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Life-Cycle Analysis of a Cement Manufacturing Plant Co-Firing Hazardous Waste In The USA

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LIFE-CYCLE ANALYSIS OF A CEMENT MANUFACTURING PLANT CO-FIRING
HAZARDOUS WASTE IN THE USA

by

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ABSTRACT

The purpose of this work was to determine the overall environmental impacts associated with the co-firing hazardous waste by burning in a cement kiln to replace the use of coal in the cement manufacturing process. This environmental assessment was conducted using LCA methodology. Understanding the environmental impacts associated with burning hazardous waste in a cement factory could help shape national environmental policy, regulations and the need for site specific human health risk assessments in the environmental regulatory permitting processes. Accordingly, the primary objective of this study was to evaluate the environmental impacts from the hazardous waste burning for energy recovery in a cement plant compared to a base scenario of burning 100% coal for baseline comparison. This study relied on real-time primary data from a hazardous waste burning cement plant and the functional unit for this LCA is one kilogram of cement.

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LIST OF SYMBOLS

\rightarrow Yields and maps element a to b.

\therefore Therefore.

\times Multiplication sign.

$=$ Equal to.

ω Rotational velocity.

β Kiln slope.

LIST OF ABBREVIATIONS

Al ₂ O ₃	Aluminum Oxide
AP	Acidification Potential
C	Carbon
CaO.....	Calcium Oxide or Lime
CaCO ₃	Calcium Carbonate
Ca(OH) ₂	Calcium Hydroxide
C3S	Tricalcium Silicate
CEMs	Continuous Emissions Monitoring Systems
CFR	Code of Federal Regulations
CO ₂	Carbon Dioxide
CO ₂ e	Carbon Dioxide Equivalent
CTUe	Comparative Toxic Units for Ecosystem
CTUh	Comparative Toxic Units for Humans
Eco tox.....	Ecosystem Toxicity
EP	Eutrophication Potential
EPA	United States Environmental Protection Agency
Fe ₂ O ₃	Iron Oxide
FFBH	Fabric Filter Baghouse
FU.....	Functional Unit
GaBi.....	Ganzheitliche Bilanz (software)
GHG	Greenhouse gases
GWP	Global Warming Potential

HCl	Hydrochloric Acid
Hg.....	Mercury
HHV	Higher Heat Value
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
LCA	Life-Cycle Assessment
LCI	Life-Cycle Inventory
LCIA.....	Life-Cycle Impact Analysis
KWSCFM.....	Kilo Wet Standard Cubic Feet per Minute
MACT.....	Maximum Achievable Control Technology
MEDEP.....	Maine Department of Environmental Protection
MM.....	Million
NOC.....	Notice of Compliance
NO _x	Nitrogen Oxides
PADEP.....	Pennsylvania Department of Environmental Protection
PM	Particulate Matter
SiO ₂	Silicon Dioxide
SO _x	Sulfur Dioxides
THC	Total Hydrocarbons
U.S.....	United States
USEPA	United States Environmental Protection Agency

CHAPTER 1

INTRODUCTION

Concrete is one of the oldest and most important building materials (Wordbook, 1985). Each year, approximately one ton of concrete is produced for every person in the world (Lippiate and Ahmad, 2005). The installed capacity in the United States is approximately 100 metric tons per year (Global Cement, 2012). The key ingredient in concrete is portland cement. Manufacturing portland cement requires significant energy, thus requiring the burning of large amounts of fuel that ultimately results in the production of high levels of greenhouse gasses (GHGs) (Madloul, 2011), accounting for approximately 5 to 6% of the total non-mobile source-generated CO₂ worldwide (Metz, 2005; Worrell, 2000).

In an attempt to mitigate such impacts, significant attention has been paid to considering the use of alternative lower emitting fuels and lower emission yielding raw materials. Results from several life cycle assessment (LCA) studies evaluating the use of alternative fuels, including refuse derived fuel (RDF), tires, other non-hazardous materials, and material selection (e.g., fly ash) (Guereca, 2015, Huntzinger, 2008, Holcim, 2009) suggest such changes do reduce cement manufacturing-related greenhouse gas production. Guereca (2015) reported that 20% substitution of RDF resulted in a 3.6% reduction in CO₂-equivalents (equiv. or e), and Huntzinger (2008) reported that blended cements (natural pozzolans, fly ash) reduce CO₂-equiv. by 5%. In addition, Holcim

(2009) reported that every ton of tires substituted for every one ton of coal reduced CO₂-equiv. by 543 kg.

Another potentially viable and plentiful, but rather unexplored, alternative fuel source is hazardous waste. Cement kilns have been burning hazardous waste as an alternative fuel since 1976 (Boateng, 2016). The United States Environmental Protection Agency (USEPA) began regulating the burning of hazardous waste in cement kilns in August 1991 (56 FR 7134). According to the USEPA, greater than 34.3 million tons of hazardous wastes (e.g., industrial waste solvents, paints, resins, petroleum based chemicals and pharmaceuticals) are generated annually (EPA 2011), often with energy values greater than 5,000 Btu/lb. In addition, these wastes generally do not require any special treatment technology other than combustion (40 CFR part 268, LDR Regulations), indicating that hazardous wastes can also be beneficially treated while substituting traditional fuels (e.g. oil and coal) in the pyro-processes of the cement industry (IPCC, 2007).

An LCA study commissioned by Febelcem (the Association of the Belgian cement producers) and conducted by TNO (2007) evaluated the life cycle emissions associated with using alternative fuels that are similar to the high BTU hazardous waste in the United States (TNO, 2007). This study mainly focused on determining whether the environmental impact of the thermal treatment of wastes in a cement kiln were higher or lower than those associated with treatment in an incinerator. Results from this study indicate that, from an environmental point of view, the thermal treatment of wastes in cement plants was favorable, lowering GHG emissions and minimizing release of toxic substances to water.

There are potentially significant environmental advantages associated with using hazardous waste as a fuel source during cement manufacturing. By using this waste stream as a fuel in cement manufacturing, the demand for fossil fuels and associated raw materials decreases, and accordingly so do emissions associated with each (Guereca, 2015, Galvez-Martos, 2014, Huntzinger, 2008). Similarly, the IPCC (2007) reports that cement kilns are viable candidates for use of a wide variety of fuels, including waste fuels, which may ultimately reduce CO₂ emissions when compared to their disposal via landfilling or burned without energy recovery (IPCC, 2007). However, before widespread adoption of this practice occurs, there is a need for a more complete life cycle assessment of the use of hazardous waste as a fuel in cement manufacturing. More scientific LCA studies extending past GHG emissions are needed to assess their total potential environmental impacts.

1.1 PROJECT PURPOSE

The purpose of this study is to evaluate the environmental impacts associated with the use of hazardous waste as an alternative fuel in the cement manufacturing process. The alternative cement production option in this study involved the co-burning of hazardous waste for energy recovery in the cement industry. The cement industry offers a unique waste management alternative by reducing the consumption of natural resources (e.g. coal) while destroying or combusting the hazardous waste (Mokrzychi and Ulias-Bochenczyk, 2003).

LCA is also a framework that can be used to evaluate the impacts of processes on the environment (ISO 14040, 2006) by considering all inputs and outputs associated with a system throughout its lifecycle (Matthews, 2014). The use of an LCA

is dependent on the quality of the raw data and how representative of the real process the data really is to the actual processes life cycle (Galvez-Martos 2014).

1.2 PROJECT SCOPE AND THESIS ORGANIZATION

Three portland cement production scenarios, each with a different fuel source, were modeled: (1) coal only (representing a traditional plant), (2) co-fired (use of coal and hazardous waste), and (3) waste only fired (only hazardous waste is used as the fuel source). A life cycle inventory (LCI) of emissions and process data representing operations of these three scenarios was populated using publicly available files associated with a cement manufacturing facility operating a modern preheater/precalciner portland cement kiln system in the United States (PADEP, 2013, MEDEP 2013). An impact analysis was subsequently conducted and impact category-specific results were obtained and compared.

This thesis is organized in five chapters. Chapter 1 presents an introduction to the problem and project scope. Chapter 2 describes the cement manufacturing processes modeled in this study. Chapter 3 describes the methods used in this work, and chapter 4 presents the study results. Chapter 5 outlines the conclusions and recommendations associated with and resulting from this study.

CHAPTER 2

A DESCRIPTION OF THE CEMENT MANUFACTURING PROCESSES USED IN THIS STUDY

In order to fully understand the cement manufacturing process, one must first become familiar with the equipment involved in the process. The purpose of this chapter is to describe the cement manufacturing processes modeled in this study.

2.1 DESCRIPTION OF THE CEMENT MANUFACTURING PROCESS

All information associated with the cement manufacturing process modeled in this study originates from publicly available files associated with a cement manufacturing facility operating a modern preheater/precalcliner portland cement kiln system in the United States (PADEP, 2013). This facility is capable of firing hazardous waste as fuel for energy recovery in two combustion zones; the kiln and the calciner. In addition, this facility co-burns with bituminous coal and on-specification fuel oil at both locations in the combustion zones. Figure 2.1 presents a schematic of the process, including all inputs and outputs modeled in this study.

A typical modern preheater/precalcliner cement plant is typically comprised of the following major equipment/processes (PADEP 2013):

1. Quarry, Raw Mill and Feed Silo
2. Preheater Tower (cyclone preheaters)
3. Calcliner
4. Rotary Kiln

5. Air Pollution Control (Main and Bypass Baghouses)

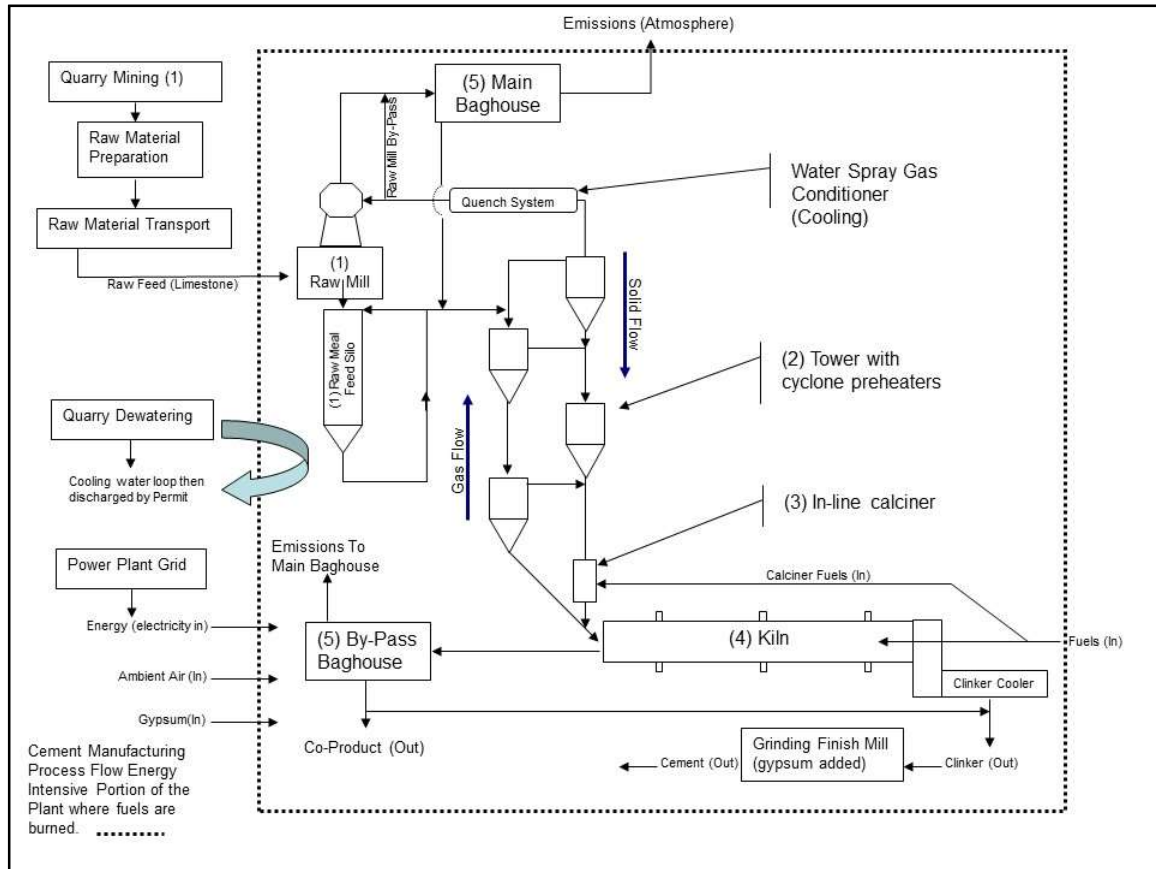


Figure 2.1 Modern Preheater/Precalciner Cement Plant

Please note that the equipment listed above is essential to the cement plant manufacturing process, starting in the quarry and ending with the production of clinker. In order to make clinker, temperatures in the kiln may reach 2800 to 3000 °F, and the calciner may encounter a typical temperature of 1600 °F. After discharge or exiting the Rotary Kiln, the clinker is further ground with a small portion of gypsum (approximately five (5) percent (%)) to control the rate of hydration and ultimately yield the final portland cement (Alsop, 2005).

2.1.1 QUARRY, RAW MILL AND RAW FEED SILO

Cement manufacturing starts in a quarry with the mining of raw materials (ore). The ore is limestone and consists primarily of CaCO_3 (calcium carbonate). The raw materials are crushed, sized and then conveyed to the in-line raw mill where they are finely ground and subsequently fed into a storage silo.

2.1.2 PREHEATER TOWER

The preheater tower consists of four stages (in series) of cyclone preheaters where raw meal is fed into the top of the tower and the hot gases simultaneously flow countercurrent to the feed. This countercurrent movement of solids and gases causes a heat exchange to take place; thereby providing the right conditions for the preheated and precalcined material to eventually enter into the rotary kiln.

2.1.3 CALCINER

The calciner, located at the base of the tower, serves to ensure that nearly 100% of the raw feed that enters the kiln is calcined or thermally decomposed by undergoing a number of consecutive reactions as it (the kiln feed) moves into the highest temperature zone of the calciner as follows (Alsop 2005):

- 1) 212 °F | Evaporation of Moisture
- 2) >930 °F | $\text{CaCO}_3 \rightarrow \text{CaO} + \text{CO}_2$ (calcination reaction)
- 3) >930 °F | Reactions between CaO and Al_2O_3 , Fe_2O_3 and SiO_2

Typically, 60% of the overall heat input into the kiln system is burned in the calciner and 40% in the kiln. This volume of overall heat input in the calciner serves to reduce the size of the kiln. The calciner co-burns hazardous waste with bituminous coal and on-specification fuel oil, as necessary.

2.1.4 ROTARY KILN

The calcined feed enters the kiln which is canted on a slope (β) such that as it rotates (ω), the feed material continues to exchange heat with the hot gases as it travels to the discharge end (where kiln fuels are introduced) of the kiln. The exit point of the kiln is the point where the highest temperatures are encountered in the process. The kiln burner is located at this exit point where flame temperatures of approximately 3000 °F are experienced. The kiln co-burns hazardous waste with bituminous coal and on-specification fuel oil, as necessary to reach these temperatures. As the feed material travels the length of the kiln the final reactions take place above 2300 °F. The formation of C3S (tricalcium silicate) and the complete combining of CaO (lime) with iron, alumina and silica take place just before exiting the kiln.

2.1.5 AIR POLLUTION CONTROL (MAIN AND BYPASS BAGHOUSES)

There are typically two baghouses directly associated with a co-fired (hazardous waste and conventional fuel) cement kiln system. The main baghouse for the cement plant is a pulse jet baghouse with six compartments and a cloth area of approximately 92,000 ft². The main baghouse controls the emissions from the kiln system (i.e., kiln, preheater/precalciner tower, and raw mill (when operating)). The bypass baghouse is also a pulse jet baghouse with one compartment and a cloth area of approximately 14,200 ft². The bypass baghouse controls a slipstream of exhaust from the rotary kiln; however, this exhaust from the bypass baghouse discharges back into the main kiln exhaust directly after the preheater tower and prior to the raw mill. Consequently, the exhaust from the main baghouse is the sole discharge point to the atmosphere for this pyro-process. Conversely, a traditional cement manufacturing process that fires only conventional fuels,

would not typically need to operate the bypass baghouse even though it may be equipped with one. When co-burning waste fuels the operation of the bypass baghouse is necessary in order to remove excess volatiles such as chlorides which can lead to plugging in the preheater tower (Alsop 2005).

CHAPTER 3

MATERIALS AND METHODS

This study consists of an LCA evaluation of three portland cement production scenarios, each with a different fuel source: (1) base case (coal only, B.1), (2) co-fired (use of coal and hazardous waste, T.1), and (3) waste only fired (only hazardous waste is used as the fuel source, T.2). The functional unit for this study is the production of one kg of portland cement, which is consistent with other LCA studies (Josa, 2007, Guereca, 2015). This study followed the four steps of an LCA, as outlined in ISO14040: 2006): 1) Determine the goal and scope, 2) Build a life cycle inventory of all inputs and outputs, 3) Model and assess the environmental impacts, and 4) Interpret the results of the study.

3.1 DEFINITION OF GOAL AND SCOPE

The goal of this study is to evaluate the environmental impact via LCA associated with using hazardous wastes as an alternative fuel in a portland cement manufacturing plant. All emissions and electricity requirements associated with all components of the cement manufacturing process were included in this modeling effort. Specifically, the following were included:

- (1) emissions and electricity associated with the combustion of primary (e.g., coal) and secondary fuels (e.g., fuel oil) is included,
- (2) electricity consumption in the quarrying, cement production, and grinding processes,

- (3) emissions and energy requirements associated with coal mining and transportation of the coal,
- (4) hazardous waste processing and transportation after centralized collection at a hazardous waste preparation facility were included, and
- (5) emissions which occur during the quarrying of limestone.

Figures 3.1, 3.2 and 3.3 provide the specific systems studied and their boundaries, illustrating all system inputs and outputs included in the LCA models.

