., calcined earth) cement manufacturing

One million dollars of demand from the cement manufacturing sector was input into EIO-LCA, resulting in the summary estimate of supply-chain wide economic impacts shown in Exhibit C-2. EIO-LCA is a linear model, thus the estimates scale in a constant fashion ($2 million of production would lead to double the results listed below). However the main point of EIO-LCA is for screening purposes, thus the specific dollar values are less relevant than the broad, economy-wide boundary which is able to show where less obvious supply chain impacts might exist. These are noted below.

EXHIBIT C-2: TOP SECTORS THAT SUPPORT CEMENT MANUFACTURING IN THE US (ECONOMIC)

	SECTOR	TOTAL ECONOMIC $ MILLIONS	VALUE ADDED $ MILLIONS	DIRECT ECONOMIC %
	Total for all sectors	**1.90**	**0.992**	**77.9**
327310	Cement manufacturing	1.06	0.543	99.6
221100	Power generation and supply	0.083	0.052	86.0
550000	Management of companies and enterprises	0.050	0.035	65.3
221200	Natural gas distribution	0.043	0.014	89.5
211000	Oil and gas extraction	0.041	0.017	2.49
420000	Wholesale trade	0.039	0.026	50.6
484000	Truck transportation	0.033	0.016	62.4
327992	Ground or treated minerals and earths manufacturing	0.027	0.017	86.6
212310	Stone mining and quarrying	0.018	0.010	82.7
212100	Coal mining	0.017	0.008	48.8

As shown in the “Total Economic” column of Exhibit C-2, there are significant purchases of electricity, oil and gas, etc. across the supply chain. This is due to the recognized significant fuel and energy inputs needed to produce cement. Also visible in the top 10 economic purchases are purchases from minerals, stone, and coal.

Exhibit C-2 also summarizes which of the purchases are “direct”, i.e., those made directly by the cement manufacturer. For example EIO-LCA estimates that 86% of the electricity purchases across the entire supply chain are direct. That means that only 14% of total electricity purchases of cement manufacturing in the supply chain come from all other sectors’ (indirect) purchases of electricity. This would include electricity bought by oil and gas production and distribution, stone and coal mining, etc. Note that this amount of direct purchases (86 percent) is a very large amount compared to the usual electricity direct purchases that come from other sectors.

EIO-LCA also displays estimates of emissions and energy use across the supply chain, as shown in Exhibits C-3 and C-4. Exhibit C-3 summarizes emissions of conventional air pollutants, and is sorted by sulfur dioxide (SO_2) emissions. Most SO_2 comes from cement manufacturing (and about 15% from power generation). While not shown explicitly in Exhibit C-3, further use of EIO-LCA shows that about 90% of nitrogen oxides and VOC emissions from cement manufacturing come from the cement manufacturing itself, 70% of carbon monoxide from the supply chain production of cement comes from cement manufacturing, followed by truck transportation. Ninety percent of PM_{10} emissions come from cement. In short, cement manufacturing itself is a very polluting process, and avoiding emissions from its manufacture can have large social benefits.

EXHIBIT C-3: AIR EMISSIONS OF TOP 10 SECTORS THAT SUPPORT CEMENT MANUFACTURING IN THE US (SORTED BY SO_2)

	SECTOR	SO_2 MT	CO MT	NOX MT	VOC MT	LEAD MT	PM_{10} MT
	Total for all sectors	27.3	20.4	31.7	23.6	0.005	3.96
327310	Cement manufacturing	22.4	14.6	28.6	22.4	0.005	3.48
221100	Power generation and supply	4.44	0.219	2.01	0.019	0.000	0.094
212310	Stone mining and quarrying	0.209	0.391	0.147	0.074	0	0.043
211000	Oil and gas extraction	0.040	0.068	0.030	0.046	0	0.001
221200	Natural gas distribution	0.027	0.001	0.052	0.183	0	0.001
483000	Water transportation	0.024	0.017	0.129	0.124	0	0.012
324110	Petroleum refineries	0.018	0.010	0.004	0.014	0	0.002
213112	Support activities for oil and gas operations	0.016	0.013	0.010	0.004	0	0.002
482000	Rail transportation	0.015	0.032	0.272	0.013	0	0.006
484000	Truck transportation	0.011	3.58	0.258	0.266	0.000	0.006

Exhibit C-4 summarizes supply chain wide use of energy and electricity for producing cement. The cement sector consumes about 80% of total supply chain primary energy use (and almost 90% of electricity, as noted above). Other sectors consuming top but less significant amounts of energy (in the form of fuels) are truck and pipeline transportation sectors and petroleum refining.

EXHIBIT C-4: TOP 10 SECTORS THAT USE ENERGY ACROSS THE SUPPLY CHAIN FROM CEMENT MANUFACTURING (SORTED BY TOTAL ENERGY USE)

	SECTOR	TOTAL TJ	ELEC MKWH
	Total for all sectors	68.4	1.96
327310	Cement manufacturing	55.1	1.80
221100	Power generation and supply	9.70	0.001
484000	Truck transportation	0.363	0.001
486000	Pipeline transportation	0.321	0.007
S00202	State and local government electric utilities	0.283	0
327992	Ground or treated minerals and earths manufacturing	0.238	0.015
324110	Petroleum refineries	0.203	0.004
483000	Water transportation	0.164	0.000
482000	Rail transportation	0.149	0.000
211000	Oil and gas extraction	0.144	0.015

In summary, from the perspective of energy and air emissions, cement manufacturing leads to large impacts, and is in general the largest source of emissions across the supply chain. Reducing the amount of cement produced through beneficial use of fly ash can lead to large supply chain-wide reductions of emissions.

Gypsum Analysis

Within EIO-LCA, the industry "Sector #212390: Other Nonmetallic Mineral Mining" was selected for analysis. This industry is aggregated to include many products and processes (and thus is less representative of a specific industry like wallboard manufacture than the sector representing cement manufacturing above). This U.S. industry comprises establishments primarily engaged in developing the mine site, mining and/or milling, or otherwise beneficiating (i.e., preparing) natural potassium, sodium, or boron compounds, phosphate rock, fertilizer raw materials, or nonmetallic minerals. There are many products of this industry, a few of which are summarized below:

- Borate, natural, mining and/or beneficiating
- Phosphate rock mining and/or beneficiating
- Gypsum mining and/or beneficiating
- Peat grinding

To estimate baseline effects, $ 1 Million Dollars of demand from the "Other nonmetallic mineral mining" sector was input into EIO-LCA, resulting in the summary estimate of supply-chain wide economic impacts shown in Exhibit C-5. As shown in the "Total Economic" column of Exhibit C-5, there are significant purchases of electricity, oil and gas, and construction machinery, etc. across the supply chain. This is due to the recognized significant fuel and energy inputs needed to produce nonmetallic minerals like gypsum.

EXHIBIT C-5: TOP SECTORS THAT SUPPORT NONMETALLIC MINERAL MINING – AS A PROXY FOR GYPSUM MANUFACTURING – IN THE US (ECONOMIC)

	SECTOR	TOTAL ECONOMIC $ MILLIONS	DIRECT ECONOMIC %
	Total for all sectors	1.98	76.3
212390	Other nonmetallic mineral mining	1.08	99.4
484000	Truck transportation	0.068	73.3
550000	Management of companies and enterprises	0.067	65.9
221100	Power generation and supply	0.055	79.2
211000	Oil and gas extraction	0.054	34.4
420000	Wholesale trade	0.042	39.5
324110	Petroleum refineries	0.035	59.0
333120	Construction machinery manufacturing	0.031	86.8
533000	Lessors of nonfinancial intangible assets	0.019	24.4
531000	Real estate	0.018	17.7

Exhibit C-5 also summarizes which of the purchases are "direct," (i.e., those made directly by the nonmetallic mineral company). For example EIO-LCA estimates that 80% of the electricity purchases across the entire supply chain of nonmetallic minerals mining are direct. That means that only 20% of total electricity purchases in the supply chain come from all other sectors' (indirect) purchases of electricity, including well-known electricity intensive sectors like manufacturing. This would include electricity purchased by oil and gas production and distribution, machinery manufacturing, etc. Note that this level of direct purchases (80 percent) is very large compared to the usual electricity direct purchases that come from other sectors.

