3.0 ENERGY AND ENVIRONMENTAL BENEFITS OF RMC USE IN FEDERAL CONCRETE PROJECTS

3.1 Introduction

This section further addresses Part (A) of the Congressional mandate, which also requires EPA to quantify the energy savings and environmental benefits associated with the substitution of RMCs for portland cement. Specifically, we address three of the four RMCs identified by Congress for further study: coal fly ash, GGBFS, and silica fume.[45] The analysis provides quantified estimates of energy savings and environmental benefits resulting from the substitution of these mineral components for finished portland cement in Federal construction projects involving concrete. RMCs can be used to offset virgin materials at more than one point in the cement production process. It is important to note that we are modeling the use of RMCs as a direct replacement for finished portland cement in concrete; this analysis does not evaluate the use of RMCs in clinker production due to current modeling limitations. The metrics used to describe impacts include resource savings (e.g., energy and water consumption), avoided air pollutant emissions, various measures of avoided GHG emissions, avoided water emissions, avoided soil emissions, and avoided end of life waste.

This section begins with a brief overview of the analytical approach and model used to respond to the Congressional mandate. We then describe the methodology used to develop estimates of the quantities of coal fly ash, GGBFS, and silica fume substituted for finished portland cement in Federal projects. We then present unit impact values related to the substitution of one metric ton of each RMC for finished portland cement in concrete. Finally, we present aggregated impact results for historical Federal RMC use quantities (years 2004 and 2005), and project RMC use quantities (years 2004 to 2015). Appendix D provides detailed results of the analysis, along with a technical discussion of the modeling inputs and calculations.

3.2 Analytical Approach and Model

Our methodology for evaluating the benefits associated with RMC use in Federal concrete applications first involves selecting an appropriate life cycle modeling tool to address a range of RMCs and impacts. We then use the model to implement a three-step analytic approach:

1) development of RMC substitution scenarios;
2) use of life-cycle inventory data to estimate environmental impacts associated with the substitution of one unit (metric ton) of RMC; and
3) calculation of the environmental impact profile for the total quantities of substituted RMCs.

We use a life-cycle analysis (LCA) approach to estimate the environmental benefits of substituting RMCs for finished portland cement. LCA allows estimation of a range of

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[45] BFSA, a material identified by Congress, is a source of aggregate in concrete and does not act as an SCM or substitute for portland cement. We focus this assessment on the benefits of substitution of portland cement. However, an illustration of the types and magnitude of benefits that can be achieved by using BFSA as a substitute for virgin aggregate in concrete, or as roadbase, can be found in Appendix D.

environmental impacts of a product across all stages in the product's life, from resource and raw material extraction through disposal. By comparing the impacts across different beneficial use scenarios in which portland cement is being replaced, it is possible to provide an estimate of the impacts associated with increases in the beneficial use of RMCs.

The analysis relies primarily on data derived from the Building for Environmental and Economic Sustainability (BEES) model. We employ the BEES model because it can be used to evaluate three of the RMCs identified by Congress (coal fly ash, GGBFS, and silica fume), providing a consistent modeling platform and set of results across the RMCs. Our comprehensive review of existing LCA models identified a number of other models that address individual RMCs, including the Waste Reduction Model (WARM) and the Pavement Life-Cycle Assessment Tool for Environmental and Economic Effects (PaLATE). Two key differences between WARM and BEES led us to select BEES for the benefits analysis in this study. First, WARM evaluates only lifecycle energy and GHG impacts in its outputs, while BEES evaluates energy, GHG, and several other environmental impacts, such as water use and pollutant emissions to air and water. In addition, the WARM model addresses only one RMC used in concrete - coal fly ash. PaLATE is another life cycle analysis tool useful for modeling energy and environmental impacts. However, at the time of this analysis, the PaLATE model had not been formerly peer reviewed under Agency guidelines. Furthermore, as with WARM, PaLATE does not allow for the consistency and comparability across all three RMCs[46]. Because these models use different data and methodologies to calculate the impacts of RMC substitution, we opted to use BEES to evaluate coal fly ash, GGBFS, and silica fume to assure consistency and comparability across the RMCs analyzed.[47]

It is important to emphasize the purpose and limitations of the application of life cycle modeling in this context. Our approach is to generally characterize the potential suite of environmental impacts related to reuse of certain materials, and to illustrate the potential magnitude of these impacts. As noted, we rely primarily on the BEES model (version 3.0) to generate this illustration, and then use the WARM model to corroborate the results for coal fly ash. The life cycle inventories of material and resource use embedded in these models are representative of productive processes in place at a given point in time. As these processes evolve, the existing life cycle inventories may become less representative and require updating.[48] As a result, the long-range projections of materials reuse and related impacts based upon current life cycle inventories should be considered with due care and in the appropriate context. For example, the

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[46] Understanding the material use, modeling, and comparative limitations, we applied the PaLATE model in an effort to estimate the potential types and magnitude of benefits that can be achieved by using BFSA as a substitute for virgin aggregate in concrete, or as roadbase. This analysis can be found in Appendix D

[47] Appendix D of this report includes a comparison of BEES and WARM results for energy and GHG impacts when coal fly ash is used in concrete. This comparison indicates that BEES and WARM result in roughly comparable energy and GHG impacts per metric ton of coal fly ash used as an SCM in concrete. We did apply the PaLATE model in an effort to estimate the potential types and magnitude of benefits that can be achieved by using BFSA as a substitute for virgin aggregate in concrete, or as roadbase. This analysis can be found in Appendix D

[48] For example, NIST recently released BEES version 4.0 subsequent to the completion of the analysis presented in this chapter. BEES version 4.0 utilizes updated life cycle inventories that differ in certain respects from version 3.0. These differences, however, do not yield material changes in the relative magnitude of impacts for the RMCs evaluated.

primary focus should be on the categories of impacts and their direction (i.e., positive versus negative impacts), as opposed to the absolute magnitude of impacts, which may change over time.