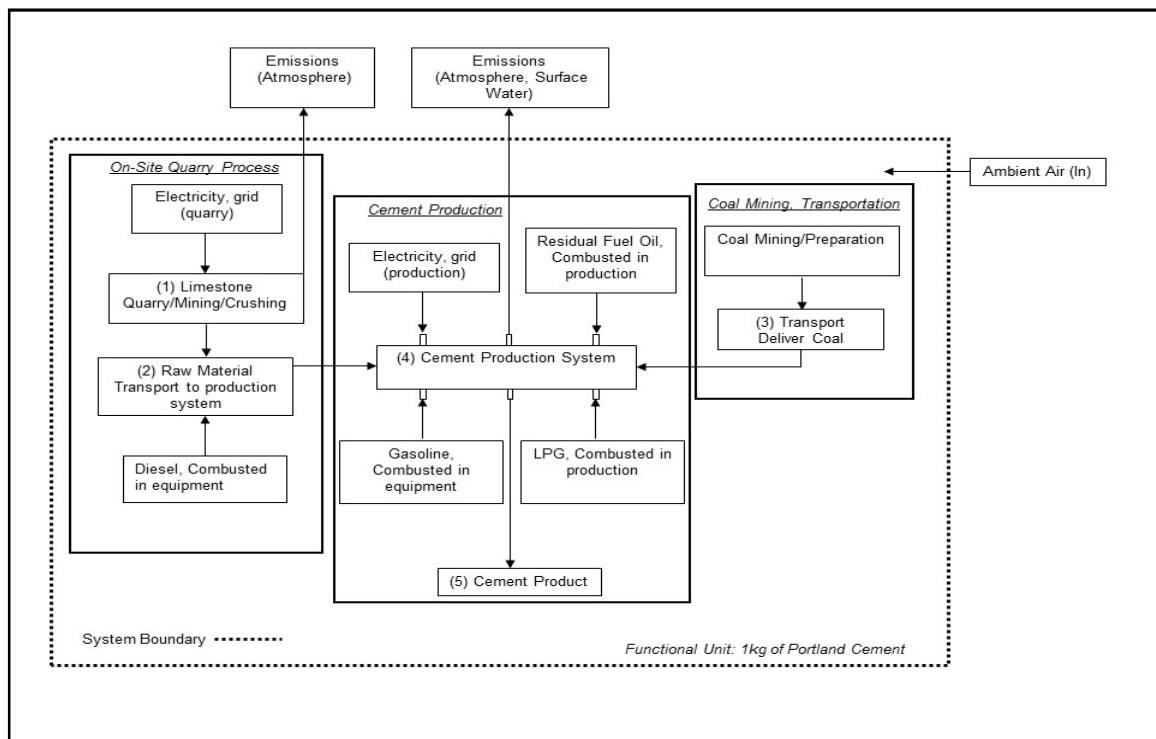


Figure 3.1 System Boundaries of the Base Scenario (B.1)

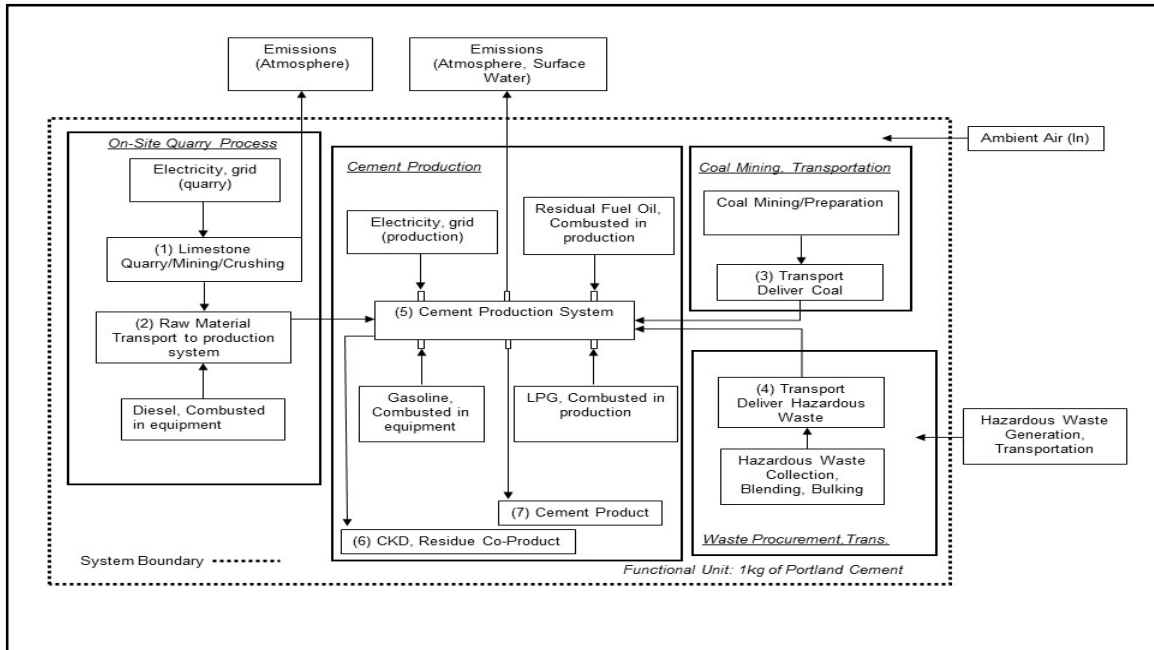


Figure 3.2 System Boundaries of the Thermal Scenario (T.1)

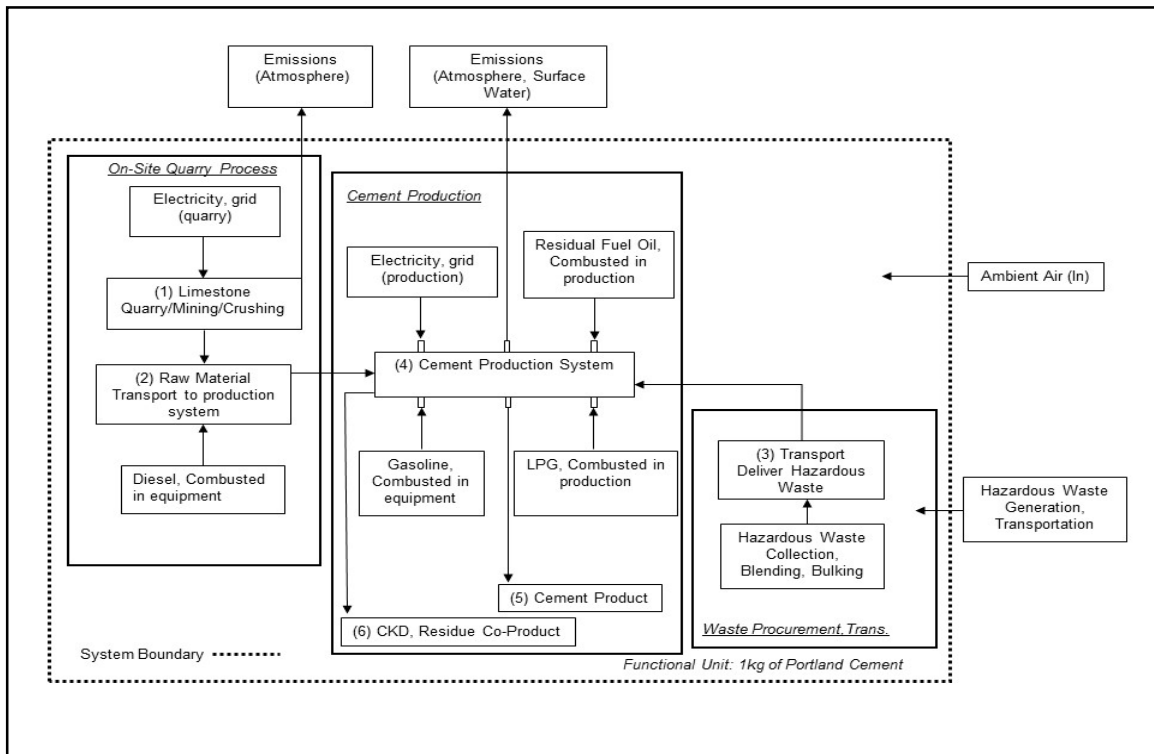


Figure 3.3 System Boundaries of the Thermal Scenario (T.2)

Three specific scenarios were modeled in this study and are defined in Table 3.1. System B.1 represents a scenario in which only coal is used as the source of fuel energy. In scenario T.1, the fuel source of hazardous waste is added to replace approximately 60% of the coal. Replacement of 60% of the coal was modeled because the data associated with the cement facility used in this study typically targets 50 to 70% fossil fuel replacement on an annual basis. In Scenario T.2, the sole source of fuel for the production system is hazardous waste.

Table 3.1 Definition of LCA Modeled Scenarios

Scenario I.D.	Model Plan Description	Fuel/Waste Burned	Functional Unit
B.1	Base Cement Manufacturing	100% Bituminous Coal	1 kg cement
T.1	Cement Manufacturing with Hazardous Waste (Co-combustion)	Coal and Hazardous Waste	1 kg cement
T.2	Waste Burning Only Cement Manufacturing	100% Hazardous Waste	1 kg cement

3.2 LIFE CYCLE INVENTORY

Inventory data for the three scenarios described in Table 3.1 were compiled for this study. Data were collected separately for the following processes: (1) on-site quarry process, (2) cement production, (3) coal mining and transportation, and (4) hazardous waste procurement and transportation. The on-site quarry process and cement production process data used in this study were based on data from the National Renewable Energy Laboratory (NREL) U.S. Life Cycle Inventory (USLCI) Database, Pennsylvania Department of Environmental Protection (PADEP) and the Maine Department of

Environmental Protection (MEDEP) public files (PADEP 2013, MEDEP 2012, USLCI, 2003, 2015). The coal mining and transportation data were based on USLCI data; coal mining was represented using the bituminous coal at mine dataset and the coal transportation truck was represented by the a U.S. Dump Truck with a twenty-six (26) ton payload dataset. No facility-specific data associated with the hazardous waste procurement and transportation process exists. Therefore, these processes were modeled using representative processes found in the USLCA databases. Hazardous waste procurement was modeled based on data associated with a benzene production facility (USLCI, 2003). The transportation of the hazardous waste was modeled as a U.S. tank truck with a twenty-five (25) ton payload (USLCI, 2015). The data inventory and resulting emissions along with any data extrapolations are described in this Chapter. A summary of the LCI inputs/outputs is also presented in this Chapter.

3.2.1 COAL AND HAZARDOUS WASTE COMPOSITION

Data from the public files contained information on the metals from coal and the hazardous waste fuel and is presented in Table 3.2. In addition, Table 3.2 presents an ultimate analysis of coal and hazardous waste fuel for comparison from a rotary kiln facility burning hazardous waste in Virginia. Additional data is included in Appendix A for hazardous waste fuels regarding typical water contents and organic composition.

Table 3.2 Ultimate Analysis and Metal Concentration Coal and Waste Fuel

Component (%)	Coal¹	Hazardous Waste^{2,3}
Moisture	2.50	15.00
Carbon	75.00	43.00
Hydrogen	5.00	10.00
Sulfur	2.30	0.09
Nitrogen	1.50	1.35
Oxygen	6.70	28.35
Ash	7.00	2.21
Total	100	100 ⁴
Typical BTU/lb	12,000 to 13,000	7,500 to 11,000
Arsenic (ppm)³	22	3
Mercury (ppm)³	0.34	0.56

1. Source EPA Publication number 450/2-80-063, ultimate analysis.
2. Virginia Solite Company, Trial Burn Plan submitted to the Virginia Department of Environmental Quality, July 1999. Hazardous waste fuel supplied by Giant Resource Recovery, Inc., typical moisture in waste fuel is 15.00% (Appendix A).
3. PADEP, 2011, ultimate analysis of hazardous waste reported on dry basis.
4. Summation accounts for typical moisture.

3.2.2 B.1, T.1 AND T.2 SCENARIO LCI DATA COLLECTION AND MODIFICATION

As described previously, a large fraction of the data associated with these scenarios was taken from publically available files describing a cement plant burning hazardous waste (PADEP 2013). To prepare these data for use in this work, some conversion/modification was required. Three random days of plant emissions data were selected from the public files, which representatively depicted the operation of the cement plant in its two operating conditions: (1) while firing 100% coal (B.1) and (2) co-burning with hazardous waste at 60% energy substitution. In both of these fuel operating conditions, the nature of the facility involves operating with an in-line vertical grinding

mill. The limestone, which is mined and transferred to the cement production facility, is crushed in the quarry and milled into a fine powder before entering the kiln system (Huntzinger, 2008). This mill switches between being on and off, during which pollutant parameter emissions vary. Therefore, it was important for the data used in this LCI to capture the operation in both fuel conditions and both grinding conditions. Accordingly, both operating scenarios (B.1 and T.1) in this study contained data with the raw grinding mill on and off.

The raw limestone grinding mill-on condition (Condition I) averaged 61% of the time and therefore the emissions from this operating condition are weighted at the same amount of time. Correspondingly, the raw limestone grinding mill-off condition (Condition II) averaged 39% of the time and was weighted, accordingly. The certified continuous emissions monitoring (CEM) systems recorded emissions data every minute and therefore, provided minute-by-minute data used in the averages for CO₂, THC, NO_x, CO and SO_x for the B.1 and T.1 operating scenarios. Data used in the T.2 scenario was extrapolated from the data set of T.1, and therefore was based on the CEM data and stack test data, but not a direct measurement while burning 100% waste fuels. Appendix A provides all of the cement plant minute-by-minute emissions and operating data.

The necessary data modification involved several steps. The first step involved taking several hours of data for each of the days available and then averaging the data into two scenarios representing B.1 and T.1 (100% coal and burning (co-firing or co-combustion) hazardous waste fuel) and then further calculating the emissions from the two operating conditions I and II in B.1 and T.1. Only valid data were considered in the calculations and therefore only normal operations with cement production were

considered (e.g. no malfunctions, system upsets or low raw feed conditions etc.). Once modified, the data were summarized in two scenarios, each with two conditions as shown in Tables 3.3 and 3.4 in a mass per time format (e.g. lb/hr) and then weighted based on the percent of time the in-line raw grinding mill was on and off in order to provide a normalized result taking into account the status of the raw mill operation and the variability in the emissions from these two observed conditions. This step was necessary in order to capture the variability between the operation of the mill on and off because the raw mill-on condition tends to have different overall emissions than the raw mill-off condition.

Table 3.3 B.1 Scenario by Condition

Parameter	Condition I (61% time weighted)	Condition II (39% time weighted)	Weighted Summary B.1
Prime Mover (KWSCFM)	222.9	186.4	208.7
Kiln Feed (ton/hr)	204.9	203.9	204.5
CO ₂ (%)	16.2	19.6	17.5
CO ₂ (mton/hr)	101.9	101.9	101.9
NO _x (lb/hr)	358.7	383.9	368.5
SO ₂ (lb/hr)	869.9	643.1	781.7
THC (lb/hr)	0.12	2.50	1.05
CO (lb/hr)	145.2	130.4	139.5
Waste Fuel (ton/hr)	0.0	0.0	0.0
Coal (ton/hr)	13.9	11.5	12.9
Energy (MMBtu/hr)	318.7	264.2	297.5
Clinker (ton/hr)	121.2	120.6	121.0
MMBtu/ton clinker	2.6	2.2	2.5
Co-Product (ton/hr)	0.0	0.0	0.0

Table 3.4 T.1 Scenario by Condition

Parameter	Condition I (61% time weighted)	Condition II (39% time weighted)	Weighted Summary T.1
Prime Mover (KWSCFM)	255.8	182.0	227.1
Kiln Feed (ton/hr)	195.1	205.0	198.9
CO ₂ (%)	13.9	20.5	16.4
CO ₂ (mton/hr)	94.5	97.4	95.6
NO _x (lb/hr)	332.5	414.2	364.3
SO ₂ (lb/hr)	735.9	550.9	663.9
THC (lb/hr)	0.10	1.63	0.69
CO (lb/hr)	113.9	142.5	124.9
Waste Fuel (ton/hr)	9.7	9.45	9.62
Coal (ton/hr)	5.7	5.8	5.76
Energy (MMBtu/hr)	349.7	345.5	348.3
Clinker (ton/hr)	115.4	121.3	117.7
MMBtu/ton clinker	3.03	2.85	2.96
Co-Product (ton/hr)	3.3	3.3	3.3

3.2.3 B.1, T.1 AND T.2 EMISSION AND PROCESS INVENTORIES

The cement LCI was generated from data available in the public files (PADEP 2013, MEDEP 2012). Figure 3.4 is a comparison of the annualized operating parameters of B.1, T.1 and T.2.

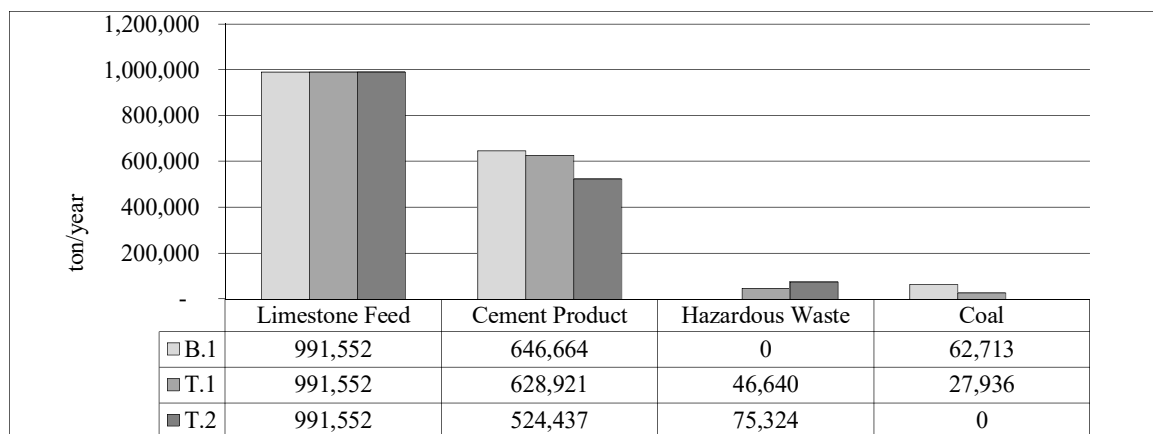


Figure 3.4 Comparison of B.1, T.1 and T.2 Annualized Operations

The cement plant emissions data for scenarios B.1 and T.1 were obtained from the continuous emissions monitor systems (CEMs) for the pollutants of NO_x, SO_x, CO, THC and CO₂. Actual air emissions stack tests were available in the public files to populate the LCI for heavy metals, hydrochloric acid and particulate matter emissions (As, Be, Cr, Cd, Pb, Hg, HCl and PM) and for all of the CEMs data (PADEP, 2013, MEDEP, 2012). Table 3.5 is a summary of the LCI inputs into the three scenarios for the cement production system as shown in Figures 3.1, 3.2 and 3.3 for each scenario.

Table 3.5 Cement Production Systems Materials Units per kg portland cement

Cement Production System Materials	B.1	T.1	T.2	Unit	Source
Electricity [Electric power]	0.256	0.263	0.316	MJ	PADEP, 2013
Bituminous coal, combusted in Kiln	0.097	0.044	0.0	kg	PADEP, 2013
Gasoline, combusted in equipment	1.33E-07	1.33E-07	1.33E-07	m ³	NREL USLCI
Liquefied petroleum gas, combusted in kiln	1.43E-08	1.43E-08	1.43E-08	m ³	NREL USLCI
Residual fuel oil, combusted in Kiln	4.42E-08	4.42E-08	4.42E-08	m ³	NREL USLCI
US: Cement bags, at plant	0.00068	0.00068	0.00068	kg	NREL USLCI
Explosives, at plant	0.00022	0.000226	0.000271	kg	PADEP, 2013
US: Filter bags, at plant	1.92E-05	1.92E-05	1.92E-05	kg	NREL USLCI
US: Grinding aids, at plant	0.00036	0.00036	0.00036	kg	NREL USLCI
US: Grinding media, at plant	0.00014	0.00014	0.00014	kg	NREL USLCI
US: Fuel Oil, combusted in Kiln	1.07E-06	1.07E-06	1.07E-06	m ³	NREL USLCI
US: Oil and grease, at plant	0.00013	0.00013	0.00013	kg	NREL USLCI
Recycling, cement kiln dust	0.0000	0.0256	0.222	kg	PADEP, 2013
US: Refractory material, unspecified, at plant	0.0006	0.0006	0.0006	kg	NREL USLCI
Hazardous Waste, solvents, combusted in Kiln	0.0	0.0742	0.1436	kg	PADEP, 2013
Gypsum (natural gypsum) [Nonrenewable resources]	0.0615	0.0615	0.0615	kg	NREL USLCI
Iron ore	0.0135	0.0135	0.0135	kg	NREL USLCI
Limestone (calcium carbonate) Quarry	1.53	1.54	1.55	kg	PADEP, 2013
Sand	0.0405	0.0405	0.0405	kg	NREL USLCI
Cooling Water (non-contact)	0.0187	0.0193	0.0193	kg	PADEP, 2013

Table 3.6 is a summary of the model inputs used for the quarried material (limestone) which is mined on-site and transported to the cement production system as shown in Figures 3.1, 3.2, and 3.3.

Table 3.6 Limestone Quarrying Materials Units per kg portland cement

Limestone Quarry Materials	B.1	T.1	T.2	Unit	Source
Electricity [Electric power]	0.439	0.451	0.541	MJ	PADEP 2013
US: Diesel, combusted in equipment	5.84E-07	5.84E-07	5.84E-07	m ³	NREL USLCI
US: Gasoline, combusted in equipment	5.11E-08	5.11E-08	5.11E-08	m ³	NREL USLCI

Table 3.7 presents a summary of the outputs associated with the three scenarios studied. As previously mentioned, the LCI was generated from data available in the public files (PADEP 2013, MEDEP 2012) and the NREL USLCI database. In addition, actual reported air emissions data for the EPA criteria pollutants was also readily available, as referenced in Table 3.7. EPA's criteria pollutants are typically considered as NO_x, SO_x, PM, CO and recently CO₂ etc. Therefore, LCIs were developed using actual cement plant reported data while burning coal and co-burning with hazardous waste.

3.3 LCA MODELING APPROACH

LCA modeling was performed using GaBi software following the general ISO 14040:2006 LCA framework developed by the International Organization for Standardization (ISO). All processes in Figures 3.1 - 3.3 were modeled, with the data described in Tables 3.3 - 3.7.