EIO-LCA also displays estimates of emissions and energy use across the supply chain, as shown in Exhibits C-6 and C-7. Exhibit C-6 summarizes emissions of conventional air pollutants, and is sorted by sulfur dioxide (SO_2) emissions. Most (85 percent) of SO_2 emitted across the supply chain of nonmetallic minerals comes from power generation (less than five percent from the mining of the nonmetallic minerals, an important note). While not shown explicitly in Exhibit C-6, further sorting of EIO-LCA emissions data estimates that about 50% of nitrogen oxides come from power generation, followed by emissions from truck and rail transport (less than ten percent from nonmetallic mineral mining). About 40% of VOC emissions result from nonmetallic minerals mining itself, 80% of carbon monoxide from truck transportation across the supply chain with nonmetallic mineral mining representing less than one percent. About 40% of PM_{10} emissions come from nonmetallic mineral mining (about 15% from power generation). In short, nonmetallic mineral mining itself is a very polluting process, and avoiding emissions from its manufacture can have large social benefits, but emissions from energy production and transportation are in some cases even more important than this sector.

EXHIBIT C-6: AIR EMISSIONS OF THE TOP 10 SECTORS THAT SUPPORT NONMETALLIC MINERAL MINING IN THE US (SORTED BY SO_2)

SECTOR	SO_2 MT	CO MT	NOX MT	VOC MT	LEAD MT	PM_{10} MT
Total for all sectors	3.47	9.41	2.85	1.72	0.000	0.421
Power generation and supply	2.94	0.145	1.33	0.013	0.000	0.062
Other nonmetallic mineral mining	0.151	0.051	0.241	0.656	0	0.169
Oil and gas extraction	0.053	0.089	0.039	0.060	0	0.002
Stone mining and quarrying	0.043	0.080	0.030	0.015	0	0.009
Petroleum refineries	0.040	0.023	0.009	0.032	0	0.004
Other basic inorganic chemical manufacturing	0.033	0.004	0.002	0.002	0	0.002
Truck transportation	0.022	7.39	0.533	0.550	0.000	0.013
Support activities for oil and gas operations	0.021	0.018	0.013	0.006	0	0.003
Iron and steel mills	0.021	0.176	0.016	0.010	0.000	0.015
Rail transportation	0.016	0.034	0.297	0.014	0	0.007

Exhibit C-7 summarizes supply chain wide use of energy and electricity for producing nonmetallic minerals. The nonmetallic mineral mining sector consumes about 70% of total supply chain primary energy (and almost 80% of electricity, as noted above). Other sectors consuming high but less significant amounts of energy (in the form of fuels) are power generation, truck and pipeline transportation sectors, and petroleum refining.

EXHIBIT C-7: TOP 10 SECTORS THAT USE ENERGY ACROSS THE SUPPLY CHAIN FROM NONMETALLIC MINERAL MINING (SORTED BY TOTAL ENERGY USE)

SECTOR	TOTAL TJ	ELEC MKWH
Total for all sectors	33.2	1.59
Other nonmetallic mineral mining	22.6	1.40
Power generation and supply	6.42	0.000
Truck transportation	0.750	0.002
Petroleum refineries	0.451	0.008
Other basic inorganic chemical manufacturing	0.370	0.033
Pipeline transportation	0.342	0.008
Iron and steel mills	0.229	0.011
State and local government electric utilities	0.225	0
Oil and gas extraction	0.189	0.019
Rail transportation	0.163	0.000

Context: Concrete production and wallboard manufacturing

While the beneficial use studies focus on the substitution of waste products for virgin products, and the estimates above identify the avoided energy, cost, and emissions of these substitutions, it is important to put into context the effects of the beneficial use. In this section we briefly show

EIO-LCA results for the broader picture of concrete manufacturing (where fly ash is used in place of some cement) and wallboard manufacturing (where FGD gypsum is used in place of virgin gypsum). We do this to see how important these raw materials (cement and gypsum) are in the supply chain of producing these final products.

Exhibit C-8 shows the top ten sectors that contribute to air emissions, and Exhibit C-9 the top ten sectors that consume energy, in the production of concrete (using $1 million as input into the ready-mix concrete sector). Exhibit C-8 (sorted by SO_2 emissions) demonstrates that in the manufacture of concrete, the emissions from cement manufacturing account for the majority of SO_2, NOx, VOC, and PM_{10} emissions. CO emissions are dominated by truck transportation. Similarly Exhibit C-9 shows that cement manufacture represents 40% of energy use, and almost 50% of electricity use. This implies that any reduction in the amount of cement needed has a large benefit in the life cycle emissions and energy use of concrete. Thus, fly ash substitution even at 20% substitution rates is quite beneficial.

EXHIBIT C-8: AIR EMISSIONS OF TOP 10 SECTORS THAT SUPPORT CONCRETE MANUFACTURING IN THE US (SORTED BY SO_2)

SECTOR	SO_2 MT	CO MT	NOX MT	VOC MT	LEAD MT	PM_{10} MT
Total for all sectors	6.29	16.9	7.90	5.64	0.001	1.03
Cement manufacturing	3.74	2.43	4.78	3.74	0.000	0.582
Power generation and supply	1.61	0.080	0.728	0.007	0.000	0.034
Stone mining and quarrying	0.570	1.07	0.401	0.202	0	0.118
Water transportation	0.072	0.050	0.382	0.367	0	0.035
Other basic inorganic chemical manufacturing	0.055	0.006	0.004	0.003	0	0.003
Truck transportation	0.034	11.3	0.814	0.840	0.000	0.020
Rail transportation	0.025	0.055	0.475	0.022	0	0.011
Oil and gas extraction	0.024	0.041	0.018	0.027	0	0.000
Petroleum refineries	0.021	0.012	0.005	0.017	0	0.002
Other miscellaneous chemical product manufacturing	0.013	0.000	0.015	0.003	0	0.001

EXHIBIT C-9: TOP 10 SECTORS THAT USE ENERGY ACROSS THE SUPPLY CHAIN FROM CONCRETE MANUFACTURING (SORTED BY TOTAL ENERGY USE)

SECTOR	TOTAL TJ	ELEC MKWH
Total for all sectors	21.6	0.655
Cement manufacturing	9.20	0.301
Power generation and supply	3.52	0.000
Ready-mix concrete manufacturing	3.12	0.080
Truck transportation	1.15	0.004
Sand, gravel, clay, and refractory mining	0.747	0.062

For gypsum in wallboard manufacturing, a similar method is used, but the sector used to model wallboard (Sector #327420: Gypsum Product Manufacturing) is more aggregated than that used to model concrete. This industry comprises establishments primarily engaged in manufacturing gypsum products such as wallboard, plaster, plasterboard, molding, ornamental moldings, statuary, and architectural plaster work. Gypsum product manufacturing establishments may mine, quarry, or purchase gypsum. Examples of activities in this sector include:

- Board, gypsum, manufacturing
- Gypsum building products manufacturing
- Gypsum products (e.g., block, board, plaster, lath, rock, tile) manufacturing
- Joint compounds, gypsum based, manufacturing
- Wallboard, gypsum, manufacturing

Despite the limitations in modeling wallboard as an exclusive product, Exhibits C-10 and C-11 show the results of the supply chain emissions and energy use from the gypsum product manufacturing sector in EIO-LCA (as a proxy for gypsum wallboard manufacturing).