As noted previously, our analysis quantifies the benefits only for coal fly ash, silica fume, and GGBFS use in concrete, and further limits consideration to those benefits associated with the use of these RMCs as a replacement for portland cement in concrete as an SCM, and not an input into the clinker or cement manufacturing process. This analysis does not consider the use of other RMCs (e.g., BFSA, foundry sand, FGD gypsum, bottom ash, and power plant boiler slag) because current data and modeling capabilities do not allow the Agency to conduct a detailed analysis of these other RMCs. Finally, we are unable to extrapolate the impacts calculated for coal fly ash, GGBFs, and silica fume to these other RMCs because the impacts modeled for portland cement replacement are not representative of the processes required to use these materials in cement and concrete applications.[49]

Nevertheless, the analysis provides an estimate of a portion of the benefits associated with certain RMCs, and also reflects a transparent and readily accepted approach for estimating potential benefits.

3.3 Current and Expanded Use Scenarios

To evaluate the environmental benefits of using RMCs in concrete, both at current use levels and under Federal initiatives to increase beneficial use rates, EPA first developed projections of future RMC use through 2015 under a variety of scenarios. The current use scenarios reflect RMC use under existing conditions and initiatives. The expanded use scenarios assume implementation of Federal initiatives to increase beneficial use rates. We then apply the environmental unit impact measures to these estimates to quantify the potential environmental benefits of historical and future RMC substitution.

Our analysis uses 2004 as a base year for projections because 2004 is the most recent year for which use data are available for the three RMCs evaluated. The benefits of RMC use in Federal concrete projects are assessed for both historical (years 2004 and 2005) and projected (years 2006 to 2015) substitution levels.[50] We discuss these scenarios in further detail below.

3.3.1 Current Use Practices

To implement the analysis, we first estimate the proportion of portland cement and RMCs used in Federal concrete projects. Specifically, to estimate the proportion of RMCs used in all Federally funded concrete projects, we use an FHWA estimate that approximately 20% of U.S.

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[49] To the extent that these materials offset extraction and processing of virgin materials, however, there are likely to be positive environmental life cycle impacts associated with their use in cement or concrete. At a minimum, the environmental benefits associated with the use of other RMCs are likely to be consistent with the energy savings and reduced impacts associated with avoiding the production of an equal quantity of virgin material.

[50] 2006 is not considered a “historical year” in this analysis because at the time of this analysis, 2006 use data were not available for all three RMCs being evaluated. Thus, it was necessary to develop projections of RMC use beginning in 2006.

concrete construction projects involve Federal funds.[51] Therefore, in this analysis, we assume: (1) that Federal projects are using RMC at the same "rate" as the national average, and (2) that the Federal projects incorporate 20% of RMCs used as a substitute for finished portland cement in concrete. Appendix D presents a detailed discussion of how this estimate was derived.

We then use available data from industry and government sources on historical and future portland cement demand to develop the following approaches:

- **Future GGBFS Use:** We assume that annual demand for GGBFS will increase proportionate to the overall U.S. demand for portland cement. PCA estimates that U.S. portland cement demand will be 195 million metric tons in 2030 (PCA, 2006a). For this analysis, we assume that demand for portland cement will increase linearly to the PCA estimated rate by 2030, or approximately 2.2% per year beyond 2005 (the last year for which actual portland cement use data are available). We apply the 2.2% growth rate to the base year (2004) quantity of GGBFS used in U.S. concrete projects (3.46 million metric tons), which equals an annual increase of approximately 76,000 metric tons. While this approach does not attempt to address a number of industry-specific uncertainties related to GGBFS supply, it is generally consistent with the estimates of potential GGBFS production and sales provided by the USGS. Future GGBFS use, depends on a number of factors, including import patterns and demand for GGBFS relative to demand for BFSA and GBFS (GGBFS, GBFS and BFSA are all made from the same supply of iron slag). The SCA projects higher GGBFS use based on an assumed increase in imports and a significant investment in grinding equipment.[52] For the purposes of this report, however, we use more conservative projections based on U.S. portland cement demand that do not assume a market shift. These projections comport with a USGS estimate that a maximum of six million metric tons of GGBFS could be available in the U.S. in the next 10 to 20 years through combined imports and domestic production.[53]

- **Future Silica Fume Use:** We assume that domestic silica fume supply is inelastic, as a result of relatively inelastic global supply of silicon metal and ferrosilicon and related ferroalloys production. Therefore, we assume that current (i.e., base year) rates of silica fume use in U.S. concrete projects will remain constant into the future (i.e., roughly 60,000 metric tons per year).[54]

- **Future Coal Fly Ash Use:** We employ a different approach to estimate future use of coal fly ash because current government and industry initiatives are designed to increase beneficial use rates. Specifically, using selected mechanisms, as outlined in Chapter 5, the C^2P^2 program has an aggressive goal of

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[51] Personal communication with Jon Mullarky, FHWA, July 17, 2007.

[52] Personal communication with Jan Prusinski, Slag Cement Association, June 6, 2007.

[53] Personal communication with Hendrik van Oss, USGS, July 12, 2007.

[54] Personal communication with Hendrik van Oss, USGS, July 12, 2007, and analysis of data from USGS *2005 Minerals Yearbook – Ferroalloys*, accessed at: http://minerals.usgs.gov/minerals/pubs/commodity/ferroalloys/feallmyb05.pdf.

increasing coal fly ash use in portland cement to 18.6 million short tons (16.9 million metric tons) by 2011.[55] We therefore use constant progress toward this goal to estimate coal fly ash use for the years 2005 through 2011. For the years 2012 through 2015, we then estimate that coal fly ash use under C^2P^2 will increase at the same rate as U.S. portland cement demand over 2004 levels (2.2%, or approximately 333,000 metric tons per year).[56] In order to estimate coal fly ash use in the absence of C^2P^2, we also employ a current use scenario in which we assume that the use of coal fly ash as a partial portland cement replacement will increase linearly for the years 2005 to 2011 at the same rate as U.S. cement demand. This scenario recognizes that meeting the C^2P^2 goals is dependent upon overcoming a number of the barriers, as identified in Chapter 4.