Table 3.7 Summary of the Outputs for the scenarios studied

Cement Production System	B.1	T.1	T.2	Unit	Source
Cement	1.0	1.0	1.0	kg	Functional Unit
Aluminum (+III) [Inorganic emissions to fresh water]	8.60E-07	8.60E-07	8.60E-07	kg	NREL USLCI
Ammonia [Inorganic emissions to air]	4.76E-06	4.76E-06	4.76E-06	kg	NREL USLCI
Ammonium / ammonia [Inorganic emissions to fresh water]	9.48E-07	9.48E-07	9.48E-07	kg	NREL USLCI
Arsenic (+V) [Heavy metals to air]	4.10E-06	2.12E-06	2.96E-07	kg	PADEP, 2013
Beryllium [Inorganic emissions to air]	6.24E-07	5.33E-07	2.96E-07	kg	PADEP, 2013
Cadmium (+II) [Heavy metals to air]	1.01E-06	5.33E-07	8.60E-08	kg	PADEP, 2013
Carbon dioxide [Inorganic emissions to air]	0.841	0.811	0.750	kg	PADEP, 2013
Carbon monoxide [Inorganic emissions to air]	0.522	0.481	0.468	kg	PADEP, 2013
Chloride [Inorganic emissions to fresh water]	0.000727	0.000727	0.000727	kg	NREL USLCI
Chromium (+III) [Heavy metals to air]	1.17E-05	5.60E-06	2.96E-07	kg	PADEP, 2013
Dust (PM10) [Particles to air]	0.0109	0.0112	0.0134	kg	PADEP, 2013
Dust (PM2,5 - PM10) [Particles to air]	0.000296	0.000296	0.000296	kg	NREL USLCI
Dust (unspecified) [Particles to air]	0.00235	0.00235	0.00235	kg	NREL USLCI
Hydrocarbons (unspecified) [air (group VOC)]	0.00392	0.00264	0.00165	kg	PADEP, 2013
Hydrogen chloride [Inorganic emissions to air]	3.51E-05	0.0721	1.40E-01	kg	PADEP, 2013
Lead (+II) [Heavy metals to air]	9.67E-06	4.50E-06	8.60E-08	kg	PADEP, 2013
Mercury (+II) [Heavy metals to air]	5.32E-06	7.10E-06	9.70E-06	kg	PADEP, 2013, MEDEP, 2012
Methane [Organic emissions to air (group VOC)]	3.95E-05	3.95E-05	3.95E-05	kg	NREL USLCI
Nitrate [Inorganic emissions to fresh water]	5.90E-06	5.90E-06	5.90E-06	kg	NREL USLCI
Nitrogen oxides [Inorganic emissions to air]	1.38	1.40	1.49	kg	PADEP, 2013
Oil (unspecified) [Hydrocarbons to fresh water]	7.52E-06	7.52E-06	7.52E-06	kg	NREL USLCI
Phenol (hydroxy benzene) [Hydrocarbons to fresh water]	2.20E-08	2.20E-08	2.20E-08	kg	NREL USLCI
Phosphorus [Inorganic emissions to fresh water]	5.51E-09	5.51E-09	5.51E-09	kg	NREL USLCI
Polychlorinated dibenzo-p-dioxins (2,3,7,8 - TCDD) [emissions]	9.98E-11	9.98E-11	9.98E-11	kg	NREL USLCI
Solids (suspended) [Particles to fresh water]	0.000234	0.000234	0.000234	kg	NREL USLCI
Sulphate [Inorganic emissions to fresh water]	0.000616	0.000616	0.000616	kg	NREL USLCI
Sulphide [Inorganic emissions to fresh water]	6.61E-08	6.61E-08	6.61E-08	kg	NREL USLCI
Sulphur dioxide [Inorganic emissions to air]	2.93	2.56	2.35	kg	PADEP, 2013
Total dissolved organic bounded carbon [to fresh water]	1.38E-05	1.38E-05	1.38E-05	kg	NREL USLCI
Zinc (+II) [Heavy metals to fresh water]	3.31E-08	3.31E-08	3.31E-08	kg	NREL USLCI
Quarry Materials and Emissions					
Limestone [Minerals]	1.0	1.0	1.0	kg	PADEP, 2013
Dust (unspecified) [Particles to air]	5.11E-05	5.11E-05	5.11E-05	kg	NREL USLCI

3.3.1 IMPACT ANALYSIS

Five International Reference Life Cycle Data System (ILCD) categories were evaluated and compared in this work, as summarized in Table 3.8. The categories

include: global warming potential (GWP), including biogenic carbon, human toxicity for cancer (HT-C), acidification potential (AP), terrestrial eutrophication potential (TEP) and Eco toxicity (ET). These categories were chosen because they are considered to be the most likely of a concern when shaping national policy or establishing emissions limitations for these facilities (SAIC, NRML, 2006). No weighting or normalization of the LCA impacts was performed in this work.

Table 3.8 Impact Categories Used in this Study

ILCD Impact Category	Abbreviation	Unit/kg
Climate Change	GWP	kg CO ₂ -eq.
Acidification Potential ^a	AP	Mole H ⁺ eq.
Terrestrial Eutrophication Potential ^b	TEP	Mole N eq.
Human Toxicity, cancer effect ^c	HT-C	CTU _h
Freshwater Ecotoxicity ^d	ET	CTU _e

^a AP (Mole H⁺ eq): ability of substance to build and release H⁺ ions.

^b TEP (Mole N eq.):

^c CTU_h: comparative toxic unit for humans.

^d CTU_e: comparative toxic unit for ecosystem.

3.4 SCENARIO ANALYSIS

Analyses were performed to understand the impact specific processes on system environmental impacts. Impacts associated with modifying two specific processes were investigated: (1) emissions associated with hazardous waste blending and (2) coal substitution rate.

In the development of the scenarios involving the burning of hazardous waste (T.1 and T.2), no specific data associated with the hazardous waste procurement and transportation facility (Figures 3.2 and 3.3) existed. Therefore, the hazardous waste blending facility was modeled based on a benzene production facility. Because of the uncertainty associated with this operation, scenarios were run in which this process was

replaced and modeled based on two other potential similar processes: ethanol blending terminal and ethanol blending station. The purpose of these simulations was to evaluate the influence of different hazardous waste procurement, transportation, and blending facilities (Figure 3.2 and 3.3) in the LCA model. The specific USLCI data for these processes is included in Appendix A.

Lastly, two additional waste co-burning scenarios were modeled in order to compare their total ILCD impacts to the scenarios B.1, T.1 and T.2. Since T.1 represented 60% coal replacement and T.2 represented 100%, the additional model simulations were run at 40% and 80% fossil fuel replacement, T.1_{s3} (40%) and T.1_{s4} (80%), respectively.

3.5 MODEL ASSUMPTIONS

For the hazardous waste fuel blending which operated on the cement plant property site to test, store and blend the hazardous waste fuel the infrastructure was assumed to be in place and therefore no additional impacts were quantified. Therefore, any impacts associated with the infrastructure necessary to operate the on-site hazardous waste storage facility were not included in this study. In addition, for the purposes of this study, it was assumed all emissions are associated with the cement product.

CHAPTER 4

RESULTS FROM THE LIFE-CYCLE ANALYSIS OF A CEMENT PLANT CO-BURNING HAZARDOUS WASTE COMPARED TO ITS BASE CASE

4.1 INFLUENCE OF FUEL TYPE ON SYSTEM ENVIRONMENTAL IMPACTS

Five ILCD recommended impact categories were evaluated as part of this study (Table 3.8). Figure 4.1 provides an overall summary of the ILCD categorical impact results for the three scenarios modeled.

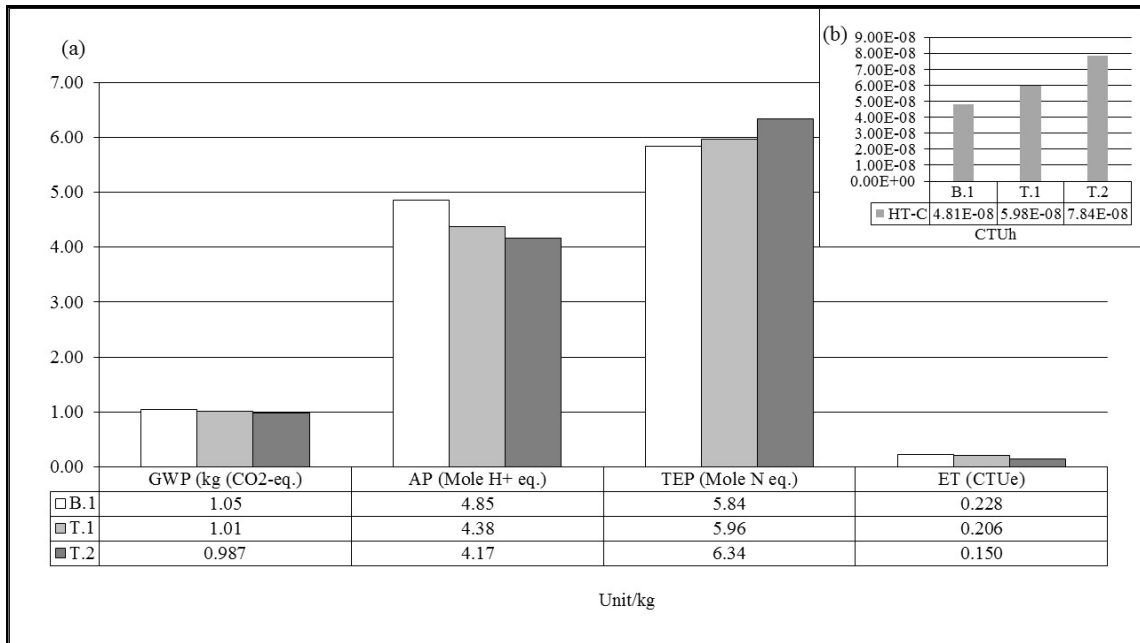


Figure 4.1 ILCD Impacts for (a) GWP, AP, TEP and ET and (b) HT-C

Overall, as illustrated in Figure 4.1a, GWP, AP and ET impacts decrease as the facility reduces their consumption of coal, mainly due to decreases in direct emissions of carbon dioxide (GWP), sulfur dioxide (AP), and pentavalent Arsenic (ET). The ET

category resulted in the greatest change (34%) when transitioning from 100% coal (B.1) to 100% hazardous waste (T.2) energy substitution. The TEP impact results, however, suggest that greater eutrophication impacts to the environment will result as fossil fuel is replaced with waste fuel. This increase in impact, as will be described in greater detail later in this chapter, results mainly from nitrogen oxides released during hazardous waste combustion due to the increase in airflow which causes an increase in thermal NO_x from the oxidation of the molecular nitrogen in the combustion air.

The HT-C impacts also increase (62%, when comparing B.1 to T.2) as the facility reduces its consumption of coal and increases the burning of hazardous waste. This increase in impact results mainly from increases in mercury, dioxin, furan, and arsenic emissions associated with the direct burning of large amounts of hazardous wastes, as will be described in more detail later in this chapter.

The individual processes (Figures 3.1 – 3.3) contributing the most to each impact category for each scenario are illustrated in Table 4.1. The impacts have been separated into three categories: (1) Quarrying, (2) Cement Manufacturing, and (3) Fuel Source Acquisition. Each of these three categories are broken into two types of impacts:

- Quarry: (1) grid purchased electricity (Quarry Electricity) and (2) quarrying impacts at the plant site (Quarry Plant Emissions)
- Cement Manufacturing: (1) grid purchased electricity (Cement Electricity) and (2) manufacturing impacts at the plant site (Cement Plant Emissions), including emissions associated with the coal and/or hazardous waste combustion for on-site energy generation

- Fuel source acquisition: (1) coal impacts (Coal), including off-site mining and the transportation of the coal to the cement manufacturing facility for storage and (2) hazardous waste impacts, including the collection, consolidation of blending the wastes, and transporting the wastes to the cement plant for storage.

As illustrated in Figure 4.1, direct emissions associated with the cement manufacturing process represent the greatest contribution to each impact category. Electricity requirements from both the quarry and cement manufacturing process (quarry electricity and cement electricity) represent the next largest contributions to each category, but only significantly impact the GWP, HT-C, and ET. The acquisition of each primary fuel source (e.g., coal and hazardous wastes) represents relatively minor contributions to each of the impact categories, with the acquisition of coal playing the largest role in the ET impact category (scenario B.1 and T.1, see Table 4.1). It should be noted that emissions associated with the burning of each of these fuels are included in the direct emissions associated with the cement manufacturing process.

Table 4.1 Contribution of Individual Processes on the Environmental Impacts¹

Scenario	Impact Category	Quarry		Cement Manufacturing		Primary Fuel Source Acquisition ²			
		Electricity ³	Plant Emissions	Electricity ³	Plant Emissions	Coal ⁴		Hazardous Waste ⁵	
B.1	GWP	0.134 (12.78)	0.00283 (0.27)	0.051 (4.87)	0.843 (80.42)	0.0174 (1.7)	NA	NA	NA
	AP	0.000494 (0.01)	4.22E-05 (8.70E-04)	0.00018 (3.71E-03)	4.85 (99.98)	5.18E-05 (1.07E-03)	NA	NA	NA
	TEP	0.000595 (0.01)	0.000212 (3.63E-03)	0.000226 (3.87E-03)	5.84 (99.98)	0.000106 (1.81E-03)	NA	NA	NA
	HT-C	4.14E-09 (8.61)	4.20E-11 (0.09)	1.57E-09 (3.26)	4.23E-08 (87.93)	5.40E-11 (0.11)	NA	NA	NA
	ET	0.0438 (19.19)	0.00774 (3.39)	0.0167 (7.32)	0.15 (65.72)	0.01 (4.38)	NA	NA	NA
T.1	GWP	0.138 (13.62)	0.00282 (0.28)	0.0505 (4.98)	0.811 (80.02)	0.00796 (0.79)	0.00319 (0.31)		
	AP	5.07E-04 (0.01)	4.22E-05 (9.63E-04)	0.00019 (4.34E-03)	4.38 (99.98)	2.37E-05 (5.41E-04)	3.58E-05 (8.17E-04)		
	TEP	0.00061 (0.01)	0.000212 (3.56E-03)	0.00023 (3.86E-03)	5.96 (99.98)	4.82E-05 (8.09E-04)	3.90E-05 (6.54E-04)		
	HT-C	4.25E-09 (7.10)	4.19E-11 (0.07)	1.62E-09 (2.71)	5.39E-08 (90.08)	2.46E-11 (0.04)	1.79E-17 (2.99E-08)		
	ET	0.0449 (21.76)	0.00774 (3.75)	0.0171 (8.29)	0.132 (63.98)	0.00458 (2.22)	4.87E-09 (2.36E-06)		
T.2	GWP	0.165 (16.72)	0.00282 (0.29)	0.0628 (6.36)	0.750 (76.00)	NA	NA	0.00621 (0.63)	
	AP	0.000608 (0.01)	4.22E-05 (1.01E-03)	0.00023 (0.01)	4.17 (99.98)	NA	NA	6.97E-05 (1.67E-03)	
	TEP	0.000732 (0.01)	0.000212 (3.34E-03)	0.00027 (4.26E-03)	6.34 (99.98)	NA	NA	7.58E-05 (1.20E-03)	
	HT-C	5.09E-09 (6.49)	4.19E-11 (0.05)	1.94E-09 (2.48)	7.13E-8 (90.98)	NA	NA	3.48E-17 (4.44E-08)	
	ET	0.0539 (35.95)	0.00774 (5.16)	0.0205 (13.67)	0.0678 (45.22)	NA	NA	9.48E-09 (6.32E-06)	

1. Numbers in parentheses indicate percent contribution of that impact to the total impact category.
2. Impacts associated with the processes required for source acquisition.
3. Electricity-related emissions, including electricity at the grid as well as any electricity associated with any start-up fuels.
4. Includes emission associated with mining and transportation to the cement plant.
5. Includes emissions associated with necessary hazardous waste blending and transportation to the cement plant.

4.2 GWP RESULTS

Detailed GWP impact category results for each scenario (B.1, T.1 and T.2) are depicted in Figure 4.2, and indicate that the GWP impact is dominated by on-site direct emissions associated with the cement manufacturing process (which includes the combustion of hazardous waste and/or coal), with the electricity requirements for the quarry representing the second most significant contribution to the GWP impact. The GWP-related impacts associated with the acquisition of the coal and/or hazardous waste, emissions at the quarry, and cement manufacturing electricity needs all represent small contributions to this category, with a combined contribution of < 7%.

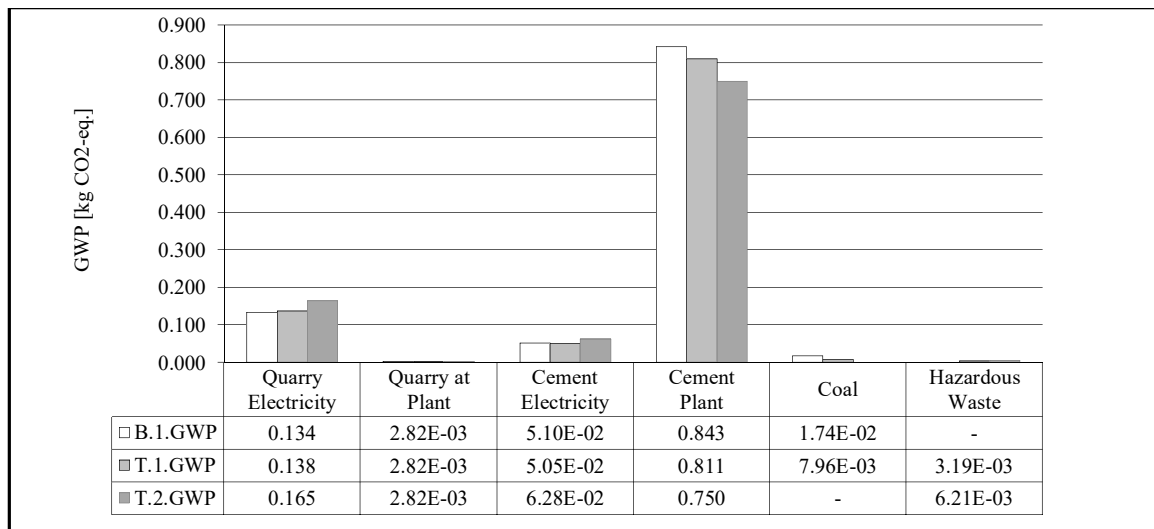


Figure 4.2 ILCD Impacts for GWP

The GWP impact associated with the on-site direct emissions associated with the cement manufacturing process (which includes the combustion of hazardous waste and/or coal) decrease as the facility shifts from burning 100% coal to burning 100 % hazardous waste. This change in impact results mostly from a reduction in carbon dioxide

emissions (Table 4.2) when burning hazardous waste, consistent with the lower carbon content of the hazardous waste when compared to coal (see Table 3.2) (Boateng, 2016).

The GWP-related impacts associated with the electric grid (quarry and cement) trended in the opposite direction because of greater electricity needs per kg of cement when burning hazardous waste. The need for additional electricity is because the kiln experiences lower performance in terms of cement per BTU of energy when using hazardous waste (Boesch and Hellweg, 2009). This performance reduction is due in part to increases in required energy to evaporate the higher water content found in waste fuels (i.e., 9 to 15%, see Table 3.2)(VSTPB, 1999). These results are consistent with the results of other cement plants burning alternative fuels (e.g., RFD, solvents, tires) (Valderrama, 2011 and Galvez-Martos, 2014, Strazza, 2011).

Table 4.2 lists the three pollutants contributing most significantly to each process within each scenario. Interestingly, the carbon dioxide, either from direct plant emissions from cement manufacturing or electricity, appear to dominate the GWP impact. Methane emissions also contribute significantly to this impact category, with nitrous oxide emissions making a relatively small contribution.

Table 4.2 Summary of GWP Scenario by Process

Scenario	Pollutants Contributing Most Significantly ¹ GWP [kg CO2e]																	
	Quarry					Cement Manufacturing					Secondary Fuel Source Acquisition ²							
	Pollutant	Electricity ³		Pollutant	Plant Emissions		Pollutant	Electricity ³		Pollutant	Plant Emissions		Pollutant	Coal ⁴		Pollutant	Hazardous Waste ⁵	
B.1	CO ₂	0.124	(95.40)	CO ₂	2.72E-03	(96.60)	CO ₂	4.70E-02	(95.40)	CO ₂	0.842	(99.87)	Methane	9.95E-03	(57.50)	NA	NA	NA
	Methane	5.16E-03	(3.99)	Methane	9.44E-05	(3.35)	Methane	1.96E-03	(3.99)	Methane	1.00E-03	(0.12)	CO ₂	7.35E-03	(42.47)	NA	NA	NA
	Nitrous Oxide	7.03E-04	(0.54)	Nitrous Oxide	6.37E-07	(0.02)	Nitrous Oxide	2.68E-04	(.054)	Nitrous Oxide	3.22E-06	(3.83E-04)	Nitrous Oxide	1.10E-5	(0.03)	NA	NA	NA
T.1	CO ₂	0.127	(95.40)	CO ₂	2.72E-03	(96.60)	CO ₂	4.82E-02	(95.40)	CO ₂	0.810	(99.87)	Methane	4.55E-03	(57.50)	CO ₂	3.15E-03	(99.97)
	Methane	5.29E-03	(3.99)	Methane	9.44E-05	(3.35)	Methane	2.01E-03	(3.99)	Methane	1.00E-03	(0.12)	CO ₂	3.36E-03	(42.47)	Nitrous Oxide	7.93E-07	(0.03)
	Nitrous Oxide	7.22E-04	(0.54)	Nitrous Oxide	6.37E-07	(0.07)	Nitrous Oxide	2.75E-04	(0.54)	Nitrous Oxide	3.22E-06	(3.97E-04)	Nitrous Oxide	5.01E-06	(0.03)	Methane	5.62E-08	(1.78E-03)
T.2	CO ₂	0.152	(95.40)	CO ₂	2.72E-03	(96.60)	CO ₂	5.78E-02	(95.40)	CO ₂	0.749	(97.87)	NA	NA	NA	CO ₂	6.14E-03	(98.80)
	Methane	6.35E-03	(3.99)	Methane	9.44E-05	(3.35)	Methane	2.42E-03	(3.99)	Methane	1.00E-03	(0.12)	NA	NA	NA	Nitrous Oxide	1.54E-06	(.03)
	Nitrous Oxide	8.65E-04	(0.54)	Nitrous Oxide	6.37E-07	(0.02)	Nitrous Oxide	3.29E-04	(0.54)	Nitrous Oxide	3.22E-06	(4.30E-04)	NA	NA	NA	Methane	1.09E-07	(1.78E-03)

1. Numbers in parentheses indicate percent contribution of that impact to the total impact category.
2. Impacts associated with the processes required for source acquisition.
3. Electricity-related emissions, including electricity at the grid as well as any electricity associated with any start-up fuels.
4. Includes emission associated with mining and transportation to the cement plant.
5. Includes emissions associated with necessary hazardous waste blending and transportation to the cement plant.