EXHIBIT C-10: SUPPLY CHAIN EMISSIONS FROM THE GYPSUM PRODUCT MANUFACTURING SECTOR

SECTOR	SO_2 MT	CO MT	NOX MT	VOC MT	LEAD MT	PM_{10} MT
Total for all sectors	3.44	18.1	3.94	5.23	0.000	1.02
Power generation and supply	2.22	0.109	1.00	0.010	0.000	0.047
Stone mining and quarrying	0.508	0.951	0.358	0.180	0	0.105
Cement manufacturing	0.284	0.185	0.363	0.284	0.000	0.044
Water transportation	0.071	0.049	0.374	0.360	0	0.035
Paper and paperboard mills	0.060	0.406	0.085	0.033	0	0.045
Truck transportation	0.039	12.7	0.918	0.947	0.000	0.022
Oil and gas extraction	0.036	0.061	0.027	0.041	0	0.001
Petroleum refineries	0.025	0.014	0.006	0.020	0	0.003
Rail transportation	0.019	0.041	0.354	0.017	0	0.008
Natural gas distribution	0.019	0.000	0.036	0.129	0	0.001

Exhibit C-10 summarizes the air emissions across the manufacturing supply chain for gypsum products (sorted by SO_2 emissions). Recall that gypsum was modeled by production of the nonmetallic mineral mining sector (and this is the virgin product we would be replacing). Nonmetallic mineral mining is not in the top ten emissions sources in any of the tracked conventional air emissions for gypsum product manufacturing. Exhibit C-11 shows that the nonmetallic mineral mining sector represents about five percent of total energy use of gypsum products.

EXHIBIT C-11: ENERGY USE FOR THE GYPSUM PRODUCT MANUFACTURING SECTOR

SECTOR	TOTAL TJ	ELEC MKWH
Total for all sectors	24.0	0.810
Gypsum product manufacturing	9.50	0.368
Power generation and supply	4.84	0.000
Paper and paperboard mills	2.16	0.130
Truck transportation	1.29	0.004
Other nonmetallic mineral mining	1.25	0.077

As compared to the results for concrete manufacturing sector above, this wallboard example is less clear. The wallboard sector was approximated by a highly aggregated sector and is not an accurate representation of wallboard manufacturing in our attempt to model gypsum substitution. This sector seems to more generally depend on stone sectors for its inputs.

APPENDIX D | DETAILS OF FLY ASH AND FGD GYPSUM LIFE CYCLE ANALYSIS METHODOLOGIES

BEES ANALYSIS OF FLY ASH IN CONCRETE

We calculate the unit impacts of using fly ash as a substitute for finished portland cement in concrete as the difference in impacts between concrete made with 100% portland cement and concrete made with 15% fly ash and 85% portland cement. Exhibits D-1 and D-2 show the lifecycle stages modeled by BEES in the production of concrete with and without blended cement. These diagrams represent the baseline and beneficial use scenarios evaluated in the fly ash analysis.

EXHIBIT D-1: CONCRETE WITHOUT BLENDED CEMENT FLOW-CHART (BASELINE SCENARIO)

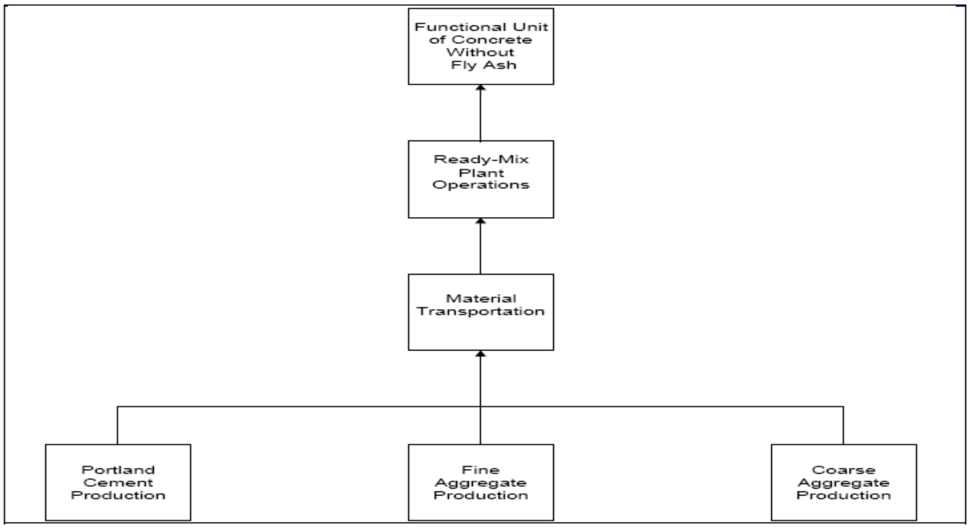
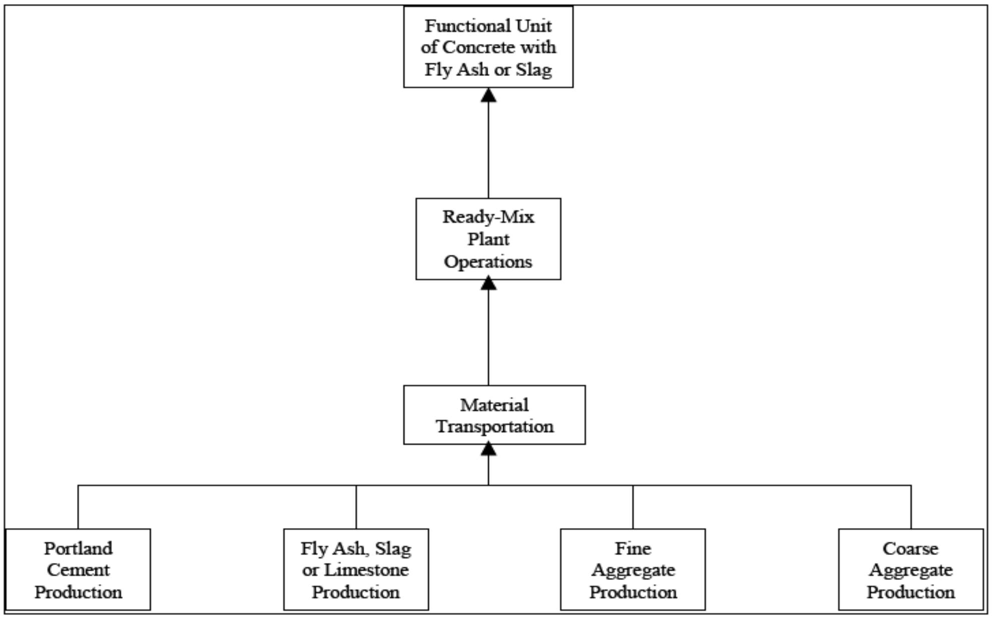


EXHIBIT D-2: CONCRETE WITH BLENDED CEMENT FLOW-CHART (BENEFICIAL USE SCENARIO)



It is important to note that in Exhibit D-2, BEES does not actually model the impacts of fly ash “production” from coal combustion (i.e. BEES does not allocate electricity production impacts to fly ash).