3.3.2 Expanded Use Scenarios

In addition to the current use estimates, we also developed expanded use estimates for coal fly ash as an SCM in concrete to capture incremental changes in use from current levels. These scenarios are designed to provide insight into the specific impacts of ongoing and emerging efforts by EPA and other Federal agencies and stakeholders to increase the beneficial use of coal fly ash. We limit our evaluation of an expanded use scenario to coal fly ash because, unlike GGBFS and silica fume, coal fly ash is currently underutilized (with respect to supply availability) and therefore has the capacity for expanded use if barriers to its increased use are removed.[57]

We employ two expanded use scenarios to estimate the potential impacts and benefits due to initiatives to increase the use of coal fly ash. Under the first expanded use scenario (the "15 percent scenario"), coal fly ash substitution in Federal projects is assumed to increase from the current use rates (approximately 10%) to the 15% level recommended under the CPG program. Under the second alternative use scenario (the "30% scenario"), coal fly ash substitution for portland cement in Federal projects (i.e., 20% of total U.S. estimates) is assumed to increase from the current use rates to the maximum levels recommended under the CPG program (i.e., 30%).[58, 59] For non-Federal projects, our scenarios assume that RMC use would be the same as under the current use analysis. For both scenarios, we assume that the increase in use will be linear starting in the year 2009 and continuing through the year 2015.[60] Tables 3-1 and 3-2 present the current and future use estimates (incorporating the 20% adjustment factor) for coal

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[55] See www.epa.gov/epaoswer/osw/conserve/c2p2/pubs/facts508.pdf.

[56] Comments and information from Hendrik van Oss of the USGS suggest that developing any trend in future coal fly ash beneficial use is subject to significant uncertainty. We therefore use EPA goals and cement industry projections as a likely high-end estimate of potential growth.

[57] Close to 100% of GGBFS and silica fume currently generated in the U.S. is believed to be beneficially used.

[58] Note that an increase to 15% coal fly ash substitution represents an optimistic Agency goal. Therefore, the 30% scenario represents a possible, though unlikely, maximum target for increased substitution. The results of the 30% scenario should be taken as an upper bound estimate of possible environmental benefits.

[59] Both the 15% and 30% scenarios assume full attainment of the CPG recommended beneficial use levels, but do not necessarily reflect current barriers to the expanded use of coal fly ash. Additionally, the C^2P^2 scenario is an expanded use scenario using the goals set forth under the program. Therefore, the volumes beneficially used in these scenarios are optimistic Agency goals.

[60] SAFETEA-LU instructs all agency heads to implement recommendations of the 30 month study with regard to procurement guidelines no later than one year after the release of the study, or approximately early to mid 2009.

fly ash, GGBFS, silica fume, and total portland cement (including both "virgin" portland and blended cements), as well as the expanded use estimates for coal fly ash.

Table 3-1: U.S. Portland Cement Demand and RMC Use in Cement and Concrete Products, Under Current and Expanded Use Scenarios

	Cement	**Coal Fly Ash**				**GGBFS**	**Silica Fume**
Year	*Total U.S. Demand*	*Current Use Baseline*	*Current Use C^2P^2*	*15% Scenario*	*30% Scenario*	*All Scenarios*	*All Scenarios*
	million metric tons						
2004	122.0	12.8	12.8	12.8	12.8	3.5	0.06
2005	125.7	13.6	13.6	13.6	13.6	3.5	0.06
2006	128.5	13.9	14.2	14.2	14.2	3.6	0.06
2007	131.2	14.2	14.8	14.8	14.8	3.7	0.06
2008	134.0	14.5	15.4	15.4	15.4	3.8	0.06
2009	136.8	14.8	15.9	16.3	17.7	3.8	0.06
2010	139.6	15.1	16.4	17.2	20.0	3.9	0.06
2011	142.3	15.4	16.9	18.1	22.3	4.0	0.06
2012	145.1	15.7	17.2	18.9	24.6	4.1	0.06
2013	147.9	16	17.5	19.8	27.0	4.1	0.06
2014	150.6	16.3	17.9	20.6	29.5	4.2	0.06
2015	153.4	16.6	18.2	21.5	32.0	4.3	0.06

Notes:

(a) These figures include both Federal and non-Federal projects. For purposes of this analysis, we assume that Federal projects represent approximately 20% of the total quantities; non-Federal projects make-up the remaining 80%.

(b) The C^2P^2, 15%, and 30% scenarios represent aggressive policy goals.

Table 3-2: Federal Portland Cement and RMC Use Under Current and Expanded Use Scenarios

	Cement	Coal Fly Ash				GGBFS	Silica Fume
	Federal Demand	*Current Use Baseline*	*Current Use C^2P^2*	*15% Scenario*	*30% Scenario*	*All Scenarios*	*All Scenarios*
Year	*million metric tons*						
2004	24.4	2.6	2.6	2.6	2.6	0.7	0.01
2005	25.1	2.7	2.7	2.7	2.7	0.7	0.01
2006	25.7	2.8	2.8	2.8	2.8	0.7	0.01
2007	26.2	2.8	3.0	3.0	3.0	0.7	0.01
2008	26.8	2.9	3.1	3.1	3.1	0.8	0.01
2009	27.4	3.0	3.2	3.4	4.1	0.8	0.01
2010	27.9	3.0	3.3	3.7	5.1	0.8	0.01
2011	28.5	3.1	3.4	4.0	6.1	0.8	0.01
2012	29.0	3.1	3.4	4.3	7.2	0.8	0.01
2013	29.6	3.2	3.5	4.6	8.3	0.8	0.01
2014	30.1	3.3	3.6	4.9	9.4	0.8	0.01
2015	30.7	3.3	3.6	5.3	10.6	0.9	0.01

Notes:
These figures reflect Federal projects only.
GGBFS and silica fume data equal 20% of the USA totals.