It should also be noted that these GWP impact potentials are influenced by the use of biogenic carbon. The electricity mix modeled in this study represents the use of biomass in order to produce electricity, which includes the use of a small amount of biomass (3.6%), which represents a source of biogenic carbon in these scenarios. As the electricity needs increase, so does the release of this biomass-bound biogenic carbon. The biogenic carbon emissions are considered neutral, and are therefore ultimately subtracted from this category. The fraction of biogenic carbon subtracted from each GWP impact is < 1% of the total impact potential for each scenario, indicating its influence on overall GWP impact is small.

4.3 AP RESULTS

The AP impact potential results are presented in Figure 4.3 and Table 4.3. Only inorganic emissions to air result in AP-related environmental impacts. As with GWP, the AP impact is dominated by on-site direct emissions associated with the cement manufacturing process (which includes the combustion of hazardous waste and/or coal). The impact potentials associated with these emissions are 4 to 5 orders of magnitude greater than the impact potentials associated with all other processes (Table 4.3). As the fuel source transitions from 100% coal (B.1) to 100% hazardous waste (T.2), the AP-related impact decreases by 14% and results from a reduction in sulfur dioxide (Table 4.3). Sulfur in the waste fuel is significantly less than that of coal (Table 3.2), thus the shift to waste fuel results in less emissions of sulfur dioxide (Table 3.2) (VSTBP, 1999).

Similar to that associated with the GWP impact potentials, the AP-related impact potentials associated with the system electricity needs (e.g., US grid electricity for both

the quarry and cement manufacturing) increase as the fuel source transitions from coal to hazardous waste, consistent with a greater need for electricity when burning hazardous wastes. As noted previously, however, the overall contribution of these emissions on the AP impact potential is small ($< 0.01\%$, Table 4.1).

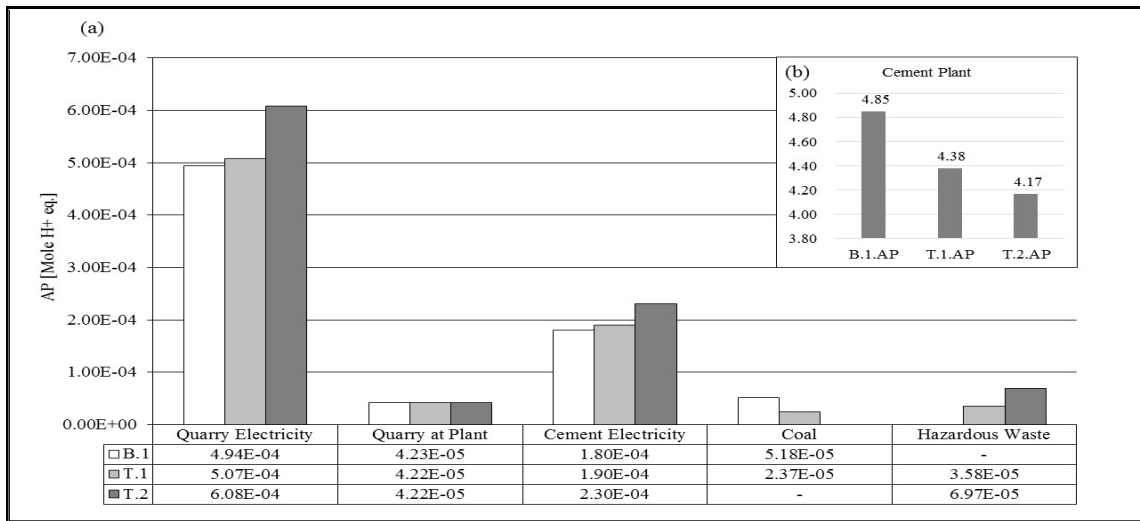


Figure 4.3 AP Impact potentials for (a) quarry and cement electricity, direct quarry, and acquiring coal and hazardous waste and (b) direct emissions at the cement manufacturing plant

Table 4.3 presents a detailed summary of the results associated with this impact category. Overall, these results indicate that as the facility shifts its use of coal to hazardous waste, lower amounts of sulfur dioxide are emitted, while slightly greater amounts of nitrogen oxides are emitted. The increase in nitrogen oxide emissions results from a need for increased thermal energy to produce the cement while burning waste fuels because of energy efficiency loss (Galvez-Martos, 2014). This results in greater amounts of hazardous waste being burning which in turn causes an increase in combustion air flow and an increase in NOx emissions due to thermal NOx from the oxidation of the molecular nitrogen in the combustion air (Boateng, 2016). The reduction

in SO₂ is primarily due to reductions in the sulfur content of the hazardous waste (Table 3.2).

4.4 TEP RESULTS

Results associated with the TEP impact category are presented in Figure 4.4 and Table 4.4. Overall, the total TEP impact potential increases as hazardous waste is used in place of coal (Figure 4.1); a 7.9% increase in this impact category results when completely replacing coal with hazardous waste. As shown in Figure 4.4, direct emissions from the cement fuel burning processes dominated the impacts in each category, accounting for 99.98% of the overall impact (Table 4.1). Within this process category, nearly 100% of the impacts from the direct cement plant emissions are from nitrogen oxides (Table 4.4). This increase in nitrogen oxide emissions is a result of greater amount of waste fuels used when compared to that of coal. Additionally, along with the increase in thermal energy needed to produce cement there is an increase in air flow in the system due to the need to evaporate the water in the waste fuels in addition to supplying the necessary energy to the cement manufacturing system. Increased airflow causes an increase in thermal NO_x from the oxidation of the molecular nitrogen in the combustion air (Boateng, 2016).

Table 4.3 Summary of AP Scenario by Process

Scenario	Pollutants Contributing Most Significantly ¹ AP [Mole of H+ eq.]													
	Quarry				Cement Manufacturing				Secondary Fuel Source Acquisition ²					
	Pollutant	Electricity ³	Pollutant	Plant Emissions	Pollutant	Electricity ³	Pollutant	Plant Emissions	Pollutant	Coal ⁴	Pollutant	Hazardous Waste ⁵		
B.1	Sulfur Dioxide	0.00039 (78.90)	Nitrogen Oxides	3.69E-05 (87.00)	Sulfur Dioxide	0.000148 (78.90)	Sulfur Dioxide	3.84 (79.10)	Sulfur Dioxide	3.34E-05 (64.50)	NA	NA	NA	
	Nitrogen Oxides	0.000101 (20.30)	Sulfur Dioxide	5.43E-06 (12.80)	Nitrogen Oxides	3.83E-05 (20.30)	Nitrogen Oxides	1.01 (20.90)	Nitrogen Oxides	1.82E-05 (35.10)	NA	NA	NA	
	Ammonia	3.40E-06 (0.69)	Ammonia	5.20E-08 (0.12)	Ammonia	1.29E-06 (0.69)	Ammonia	1.44E-05 (2.96E-04)	Ammonia	1.74E-07 (0.34)	NA	NA	NA	
T.1	Sulfur Dioxide	0.0004 (78.90)	Nitrogen Oxides	3.68E-05 (87.00)	Sulfur Dioxide	0.000152 (78.90)	Sulfur Dioxide	3.34 (76.30)	Sulfur Dioxide	1.53E-05 (64.50)	Sulfur Dioxide	2.90E-05 (81.10)		
	Nitrogen Oxides	0.000103 (20.30)	Sulfur Dioxide	5.42E-06 (12.80)	Nitrogen Oxides	3.93E-05 (20.30)	Nitrogen Oxides	1.04 (23.70)	Nitrogen Oxides	8.31E-06 (35.10)	Nitrogen Oxides	6.71E-06 (18.70)		
	Ammonia	3.49E-06 (0.69)	Ammonia	5.19E-08 (0.12)	Ammonia	1.33E-06 (0.69)	Ammonia	1.44E-05 (3.28E-04)	Ammonia	7.94E-08 (0.34)	Ammonia	7.39E-08 (0.21)		
T.2	Sulfur Dioxide	0.00048 (78.90)	Nitrogen Oxides	3.68E-05 (87.00)	Sulfur Dioxide	0.000183 (78.90)	Sulfur Dioxide	3.07 (73.60)	NA	NA	NA	Sulfur Dioxide	5.65E-05 (81.10)	
	Nitrogen Oxides	0.000124 (20.30)	Sulfur Dioxide	5.42E-06 (12.80)	Nitrogen Oxides	4.71E-05 (20.30)	Nitrogen Oxides	1.1 (26.40)	NA	NA	NA	Nitrogen Oxides	1.31E-05 (18.70)	
	Ammonia	4.18E-06 (0.69)	Ammonia	5.19E-08 (0.12)	Ammonia	1.59E-06 (0.69)	Ammonia	1.44E-05 (3.44E-04)	NA	NA	NA	Ammonia	1.44E-07 (0.21)	

1. Numbers in parentheses indicate percent contribution of that impact to the total impact category.
2. Impacts associated with the processes required for source acquisition.
3. Electricity-related emissions, including electricity at the grid as well as any electricity associated with any start-up fuels.
4. Includes emission associated with mining and transportation to the cement plant.
5. Includes emissions associated with necessary hazardous waste blending and transportation to the cement plant.

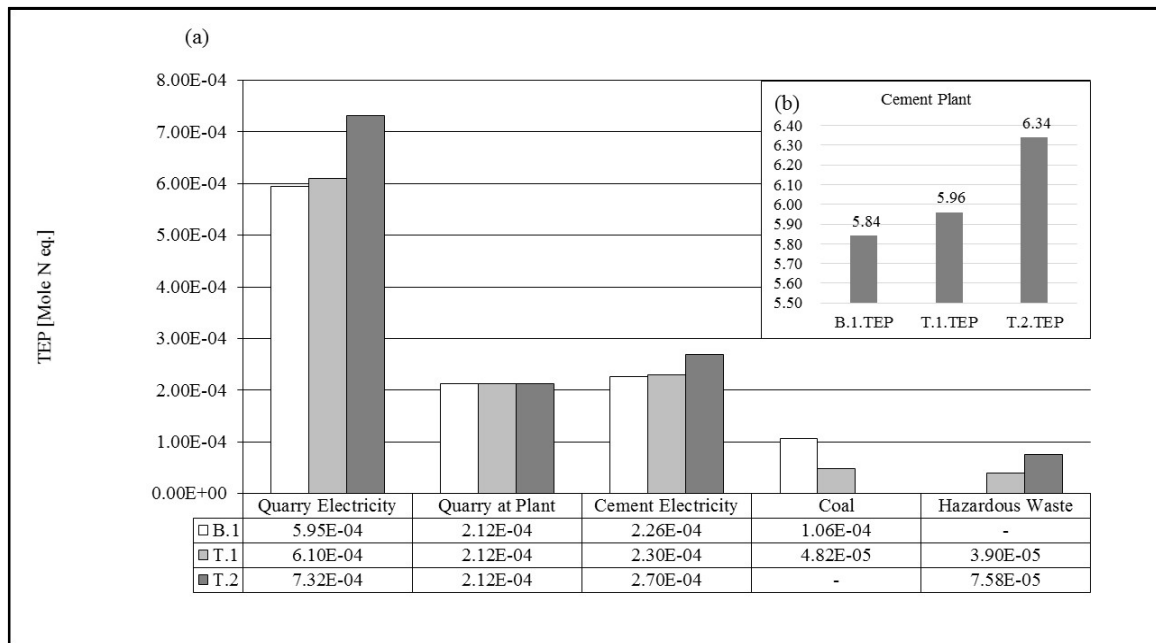


Figure 4.4 TEP Impact potentials for (a) quarry and cement electricity, direct quarry, and acquiring coal and hazardous waste and (b) direct emissions at the cement manufacturing plant

Table 4.4 Summary of TEP Scenario by Process

Scenario	Pollutants Contributing Most Significantly ¹ TEP [Mole of N eq.]												
	Quarry				Cement Manufacturing				Secondary Fuel Source Acquisition ²				
	Pollutant	Electricity ³	Pollutant	Plant Emissions	Pollutant	Electricity ³	Pollutant	Plant Emissions	Pollutant	Coal ⁴	Pollutant	Hazardous Waste ⁵	
B. 1	Nitrogen Oxides	0.000579 (97.30)	Nitrogen Oxides	0.000212 (99.90)	Nitrogen Oxides	0.00022 (97.30)	Nitrogen Oxides	5.84 (100.00)	Nitrogen Oxides	1.05E-04 (99.30)	NA	NA	NA
	Ammonia	1.52E-05 (2.55)	Ammonia	2.32E-07 (0.11)	Ammonia	5.77E-06 (2.55)	Ammonia	6.42E-05 (0.00110)	Ammonia	7.75E-07 (0.73)	NA	NA	NA
	Nitrogen Monoxide	8.34E-07 (0.14)	NA	NA NA	Nitrogen Monoxide	3.18E-07 (0.14)	NA	NA NA	NA	NA NA	NA	NA	NA
T. 1	Nitrogen Oxides	0.000594 (97.30)	Nitrogen Oxides	0.000212 (99.90)	Nitrogen Oxides	0.000226 (97.30)	Nitrogen Oxides	5.96 (100.00)	Nitrogen Oxides	4.79E-05 (99.30)	Nitrogen Oxides	3.86E-05 (99.20))
	Ammonia	1.55E-05 (2.55)	Ammonia	2.32E-07 (0.11)	Ammonia	5.92E-06 (2.55)	Ammonia	6.40E-05 (0.00107)	Ammonia	3.54E-07 (0.73)	Ammonia	3.29E-07 (0.85)	
	Nitrogen Monoxide	8.56E-07 (0.14)	NA	NA NA	Nitrogen Monoxide	3.26E-07 (0.14)	NA	NA NA	NA	NA NA	NA	NA	NA
T. 2	Nitrogen Oxides	0.000712 (97.30)	Nitrogen Oxides	0.000212 (99.90)	Nitrogen Oxides	0.000271 (97.30)	Nitrogen Oxides	6.34 (100.00)	NA	NA NA	Nitrogen Oxides	7.52E-05 (99.20))
	Ammonia	1.86E-05 (2.55)	Ammonia	2.32E-07 (0.11)	Ammonia	7.09E-06 (2.55)	Ammonia	6.40E-05 (0.00101)	NA	NA NA	Ammonia	6.41E-07 (0.85)	
	Nitrogen Monoxide	1.03E-06 (0.14)	NA	NA NA	Nitrogen Monoxide	3.91E-07 (0.14)	NA	NA NA	NA	NA NA	NA	NA	NA

1. Numbers in parentheses indicate percent contribution of that impact to the total impact category.
2. Impacts associated with the processes required for source acquisition.
3. Electricity-related emissions, including electricity at the grid as well as any electricity associated with any start-up fuels.
4. Includes emission associated with mining and transportation to the cement plant.
5. Includes emissions associated with necessary hazardous waste blending and transportation to the cement plant.

4.5 ET RESULTS

Results associated with the ET impact potential are presented in Figure 4.5 and Table 4.5. As shown, and consistent with previously described impact potentials, on-site direct emissions associated with the cement manufacturing process (which includes the combustion of hazardous waste and/or coal) represent the largest ET-related environmental impacts, ranging from 45% (T.2) to 66% (B.1) of the total ET impact potential (Table 4.1). This impact potential decreases as the facility transitions from using coal as a fuel to that of hazardous waste. This reduction is primarily attributed to a reduction in metal emissions; hazardous wastes generally have lower metal contents than coal for certain metals (e.g. Arsenic), see Table 3.2.

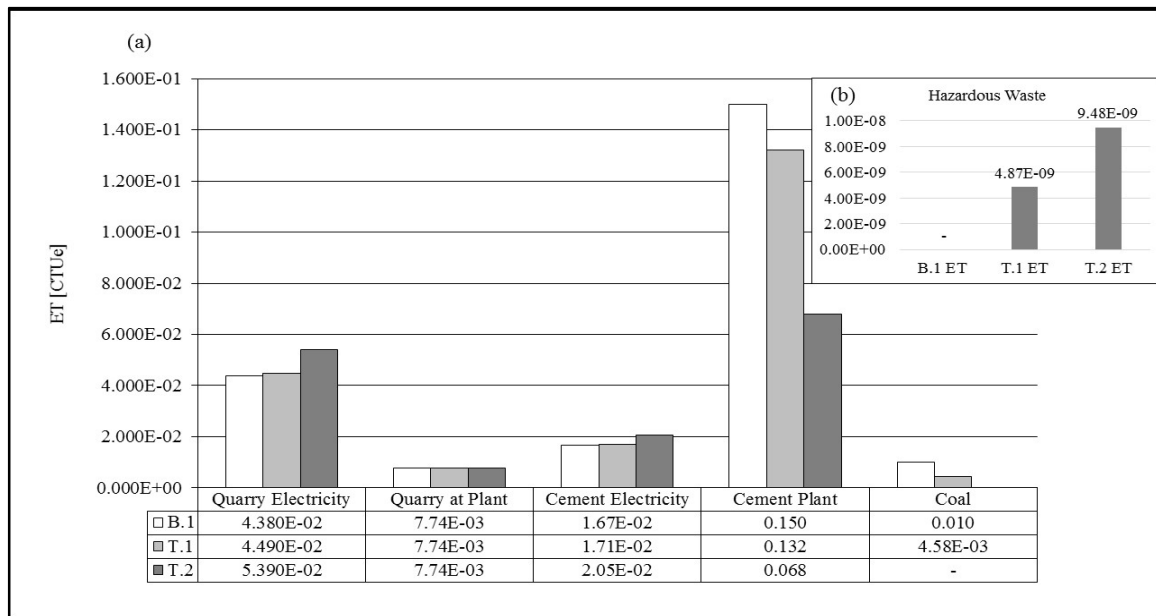


Figure 4.5 ET Impact potentials for (a) quarry and cement electricity, direct quarry, and acquiring coal and hazardous waste and (b) direct emissions at the cement manufacturing plant

The highest observed ET-related impacts associated with emissions at the cement manufacturing plant in the B.1 scenario are from heavy metals to air where arsenic,

mercury, and chromium represent the most significant pollutants. As the facility shifts from burning coal (B.1) to burning hazardous waste (T.1 and T.2), the cement manufacturing ET impact related emissions decrease primarily because of decreases in arsenic emissions. Coal generally contains 24 ppm of arsenic (Bragg, 1998, also see Table 3.2), so as coal combustion is reduced, so are the arsenic emissions; a 92.7% reduction of arsenic emissions occurs when eliminating the use of coal for on-site combustion. However, it should be noted that the trends associated with Hg-related impacts increase, as shown in Figure 4.6, and are consistent with the higher mercury contents associated with the hazardous waste (Table 3.2).

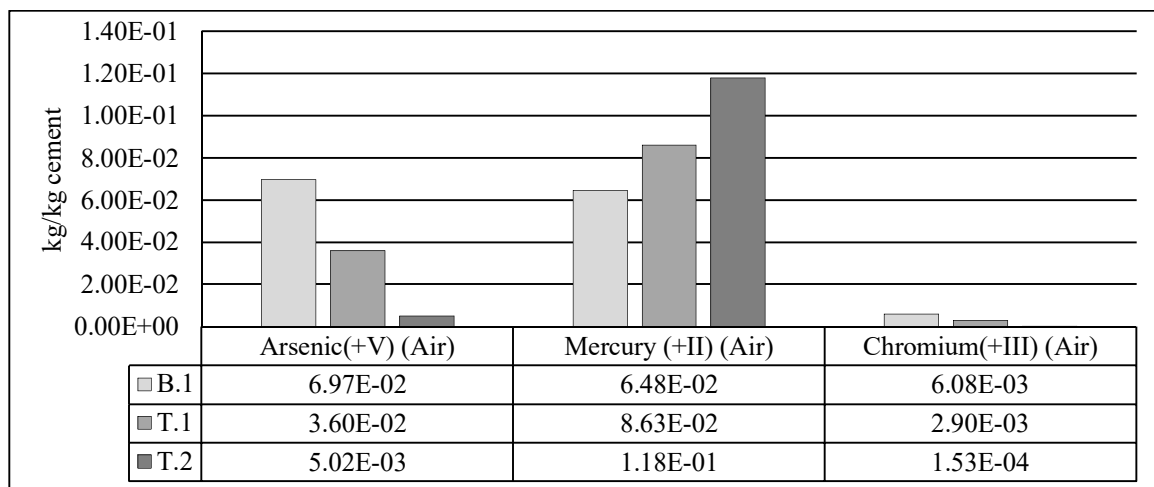


Figure 4.6 ET Comparison Arsenic (+V), Mercury (+II), Chromium (+III)

Unlike the previously described impact categories, the ET-related contributions associated with other system processes (e.g., quarry and cement manufacturing electricity, direct quarry emissions, and coal and hazardous waste acquisition) are significant, contributing up to 55% of the total ET impact. The importance of these other system processes increases as the fraction of hazardous waste burned for energy increases because metal emissions as the cement manufacturing plant decrease. This result also

suggests that substituting coal generated energy/electricity with that of on-site hazardous waste-generated power could reduce ET impacts. The evaluation of alternative sources of energy (e.g., heat recovery) for other electricity needs should be considered for on-site co-generation.