BEES Life Cycle inventory Data

Exhibit D-3 presents the complete BEES lifecycle inventory data for a generic concrete beam made with and without blended cement (i.e. fly ash). The data fields in Exhibit D-3 are defined as follows:

- XPORT DIST: Transport distance of concrete beam to construction site.
- FLOW: The environmental impact being reported.
- UNIT: The unit in which the environmental flow is reported.
- TOTAL: The total impact across all life cycle stages for all three components (i.e., the sum of fields COMP1, COMP2 and COMP3).
- COMP1: The total impact across all life cycle stages for Component 1. Component 1 is the main component, which is a 1 cubic yard concrete beam.
- COMP2: The total impact across all life cycle stages for Component 2. Component 2 refers to the first installation component associated with the concrete beam, but BEES does not provide a specific definition.
- COMP3: The total impact across all life cycle stages for Component 3. Component 3 refers to the second installation component associated with the concrete beam, but BEES does not provide a specific definition.
- RAW1: Impacts associated with raw materials extraction for Component 1.
- RAW2: Impacts associated with raw materials extraction for Component 2.
- RAW3: Impacts associated with raw materials extraction for Component 3.
- MFG1: Impacts associated with manufacturing of Component 1.
- MFG2: Impacts associated with manufacturing of Component 2.
- MFG3: Impacts associated with manufacturing of Component 3.
- XPORT1: Impacts associated with transport of Component 1.
- XPORT2: Impacts associated with transport of Component 2.
- XPORT3: Impacts associated with transport of Component 3.
- USE1: Impacts associated with use of the total product (all three components).
- WASTE1: Impacts associated with disposal of the total product (all three components).

EXHIBIT D-3: BEES LIFE CYCLE INVENTORY DATA FOR CONCRETE BEAM WITHOUT BLENDED CEMENT

BEES Data file B1011A: Generic Concrete Beam, 100% Portland Cement (4KSI)

XPORT DIST	FLOW	UNIT	TOTAL	COMP1	COMP2	COMP3	RAW1	RAW2	RAW3	MFG1	MFG2	MFG3	XPORT1	XPORT2	XPORT3	USE1	WASTE1
20	Water Used (total)	liter	1,702.10	1,055.10	570.94	4.39	1,011.14	570.02	4.25	6.05	0.00	0.07	37.91	0.92	0.08	71.67	71.67
20	Concrete Beam	Cu yd	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	Installation component 1	kg	65.77	0.00	65.77	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	Main component	kg	1,817.58	1,817.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	Installation component 2	kg	28.57	0.00	0.00	28.57	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	Component 4	kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	Component 5	kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	Component 6	kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	(a) Carbon Dioxide (CO2, fos	g	266,110.00	213,972.00	50,991.90	1,146.09	207,804.00	50,863.70	815.22	862.43	0.00	319.85	5,305.62	128.19	11.02	0.00	0.00
20	(a) Carbon Tetrafluoride (CF	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	(a) Lead (Pb)	g	0.43	0.01	0.42	0.00	0.01	0.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	(a) Mercury (Hg)	g	0.01	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	(a) Methane (CH4)	g	297.63	206.68	88.66	2.29	202.58	88.57	1.55	0.57	0.00	0.73	3.52	0.09	0.01	0.00	0.00
20	(a) Nitrogen Oxides (NOx as	g	1,299.12	1,171.98	118.58	8.56	1,096.00	117.07	4.87	13.60	0.00	3.56	62.38	1.51	0.13	0.00	0.00
20	(a) Nitrous Oxide (N2O)	g	7.10	6.71	0.28	0.12	5.95	0.26	0.08	0.03	0.00	0.04	0.73	0.02	0.00	0.00	0.00
20	(a) Particulates (PM 10)	g	0.01	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	(a) Sulfur Oxides (SOx as SO	g	608.93	479.47	125.58	3.88	471.71	125.41	2.64	0.71	0.00	1.23	7.06	0.17	0.01	0.00	0.00
20	(s) Aluminum (Al)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	(s) Arsenic (As)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	(s) Cadmium (Cd)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	(s) Carbon (C)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	(s) Calcium (Ca)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	(s) Chromium (Cr III, Cr VI)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	(s) Cobalt (Co)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

BEES Data file B1011A: Generic Concrete Beam, 100% Portland Cement (4KSI)

XPORT DIST	FLOW	UNIT	TOTAL	COMP1	COMP2	COMP3	RAW1	RAW2	RAW3	MFG1	MFG2	MFG3	XPORT1	XPORT2	XPORT3	USE1	WASTE1
20	(s) Copper (Cu)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	(s) Iron (Fe)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	(s) Lead (Pb)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	(s) Manganese (Mn)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	(s) Mercury (Hg)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	(s) Nickel (Ni)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	(s) Nitrogen (N)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	(s) Oils (unspecified)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	(s) Phosphorus (P)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	(s) Sulfur (S)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	(s) Zinc (Zn)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	(w) BOD5 (Biochemical Oxygen	g	15.80	7.04	7.47	1.28	6.25	7.45	1.28	0.11	0.00	0.00	0.68	0.02	0.00	0.00	0.00
20	(w) COD (Chemical Oxygen Dem	g	82.36	59.57	20.40	2.39	52.89	20.26	2.37	0.92	0.00	0.01	5.76	0.14	0.01	0.00	0.00
20	(w) Copper (Cu+, Cu++)	g	0.08	0.00	0.08	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	(w) Suspended Matter (unspec	g	43.64	31.97	9.85	1.81	28.39	9.78	1.80	0.49	0.00	0.01	3.09	0.07	0.01	0.00	0.00
20	Waste (end-of-Life)	kg	1,883.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1,883.35
20	E Total Primary Energy	MJ	2,779.14	1,994.61	658.19	126.35	1,904.34	656.30	121.11	12.42	0.00	5.07	77.86	1.88	0.16	0.00	0.00

EXHIBIT D-4: BEES LIFE CYCLE INVENTORY DATA FOR CONCRETE BEAM WITHOUT BLENDED CEMENT

BEES Datafile B1011B: Generic Concrete Beam, 100% Portland Cement (4KSI)

XPORT DIST	FLOW	UNIT	TOTAL	COMP1	COMP2	COMP3	RAW1	RAW2	RAW3	MFG1	MFG2	MFG3	XPORT1	XPORT2	XPORT3	USE1	WASTE1
20	Water Used (total)	liter	1,690.06	1,043.05	570.94	4.39	999.10	570.02	4.25	6.05	0.00	0.07	37.91	0.92	0.08	71.67	71.67
20	Concrete Beam	Cu yd	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	Installation component 1	kg	65.77	0.00	65.77	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	Main component	kg	1,817.58	1,817.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	Installation component 2	kg	28.57	0.00	0.00	28.57	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	Component 4	kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	Component 5	kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	Component 6	kg	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	(a) Carbon Dioxide (CO2, fos	g	243,685.00	191,547.00	50,991.90	1,146.09	185,379.00	50,863.70	815.22	862.43	0.00	319.85	5,305.62	128.19	11.02	0.00	0.00
20	(a) Carbon Tetrafluoride (CF	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	(a) Lead (Pb)	g	0.43	0.01	0.42	0.00	0.01	0.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	(a) Mercury (Hg)	g	0.01	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	(a) Methane (CH4)	g	278.61	187.66	88.66	2.29	183.56	88.57	1.55	0.57	0.00	0.73	3.52	0.09	0.01	0.00	0.00
20	(a) Nitrogen Oxides (NOx as	g	1,231.00	1,103.86	118.58	8.56	1,027.87	117.07	4.87	13.60	0.00	3.56	62.38	1.51	0.13	0.00	0.00
20	(a) Nitrous Oxide (N2O)	g	6.68	6.28	0.28	0.12	5.53	0.26	0.08	0.03	0.00	0.04	0.73	0.02	0.00	0.00	0.00
20	(a) Particulates (PM 10)	g	0.01	0.01	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	(a) Sulfur Oxides (SOx as SO	g	555.41	425.95	125.58	3.88	418.19	125.41	2.64	0.71	0.00	1.23	7.06	0.17	0.01	0.00	0.00
20	(s) Aluminum (Al)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	(s) Arsenic (As)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	(s) Cadmium (Cd)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	(s) Carbon (C)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	(s) Calcium (Ca)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	(s) Chromium (Cr III, Cr VI)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	(s) Cobalt (Co)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