3.4 RMC Unit Impact Savings

RMC unit impacts represent the energy and environmental effects of using one unit of coal fly ash, GGBFS, or silica fume in place of an equivalent unit of finished portland cement in a specified concrete application.[61] The unit impact values for each RMC provide a basis for converting Federal RMC use quantities in Table 3-2 into measures of environmental benefits. Table 3-3 presents the unit impact values applied in our model. These values are derived from BEES life cycle inventory data and represent the total life cycle savings of using RMCs as a replacement for one metric ton of finished portland cement in concrete.[62]

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[61] Silica fume does not replace portland cement in a 1:1 ratio (as is the case with coal fly ash and GGBFS). The addition of silica fume to concrete has a synergistic effect on compressive strength, making the replacement ratio complex. For simplicity, however, BEES assumes a 1:1 replacement ratio for silica fume and portland cement in concrete when modeling life cycle impacts. This is likely to over state the benefits of using this material as an SCM.

[62] See Appendix D for the detailed calculations of the RMC unit impact values.

Table 3-3: Life Cycle Impacts per Metric Ton of RMC Substituted for Finished Portland Cement in Concrete

Metric	---------------------Material --------------------		
	Coal Fly Ash[a]	**GGBFS**	**Silica Fume[b]**
Energy Savings (megajoules)	4,695.9	4,220.9	32,915.0
Energy Savings (US $)	129.1	116.1	905.2
Water Savings (Liter)	376.3	145.2	-5,111.4
Water Savings (US $)	0.2	0.1	-3.2
Avoided CO_2 Equivalent (GHG) (grams)[c]	718,000.0	*Not calculated*[e]	
Avoided CO_2 Emissions (grams)	701,377.7	668,889.1	699,923.3
Avoided CF_4 Emissions (grams)	0.0	*Not calculated*[e]	
Avoided CH_4 Emissions (grams)	594.8		
Avoided N_2O Emissions (grams)	13.2		
Passenger cars not driven for one year[d]	0.2		
Passenger cars and light trucks not driven for one year[d]	0.1		
Avoided gasoline consumption (liters)[d]	310.0		
Avoided oil consumption (barrels) [b]	1.7		
Avoided NOx Emissions (grams)	2,130.2	2,014.8	28,442.2
Avoided PM_{10} Emissions (grams)	0.0	0.0	-0.1
Avoided SOx Emission (grams)	1,673.9	1,605.8	42,560.1
Avoided CO Emissions (grams)	654.3	621.5	2,278.2
Avoided Hg Emissions (grams)	0.0	0.0	-0.3
Avoided Pb Emissions (grams)	0.0	0.0	0.6
Avoided biochemical oxygen demand in water (grams)	3.4	-0.8	-21.0
Avoided chemical oxygen demand in water (grams)	28.7	-6.5	-201.4
Avoided copper water emissions (grams)	0.0	0.0	0.0
Avoided suspended matter in water (grams)	15.4	-3.5	-55.1
Avoided emissions to soil (grams)	0.0	0.0	0.0
Avoided end of life waste (kilograms)	0.0	0.0	0.0

Notes:

a. Impact metrics based upon representative concrete products.

b. Negative values represent an incremental increase in impacts relative to the use of portland cement.

c. Avoided CO_2 equivalent is an expression of the cumulative global warming potential of all four greenhouse gasses for which BEES data were available (CO_2, CF_4, CH_4, and $N_2$0). It can be calculated from the global warming potentials of individual greenhouse gasses, using the global warming potential of C0_2 as the reference point. Avoided CO_2 equivalent was calculated using the Greenhouse Gas Equivalencies Calculator developed by the U.S. Climate Technology Cooperation (accessed at: http://www.usctcgateway.net/tool/).

d. The greenhouse gas metrics taken from BEES were converted to equivalent impacts such as passenger cars removed from the road for one year, passenger cars and light trucks removed from the road for one year, avoided gasoline consumption, and avoided oil consumption, using the Greenhouse Gas Equivalencies Calculator. It is important to note that these metrics are equivalent expressions of the avoided greenhouse gas metrics reported by BEES; they do not represent additional benefits.

e. GHG equivalency metrics were not calculated for GGBFS and silica fume, due primarily to the fact that use of these materials is unlikely to change significantly across scenarios.

As shown in Table 3-3, use of one metric ton of RMC in place of one metric ton of finished portland cement results in a range of environmental benefits. For example, substituting one metric ton of coal fly ash results in 0.72 metric tons of avoided CO_2 equivalent emissions, of which 0.70 metric tons is avoided CO_2. In comparison, use of one metric ton GGBFS results in 0.67 metric tons of avoided CO_2 emissions.

For all metrics, the energy and environmental benefits of using GGBFS in concrete are less than the benefits of using coal fly ash in concrete. GGBFS generally is produced by quenching molten slag with water and then grinding the cooled material to a fine cement-like consistency. The resource use and air emissions associated with the mechanical processing of GGBFS offset some of the environmental benefits from the avoided production of portland cement. In contrast, coal fly ash generally does not require grinding prior to its beneficial use in concrete and is therefore modeled as an environmentally "neutral" input to concrete production.[63] Thus, the benefits of coal fly ash substitution directly represent the environmental benefits associated with avoiding the production of one metric ton of portland cement.

It is important to note that the unit impact values for silica fume are not directly comparable to the unit impact values for coal fly ash and GGBFS. Silica fume is not generally used as a direct, complete substitute for finished portland cement, but is instead a partial supplement that offsets some portland cement use, and also increases the strength and reduces the water permeability of concrete.[64] Substitution of silica fume in concrete can yield both positive and negative environmental impacts. For example, its use as a partial substitute can lower energy consumption and carbon dioxide emissions relative to mixes with 100% portland cement. The most significant negative impact is increased water use when silica fume is used as a partial substitute in place of portland cement in concrete. As described in Appendix B of this report, the high surface area of silica fume increases water demand in concrete.