The grid purchased electricity (quarry) emissions represent the second most significant fraction of the ET impact potential; as the facility transitions from coal to hazardous waste, the quarry electricity requirements increase, as does the magnitude of this contribution. The metal contributing most significantly to these impacts is chromium (Table 4.5), which is a direct result of increases in electricity use. Cement purchased electricity also accounts for a significant amount of the impacts in all three scenarios where chromium, copper and arsenic impacts to water occur and increase as the fraction of coal used decreases.

4.6 HT-C RESULTS

The HT-C impact potential results are presented in Figure 4.7 (a-f) and Table 4.6. In Figure 4.7(d), it is observed that the direct effect of shifting facility fuel consumption from coal to waste fuels results in increasing the HT-C-related impacts by 68.6%. As the facility shifts from burning coal (B.1) to hazardous waste (T.1 & T.2), Hg emissions to air increase by 82% (Table 4.6), while total chromium emissions to freshwater for all of the purchased electricity (quarry and cement) increase by 23.3%. The chromium impacts to freshwater are the result of flue gas cleaning of the electric utility. The mercury impacts to air are from the increased rate of burning waste fuels which have higher emissions of mercury compared to when burning coal.

Table 4.5 Summary of ET Scenario by Process

Scenario	Pollutants Contributing Most Significantly ¹ ET [CTHe]																	
	Quarry				Cement Manufacturing				Secondary Fuel Source Acquisition ²									
	Pollutant	Electricity ³		Pollutant	Plant Emissions		Pollutant	Electricity ³		Pollutant	Plant Emissions		Pollutant	Coal ⁴		Pollutant	Hazardous Waste ⁵	
B.1	Chromium (Water)	4.09E-02	(93.50)	Barium (Water)	5.67E-03	(73.20)	Chromium (Water)	1.56E-02	(93.50)	Arsenic (+V) (Air)	6.97E-02	(46.40)	Barium (Water)	7.13E-03	(71.10)	NA	NA	NA
	Copper(+II) (Water)	6.38E-04	(1.46)	Silver (Water)	1.28E-03	(16.50)	Copper(+II) (Water)	2.43E-04	(1.46)	Mercury (+II) (Air)	6.48E-02	(43.20)	Silver (water)	1.83E-03	(18.30)	NA	NA	NA
	Arsenic(+V) (Water)	3.96E-04	(0.91)	Chromium (Water)	4.08E-03	(5.27)	Arsenic(+V) (Water)	1.51E-04	(0.91)	Chromium (+III) (Air)	6.08E-03	(4.05)	Chromium (Water)	5.09E-04	(5.08)	NA	NA	NA
T.1	Chromium (Water)	4.20E-02	(93.50)	Barium (Water)	5.67E-03	(73.20)	Chromium (Water)	1.60E-02	(93.50)	Mercury (+II) (Air)	8.63E-02	(65.50)	Barium (Water)	3.26E-03	(71.10)	Benzene (Water)	4.87E-09	(100.00)
	Copper(+II) (Water)	6.54E-04	(1.46)	Silver (Water)	1.28E-03	(16.50)	Copper(+II) (Water)	2.49E-03	(1.46)	Arsenic (+V) (Air)	3.60E-02	(27.30)	Silver (water)	8.38E-04	(18.30)	NA	NA	NA
	Arsenic(+V) (Water)	4.07E-03	(0.91)	Chromium (Water)	4.08E-03	(5.27)	Arsenic(+V) (Water)	1.55E-04	(0.91)	Chromium (+III) (Air)	2.90E-03	(2.20)	Chromium (Water)	2.33E-04	(5.08)	NA	NA	NA
T.2	Chromium (Water)	5.04E-02	(93.50)	Barium (Water)	5.67E-03	(73.20)	Chromium (Water)	1.92E-03	(93.50)	Mercury (+II) (Air)	1.18E-01	(93.00)	NA	NA	NA	Benzene (Water)	9.48E-09	(100.00)
	Copper(+II) (Water)	7.85E-04	(1.46)	Silver (Water)	1.28E-03	(16.50)	Copper(+II) (Water)	2.99E-04	(1.46)	Arsenic (+V) (Air)	5.02E-03	(3.96)	NA	NA	NA	NA	NA	NA
	Arsenic(+V) (Water)	4.88E-04	(0.91)	Chromium (Water)	4.08E-03	(5.27)	Arsenic(+V) (Water)	1.86E-04	(0.91)	Cadmium (+II) (Air)	3.38E-04	(0.27)	NA	NA	NA	NA	NA	NA

1. Numbers in parentheses indicate percent contribution of that impact to the total impact category.
2. Impacts associated with the processes required for source acquisition.
3. Electricity-related emissions, including electricity at the grid as well as any electricity associated with any start-up fuels.
4. Includes emission associated with mining and transportation to the cement plant.
5. Includes emissions associated with necessary hazardous waste blending and transportation to the cement plant.

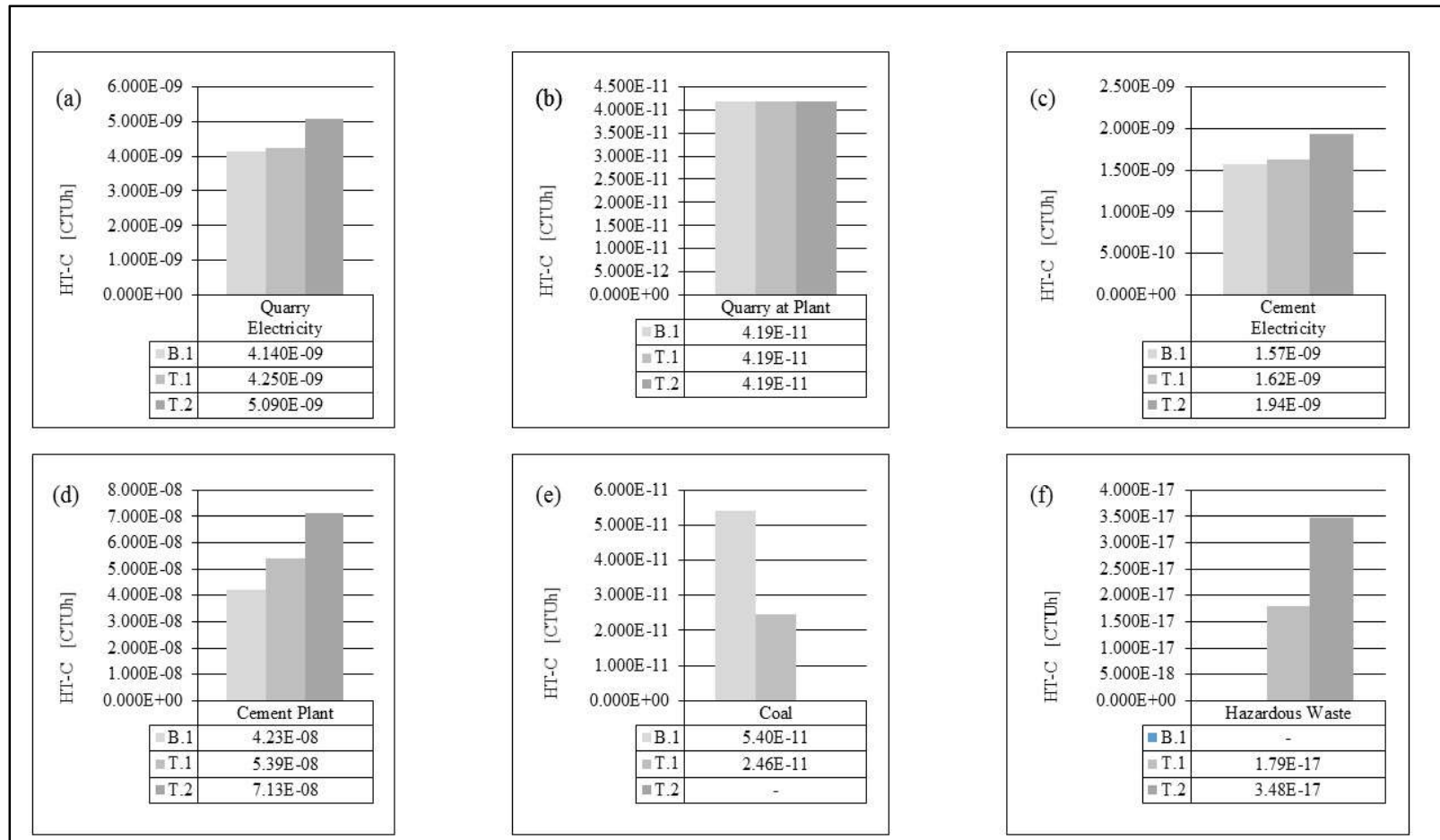


Figure 4.7 HT-C Impact potentials for (a) quarry electricity, (b) direct quarry, (c) cement electricity, (d) cement manufacturing plant, (e) coal and (f) hazardous waste

Table 4.6 Summary of HT-C by Process

Scenario	Pollutants Contributing Most Significantly ¹ HT-C [CTHu]												
	Quarry				Cement Manufacturing				Secondary Fuel Source Acquisition ²				
	Pollutant	Electricity ³	Pollutant	Plant Emissions	Pollutant	Electricity ³	Pollutant	Plant Emissions	Pollutant	Coal ⁴	Pollutant	Hazardous Waste ⁵	
B. 1	Chromium (Water)	4.11E-09 (99.40)	Chromium (Water)	4.10E-11 (97.70)	Chromium (Water)	1.56E-09 (99.40)	Hg (+II) (Air)	3.75E-08 (88.70)	Chromium (Water)	5.12E-11 (94.80)	NA	NA	NA
	Mercury (+II) (Air)	9.14E-12 (0.22)	Chromium (+VI) (Water)	3.21E-13 (0.76)	Mercury (+II) (Air)	3.48E-12 (0.22)	D/F	2.90E-09 (6.85)	Mercury (+II) (Air)	8.30E-13 (1.54)	NA	NA	NA
	Arsenic (+V) (Air)	3.99E-12 (0.10)	Formaldehyde (Air)	3.18E-13 (0.76)	Arsenic (+V) (Air)	1.52E-12 (0.10)	Arsenic (+V) (Air)	1.37E-09 (3.23)	Chromium (Air)	4.56E-13 (0.84)	NA	NA	NA
T. 1	Chromium (Water)	4.22E-09 (99.40)	Chromium (Water)	4.10E-11 (97.70)	Chromium (Water)	1.61E-09 (99.40)	Hg (+II) (Air)	5.00E-08 (92.80)	Chromium (Water)	2.34E-11 (94.80)	Benzene (Water)	1.79E-17 (100.00)	
	Mercury (+II) (Air)	9.38E-12 (0.22)	Chromium (+VI) (Water)	3.21E-13 (0.76)	Mercury (+II) (Air)	3.57E-12 (0.22)	D/F	2.89E-09 (5.37)	Mercury (+II) (Air)	3.79E-13 (1.54)	NA	NA	NA
	Arsenic (+V) (Air)	4.09E-12 (0.10)	Arsenic (+V) (Water)	3.18E-13 (0.76)	Arsenic (+V) (Air)	1.56E-12 (0.10)	Arsenic (+V) (Air)	7.05E-10 (1.31)	Chromium (Air)	2.08E-13 (0.84)	NA	NA	NA
T. 2	Chromium (Water)	5.06E-09 (99.40)	Chromium (Water)	4.10E-11 (97.70)	Chromium (Water)	1.93E-09 (99.40)	Hg (+II) (Air)	6.83E-08 (95.70)	NA	NA	NA	Benzene (Water)	3.48E-17 (100.00)
	Mercury (+II) (Air)	1.13E-11 (0.22)	Chromium (+VI) (Water)	3.21E-13 (0.76)	Mercury (+II) (Air)	2.04E-14 (0.22)	D/F	2.89E-09 (4.06)	NA	NA	NA	NA	NA
	Arsenic (+V) (Air)	4.91E-12 (0.10)	Arsenic (+V) (Water)	3.18E-13 (0.76)	Arsenic (+V) (Air)	1.69E-12 (0.10)	Arsenic (+V) (Air)	9.84E-11 (0.14)	NA	NA	NA	NA	NA

1. Numbers in parentheses indicate percent contribution of that impact to the total impact category.
2. Impacts associated with the processes required for source acquisition.
3. Electricity-related emissions, including electricity at the grid as well as any electricity associated with any start-up fuels.
4. Includes emission associated with mining and transportation to the cement plant.
5. Includes emissions associated with necessary hazardous waste blending and transportation to the cement plant.

4.7 SCENARIO ANALYSIS

4.7.1 INFLUENCE OF MODEL SELECTION FOR HAZARDOUS WASTE BLENDING FACILITY

Two additional model simulations were run by replacing the benzene production data set with an ethanol blending terminal (T.1.s₁) and an ethanol blending station (T.1.s₂). The results of the simulations are presented in Table 4.7.

Table 4.7 LCA Summary with Simulations S1 and S2

Scenario	GWP (kg (CO ₂ -eq.))	AP (Mole H+ eq.)	TEP (Mole N eq.)	ET (CTUe)	HT-C (CTUh/kg)
B.1	1.05	4.85	5.84	0.228	4.81E-08
T.1.s ₁	1.44	4.39	6.01	0.997	7.05E-08
T.1	1.01	4.38	5.96	0.206	5.98E-08
T.1.s ₂	1.42	4.39	6.01	0.997	7.05E-08
T.2	0.987	4.17	6.34	0.150	7.84E-08

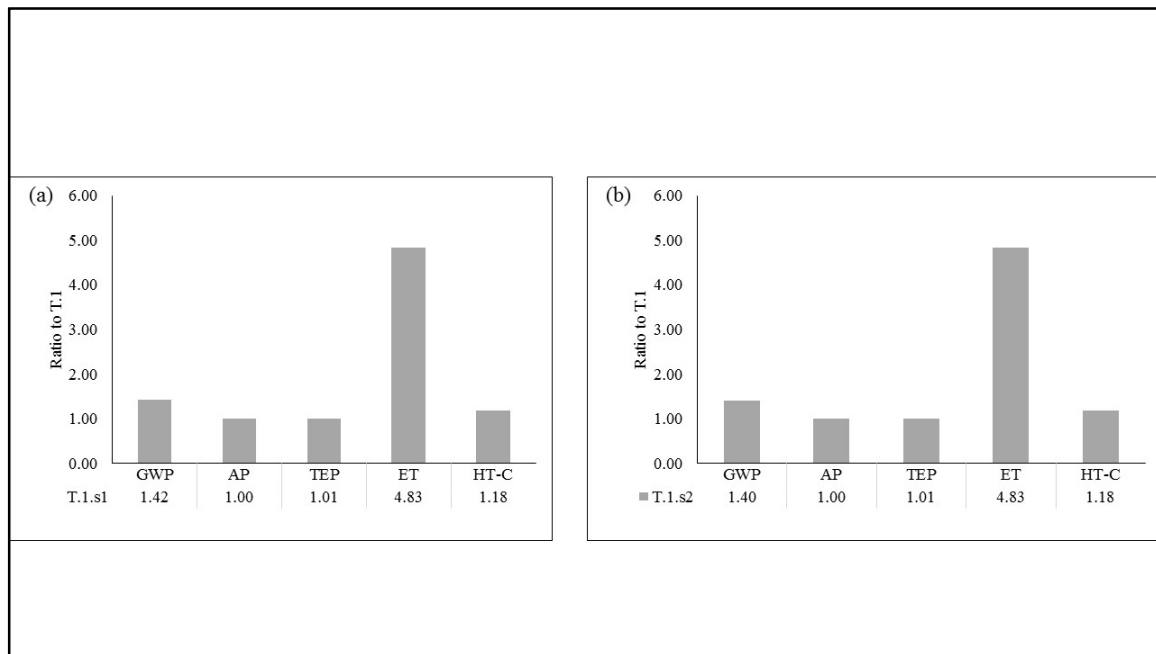


Figure 4.8 Simulation Comparison, (a) T.1s1 to T.1 and (b) T.1.s2 to T.1

Model simulation ratios (e.g. $T.1_{s1}/T.1$) were calculated by comparing the results $T.1_{s1}$ and $T.1_{s2}$ to $T.1$ in each impact category (Figure 4.8). Values greater than 1.0 represent increased impacts and values equal to 1.0 are neutral or no significant change. The change in the selection of the process that simulated the hazardous waste collection facility indicate there was little change in the impacts of AP (0.2%) and TEP (0.8%). The greatest observed impacts associated with changing these facilities from a benzene production facility to either an ethanol blending terminal or station were in the ET (383%), GWP (41%), and HT-C (17.8) impact categories. These results clearly demonstrate that overall environmental impacts in this study from GWP, ET and HT-C are influenced by the type of facility used to blend the hazardous waste for preparation for use as a fuel. The type of blending facility imparts the greatest influence on the ET-related impacts because of the organic emission impacts to freshwater.

4.7.2 INFLUENCE OF HAZARDOUS WASTE REPLACEMENT

Two additional model simulations were run in order to ascertain what relative changes in the total environmental impacts would be observed as waste fuel energy was substituted for coal energy at rates of 20% less and 20% (substitution rate) greater than those modeled in $T.1$ (i.e. 60%). Therefore, the LCI data was extrapolated and two additional model simulations ($T.1_{s3}$: 40% hazardous waste substitution rate and $T.1_{s4}$: 80% hazardous waste substitution rate) were conducted. Results from these model simulations are presented in Figures 4.9 through 4.13.