BEES Datafile B1011B: Generic Concrete Beam, 100% Portland Cement (4KSI)

XPORT DIST	FLOW	UNIT	TOTAL	COMP1	COMP2	COMP3	RAW1	RAW2	RAW3	MFG1	MFG2	MFG3	XPORT1	XPORT2	XPORT3	USE1	WASTE1
20	(s) Copper (Cu)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	(s) Iron (Fe)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	(s) Lead (Pb)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	(s) Manganese (Mn)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	(s) Mercury (Hg)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	(s) Nickel (Ni)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	(s) Nitrogen (N)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	(s) Oils (unspecified)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	(s) Phosphorus (P)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	(s) Sulfur (S)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	(s) Zinc (Zn)	g	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	(w) BOD5 (Biochemical Oxygen	g	15.69	6.93	7.47	1.28	6.14	7.45	1.28	0.11	0.00	0.00	0.68	0.02	0.00	0.00	0.00
20	(w) COD (Chemical Oxygen Dem	g	81.45	58.66	20.40	2.39	51.98	20.26	2.37	0.92	0.00	0.01	5.76	0.14	0.01	0.00	0.00
20	(w) Copper (Cu+, Cu++)	g	0.08	0.00	0.08	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
20	(w) Suspended Matter (unspec	g	43.14	31.48	9.85	1.81	27.90	9.78	1.80	0.49	0.00	0.01	3.09	0.07	0.01	0.00	0.00
20	Waste (end-of-Life)	kg	1,883.35	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1,883.35
20	E Total Primary Energy	MJ	2,629.00	1,844.47	658.19	126.35	1,754.19	656.30	121.11	12.42	0.00	5.07	77.86	1.88	0.16	0.00	0.00

Calculation of Unit Impacts

To illustrate the methodology used to calculate the unit impact values from the BEES life cycle inventory data, we present a sample calculation of CO_2 reductions resulting from the substitution of one ton of fly ash for finished portland cement in concrete (see Exhibit D-6).

EXHIBIT D-5: EXAMPLE CALCULATION OF IMPACT METRIC FOR WATER USAGE RELATED TO FLY ASH SUBSTITUTION IN CONCRETE

	CALCULATION	3 KSI CONCRETE PAVEMENT	NOTE/SOURCES
IMPACTS PER CUBIC YARD CONCRETE			
100% portland cement	[a]	266,110 grams per cubic yard of concrete	Values represent impacts related to a 4 KSI concrete beam as characterized in BEES data file B1011A. BEES Version 3.0 Performance Data.
15% coal fly ash	[b]	243,685 grams per cubic yard of concrete	Values represent impacts related to building products and pavement as characterized in BEES data file B1011B. BEES Version 3.0 Performance Data.
Incremental benefit	[c]=[a]-[b]	22,425 grams per cubic yard of concrete	Represents avoided CO_2, in grams per cubic yard of concrete product substituting 15% coal fly ash for portland cement.
IMPACTS PER U.S. SHORT TON FLY ASH			
lbs cement/yd^3 concrete	[d]	470 lbs cement/cubic yard of concrete	Represents proportion of one cubic yard of concrete made up of cementitious material, given a mix-design or constituent density (Lipiatt, 2002, p. 40).
Percent coal fly ash substitution	[e]	15%	Fifteen percent of cementitious material is replaced with coal fly ash.
lbs/U.S. short ton	[f]	2000 lbs/ton	Conversion factor for pounds to tons.
tons fly ash/yd^3 concrete	[g]=[d]*[e]/[f]	0.0352 tons coal fly ash/cubic yard of concrete	Conversion of quantity of coal fly ash in one cubic yard of concrete from pounds to tons.
unit impact	[h]=[c]/[g]	636,170 grams per ton of coal fly ash substituted for cement	Represent unit impact values for CO_2 (in grams), based on substitution of one ton of coal fly ash for 1 ton portland cement in concrete.

The process outlined in Exhibit D-6 is repeated for each of the environmental metrics evaluated in this analysis using the environmental performance data reported in BEES. For each environmental metric, this yields an estimate of the benefit of one ton of fly ash replacing finished portland cement in concrete.

SIMAPRO ANALYSIS OF FGD GYPSUM IN WALLBOARD

We calculate the unit impacts of using FGD gypsum in place of virgin gypsum stucco in wallboard as the difference in impacts between wallboard made with 100% virgin gypsum and wallboard made with 100% FGD gypsum. Exhibits D-6 and D-7 show the lifecycle stages in the production of wallboard with 100% virgin gypsum and 100% FGD gypsum, respectively. The boxes with dashed lines represent life cycle stages that are unique to virgin or FGD gypsum.

EXHIBIT D-6: VIRGIN GYPSUM WALLBOARD MANUFACTURE

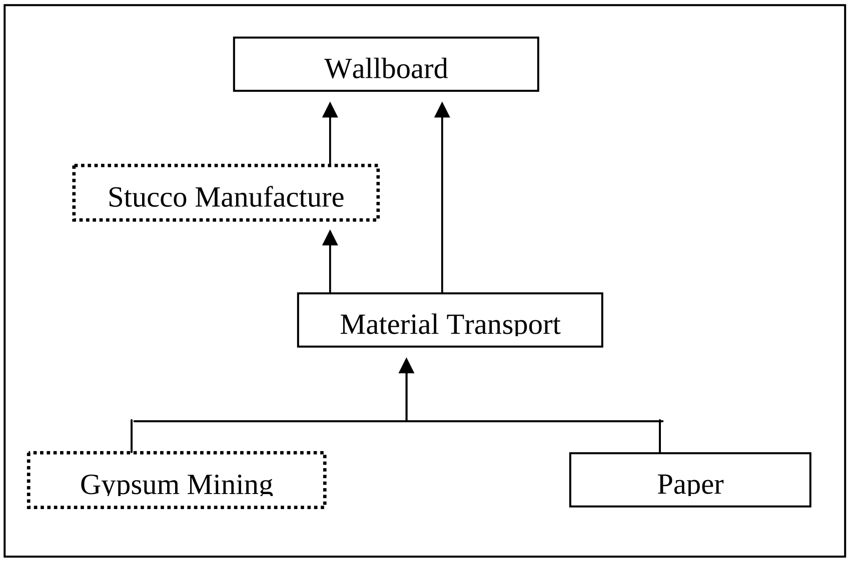
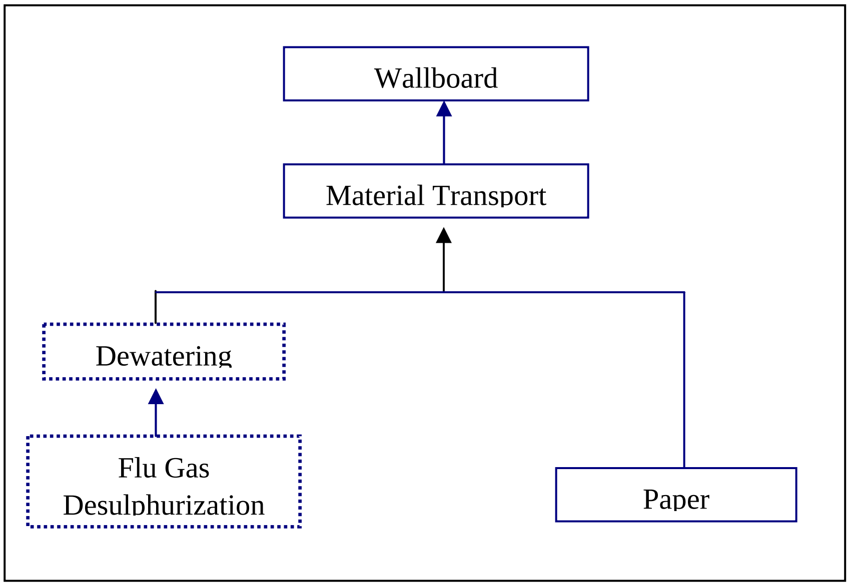