3.5 Historical Energy and Environmental Impacts of RMC Beneficial Use

To estimate energy and environmental benefits attributable to substitution of RMCs for portland cement in Federal concrete projects, we multiply the unit impact values identified in Table 3-3 by the Federal RMC use quantities for 2004 and 2005 (presented in Table 3-2). As previously discussed, our historical impacts include both 2004 and 2005, while projections cover 2006 through 2015.

We summarize the historical energy and impact estimates briefly in the bullets below, with more detailed results presented in Table 3-4.

- **Coal Fly Ash**: Federal concrete projects used an estimated 5.3 million metric tons of coal fly ash in 2004 and 2005 combined. This substitution yields a number of environmental benefits, including avoided energy use of approximately

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[63] Coal fly ash does require some quality control prior to use in concrete. Separation and beneficiation are widely practiced in the industry, but the energy impacts of these processes do not appear to be as clear or significant as the grinding required for GGBFS. As a result, many life cycle models, including BEES, do not attribute processing energy to coal fly ash.

[64] For a further explanation of the limitations of the unit impact estimates for silica fume, see Appendix D.

25 billion megajoules; avoided water consumption of two billion liters; and avoided carbon dioxide equivalent emissions of 3.8 million metric tons.

Energy and water savings represent two significant impacts that can be monetized using market prices. Results indicate that the beneficial use of coal fly ash in 2004 and 2005 resulted in energy savings valued at approximately $0.7 billion, and water savings valued at approximately $1.2 million.

- **GGBFS**: An estimated 1.4 million metric tons of GGBFS were used in Federal concrete projects in 2004 and 2005 combined. This substitution yields a suite of positive and negative environmental impacts, including avoided energy use of approximately six billion megajoules; avoided water consumption of approximately 0.2 billion liters; and avoided carbon dioxide emissions of approximately one million metric tons. The negative benefits include increased chemical oxygen demand and increased suspended matter in water discharges.

- **Silica Fume**: The impact estimates for silica fume result from an estimated use of 24,000 tons in 2004 and 2005. Consistent with the unit impact measures, silica fume substitution results in both positive and negative impacts, including avoided energy use of approximately one billion megajoules, increased water consumption of 0.1 billion liters, and positive and negative impacts across the various air emissions metrics.

Table 3-4: Historical Impacts of Using Coal Fly Ash, GGBFS, and Silica Fume in Federal Concrete Projects (2004 plus 2005)

		COAL FLY ASH	**GGBFS**	**SILICA FUME**
		Beneficial Use Quantity (metric tons, 2004 plus 2005)		
		5,282,000	1,399,000	24,000
Environmental Metric		**Historical Energy and Environmental Impacts**		
Energy Savings	billion megajoules	24.8	5.9	0.8
	billion ($ 2006)	0.7	0.2	0.0
	billion ($ discounted @ 7%)	0.7	0.2	0.0
Water Savings	billion liters	2.0	0.2	-0.1
	million ($ 2006)	1.2	0.1	-0.1
	million ($ discounted @7%)	1.2	0.1	-0.1
Avoided CO_2 Equivalent (air)	million metric tons	3.8	*Not calculated*[b]	
Avoided CO_2	million metric tons	3.7	0.9	0.0
Avoided CF_4	metric tons	0.0	*Not calculated*[b]	
Avoided CH_4	thousand metric tons	3.1		
Avoided N_2O	metric tons	69.7		
Passenger cars not driven for one year	million passenger cars	0.8		
Passenger cars and light trucks not driven for one year	million passenger cars and light trucks	0.7		
Avoided gasoline consumption	billion liters	1.6		
Avoided oil consumption	billion barrels	0.0		
Avoided NOx (air)	thousand metric tons	11.3	2.8	0.7
Avoided PM10 (air)	metric tons	0.1	0.0	0.0
Avoided SOx (air)	thousand metric tons	8.8	2.2	1.0
Avoided CO (air)	thousand metric tons	3.5	0.9	0.1
Avoided Hg (air)	metric tons	0.2	0.1	0.0
Avoided Pb (air)	metric tons	0.2	0.0	0.0
Avoided biochemical oxygen demand (water)	metric tons	17.9	-1.1	-0.5
Avoided chemical oxygen demand (water)	metric tons	151.4	-9.1	-4.8
Avoided copper (water)	metric tons	0.0	0.0	0.0
Avoided suspended matter (water)	metric tons	81.3	-4.9	-1.3
Avoided soil emissions	metric tons	0.0	0.0	0.0
Avoided end of life waste	metric tons	0.0	0.0	0.0

Notes:

a. BEES reports CO separate from CO_2 emissions, but it is important to note that the Intergovernmental Panel on Climate Change (IPCC) considers CO emitted from portland cement manufacture a precursor to CO_2.

b. GHG equivalency metrics were not calculated for GGBFS and silica fume is part due to the fact that use of these materials is unlikely to change significantly across scenarios.

As shown in Table 3-4, the environmental benefits associated with the historical use of coal fly ash are significantly larger than the benefits associated with the historical use of GGBFS. These differences are a function of both the historical quantities of each RMC used in Federal concrete projects and the unit impacts for the use of one ton of each RMC in concrete. Specifically, greater quantities of coal fly ash have been used historically than GGBFS, and the unit impacts calculated for coal fly ash are higher than those of GGBFS.

While avoided releases of different substances, and savings in energy and water use are generally additive, a full assessment of the economic benefits would require identifying the specific receptors (i.e., populations and water bodies) whose quality has been improved. Moreover, certain GHG equivalent metrics such as "avoided oil consumption" and cars removed from the road represent different ways of describing the same impact (i.e., avoided greenhouse gas emissions), and are not additive.