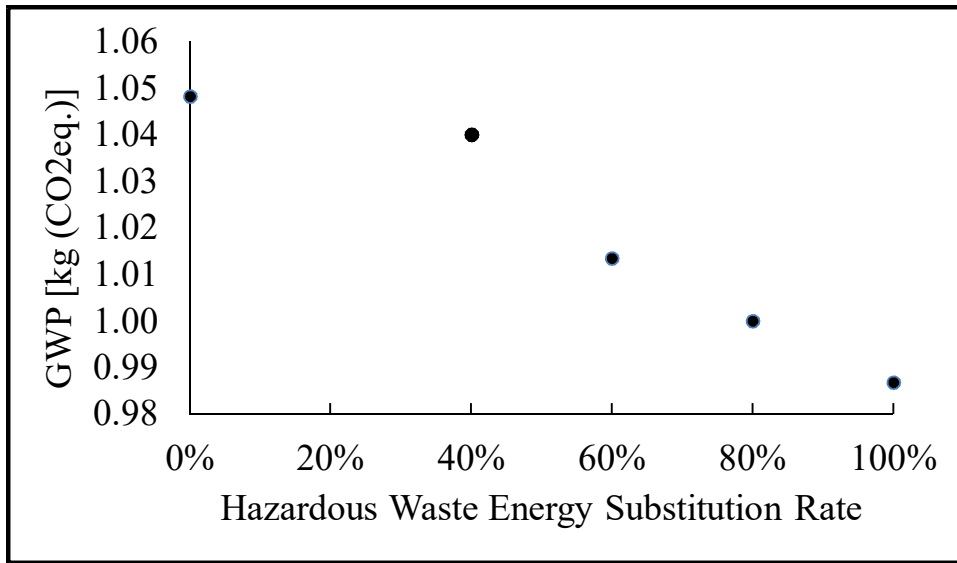


Figure 4.9 ILCD Impacts, GWP

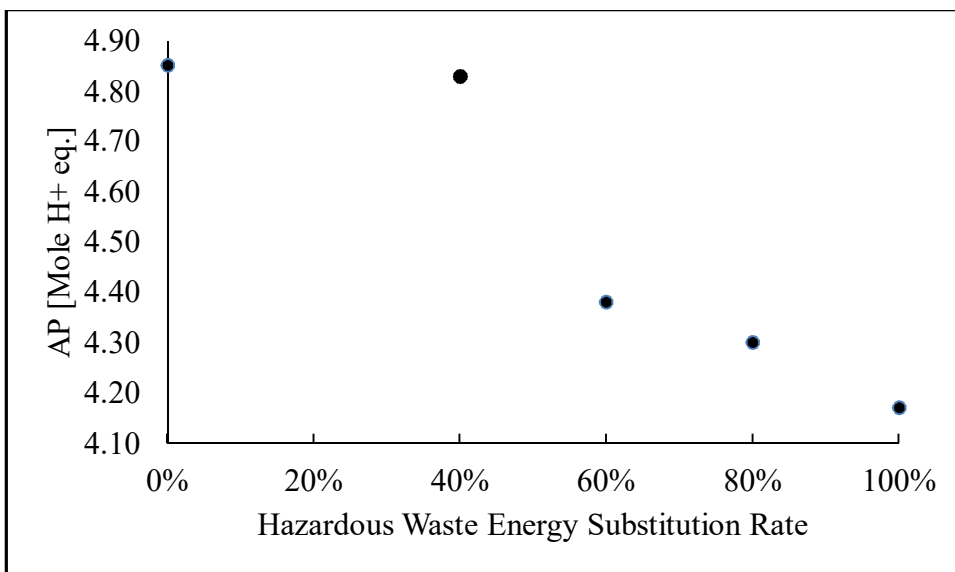


Figure 4.10 ILCD Impacts, AP

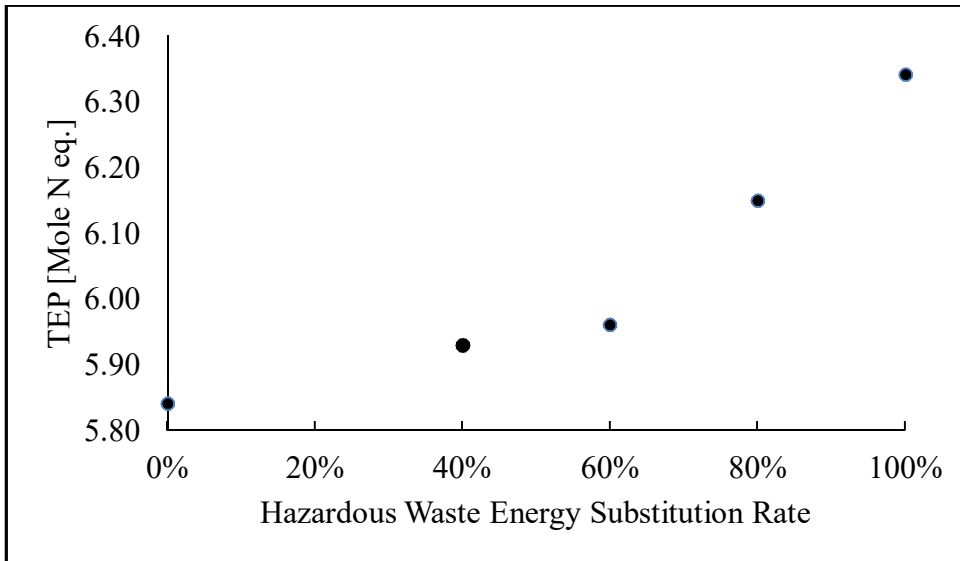


Figure 4.11 ILCD Impacts, TEP

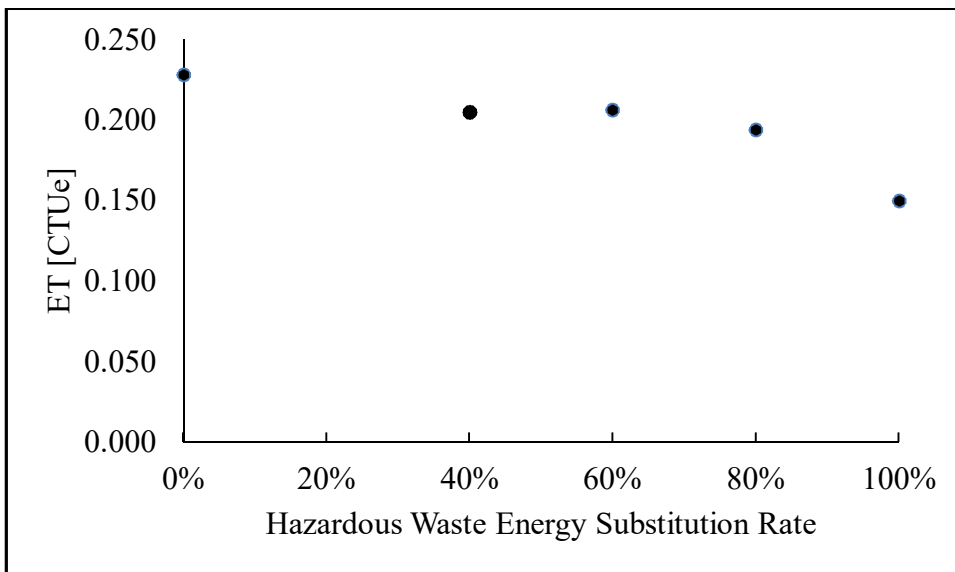


Figure 4.12 ILCD Impacts, ET

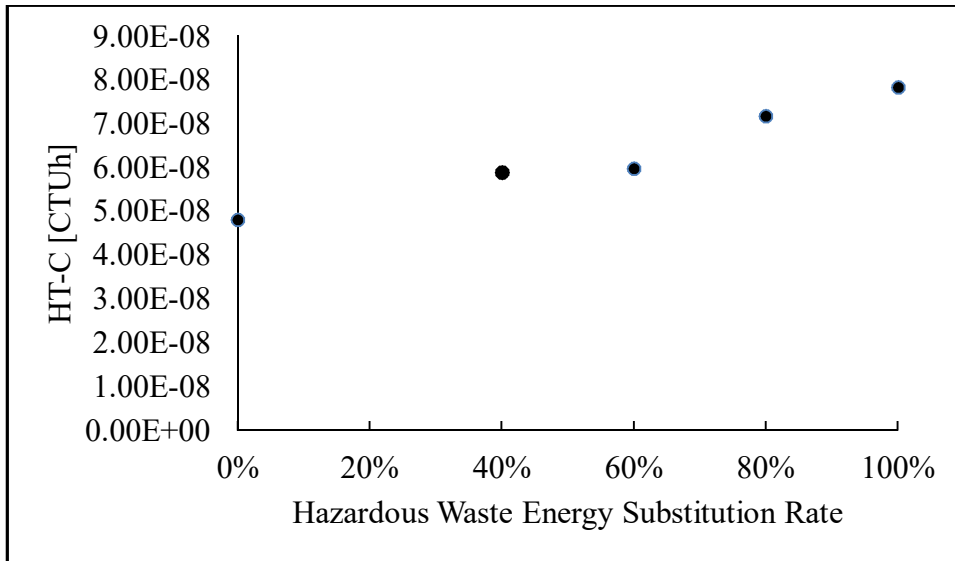


Figure 4.13 ILCD Impacts, HT-C

The trends associated with Figures 4.9 to 4.13 can be explained by changes in emissions when transitioning from coal-based fuel to hazardous waste-based fuel. In Figure 4.9, the trend associated with changes in the GWP impact category correlate with the reduction of coal usage and the corresponding reduction in the carbon content of the fuels. In Figure 4.10, changes in the AP impact category are attributed to changes in SO₂ and NO_x emissions (Table 4.3); the trend corresponds to reductions in the sulfur content of the fuel. In Figure 4.11, the TEP impact category is mostly impacted by changes in NO_x emissions, which, as described previously, increase as the thermal energy requirements of the system increased with greater amounts of waste being burned. The ET impact category (Figure 4.12) results are relatively unchanged from 40% to 80% substitution rates. The HT-C impact category results (Figure 4.13) increased as more hazardous waste was burned. Additionally, the impacts were observed to increase with greater emissions of Hg to air and Cr to freshwater.

In each of the impact categories of GWP, AP and ET points on the curves where change as a result of fuel substitution are GWP (40%), AP (40%) and ET (80%). The substitution rate of hazardous waste (60%) for coal is also the rate at which a noticeable change in the impacts of HT-C and ET such that the slopes are noticeably increasing at a great rate compared to before the 60% point. Accordingly, GWP, AP and ET resulted in a trend of less overall impacts to the environment while TEP and HT-C resulted in a trend of greater overall impacts as the burning of waste fuel increased to 40% for GWP and AP, and 80% for ET. For TEP and HT-C 60% was the observed highest sloping trend in greater overall impacts.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

The LCA conducted in this study compared the environmental impacts associated using hazardous waste as an alternative fuel in a cement manufacturing facility. Results from this study indicate that replacing coal with hazardous waste (T.1 and T.2) reduces the environmental impacts associated with GWP, AP and ET. However, the human toxicity impacts for cancer (HT-C) and TEP-related environmental impacts increase as the amount of coal used decreases. Mercury emissions to air from the cement manufacturing and chromium emissions to water from the electric grid were shown to be the primary pollutants of concern associated with this increase in the HT-C impact potentials.

These results confirm that there are certain positive environmental effects associated with the co-burning hazardous waste in an energy recovery process (e.g. cement manufacturing) and replacing fossil fuels, such as coal, with high BTU hazardous waste. Among those are predicted lower impacts of GWP, ET and AP. However, these results also confirm that EPA's use of Site Specific Human Risk Assessments (SSRA's) in the process of setting environmental limitations for facilities burning hazardous waste is greatly supported because of the predicted increase in HT-C (cancer) and TEP impacts to the environment (RCRA §3005(c)(3)). The results of this study indicate that Hg, As, Cr

and Ba impacts compared to other metals have significant environmental impacts and should be further studied.

GWP was not significantly reduced by the replacement of coal with hazardous waste, but it was reduced. AP was significantly reduced with the replacement of coal by 14% and ET was reduced by 34%. Conversely, HT-C and TEP increased by 68.6% and 8.5%, respectively.

From the simulations in the scenario analysis the results of this study could be improved with an actual LCI from a typical hazardous waste procurement facility, however the results obtained using a benzene production facility confirm that the main processes of the cement plant represent the largest component for influencing the evaluated environmental impacts. The influence of waste fuel substitution rate in all evaluated environmental impact categories tends to show that areas when coal or waste tend to have the greatest influence on the results varies by impact category. GWP and AP showed the greatest decreasing trend at 40%. The ET impacts showed the greatest decreasing trend at 80%. For both TEP and HT-C the 60% point was where the impacts showed the highest increasing trend.

The production of portland cement is an ongoing process and it requires electrical energy and a fuel supply. The supply of fuels can originate from fossil fuels or it can be energy substituted by hazardous waste fuels. Certain environmental impacts can be reduced and others will increase as a facility shifts from burning coal to hazardous waste.

5.1 RECOMMENDATIONS

For a cement manufacturing facility considering implementing an alternative fuels program for hazardous waste and in the context of this study several points should be

considered. First, a minimum substitution rate of 60% should be considered since it not only replaces more than 50% of the fossil fuel, this study also shows that reductions in two of the five impact categories can predict improved environmental performance (GWP and AP). Secondly, given the HT-C results showed an increase as fuel substitution rates increased whereby mercury emissions played a role then placing a limit on mercury in the waste fuel to restrict fuel related mercury emissions should be considered to at least confirm that any mercury in the waste fuel is minimized and the environmental impacts would also be minimized. Reducing grid purchased electricity by recuperating waste heat from the process, cooling the exhaust gases and generating electricity to offset electrical demand, would reduce environmental impacts associated with off-site grid purchased electricity. The avoided cost of electricity may provide the capital necessary to support the project. Lastly, the environmental impacts associated with constructing and operating an on-site hazardous waste storage and blending facility should be taken into account as part of the overall environmental impacts.

5.2 LCA MANAGEMENT DECISIONS

With the awareness and concern over environmental impacts associated with products in today's global economy stakeholders (e.g. – regulators, community, employees etc.) desire to see company's set and achieve sustainability goals. An LCA should be considered as a management tool to for helping a company setting and targeting changes in its processes, materials used, methods of transportation for its goods purchased and sold to define those goals and to make management decisions on how to ascertain which goals can be realistically achieved in the short term and long term.

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APPENDIX A: HAZARDOUS WASTE BLENDING DATA

Benzene Production Facility		
In Electricity [Electric power]	Energy (net calorific value)	0.057300742 0.057300742 MJ
Pyrolysis gas [Organic intermediate products]	Mass	0.335 0.335 kg
US: Diesel, combusted in industrial boiler [Products and Intermediates]	Volume	3.34E-06 3.34E-06 m3
US: Natural gas, combusted in industrial boiler [Products and Intermediates]	Volume	0.03923 0.03923 m3
US: Natural gas, processed, at plant [Products and Intermediates]	Volume	0.0339 0.0339 m3
US: Petroleum refining coproduct, unspecified, at refinery [Products and Intermediates]	Mass	0.679 0.679 kg
US: Residual fuel oil, combusted in industrial boiler [Products and Intermediates]	Volume	3.23E-05 3.23E-05 m3
US: Transport, barge, diesel powered [Products and Intermediates]	kgkm	34.809 34.809 kgkm
US: Transport, barge, residual fuel oil powered [Products and Intermediates]	kgkm	123.41 123.41 kgkm
US: Transport, combination truck, diesel powered [Products and Intermediates]	kgkm	29.197 29.197 kgkm
US: Transport, train, diesel powered [Products and Intermediates]	kgkm	18.678 18.678 kgkm
US: Dummy_Disposal, solid waste, unspecified, to municipal incineration [Dummy Flows]	Mass	4.80E-05 4.80E-05 kg
US: Dummy_Disposal, solid waste, unspecified, to unspecified landfill [Dummy Flows]	Mass	0.00048 0.00048 kg
US: Dummy_Electricity, at cogenerating unit, unspecified [Dummy Flows]	Energy (net calorific value)	0.03254014 0.03254014 MJ
US: Dummy_Transport, pipeline, unspecified petroleum products [Dummy Flows]	kgkm	249.81 249.81 kgkm
Out		
Benzene [Organic intermediate products]	Mass	1 1 kg
RNA: Recovered energy, at benzene production [Products and Intermediates]	Energy (net calorific value)	4.466 4.466 MJ
Benzene [Hydrocarbons to fresh water]	Mass	1.00E-09 1.00E-09 kg
Biological oxygen demand (BOD) [Analytical measures to fresh water]	Mass	0.00047 0.00047 kg
Carbon dioxide [Inorganic emissions to air]	Mass	0.0301 0.0301 kg
Carbon monoxide [Inorganic emissions to air]	Mass	1.00E-05 1.00E-05 kg
Chemical oxygen demand (COD) [Analytical measures to fresh water]	Mass	0.00072 0.00072 kg
Chlorine [Inorganic emissions to air]	Mass	1.00E-07 1.00E-07 kg
Dust (PM2.5 - PM10) [Particles to air]	Mass	1.00E-06 1.00E-06 kg
Dust (unspecified) [Particles to air]	Mass	3.00E-05 3.00E-05 kg
Hydrogen [Inorganic emissions to air]	Mass	1.00E-09 1.00E-09 kg
Nitrogen oxides [Inorganic emissions to air]	Mass	4.20E-05 4.20E-05 kg
NM VOC (unspecified) [Group NM VOC to air]	Mass	1.00E-05 1.00E-05 kg
Oil (unspecified) [Hydrocarbons to fresh water]	Mass	1.20E-05 1.20E-05 kg
Solids (dissolved) [Analytical measures to fresh water]	Mass	7.00E-05 7.00E-05 kg
Solids (suspended) [Particles to fresh water]	Mass	1.00E-06 1.00E-06 kg
Sulphide [Inorganic emissions to fresh water]	Mass	1.00E-06 1.00E-06 kg
Sulphur dioxide [Inorganic emissions to air]	Mass	0.0003 0.0003 kg
Total organic bounded carbon [Analytical measures to fresh water]	Mass	1.00E-08 1.00E-08 kg

100% of technosphere and elementary flows allocated to benzene, and 0% to recovered heat. Important note: although most of the data in the US LCI database has undergone some sort of review, the database as a whole has not yet undergone a formal validation process. Please email comments to lc@nrel.gov. The original datasets and documentation can be found online: <https://www.lcccommons.gov/nrel/search>

APPENDIX B: COAL AND HAZARDOUS WASTE ANALYSIS

SAMPLE NATURAL GAS ANALYSES

Sample No. Source of Gas		1 Pa.	2 So. Cal.	3 Ohio	4 La.	5 Okla.
Analyses						
Constituents, % by vol						
H ₂	Hydrogen	—	—	1.82	—	—
CH ₄	Methane	83.40	84.00	93.33	90.00	84.10
C ₂ H ₄	Ethylene	—	—	0.25	—	—
C ₂ H ₆	Ethane	15.80	14.80	—	5.00	6.70
CO	Carbon monoxide	—	—	0.45	—	—
CO ₂	Carbon dioxide	—	0.70	0.22	—	0.80
N ₂	Nitrogen	0.80	0.50	3.40	5.00	8.40
O ₂	Oxygen	—	—	0.35	—	—
H ₂ S	Hydrogen sulfide	—	—	0.18	—	—
Ultimate, % by wt						
S	Sulfur	—	—	0.34	—	—
H ₂	Hydrogen	23.53	23.30	23.20	22.68	20.85
C	Carbon	75.25	74.72	69.12	69.26	64.84
N ₂	Nitrogen	1.22	0.76	5.76	8.06	12.90
O ₂	Oxygen	—	1.22	1.58	—	1.41
Specific gravity (rel to air)		0.636	0.636	0.567	0.600	0.630
Higher heat value						
Btu/cu ft @ 60F & 30 in. Hg		1,129	1,116	984	1,002	974
Btu/lb of fuel		23,170	22,904	22,077	21,824	20,160

EXAMPLE COAL ANALYSES

PROXIMATE		ULTIMATE (as received)		ULTIMATE (dry basis)	
Component	Weight, %	Component	Weight, %	Component	Weight, %
Moisture (free)	2.5	Moisture (free)	2.5	Carbon	76.9
Volatile matter	37.6	Carbon	75.0	Hydrogen	5.1
Fixed carbon	52.9	Hydrogen	5.0	Sulfur	2.4
Ash	7.0	Sulfur	2.3	Nitrogen	1.5
Total	100.0	Nitrogen	1.5	Oxygen	6.9
Heating value.		Oxygen	6.7	Ash	7.2
Btu/lb	13,000	Ash	7.0	Total	100.0
		Total	100.0		

REF: EPA 450/2-80-063

TABLE 3.1

Virginia Public Files (VADEQ)

Typical Organic Composition of LBM Including Appendix VIII Constituents

Resin and Polymers (Noncombustible Residue: 5.00%)	20.8000%
Water, Free and Miscible	15.1000%
Toluene	15.1000%
Methyl Ethyl Ketone	13.6000%
Xylene	11.9000%
Used Oil	10.1000%
Acetone	2.7000%
Ethyl Benzene	2.6510%
Methanol	1.9994%
Cyclohexane	1.0000%
4-Methyl-2-Pentanone	1.0000%
Acetoni trile	0.9700%
Methyl Isobutyl Ketone	0.5000%
1,1,1-Trichloroethane	0.4500%
Tetrachloroethylene	0.3500%
Ethylene Glycol	0.3500%
Trichloroethylene	0.2600%
Chloroform	0.1900%
Bis(2-ethylhexyl)phthalate	0.1530%
Phenol	0.1400%
Isopropyl Alcohol	0.1200%
Methylene Chloride	0.0860%
Isophorone	0.0780%
Acrylonitrile	0.0700%
Di-n-butyl Phthalate	0.0590%
Naphthalene	0.0530%
1,1,2-Trichloroethane	0.0390%
1,2-Dichlorobenzene	0.0310%
2-Hexanone	0.0350%
Styrene	0.0200%
Phthalic Anhydride	0.0200%
1,2,4 Trichlorobenzene	0.0180%
Benzene	0.0140%
Benzyl Alcohol	0.0110%
Butyl Benzyl Phthalate	0.0100%
Trichlorofluoromethane	0.0080%
Carbon Disulfide	0.0070%
Formaldehyde	0.0050%
1,2-Dichloroethane	0.0050%
n-Butyl Alcohol	0.0045%
1,1-Dichloroethane	0.0020%
Chlorobenzene	0.0020%
Vinyl Chloride	0.0010%
Dichloromethane	0.0010%
Hexachlorobutadiene	0.0010%
Dibutyl Phthalate	0.0004%
Carbon Tetrachloride	0.0002%
TOTAL	100.0%

Notes:

- 1) This typical composition is from multiple samples of fuel taken from fuels sampled in the Solite/GRR system.
- 2) Values presented are in a weight percent basis.
- 3) Some constituents were at non-detect levels and may not be constituents of LBM.