EXHIBIT D-7: FGD GYPSUM WALLBOARD MANUFACTURE



As shown in Exhibits D-6 and D-7, by replacing virgin gypsum stucco with FGD gypsum, gypsum mining and stucco manufacture can be avoided but a dewatering step is added to the lifecycle. We model these impacts as one ton of avoided "stucco" manufacture in SimaPro.[75] Stucco is the term used in SimaPro to describe the gypsum material used in wallboard. We selected the EcoInvent data set because it includes gypsum mining but also includes the processing of gypsum for use in wallboard (i.e., burning of gypsum and milling of stucco for use in gypsum wallboard). Thus, this dataset includes all the processes that would be avoided if an equivalent quantity of FGD gypsum were used in place of stucco in wallboard. The production of FGD gypsum through the coal combustion process is not modeled, as discussed in Chapter 4. In addition, this analysis assumes that FGD gypsum dewatering occurs via holding ponds and that the environmental impacts are negligible.[76] This analysis also does not model transport distance; we assume FGD gypsum would have the same transport distances to the construction site as virgin gypsum.[77] Thus avoided gypsum mining and avoided processing of gypsum into stucco, as represented by the EcoInvent stucco manufacturing data set, are the only lifecycle stages modeled in SimaPro.

Exhibit D-8 presents the assumed life cycle system boundaries for the EcoInvent stucco manufacturing data set. The cut-off node for the process flow tree depicted in Exhibit D-8 is set to 0.5% so that the entire tree could be viewed. Thus, this process tree lists the flows associated with 99.5% of the total life cycle impacts for one ton of stucco manufacture.[78] The numbers that appear in the bottom left-hand corner of each box in the tree are partition factors used by SimaPro and are not central to this analysis.

The EcoInvent dataset for stucco manufacture is the only stucco dataset available in SimaPro, but because it reflects Swiss manufacturing processes and electricity mix, we modified the data for stucco manufacture to reflect the average U.S. electricity mix. We made this modification by substituting the electricity used to make stucco from gypsum, as well as the electricity used further down the production chain in gypsum mining, with the Franklin data set for average U.S. electricity mix titled "Electricity avg. kWh USA". The Franklin data set includes the fuel consumption associated with the generation and delivery of an average kilowatt-hour in the USA using average USA technology in the late 1990's. While we did not substitute the U.S. electricity mix at points further down the stucco production chain, the stucco manufacturing and gypsum mining processes account for the majority of electricity use in this analysis.[79]

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[75] We use the EcoInvent data set titled "Stucco, at plant/CH U" for this purpose.

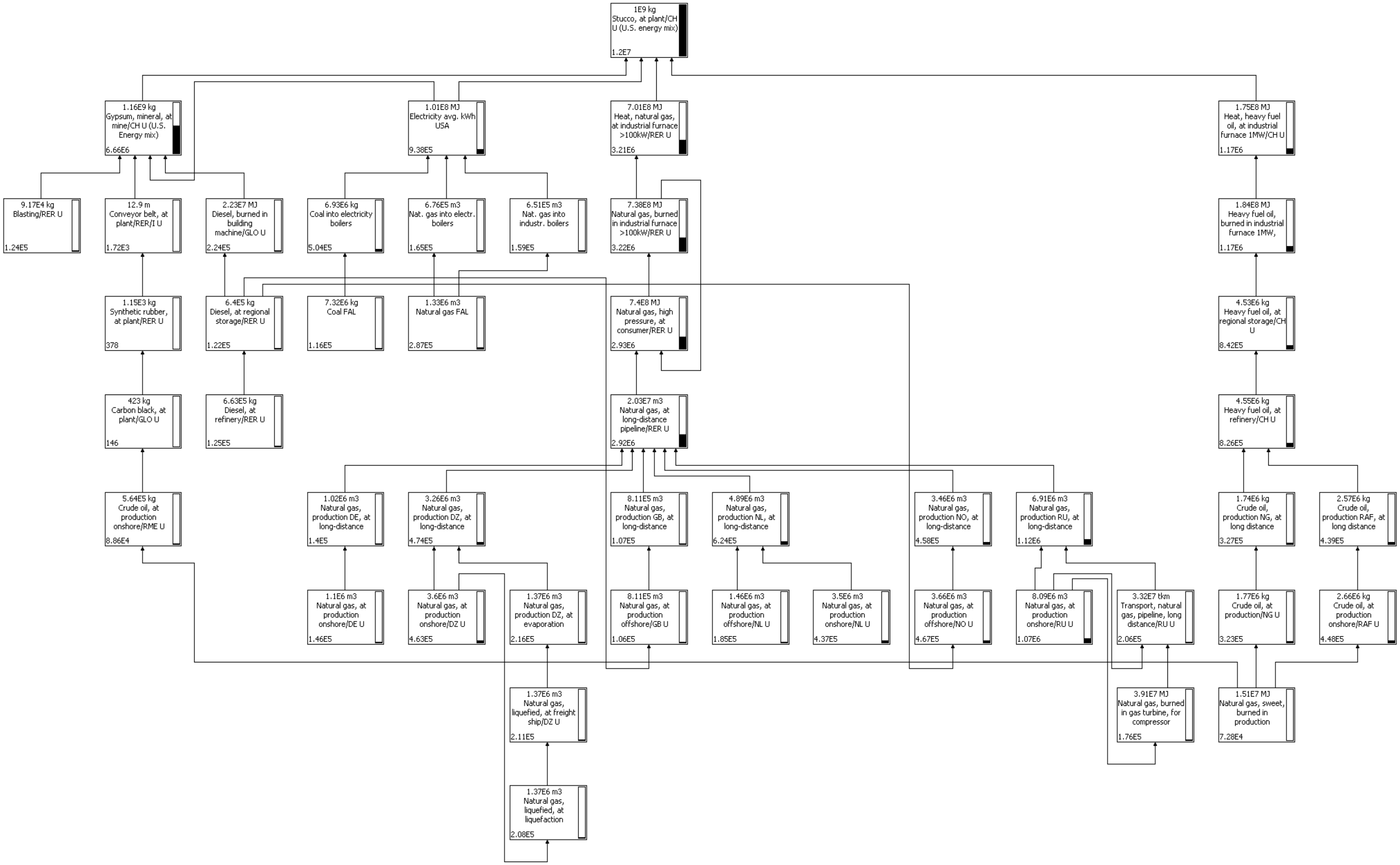
[76] There may actually be emissions/dusting impacts associated with dewatering in a holding pond, but we have been unable to identify quantified estimates of these impacts. Alternatively, dewatering may be accomplished through mechanical processes but we were also unable to identify the energy impacts of mechanical dewatering.

[77] We do not model a transport differential between virgin and FGD gypsum to be consistent with the transport assumptions used in the BEES fly ash analysis, which helps preserve the comparability of the fly ash and FGD gypsum unit impact values. It is important to note, however, that an increasing number of new gypsum wallboard plants are being constructed adjacent to coal-fired power plants, so transport distance of FGD gypsum to the wallboard manufacturing facility may, in some cases, be less than the transport distance of virgin gypsum.

[78] The tree is presented for the "single score" of all life cycle impacts, calculated using the Eco-Indicator 99-H, v2.04 impact assessment method.

[79] One limitation of substituting the Franklin U.S. electricity data set is that it represents low-voltage electricity production, but was used in place of medium-voltage European electricity production. This has the effect of slightly overstating the environmental impacts associated with electricity production in this analysis. Franklin U.S. electricity data set is the only data set in IEc's version of SimaPro for average U.S. electricity production; a data set for medium-voltage U.S. electricity production is not available.