3.6 Projected Energy and Environmental Impacts of RMC Beneficial Use

In addition to assessing the historical benefits of the use of RMCs, this analysis also considers how the benefits may accrue over time under projected use scenarios. As described above, for each RMC analyzed, we developed projections, through the year 2015, of potential substitution levels based upon current use, forecasted supply, and potential demand of each RMC, as well as estimates based on alternative procurement goals. The projected annual substitution levels (in metric tons) are then multiplied by the unit impact values (i.e., impacts per metric ton of RMC) to derive projected environmental benefits.

Table 3-5 below presents aggregate benefits and impacts summed across the years 2004 to 2015 under the four beneficial use scenarios developed in this analysis (i.e. the baseline scenario, the C^2P^2 goals scenario, the 15% expanded use scenario for coal fly ash, and the 30% expanded use scenario for coal fly ash). The results are presented in aggregate for the years 2004 to 2015 to show the total magnitude of possible impacts during the period of analysis. The results illustrate the incremental gains achieved by moving to higher levels of coal fly ash use. Appendix D presents these findings in more detail.

As in the historical scenario, energy and water savings represent two major impacts, and illustrate the differences between the various scenarios. Results indicate that use of the analyzed RMCs (coal fly ash, GGBFS, and silica fume) in concrete from 2004 through 2015 may result in energy savings valued at nearly $6 billion (2006 dollars) under baseline conditions. Achieving the 15% substitution rate (coal fly ash for Portland cement) for coal fly ash would increase the value of energy savings to nearly $7 billion, and achieving a 30% substitution rate would increase benefits to an estimated $9.6 billion for the three RMCs. Water savings results for the three RMCs reflect a similar pattern, showing a 30% substitution rate for coal fly ash would save approximately 25 billion litres, compared with a 14.1 billion litre savings under baseline assumptions.

Figures 3-1 through 3-3 below present graphic representations of the trends for selected energy and environmental metrics for all coal fly ash and GGBFS use scenarios.[65] Consistent with the Congressional requirement, the metrics selected - energy savings, carbon dioxide emissions, and water use impacts, represent the largest environmental benefits associated with use of the RMCs in concrete.

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[65] We do not present trend results for silica fume in these tables due to the higher degree of uncertainty associated with the silica fume analysis.

Table 3-5: Total Projected Impacts of Using Coal Fly Ash, GGBFS, and Silica Fume in Federal Concrete Projects Under Current and Expanded Rate Use Scenarios for Years 2004 – 2015 (Footnotes on next page)

Metric	Units	**Current Use Baseline Scenario**[a]	**Current Use C^2P^2 Scenario**[b]	**Incremental Impacts**[c] (Current Use C^2P^2 minus Current Use Baseline)	**Expanded Use 15% Substitution Scenario**[d]	**Incremental Impacts**[e] (15% Scenario minus Baseline Scenario)	**Incremental Impacts**[f] (15% Scenario minus Current Use C^2P^2)	**Expanded Use 30% Substitution Scenario**[g]	**Incremental Impacts**[h] (30% Scenario minus Baseline Scenario)	**Incremental Impacts**[i] (30% Scenario minus Current Use C^2P^2)	**Incremental Impacts**[j] (30% Scenario minus 15% Scenario)
Energy Savings	billion megajoules	212.1	223.2	11.2	252.5	40.4	29.3	348	135.9	124.8	95.5
	billion ($ 2006)	5.8	6.1	0.3	6.9	1.1	0.8	9.6	3.8	3.4	2.6
	billion ($ discounted @ 7%)	4.5	4.7	0.2	5.2	0.7	0.5	6.8	2.3	2.1	1.6
Water Savings	billion liters	14.1	15	0.9	17.3	3.2	2.3	25	10.9	10	7.7
	million ($ 2006)	8.7	9.3	0.6	10.7	2	1.4	15.4	6.7	6.2	4.7
	million ($ discounted @ 7%)	6.7	7.1	0.4	7.9	1.2	0.9	10.8	4.1	3.7	2.9
Avoided CO_2 Equivalent (air)[k]	million metric tons	25.7	27.4	1.7	31.9	6.2	4.5	46.5	20.8	19.1	14.6
Avoided CO_2	*million metric tons*	31.4	33.1	1.7	37.5	6.1	4.4	51.7	20.3	18.6	14.3
Avoided CF_4	*metric tons*	0	0	0	0	0	0	0	0	0	0
Avoided CH_4	*thousand metric tons*	21.3	22.7	1.4	26.4	5.1	3.7	38.5	17.2	15.8	12.1
Avoided N_2O	*metric tons*	471.9	503.3	31.4	585.4	113.5	82.2	853.7	381.8	350.5	268.3
Passenger cars not driven for one year	million passenger cars	5.7	6.1	0.4	7.1	1.4	1	10.4	4.7	4.3	3.3
Passenger cars and light trucks not driven for one year	million passenger cars and light trucks	4.7	5	0.3	5.8	1.1	0.8	8.4	3.7	3.5	2.6
Avoided gasoline consumption	billion liters	11.1	11.8	0.7	13.8	2.7	1.9	20.1	9	8.2	6.3
Avoided oil consumption	billion barrels	0.1	0.1	0	0.1	0	0	0.1	0	0	0
Avoided NOx (air)	thousand metric tons	99.1	104.1	5.1	117.4	18.3	13.3	160.8	61.7	56.6	43.3
Avoided PM10 (air)	metric tons	0.4	0.5	0	0.5	0.1	0.1	0.8	0.4	0.3	0.2
Avoided SOx (air)	thousand metric tons	81	85	4	95.4	14.4	10.4	129.4	48.4	44.5	34.1
Avoided CO (air)[l]	thousand metric tons	29.5	31.1	1.6	35.2	5.7	4.1	48.5	19	17.4	13.3
Avoided Hg (air)	metric tons	1.9	2	0.1	2.2	0.3	0.3	3.1	1.2	1.1	0.9
Avoided Pb (air)	metric tons	1.5	1.6	0.1	1.8	0.3	0.2	2.4	0.9	0.8	0.6
Avoided biochemical oxygen demand (water)	metric tons	111	119.1	8.1	140.2	29.2	21.1	209.1	98.1	90	68.9
Avoided chemical oxygen demand (water)	metric tons	936.2	1,004.40	68.2	1,183.00	246.8	178.6	1,766.20	830	761.8	583.2
Avoided copper (water)	metric tons	0	0	0	0	0	0	0	0	0	0
Avoided suspended matter (water)	metric tons	510.3	546.9	36.6	642.8	132.5	95.9	955.8	445.5	409	313.1
Avoided soil emissions	metric tons	0	0	0	0	0	0	0	0	0	0
Avoided end of life waste	metric tons	0	0	0	0	0	0	0	0	0	0