Republic Environmental
Systems (Pennsylvania), LLC

2869 Sandstone Dr. Hatfield Pa. 19440
(tel)215-822-8985 (fax)215-822-1293

Certificate of Analytical Results

Date: 31-May-11

CLIENT: Weston Solutions, Inc.
1400 Weston Way
West Chester, PA 19380-1499
Lab Order: R11050028
Project: 02329.047.001.0001

Lab ID:	R11050028-20	Date Received:	05/13/2011	Date Sampled:	05/11/2011 0:00	
Client Sample ID:	KC-B-LWFK-	Matrix: AQUEOUS				
Analyses	Result	Limit	Qual	Units	DF	Date Analyzed
ASH, OIL	D482					Analyst: VJO
Ash	3.06	0.0100		%	1	5/16/2011
CARBON, HYDROGEN, NITROGEN (OIL)	D5291					Analyst: VJO
Carbon	38.8	0.01		%	1	5/25/2011
Hydrogen	11.0	0.01		%	1	5/25/2011
Nitrogen	2.21	0.01		%	1	5/25/2011
OXYGEN BY DIFFERENCE	D5291					Analyst: VJO
Oxygen	44.9	0.0100		%	1	5/25/2011
SULFUR	D1552					Analyst: JCW
Sulfur	0.0600	0.0100		%	1	5/18/2011

Qualifiers:

BRL - Below Reporting Limit	S - Spike Recovery outside accepted recovery limits
J - Analyte detected below quantitation limits	R - RPD outside accepted recovery limits
B - Analyte detected in the associated Method Blank	E - Value above quantitation range
* - Value exceeds Maximum Contaminant Level	H - Hold Time exceedance
N - Tentatively identified compound based on mass spectral library search	



Republic Environmental
Systems (Pennsylvania), LLC

2869 Sandstone Dr., Hatfield Pa. 19440

(tel)215-822-8995 (fax)215-822-1283

Certificate of Analytical Results

Date: 31-May-11

CLIENT: Weston Solutions, Inc.
1400 Weston Way
West Chester, PA 19380-1499
Project: 02329.047.001.0001

Lab Order: R11050028

Lab ID: R11050028-16 **Date Received:** 05/13/2011 **Date Sampled:** 05/10/2011 0:00

Client Sample ID: KC-B-LWFK

Matrix: AQUEOUS

Analyses	Result	Limit	Qual	Units	DF	Date Analyzed
ASH, OIL		D482				Analyst: VJO
Ash	2.02	0.0100		%	1	5/16/2011
CARBON, HYDROGEN, NITROGEN (OIL)		D5291				Analyst: VJO
Carbon	64.6	0.01		%	1	5/19/2011
Hydrogen	12.0	0.01		%	1	5/19/2011
Nitrogen	0.90	0.01		%	1	5/19/2011
OXYGEN BY DIFFERENCE		D5291				Analyst: VJO
Oxygen	20.3	0.0100		%	1	5/19/2011
SULFUR		D1552				Analyst: JCW
Sulfur	0.150	0.0100		%	1	5/18/2011

Qualifiers:

BRL - Below Reporting Limit

J - Analyte detected below quantitation limits

B - Analyte detected in the associated Method Blank

* - Value exceeds Maximum Contaminant Level

N - Tentatively identified compound based on mass spectral library search

S - Spike Recovery outside accepted recovery limits

R - RPD outside accepted recovery limits

E - Value above quantitation range

H - Hold Time exceedance

APPENDIX C: INPUT EMISSION DATA

**HAZARDOUS WASTE COMBUSTOR MACT
40 CFR PART 63, SUBPART EEE
NOTIFICATION OF COMPLIANCE (NOC)**

**KEYSTONE CEMENT COMPANY
BATH, PENNSYLVANIA**

August 2011

Submitted to: **Pennsylvania Department of
Environmental Protection
2 Public Square
Wilkes-Barre, Pennsylvania 18711**

Prepared by: **Keystone Cement Company
Route 329, P.O. Box A
Bath, Pennsylvania 18014**

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Keystone Cement Company – Bath, Pennsylvania
40 CFR Part 63, Subpart EEE
Hazardous Waste Combustor MACT
Notification of Compliance
August 2011

1.0 Introduction

Keystone Cement Company (Keystone) operates one preheater/precalciner portland cement kiln system at its facility in Bath, Pennsylvania. The kiln is capable of firing hazardous waste as fuel for energy recovery in two combustion zones; therefore, the facility is subject to the requirements contained in 40 Code of Federal Regulations (CFR) Part 63 Subpart EEE – National Emission Standards for Hazardous Air Pollutants from Hazardous Waste Combustors (HWC), also known as the HWC Maximum Achievable Control Technology (MACT) regulations. The initial HWC MACT regulations were promulgated on September 30, 1999, with a compliance date of September 30, 2003.¹ The HWC MACT regulations have been revised several times since the initial compliance date. In December 2008, Keystone submitted a Comprehensive Performance Test (CPT) Plan to the Pennsylvania Department of Environmental Protection (PADEP) to comply with the requirements of 40 CFR Part 63, Subpart EEE. PADEP granted approval of the plan in February 2009. Keystone submitted a revision to the CPT Plan in February 2011, which was approved by PADEP in April 2011. Keystone also prepared and operated under a Documentation of Compliance (DOC) from the time that the kiln system became operational (December 2009) until submission of this Notification of Compliance (NOC) as required under Subpart EEE.² The NOC contains the current information necessary to certify that the Keystone facility is in compliance with the requirements of Subpart EEE as well as the operating limits established as part of the CPT, and includes the certification statement required by the rule.

¹ The original compliance date of the September 30, 1999, regulations was September 30, 2002, but due to legal challenges and vacatur of the rule, Interim Standards were promulgated with a compliance date of September 30, 2003.

² See further discussion in Section 2.2.

The required content of a NOC is identified in §§63.7(g), 63.9(h), and specific subsections in §§63.1206, 63.1207, 63.1209, and 63.1210. Keystone has been issued a Title V permit; however, as a conservative measure, Keystone is also including in this NOC the contents detailed under §63.9(h)(2)(i). Keystone has summarized the specific citations that apply to the facility's NOC in Table 1-1. The following sections of this NOC contain the information necessary to document that the Keystone facility is in compliance with the requirements of 40 CFR Part 63, Subpart EEE.

2.0 NOC Requirements - 40 CFR 63.7 and 63.9

2.1 Methods Used to Determine Compliance - §63.9(h)(2)(i)(A)

In December 2008, Keystone submitted a CPT Plan that summarized the pollutants and standards for which compliance with Subpart EEE must be demonstrated. Additionally, the CPT Plan described the continuous monitoring systems (CMS) that monitor required kiln systems and emissions as well as establish operating parameter limits (OPLs) so that the facility can operate in compliance with Subpart EEE. The CPT Plan proposed testing for the following pollutants/standards as required by §63.1207:

- Destruction and removal efficiency (DRE);
- Low-volatile metals (LVMs) – arsenic, beryllium, and chromium;
- Semi-volatile metals (SVMs) – cadmium and lead;
- Mercury;³
- Hydrogen chloride/chlorine gas (HCl/Cl₂);
- Particulate Matter (PM);
- Total hydrocarbons (THC) at the main stack; and
- Dioxins and furans (D/F).

Keystone performed the HWC MACT CPT on May 6-12, 2011, to demonstrate compliance with the pollutants and standards identified above. Further information regarding the CPT testing and evaluation of the data are provided and/or referenced in Section 2.2 of this NOC.

The CPT Plan provided extrapolation procedures for the LVMs and SVMs (for both feedrates and hazardous waste thermal concentrations), and mercury (if appropriate) based on the data obtained during the CPT. The extrapolation of LVMs and SVMs are provided in Appendix E.

³ As provided in the CPT Plan, emissions testing for mercury was not conducted. Keystone demonstrated compliance with the maximum theoretical emission concentration (MTEC) emission standard during the testing (see Appendix E), and intends to comply with the mercury standard using this option. Further information regarding compliance with the mercury standard is provided in Section 2.3.

2.2 Performance Test Results – §§63.7(g)(1) and 63.9(h)(2)(i)(B)

As noted above, comprehensive performance testing was performed on kiln no. 1 to demonstrate compliance with the pollutants/standards noted in Section 2.1. The performance test program included monitoring and sampling of feedstreams, process parameters and exhaust gases. The testing and monitoring were conducted using approved methods as detailed in Section 5 of the CPT Plan. The test results compared to Subpart EEE limits for kiln no. 1 are presented in Tables 2-1 and 2-2 demonstrating that the kiln emissions meet the standards of 40 CFR Part 63, Subpart EEE. Supporting documentation including detailed emissions and feedrate data for the May 6-12, 2011 testing is included in Appendices A and B.

The CPT Plan included a discussion of the Subpart EEE-regulated CMSs. Keystone installed and operates the CMSs in accordance with the manufacturers' recommendations. The Keystone facility developed and follows a CMS Quality Assurance/Quality Control (QA/QC) Plan for the Subpart EEE-regulated CMSs required to demonstrate compliance with the regulation. The CMS QA/QC Plan is provided in Appendix D along with performance evaluation data for the Subpart EEE-regulated CMSs. Keystone maintains copies in the operating record of the required monitoring system performance evaluations.

2.3 Methods Used to Determine Continuing Compliance - §63.9(h)(2)(i)(C)

Data developed during the CPT were used to establish operating limits that will confirm compliance with applicable Subpart EEE emission standards. These limits are summarized in Tables 2-3 through 2-6. The LVM and SVM feedrate limitations detailed in Tables 2-3 through 2-6 are based on current extrapolated feedrates using a methodology approved in the December 2008 CPT Plan. The extrapolation calculations are provided in Appendix E.

Continuous monitors are in place to measure stack and process parameters to confirm ongoing compliance. The Subpart EEE monitoring requirements are specified in §63.1209. Under these rules, Keystone's kiln is required to be equipped with a variety of

different CMSs including continuous emissions monitoring systems (CEMS) for oxygen (O₂) and total hydrocarbons (THC) as well as process and air pollution control system parametric monitoring systems. The O₂ and THC CEMS are used to measure the THC emissions, corrected to 7% O₂, for compliance with the main stack THC emissions standard.

In addition to the CEMS, the following CMSs are installed and operating on Keystone's cement kiln system and serve to satisfy the CMS requirements of the rule:

- Liquid hazardous waste derived fuel feedrate monitors (flow monitors);
- Raw material (kiln feed, hydrated lime) feedrate monitors (feeder controllers);
- Kiln and in-line calciner⁴ exit temperature monitors (thermocouples);
- Particulate matter control device inlet temperature monitors (thermocouples);
- Kiln system differential pressure monitors (pressure sensors);
- Flue gas flow rate monitor (airflow monitor);
- Traditional fuel (e.g., coal, oil) feedrate monitors (flow monitors).

The CMSs are used to continuously monitor compliance with parametric limits established during the CPT. As required by the MACT regulation, each of the CMSs used to monitor these parameters has been installed and is being operated according to the manufacturer's written specifications or recommendations for installation, operation, and calibration.

It should be noted that the constituent feedrate limits specified in Tables 2-3 through 2-6 under Subpart EEE are based on a twelve-hour rolling average per the provisions of §63.1209(n) and (o). Keystone received PADEP approval to employ alternate monitoring as provided by §63.1209(g) for compliance with these limits based on hourly rolling averages if desired.⁵

⁴ The precalciner consists of two parts: the in-line calciner (ILC) and the down-draft calciner (DDC). See Figure 2-1 of the CPT Plan for the location of these portions of the precalciner.

⁵ Keystone requested the alternate monitoring in the CPT Plan, which was subsequently approved by PADEP.

Subpart EEE specifies the monitoring requirements for demonstrating compliance with the regulation's feedrate limits in §63.1209(c)(4). This subsection of the regulations requires the following:

- (i) Determining and recording the value of the parameter for each feedstream by sampling, analysis or other method;
- (ii) Determining and recording the mass or volume flowrate for each feedstream by a CMS; and
- (iii) Calculating and recording the mass feedrate of the parameter per unit of time.

Rather than continuously calculating and recording the parameter mass feedrate per unit of time, Keystone uses a program that incorporates the maximum hazardous waste fuel flowrate limits, conservatively high default values for other kiln feedstream flowrates, analytical data from each HWF tanker truck used to develop each HWF burn tank, and analytical data for the constituents in the other feedstreams (i.e., the 95% upper tolerance limit (UTL)) to calculate the maximum constituent levels for each tank of hazardous waste fuel fired. This approach, referred to as the "max-max" approach and approved by PADEP as part of the December 2008 CPT Plan (as revised) was designed to ensure that the total parameter feedrate limits for the kiln are never exceeded.

Dioxins and Furans (D/F), and Destruction and Removal Efficiency (DRE)

Keystone is complying with the D/F standards in §63.1220(b)(1)(ii) and the DRE standards in §63.1220(c)(1) by operating each combustion chamber in accordance with the limits specified in Tables 2-3 through 2-6, which include:

- Operation at greater than the minimum combustion chamber temperature (DRE standard only, see §63.1209(j)(1));
- Operation at or below the maximum airflow rate (see §63.1209(j)(2) and (k)(3));
- Operation at or below the maximum hazardous waste fuel feedrate (see §63.1209(j)(3) and (k)(4)); and

- Inlet gas temperature to the air pollution control equipment of 400°F or less (D/F standard only, see §63.1209(k)(1)).

Particulate Matter (PM)

Keystone complies with the PM emissions standard at §63.1220(b)(7) by maintaining the airflow rate at or below the maximum airflow rate (see §63.1209(m)(2)). Additionally, the facility maintains the dust collectors in accordance with the CMS QA/QC Plan.

Low-Volatile Metals (LVMs), Semi-Volatile Metals (SVMs), and Hydrogen Chloride/Chlorine Gas (HCl/Cl₂)

In order to comply with the LVM, SVM, and HCl/Cl₂ emission standards in §63.1220(b), Keystone operates at or below the maximum airflow limits (see §63.1209(n)(5) and (o)(2)) as well as the maximum chloride/chlorine feedrates (see §63.1209(n)(4) and (o)(1)) specified in Tables 2-3 through 2-6. For SVMs and LVMs, Keystone has extrapolated the LVM and SVM feedrates and hazardous waste thermal concentrations in accordance with the provisions of §63.1209(n)(2) and Keystone's approved December 2008 CPT Plan (see Appendix E), and operates at or below the maximum inlet temperatures to the particulate matter air pollution control device limits specified in Tables 2-3 through 2-6 (see §63.1209(n)(1)). Although Keystone identified in its CPT Plan that it may comply with the LVM and SVM emissions standards using emissions averaging as provided in §63.1220(d)(2), it has not elected to do so at this time. Therefore, while Keystone maintains the operating hours of the raw mill when combusting hazardous waste derived fuel (i.e., raw mill on hours vs. raw mill off hours), it will not need to utilize the raw mill on/off hours to demonstrate compliance with the LVM and SVM emissions standards. It will comply with the LVM and SVM emission standards by complying with the feedrate limits established during the CPT (see Tables 2-3 through 2-6) irrespective of the on or off condition of the raw mill.

Mercury

For mercury (Hg), Keystone will comply with the as-fired mercury concentration in §63.1220(b)(2)(i) and the maximum theoretical emission concentration (MTEC)

approach as provided in §63.1220(b)(2)(ii)(B). To comply with these requirements, Keystone:

- Monitors and records the feedrate of mercury for each hazardous waste feedstream to each combustion zone;
- Interlocks if the maximum feedrate limit of mercury is exceeded; and
- Interlocks if the minimum airflow rate is exceeded (i.e., the airflow drops below the established minimum airflow rate).

The maximum feedrate limit and minimum airflow rate are provided in Tables 2-3 through 2-6.

The facility has and will continue to submit the reports required by Subpart EEE and the General Provisions. The following additional reports will be submitted as required:

- Excess emissions and continuous monitoring system performance reports semi-annually;
- Periodic start-up, shutdown and malfunction (SSM) reports semi-annually;
- Immediate SSM reports, as required, orally within two days and written within seven days;
- Exceedance reports for exceedances of a MACT standard or operating requirement when hazardous waste fuel remained in the kiln, within five days after each set of ten exceedances within a sixty-day block period;
- Reports of performance tests conducted on the CEMS and other CMS annually (as appropriate);
- Performance test protocols in advance of testing; and
- Reports on performance test results.

2.4 Type and Quantity of HAPs Emitted - §63.9(h)(2)(i)(D)

The type and quantity of hazardous air pollutants (HAPs) emitted by the kiln system at Keystone, after emissions controls, are reported in Tables 2-1 and 2-2. The values that are reported in these tables are consistent with the units and averaging times for the test methods used to demonstrate compliance with the relevant standards.

2.5 Status as Major Source or Area Source - §63.9(h)(2)(i)(E)

A major source of HAPs is a source that has the potential to emit 10 tons per year of a single HAP or a combined 25 tons per year of HAPs. As a portland cement kiln burning hazardous waste, the Keystone facility does not meet the definition of an area source. The potential annual amount of HCl emissions from the facility confirms the facility's status as a major source. Based on the HWC MACT regulations, the facility's potential to emit HCl/Cl₂ is 86 ppmv at 7% O₂. Based on the annual average emissions calculated using the May 2011 CPT emissions concentrations and a kiln system uptime of just over 90% (i.e., 330 hours/year), the average HCl/Cl₂ emission rate is approximately 59.6 tons/year (assuming 65% raw mill on time / 35% raw mill off time). The annual emissions of other HAPs are low relative to HCl annual emissions, and since the facility is considered a major source for HCl, a discussion of other HAPs is not included here. The HCl/Cl₂ emission rate calculation is presented in Table 2-7.

2.6 Description of Air Pollution Control Equipment - §63.9(h)(2)(i)(F)

There are two baghouses directly associated with Keystone's cement kiln system. The main baghouse is a pulse jet baghouse with six compartments that is manufactured by Solios Environment. It has a cloth area of approximately 91,667 ft². The main baghouse controls the emissions from the kiln system (i.e., kiln, preheater/precalciner tower, raw mill (when operating)). The bypass baghouse is also a pulse jet baghouse that is manufactured by FLSmidth. It has 1 compartment and a cloth area of approximately 14,148 ft². It controls a slipstream of exhaust from the rotary kiln; however, the exhaust from the bypass baghouse discharges back into the main kiln exhaust after the preheater tower and prior to the raw mill. Therefore, the exhaust from the main baghouse is the only discharge point to the atmosphere for the pyroprocess.

Control efficiencies for the kiln system were calculated based on an analysis of the feedstreams and a determination of the metals mass emission rates measured at the testing location (i.e., main stack, which is after the discharge (i.e., clean) side of the main baghouse) during the May 2011 CPT. A summary of the control efficiencies for the

LVMs, SVMs, and HCl/Cl₂ as determined from the May 2011 CPT is provided in Table 2-8.

2.7 Statement of Compliance - §63.9(h)(2)(i)(G)

By submitting this NOC, Keystone is stating that the facility is in compliance with the requirements of 40 CFR Part 63, Subpart EEE. Section 4.0 of this NOC includes a signed certification attesting to the status of the Keystone facility relative to the requirements of 40 CFR 63, Subpart EEE.

3.0 NOC Requirements Contained in 40 CFR Parts 63.1206, 63.1207, 63.1209, 63.1210, and 63.1220

Specific NOC requirements that are contained in 40 CFR Part 63, Subpart EEE are addressed in the following subsections.

3.1 Statement of Compliance Using Emissions Averaging – §63.1220(d)(2)(iii)(C)

As noted in Section 2.3 above, Keystone does not intend at this time to demonstrate compliance using the emissions averaging provisions of §63.1220(d)(2). Compliance will be based on the feedrates established during the CPT (as provided in Tables 2-3 and through 2-6).

3.2 Calculations of Hazardous Waste Residence Time – §63.1206(b)(11)

The calculated hazardous waste residence time is considered the time beginning when the AWFCO valves are completely closed and ending when the combustion gases from the hazardous waste fuel leave the combustion chamber. Keystone has calculated the hazardous waste residence time in each combustion chamber based upon the dimensions of the combustion chambers (i.e., kiln and precalciner (i.e., DDC and ILC)). In order to calculate the hazardous waste fuel residence time in each combustion chamber as required under §63.1206(b)(11), Keystone utilized design flow rate information provided by the original equipment manufacturer, and considered that 7% of the kiln volume would be occupied by the product and/or raw material present in the kiln.

The approximate hazardous waste residence times for each combustion zone are summarized below. The hazardous waste residence time calculations are included in Table 3-1.

	Rotary Kiln	Calciner (DDC/ILC)
Calculated Residence Time	8.8 seconds	10.5 seconds

3.3 Summary of Operating Requirements – §63.1206(c)(1)(ii)

As detailed in Section 2.3, Keystone complies with the operating requirements specified for kiln no. 1 in Tables 2-3 through 2-6.

3.4 Combustion System Leaks – §63.1206(c)(5)(ii)

Pressure sensors are located at the firing hood of the kiln and at the exit of the ILC. The firing hood pressure sensor monitors the pressure at the rotary kiln combustion zone, and the pressure sensor at the exit of the ILC monitors the pressure of the precalciner combustion zone. These pressure sensors ensure that the combustion systems (i.e., the kiln and DDC/ILC) are maintained under a negative pressure when hazardous waste is present in the kiln system. The sensors monitor the pressure continuously and the PLC system selectively interrogates the sensors every 15 seconds. A differential pressure reading greater than or equal to -0.01 inches of water results in an AWFCO.

3.5 Schedule for Submitting the NOC – §63.1207(j)

Keystone prepared a Documentation of Compliance (DOC) prior to the initial startup of the facility (December 9, 2009), and revised the DOC prior to the commencement of WDF combustion (May 14, 2010). The facility has operated under a DOC since December 2009. The facility initiated the HWC MACT CPT for kiln no. 1 on May 6, 2011, and completed the testing activities on May 12, 2011. Keystone is submitting this NOC no later than 90 days following the completion of the comprehensive performance testing to satisfy the requirements of 40 CFR 63.1207(j).