EXHIBIT D-8: LIFE CYCLE SYSTEM BOUNDARIES FOR STUCCO MANUFACTURE, 0.5% CUT-OFF



SimaPro Life Cycle Inventory Data

Exhibit D-9 presents the SimaPro lifecycle inventory data for stucco manufacture for the same metrics evaluated in the BEES analysis.

In order to easily compare the results of the FGD gypsum analysis with those of the fly ash analysis, it was necessary to convert the environmental metrics reported by SimaPro into the same units that are reported by BEES. For most metrics, this required only a simple conversion between different units of mass. In the case of energy use, however, SimaPro reports quantities of various fossil fuels consumed whereas BEES reports energy consumed in megajoules. To convert the fossil fuel quantities reported by SimaPro into equivalent energy content in megajoules, we relied on the Energy Information Administration's Coal, Natural Gas, and Crude Oil Conversion Calculators.[80]

In addition, SimaPro does not report a single "water use" metric, as is done in BEES, but breaks out fresh water use by origin (e.g., lake, river, well, etc.) and application (cooling, turbine, etc). We sum the following metrics (converted to liters) to obtain the water use figure in the FGD gypsum analysis: 1) Water, cooling, unspecified natural origin/m^3, 2) Water, lake, 3) Water, river, 4) Water, turbine use, unspecified natural origin, 5) Water, unspecified natural origin/m^3, and 6) Water, well, in ground.

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[80] Accessed at: http://www.eia.doe.gov/kids/energyfacts/science/energy_calculator.html#coalcalc.

EXHIBIT D-9: SIMAPRO LCI DATA FOR ONE TON STUCCO, AT PLANT

SUBSTANCE	COMPARTMENT	UNIT	STUCCO, AT PLANT/CH U (U.S. ENERGY MIX)	CONVERTED TO BEES UNITS		NOTES
Gypsum, in ground	Raw	tn.lg	1.046899978			
Total Energy				**MJ**	**12,582.66**	
Non-Renewable Energy				**MJ**	**12,568.97**	
Coal, 26.4 MJ per kg, in ground	Raw	kg	6.756131931	MJ	178.36	
Coal, brown, in ground	Raw	g	315.4661176	MJ	7.61	*converted using the EIA's Energy Calculator[a]
Coal, hard, unspecified, in ground	Raw	g	412.5766501	MJ	9.96	*converted using the EIA's Energy Calculator[a]
Gas, natural, 46.8 MJ per kg, in ground	Raw	kg	1.156160311	MJ	54.11	
Gas, natural, in ground	Raw	m3	20.95771832	MJ	799.32	*converted using the EIA's Energy Calculator[a]
Oil, crude, 42 MJ per kg, in ground	Raw	g	268.9543393	MJ	11,296.08	
Oil, crude, in ground	Raw	kg	4.981418424	MJ	223.53	*converted using the EIA's Energy Calculator[a]
Renewable Energy				MJ	13.69	
Energy, from hydro power	Raw	MJ	9.697825819	MJ	9.70	
Energy, gross calorific value, in biomass	Raw	kJ	454.7219368	MJ	0.45	
Energy, kinetic, flow, in wind	Raw	kJ	235.1774187	MJ	0.24	
Energy, potential, stock, in barrage water	Raw	MJ	3.294986059	MJ	3.29	
Energy, solar	Raw	kJ	3.740125096	MJ	0.00	
Fresh Water Use				**liter**	**14,214.60**	
Water, cooling, unspecified natural origin/m3	Raw	dm3	58.63469673	liter	58.63	

SUBSTANCE	COMPARTMENT	UNIT	STUCCO, AT PLANT/CH U (U.S. ENERGY MIX)	CONVERTED TO BEES UNITS		NOTES
Water, lake	Raw	cm3	149.6500813	liter	0.15	
Water, river	Raw	cu.in	704.9737212	liter	11.55	
Water, turbine use, unspecified natural origin	Raw	m3	14.11964941	liter	14,119.65	
Water, unspecified natural origin/m3	Raw	dm3	22.25850268	liter	22.26	
Water, well, in ground	Raw	cu.in	143.8279244	liter	2.36	
Carbon dioxide, biogenic	Air	g	39.8286174			
Carbon dioxide, fossil	Air	kg	77.75423811	g	77,754.24	
Carbon Monoxide				g	39.059865	
Carbon monoxide	Air	g	9.12143624			
Carbon monoxide, fossil	Air	g	29.9384285			
Lead	Air	mg	28.76417316	g	0.03	
Mercury	Air	µg	976.1346395	g	0.00	
Methane				g	175.51	
Methane	Air	g	39.14177696			
Methane, fossil	Air	g	136.3669305			
Nitrogen oxides	Air	g	168.024936	g	168.02	
Ozone	Air	mg	11.45337237	g	0.0114534	
Particulates < PM10				**g**	**520.9278**	
Particulates, < 10 um	Air	g	3.45821205			
Particulates, < 2.5 um	Air	g	90.43917261			
Particulates, > 2.5 um, and < 10um	Air	g	427.0304396			
Particulates, > 10 um	**Air**	**kg**	**1.194254106**	**g**	**1,194.25**	
Particulates, unspecified	**Air**	**g**	**17.10845282**	**g**	**17.11**	

SUBSTANCE	COMPARTMENT	UNIT	STUCCO, AT PLANT/CH U (U.S. ENERGY MIX)	CONVERTED TO BEES UNITS		NOTES
Sulfur oxides	Air	g	139.1401881	g	139.1402	
BOD5, Biological Oxygen Demand	Water	g	21.86848366	g	21.87	
COD, Chemical Oxygen Demand	Water	g	24.71218062	g	24.71	
Copper, ion	Water	mg	23.66432149	g	0.02	
Lead	Water	mg	7.909309986	g	0.01	
Mercury	Water	µg	306.2803191	g	0.00	
Suspended solids, unspecified	Water	g	23.59769783	g	23.60	
Selenium	Water	µg	286.8551494	g	0.00	
Waste, solid	Waste	kg	3.115903858	kg	3.12	
Notes:						
a. Accessed at: http://www.eia.doe.gov/kids/energyfacts/science/energy_calculator.html#coalcalc.						

APPENDIX E | POTENTIAL IMPACTS OF ALLOCATION OF LCI RESULTS TO CCPs

While the background literature (ISO framework, etc.) are relatively consistent in their discussion that only co-products should share allocation of input and output system flows, this rule leaves out the consideration of current and future “waste streams” that have beneficial use potential, or market value that suggests that they may be usefully treated as co-products.

This observation is inspired by the need to consider the net impacts of CCPs in electricity generation when looking at the life cycle impacts associated with beneficial use. While there are beneficial substitutions possible of fly ash for cement, FGD gypsum for virgin gypsum, etc., it is possible that if the CCPs were in fact treated as co-products instead of as wastes, that there would be non-negligible inputs and outputs from coal-fired electricity generation that merited attention when estimating net impacts. In this section we consider some hypothetical macro-level scenarios for coal-fired power generation, as well as macro-level flows of several key CCPs. These scenarios are then applied in an assessment of implications of allocating the environmental effects of power generation to both the energy product and the CCPs.

Traditional LCA allocation rules suggest that product and co-product allocation by economic value, mass, energy, etc., are all legitimate methods – there is no single approach to allocating that is correct. For the first illustration, we show an approximate economic value based allocation and the resulting effects for CCPs, followed by a prospective mass-based method.