Notes:

a. Calculated as the sum of impacts for coal fly ash current use baseline, GGBFS and silica fume current use scenarios, years 2004 to 2015.
b. Calculated as the sum of impacts for coal fly ash current use C^2P^2, GGBFS and silica fume current use scenarios, years 2004 to 2015.
c. Calculated as the difference between the current use baseline totals and the current use C^2P^2 totals. This represents the impacts attributable to increased coal fly ash use under EPA's C^2P^2 program.
d. Calculated as the sum of impacts for the coal fly ash 15% expanded use, GGBFS current use and silica fume current use scenarios for years 2004 to 2015. Expanded use scenarios were not developed for GGBFS and silica fume.
e. Calculated as the difference between 15% expanded use scenario totals and current use baseline totals. This represents the impacts achieved by moving from coal fly ash use levels without influence from EPA's C^2P^2 program, to coal fly ash use levels under the CGP-recommended 15% substitution.
f. Calculated as the difference between 15% expanded use scenario totals and current use C^2P^2 totals. This represents the impacts achieved by moving from coal fly ash use levels under EPA's C^2P^2 program, to coal fly ash use levels under the CGP-recommended 15% substitution.
g. Calculated as the sum of impacts for the coal fly ash 30% expanded use, GGBFS current use and silica fume current use scenarios for years 2004 to 2015. Expanded use scenarios were not developed for GGBFS and silica fume.
h. Calculated as the difference between the 30% expanded use scenario totals and the current use baseline totals. This represents the impacts achieved by moving from coal fly ash use levels without influence from EPA's C^2P^2 program, to coal fly ash use levels under the CGP-maximum 30% substitution.
i. Calculated as the difference between the 30% expanded use scenario totals and the current use C^2P^2 totals. This represents the impacts achieved by moving from coal fly ash use levels under EPA's C^2P^2 program, to coal fly ash use levels under the CGP-maximum 30% substitution.
j. Calculated as the difference between 30% expanded use scenario totals and 15% expanded use scenario totals. This represents the impacts of moving from coal fly ash use levels under EPA's C^2P^2 program, to coal fly ash use levels under the CGP-maximum 30% substitution.
k. For avoided CO_2 equivalent, CF_4, CH_4, N_2O, passenger cars removed, passenger cars and light trucks removed, and avoided gas and avoided oil consumption, impacts are attributable to coal fly ash only as these metrics were not evaluated for GGBFS or silica fume.
l. BEES reports CO separate from CO_2 emissions, but it is important to note that the Intergovernmental Panel on Climate Change (IPCC) considers CO emitted from portland cement manufacture a precursor to CO_2.

Figure 3-1: Avoided Energy Use for Coal Fly Ash and GGBFS, All Scenarios (Federally Funded Projects Only)