ECONOMIC ALLOCATION

The electricity industry has about $300 billion per year in gross revenues. Roughly 50% of generation is coal-fired at the national level. Even though the costs and revenues per kilowatt hour vary across generation types, and the total value includes generation, transmission, and distribution, for simplicity we assume that there is 50 percent, or $150 billion of revenues from coal-fired power generation. If we were to adjust for the variations in price per kilowatt hour, this value would likely be closer to $100 billion from coal-fired generation, as coal represents a lower-cost form of energy production.

From ACAA (2005) and USGS (2006), we consider the upper bound economic value of various CCPs, using both the high end of estimated market value for the CCPs, as well as the high end estimate of CCPs produced, and not the quantity used. Table E-1 summarizes these results for the top three CCPs in terms of market value and production.

TABLE E-1: OPTIMISTIC SCENARIO OF CCP MARKET VALUES (ACAA 2005, USGS 2006)

CCP	MARKET VALUE (PER TON)	CCP PRODUCTION (MILLION TONS)	TOTAL MARKET VALUE (ABSOLUTE UPPER BOUND)
Fly Ash	$45	71	$3.00 billion
FGD Gypsum	$31	12	$0.37 billion
Bottom Ash	$8	18	$0.14 billion
Total --	-------	101	$3.51 billion

Summing the total value of these three products yields $3.5 billion. Even this optimistic, upper-bound estimate is only 2% to 4% of the value of the electricity produced , if considered as shares of the total economic value of the product (electricity) and co-products (CCPs) created by coal-fired power plants. Of course, the values in Table E-1 are highly optimistic, and USGS estimates that fly ash market value ranges from $0-45/ton, and bottom ash from $4-8 per ton. Thus, the actual economic value allocation would likely be significantly smaller, probably **less than one percent**. As these were the “best case” allocation results, it seems that allocating by economic value would lead to negligible results.

MASS-BASED ALLOCATION

The example above is straightforward in demonstrating that economic allocation is possible and feasible, but leads to negligible results. Another alternative in LCA is to use mass-based allocation of impacts from products and co-products of a process. In the case of CCPs from coal-fired power generation, the product is electricity, which has no mass, which means it is impossible to purely allocate by mass. However, as an illustration, we consider the allocation results assuming that the electricity generated is completely tied to the combustion of coal, which has known mass. This is a simplifying but fair assumption since there are few other significantly large mass based inputs into coal combustion processes (process water is generally reused and returned).

If the mass-based allocation were considered as such, and thinking again at the macro-level of all coal-fired power plants, there are about one billion tons of coal used as input. As summarized in Table E-1, there are about 100 million tons of the top three market value CCPs, and about 120 million tons total CCPs, generated per year by the power plants. Thus, CCPs represent about 12% of the mass, with individual mass allocations of about 7% for fly ash, one percent for gypsum, and 0.2% for boiler slag. Thus, in this hypothetical example, the mass-based allocations would, in fact be much larger than the economic value allocations, but still generally a small percentage of total "mass" production. Further, considering the other major mass flows in the plant, these numbers may, in fact, be smaller. Another caveat is that not all CCPs produced are beneficially used. Thus, the mass allocations may converge back to the shares estimated above for economic allocation.

SAMPLE CALCULATIONS

Given the substitution of CCPs for virgin materials production, and the potential effects of allocating some of the environmental flows of electric power generation to CCPs, we investigated what the comparative net effects would be if the estimated low range of mass or dollar based allocations for CCPs (of coal-fired generation) were compared to the avoided emissions from coal fly ash and FGD gypsum beneficial use. For simplicity we consider CO_2 and SO_2 emissions only.

In 2005 there were 2.5 billion metric tons of CO_2 emitted in all electricity generation.[81] The latest data available from DOE that show emissions by generation type (1999) suggests that 80% of CO_2 emissions come from coal-fired generation, with an effective emissions factor of 2 lbs/kWh (or roughly 1 short ton/MWh).[82] Assuming the same emissions rate, the 1.5 billion MWh of coal-fired generation in 2005 would have emitted 1.5 billion tons of CO_2.[83] Given the published 2005 emissions of 2.5 billion metric tons CO_2, this 1.5 billion metric ton estimate is less than 60% of CO_2 emissions, and thus may be low.

From our overview of potential allocation values for CCPs from coal-fired generation, we estimated that the percent allocations would be, in sum, on the order of about one percent. If we allocated one percent of CO_2 emissions from coal-fired electricity generation to the CCPs, then about 15 million (short) tons of

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[81] DOE, "Emissions from Energy Consumption for Electricity Production and Useful Thermal Output at Combined-Heat-and-Power Plants," http://www.eia.doe.gov/cneaf/electricity/epa/epat5p1.html, last accessed Aug 29th 2007.

82 DOE, "Carbon Dioxide Emissions from the Generation of Electric Power in the United States," http://www.eia.doe.gov/cneaf/electricity/page/co2_report/co2report.html#electric, last accessed Aug 29th 2007.

83 DOE, "Emissions from Energy Consumption for Electricity Production and Useful Thermal Output at Combined-Heat-and-Power Plants," http://www.eia.doe.gov/cneaf/electricity/epa/epat5p1.html, last accessed Aug 29th 2007.

CO_2 would be allocated to their "production." In comparing this one percent allocated value to the CO_2 benefits estimated separately by BEES and Simapro, we see that the avoided portland cement and virgin gypsum use accounts for about 11.5 million short tons of CO_2 emission benefits. Similarly, for SO_2, coal-fired generation leads to most electricity generation emissions, which total about 10 million metric tons per year.[84] One percent of this number is about 100,000 metric tons SO_2, though this includes emissions from all Conventional Power Plants and Combined-Heat-and-Power Plants and therefore overstates the impact of coal combustion. However, Exhibit 5-3 in Chapter 5 of this report estimates avoided cement and gypsum manufacturing SO_2 emissions to be 26,000 short tons (23.9 million metric tons or 23.9 billion grams), suggesting that SO_2 emissions reductions associated with beneficial reuse are small when compared with the allocated emissions impacts associated with energy production from coal.

As indicated in our high-end CO_2 and SO_2 examples presented above, allocated emissions from primary production (i.e., coal combustion) may occasionally be greater than the documented benefits of beneficial use for some metrics. However, it is important to note that this allocation procedure reflects an accounting procedure designed only to more accurately apportion emission impacts across co-products. It can be correctly interpreted as an indication that the beneficial use of CCPs may not be an efficient method for reducing overall emissions of CO_2 and SO_2 to the environment. However, the actual CO_2 and SO_2 emissions avoided from the beneficial use of coal fly ash and FGD gypsum remain positive, as reported.

While this analysis has focused only on CO_2 and SO_2 (there are similar emissions from coal-fired generation of NOx, PM_{10}, etc.), it demonstrates the type of framework that could be in place to help assess the efficiency of beneficial use. It is likely that within such a framework that life cycle inventory data would be greater for one effect and lower for others, rather than a vector dominance situation. Thus, appropriate weighting methods should be identified to help balance the overall perceived benefit of such substitutions. EPA's TRACI model and the BEES model itself could serve to normalize and weight preferences of environmental flows against each other to lead to singular assessments of results.

SUMMARY

LCA allows for the allocation of input and output flows across the life cycle to the various products and co-products of processes and systems. However CCPs are generally considered waste, and not co-products of power generation. Even if they were considered co-products, the allocated input and output flows from coal-fired generation would associate only very small flows to the CCPs relative to the electricity produced. For this reason, and because our assessment here represents a high-end screening analysis, we do not include either an economic or mass-based allocation of coal combustion impacts to fly ash or FGD gypsum in our presentation of extrapolated findings in chapter 5.

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[84] DOE, "Emissions from Energy Consumption for Electricity Production and Useful Thermal Output at Combined-Heat-and-Power Plants", http://www.eia.doe.gov/cneaf/electricity/epa/epat5p1.html, last accessed Aug 29th 2007.

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