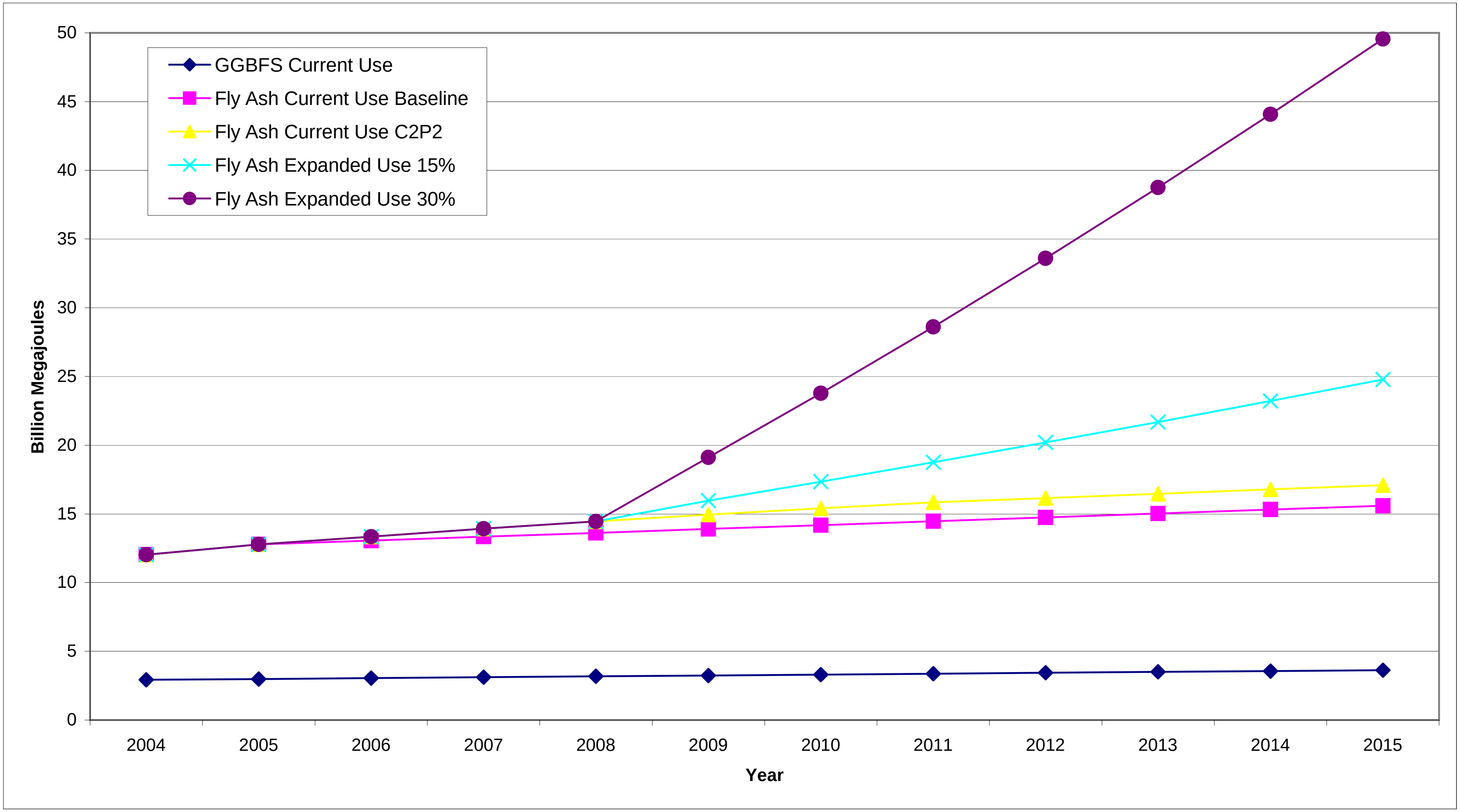

Figure 3-2: Avoided Water Use for Coal Fly Ash and GGBFS, All Scenarios (Federally Funded Projects Only)

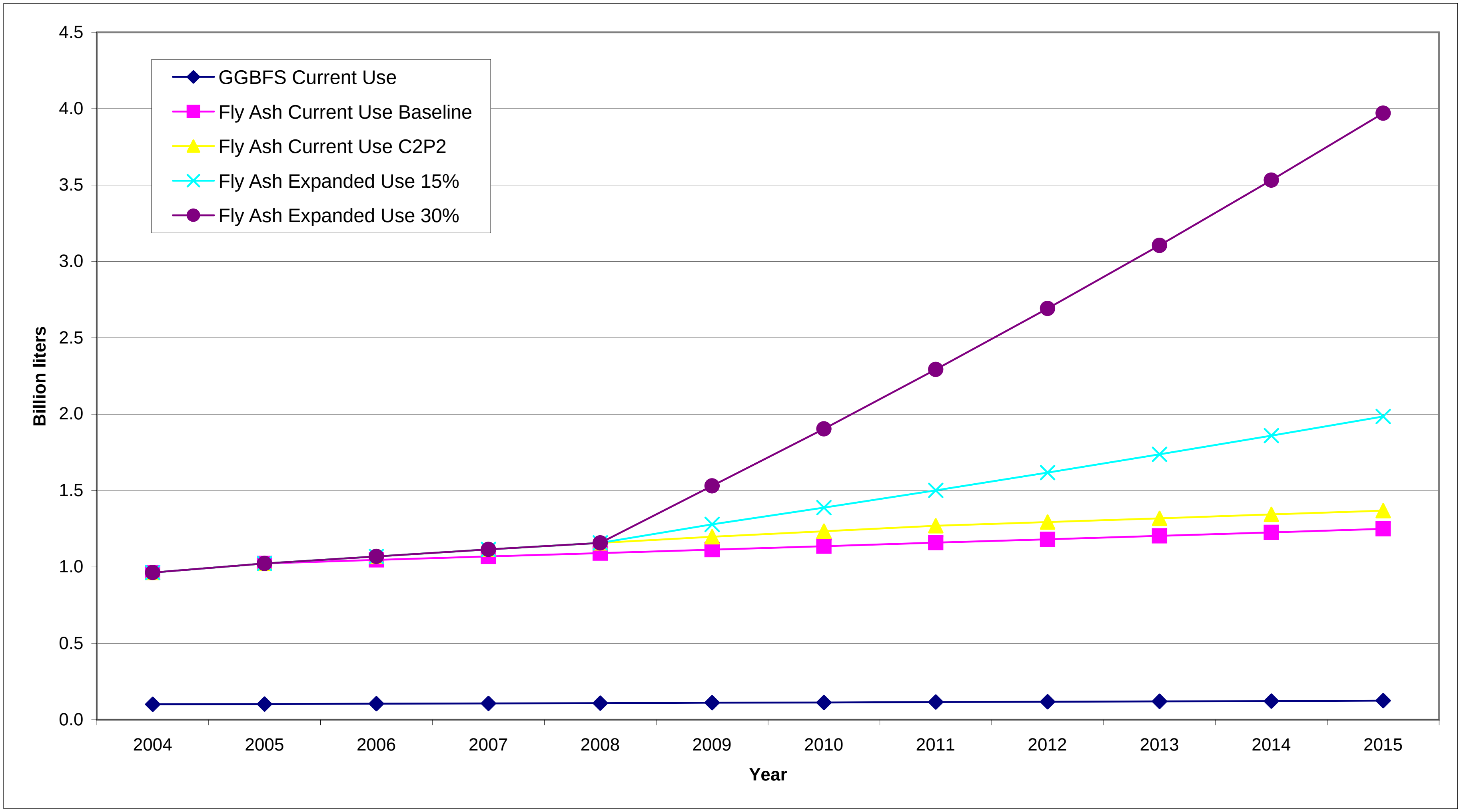

Figure 3-3: Avoided CO_2 Air Emissions for Coal Fly Ash and GGBFS, All Scenarios (Federally Funded Projects Only)