3.6 Documentation of Alternate Modes of Operation – §63.1209(q)(1)(ii)

Section 4.1 of the December 2008 CPT Plan (as revised) identified potential operating scenarios for the Keystone facility, including the possibility that Keystone may elect to comply with otherwise applicable requirements (i.e., the Portland Cement MACT) when the facility is not combusting hazardous waste. However, Keystone has currently elected to comply with the HWC MACT emission standards and established OPLs at all times

regardless of whether or not the facility is combusting HWF, except during periods of startup, shutdown, and malfunction.

For the purpose of HWC MACT compliance, there are two distinct modes of operation: (1) normal operations with the in-line raw mill on; and (2) normal operations with the in-line raw mill off. During periods of HWF combustion, the facility will comply with the emissions standards and OPLs identified in Tables 2-3 and 2-5. However, Keystone understands that certain HWC MACT requirements are not applicable after the residence time has expired. According to the February 14, 2002 Federal Register (pp. 6979-6980), it is “self-evident which provisions are applicable after the hazardous waste residence time has expired” (see Appendix F). Using the language from the referenced Federal Register, the results of the May 6-12, 2011 CPT, and engineering judgment, Keystone has developed Tables 2-4 and 2-6 indicating the applicable Subpart EEE OPLs during periods of time when the facility is not combusting HWF and the residence time has expired. Therefore, Keystone is not currently electing to comply with otherwise applicable requirements during periods when the kiln system is not combusting HWF.

3.7 Notification of Compliance Requirements – §63.1210(d)

40 CFR 63.1210(d) provides that a Notice of Compliance (NOC) is required for the initial comprehensive performance test and each subsequent comprehensive and confirmatory performance test. The NOC must be postmarked before the close of business on the ninetieth day following the completion of the test. All operating limits in the NOC become effective upon postmark and supersede any prior NOC or DOC. As detailed in Section 2.1, Keystone performed comprehensive performance testing during May 6-12, 2011, to establish all operating limits and parameters required by the HWC MACT regulation. As required, Keystone submits this NOC within 90 days of the completion of the initial CPT. This NOC is hereby made part of the facility operating record pursuant to the provisions of §63.1206(b)(5)(ii).

4.0 NOC Statement of Compliance (40 CFR 63.9(h)(2)(i)(G))

Keystone Cement Company, Bath, Pennsylvania

To the best of my knowledge and belief and based on an engineering evaluation prepared under my direction or supervision in accordance with a system designed to ensure that qualified personnel properly gathered and evaluated the information and supporting documentation, and considering at a minimum the design, operation, and maintenance characteristics of the combustor and emissions control equipment, the types, quantities, and characteristics of feedstreams, and available emissions data:

- Keystone is in compliance with the emission standards of this subpart; and
- The limits on the operating parameters required by §63.1209 ensure compliance with the emission standards of this subpart.

Further, to the best of my knowledge and belief, all HWC MACT required CEMS and CMS are installed, calibrated, and continuously operating in compliance with the requirements of Subpart EEE.

Stephen J. Hayden, Jr.
Name (Typed or Printed)


Signature

August 10, 2011
Date:

Table 1-1
Notice of Compliance Applicable 40 CFR Part 63 Citations
Keystone Cement Company
Bath, Pennsylvania

Regulatory Citation	Description
40 CFR 63.7(g)(1)	Report performance test results in NOC
40 CFR 63.9(h)(2)(i)	Minimum contents of a NOC are specified as follows:
40 CFR 63.9(h)(2)(i)(A)	Methods used to determine compliance
40 CFR 63.9(h)(2)(i)(B)	Results of performance tests
40 CFR 63.9(h)(2)(i)(C)	Methods used to determine continuing compliance
40 CFR 63.9(h)(2)(i)(D)	Type and quantity of HAPs emitted
40 CFR 63.9(h)(2)(i)(E)	Status as a major or area source
40 CFR 63.9(h)(2)(i)(F)	Description of air pollution control equipment
40 CFR 63.9(h)(2)(i)(G)	Statement of compliance
40 CFR 63.1206(b)(11)	Calculations of hazardous waste residence time
40 CFR 63.1206(c)(1)(ii)	Summary of operating requirements
40 CFR 63.1206(c)(5)(ii)	Combustion system leak prevention method
40 CFR 63.1207(j)	Schedule for submitting NOC
40 CFR 63.1209(q)(1)(ii)	Documentation of alternate mode of operation
40 CFR 63.1210(d)	Notification of Compliance requirements
40 CFR 63.1220(d)(2)(iii)(C)	Statement of compliance using emissions averaging

Table 2-1
Subpart EEE Standards and CPT Results
Kiln No. 1, Scenario B – Raw Mill On
Keystone Cement Company
Bath, Pennsylvania

Pollutant	Limit	CPT Results
Mercury ⁽¹⁾	120 ug/dscm MTEC ⁽²⁾	3.33 ug/dscm @ 7% O ₂ MTEC ⁽²⁾
Dioxins and Furans (D/F)	0.4 ng TEQ/dscm @ 7% O ₂	0.0025 ng TEQ/dscm @ 7% O ₂
SVM (Cadmium and Lead (combined))	180 ug/dscm @ 7% O ₂	5.43 ug/dscm @ 7% O ₂
SVM Hazardous Waste Thermal Limit	6.2E-05 lbs SVM emitted from HWF/MMBtu HWF	9.3E-08 lbs SVM emitted from HWF/MMBtu HWF ⁽³⁾
LVM (Arsenic, Beryllium, and Chromium (combined))	54 ug/dscm @ 7% O ₂	1.76 ug/dscm @ 7% O ₂
LVM Hazardous Waste Thermal Limit	1.5E-05 lbs LVM emitted from HWF/MMBtu HWF	2.1E-07 lbs SVM emitted from HWF/MMBtu HWF ⁽³⁾
HCl and Cl ₂ (as Cl ⁻ equivalents, combined)	86 ppmvd @ 7% O ₂	6.46 ppmvd @ 7% O ₂
Total Hydrocarbons (HRA) ⁽⁴⁾ Main Stack	20 ppmvd @ 7% O ₂ (HRA)	0.2 ppmvd @ 7% O ₂ (HRA)
Particulate Matter	0.0069 gr/dscf @ 7% O ₂	0.0022 gr/dscf @ 7% O ₂
	≤20% opacity ⁽⁵⁾	⁽⁵⁾

⁽¹⁾ Keystone demonstrated compliance during the May 2011 CPT with the mercury standard using a hazardous waste feed maximum theoretical emission concentration (MTEC) as provided at §63.1220(b)(2)(ii)(B), and intends to demonstrate on-going compliance using the MTEC approach.

⁽²⁾ The mercury standard at §63.1220(b)(2)(ii)(B) of 120 ug/dscm does not specify a correction for oxygen. The MTEC results reported here have been corrected to 7% oxygen. See Appendix E for the MTEC calculation based on the May 2011 CPT. The uncorrected MTEC result is 1.75 ug/dscm.

⁽³⁾ See Appendix E for the calculation of the SVM and LVM hazardous waste thermal limits based on the May 2011 CPT.

⁽⁴⁾ HRA is Hourly Rolling Average. The value reported here is the average of the maximum HRAs recorded during each run.

⁽⁵⁾ Opacity is only required if the source is not equipped with a bag leak detection system. Keystone operates and maintains a bag leak detection system, and therefore, is not subject to the opacity standard.

Table 2-2
Subpart EEE Standards and CPT Results
Kiln No. 1, Scenario A – Raw Mill Off
Keystone Cement Company
Bath, Pennsylvania

Pollutant	Limit	CPT Results
Mercury ⁽¹⁾	120 ug/dscm MTEC ⁽²⁾	4.53 ug/dscm @ 7% O ₂ MTEC ⁽²⁾
Dioxins and Furans (D/F)	0.4 ng TEQ/dscm @ 7% O ₂	0.00225 ng TEQ/dscm @ 7% O ₂
SVM (Cadmium and Lead (combined))	180 ug/dscm @ 7% O ₂	9.28 ug/dscm @ 7% O ₂
SVM Hazardous Waste Thermal Limit	6.2E-05 lbs SVM emitted from HWF/MMBtu HWF	3.6E-07 lbs SVM emitted from HWF/MMBtu HWF ⁽³⁾
LVM (Arsenic, Beryllium, and Chromium (combined))	54 ug/dscm @ 7% O ₂	6.44 ug/dscm @ 7% O ₂
LVM Hazardous Waste Thermal Limit	1.5E-05 lbs LVM emitted from HWF/MMBtu HWF	4.8E-07 lbs SVM emitted from HWF/MMBtu HWF ⁽³⁾
HCl and Cl ₂ (as Cl ⁻ equivalents, combined)	86 ppmvd @ 7% O ₂	49.32 ppmvd @ 7% O ₂
Total Hydrocarbons (HRA) ⁽⁴⁾ Main Stack	20 ppmvd @ 7% O ₂ (HRA)	1.4 ppmvd @ 7% O ₂ (HRA)
Particulate Matter	0.0069 gr/dscf @ 7% O ₂	0.0032 gr/dscf @ 7% O ₂
	≤20% opacity ⁽⁵⁾	⁽⁵⁾

⁽¹⁾ Keystone demonstrated compliance during the May 2011 CPT with the mercury standard using a hazardous waste feed maximum theoretical emission concentration (MTEC) as provided at §63.1220(b)(2)(ii)(B), and intends to demonstrate on-going compliance using the MTEC approach.

⁽²⁾ The mercury standard at §63.1220(b)(2)(ii)(B) of 120 ug/dscm does not specify a correction for oxygen. The MTEC results reported here have been corrected to 7% oxygen. See Appendix E for the MTEC calculation based on the May 2011 CPT. The uncorrected MTEC result is 2.68 ug/dscm.

⁽³⁾ See Appendix E for the calculation of the SVM and LVM hazardous waste thermal limits based on the May 2011 CPT.

⁽⁴⁾ HRA is Hourly Rolling Average. The value reported here is the average of the maximum HRAs recorded during each run.

⁽⁵⁾ Opacity is only required if the source is not equipped with a bag leak detection system. Keystone operates and maintains a bag leak detection system, and therefore, is not subject to the opacity standard.

Table 2-3
Operating Parameter Limits and Compliance Methodologies When Combusting HWF
Kiln No. 1, Scenario B – Raw Mill On
Keystone Cement Company
Bath, Pennsylvania

Operating Parameters/ Compliance Methodologies	Operating Parameter Limits, Kiln No. 1	Averaging Period	Basis of Limit	Associated Emission Standard(s)
Maximum Hazardous Waste Fuel (HWF) Feedrate – Kiln (tons/hr (gpm))	7.9 (34.9) ⁽¹⁾	HRA	May 6-12, 2011 CPT RM Off	Dioxins/Furans (D/F), DRE
Maximum Hazardous Waste Fuel (HWF) Feedrate – DDC (tons/hr (gpm))	3.3 (15.3) ⁽¹⁾	HRA	May 6-12, 2011 CPT RM Off	Dioxins/Furans (D/F), DRE
Maximum LVM Hazardous Waste Thermal Concentration (lb input attributable to HWF/MMBtu HWF)	0.17 ⁽²⁾	Fuel Limit ⁽²⁾	May 6-12, 2011 CPT RM On and Approved Extrapolation ⁽⁶⁾	LVMs
Maximum SVM Hazardous Waste Thermal Concentration (lb input attributable to HWF/MMBtu HWF)	1.27 ⁽²⁾	Fuel Limit ⁽²⁾	May 6-12, 2011 CPT RM On and Approved Extrapolation ⁽⁶⁾	SVMs
Maximum Flue Gas Flow Rate (acfm)	361,500	HRA ⁽³⁾	May 6-12, 2011 CPT RM On	Particulate Matter, LVMs SVMs, HCl/Cl ₂ , D/F, DRE
Minimum Flue Gas Flow Rate (dscfm @ 7% O ₂)	67,421	HRA	Engineering Calculation	Hg (MTEC) ⁽⁵⁾
Minimum Kiln Combustion Zone Temperature (°F)	1,881.4	HRA	May 6-12, 2011 CPT RM Off	DRE
Minimum DDC Combustion Zone Temperature (°F)	1,570.6	HRA	May 6-12, 2011 CPT RM Off	DRE
Maximum Bypass APCD Inlet Temperature (°F)	359.6	HRA	May 6-12, 2011 CPT RM On	D/F, SVMs, LVMs
Maximum Main APCD Inlet Temperature (°F)	393.9	HRA	May 6-12, 2011 CPT RM Off	D/F, SVMs, LVMs
Minimum Kiln Combustion Zone Pressure (in. w.c.)	≤ 0.0	Inst. ⁽³⁾	Regulatory Limit	Combustion System Leaks
Minimum DDC Combustion Zone Pressure (in. w.c.)	≤ 0.0	Inst. ⁽³⁾	Regulatory Limit	Combustion System Leaks
Minimum Kiln Atomization Air Pressure (psig)	≤ 0.0	Inst. ⁽³⁾	Engineering Judgment	DRE
Minimum DDC Atomization Air Pressure (psig)	≤ 0.0	Inst. ⁽³⁾	Engineering Judgment	DRE
Maximum LVM Feedrates (g/hr total (lb/hr total))	132,861 (292.9)	HRA ⁽⁴⁾	May 6-12, 2011 CPT RM On and Approved Extrapolation ⁽⁶⁾	LVMs
Maximum SVM Feedrates (g/hr total (lb/hr total))	819,399 (1,806.4)	HRA ⁽⁴⁾	May 6-12, 2011 CPT RM On and Approved Extrapolation ⁽⁶⁾	SVMs
Maximum Mercury Hazardous Waste Feedrate (g/hr total (lb/hr total)) ⁽⁵⁾⁽⁶⁾	13.6 (0.030)	HRA ⁽⁴⁾	Engineering Calculation	Hg (MTEC)
Maximum Chloride Feedrate (g/hr total (lb/hr total))	419,564 (925.0)	HRA ⁽⁴⁾	May 6-12, 2011 CPT RM On	HCl/Cl ₂ , LVMs, SVMs
THC Concentration – Main Stack (ppmv @ 7% O ₂)	20	HRA	Regulatory Limit	THC

- (1) The PADEP limitation on the total maximum hazardous waste feedrate to the kiln system (i.e., to the kiln and DDC combined) is 50.2 gpm based on the CPT. The HWC MACT limit of 11.2 tons/hr is a mass input limit based on the CPT.
- (2) Maximum flue gas flow rate is required to be established on an hourly rolling average for dioxins/furans and DRE and a 12-hour rolling average for LVMs, SVMs, and HCl/Cl₂. Therefore, as a conservative measure, Keystone is maintaining an hourly rolling average for maximum flue gas flow rate to demonstrate compliance for all standards.
- (3) The kiln and DDC combustion zone pressures are monitored continuously, and the PLC system selectively interrogates the sensors every 15 seconds.
- (4) Keystone may elect to comply with the 12-hour rolling average values using an hourly rolling average as a conservative measure.
- (5) Keystone will comply with the maximum theoretical emission concentration (MTEC) approach for mercury by establishing a maximum mercury HWF feedrate and a minimum airflow (see note (6)).
- (6) The minimum airflow is based on a maximum Hg concentration in the HWF of 1.34 ppmw; therefore, the maximum as-fired Hg concentration in the HWF will be limited to 1.34 ppmw.
- (7) These are the calculated OPLs using the LVM HWF thermal concentration standard (1.5E-05 lbs emitted attributable to HWF/MMBtu HWF) divided by one minus the measured LVM system removal efficiency (SRE) during the RM On operating scenario of 99.991%; and the SVM HWF thermal concentration standard (6.2E-05 lbs emitted attributable to HWF/MMBtu HWF) divided by one minus the measured SVM SRE during the RM On operating scenario of 99.995%.
- (8) The extrapolation methodology was provided in the CPT Plan, which was approved by PADEP on February 9, 2009.
- (9) Keystone intends to demonstrate compliance with these limits in the fuels lab prior to releasing the HWF for combustion.
- (10) The kiln and DDC atomization air is monitored by the data acquisition and handling system as a discrete signal, i.e., the air pressure is "OK" or "Not OK." A "Not OK" signal results in an A WFCO at both the kiln and DDC burner locations.

Table 2-4
Operating Parameter Limits and Compliance Methodologies After the HWF Residence Time Has Transpired
Kiln No. 1, Scenario B – Raw Mill On
Keystone Cement Company
Bath, Pennsylvania

Operating Parameters/ Compliance Methodologies	Operating Parameter Limits, Kiln No. 1	Averaging Period	Basis of Limit	Associated Emission Standard(s)
Maximum Hazardous Waste Fuel (HWF) Feedrate – Kiln (tons/hr (gpm))	0 (Monitor Only)	HRA	Self-Evident Non-Applicability	Dioxins/Furans (D/F), DRE
Maximum Hazardous Waste Fuel (HWF) Feedrate – DDC (tons/hr (gpm))	0 (Monitor Only)	HRA	Self-Evident Non-Applicability	Dioxins/Furans (D/F), DRE
Maximum LVM Hazardous Waste Thermal Concentration (lb input attributable to HWF/MMBtu HWF)	0	HWF Fuel Limit	Self-Evident Non-Applicability	LVMs
Maximum SVM Hazardous Waste Thermal Concentration (lb input attributable to HWF/MMBtu HWF)	0	HWF Fuel Limit	Self-Evident Non-Applicability	SVMs
Maximum Flue Gas Flow Rate (acfm)	361,500	HRA ⁽²⁾	May 6-12, 2011 CPT RM On	Particulate Matter, LVMs SVMs, HCl/Cl ₂ , D/F, DRE
Minimum Flue Gas Flow Rate (dscfm @ 7% O ₂)	N/A (Monitor Only)	HRA	Self-Evident Non-Applicability	Hg (MTEC)
Minimum Kiln Combustion Zone Temperature (°F)	N/A (Monitor Only)	HRA	Self-Evident Non-Applicability	DRE
Minimum DDC Combustion Zone Temperature (°F)	N/A (Monitor Only)	HRA	Self-Evident Non-Applicability	DRE
Maximum Bypass APCD Inlet Temperature (°F)	359.6	HRA	May 6-12, 2011 CPT RM On	D/F, SVMs, LVMs
Maximum Main APCD Inlet Temperature (°F)	393.9	HRA	May 6-12, 2011 CPT RM On	D/F, SVMs, LVMs
Minimum Kiln Combustion Zone Pressure (in. w.c.)	N/A (Monitor Only)	Inst.	Self-Evident Non-Applicability	Combustion System Leaks
Minimum DDC Combustion Zone Pressure (in. w.c.)	N/A (Monitor Only)	Inst.	Self-Evident Non-Applicability	Combustion System Leaks
Minimum Kiln Atomization Air Pressure (psig)	N/A (Monitor Only)	Inst.	Self-Evident Non-Applicability	DRE
Minimum DDC Atomization Air Pressure (psig)	N/A (Monitor Only)	Inst.	Self-Evident Non-Applicability	DRE
Maximum LVM Feedrates (g/hr total (lb/hr total))	132,861 (292.9)	HRA ⁽⁴⁾	May 6-12, 2011 CPT RM On and Approved Extrapolation ⁽⁸⁾	LVMs
Maximum SVM Feedrates (g/hr total (lb/hr total))	819,399 (1,806.4)	HRA ⁽⁴⁾	May 6-12, 2011 CPT RM On and Approved Extrapolation ⁽⁸⁾	SVMs
Maximum Mercury Hazardous Waste Feedrate (g/hr total (lb/hr total))	0	HRA	Self-Evident Non-Applicability	Hg (MTEC)
Maximum Chloride Feedrate (g/hr total (lb/hr total))	419,564 (925.0)	HRA ⁽⁴⁾	May 6-12, 2011 CPT RM On	HCl/Cl ₂ , LVMs, SVMs
THC Concentration – Main Stack (ppmv @ 7% O ₂)	20	HRA	Regulatory Limit	THC

- (1) Reserved.
- (2) Maximum flue gas flow rate is required to be established on an hourly rolling average for dioxins/furans and DRE and a 12-hour rolling average for LVMs, SVMs, and HCl/C_l₂. Therefore, as a conservative measure, Keystone is maintaining an hourly rolling average for maximum flue gas flow rate to demonstrate compliance for all standards.
- (3) Reserved.
- (4) Keystone may elect to comply with the 12-hour rolling average values using an hourly rolling average as a conservative measure.
- (5) Reserved.
- (6) Reserved.
- (7) Reserved.
- (8) The extrapolation methodology was provided in the CPT Plan, which was approved by PADEP on February 9, 2009.
- (9) Reserved.
- (10) Reserved.

Table 2-5
Operating Parameter Limits and Compliance Methodologies When Combusting HWF
Kiln No. 1, Scenario A – Raw Mill Off
Keystone Cement Company
Bath, Pennsylvania

Operating Parameters/ Compliance Methodologies	Operating Parameter Limits, Kiln No. 1	Averaging Period	Basis of Limit	Associated Emission Standard(s)
Maximum Hazardous Waste Fuel (HWF) Feedrate – Kiln (tons/hr (gpm))	7.9 (34.9) ⁽¹⁾	HRA	May 6-12, 2011 CPT RM Off	Dioxins/Furans (D/F), DRE
Maximum Hazardous Waste Fuel (HWF) Feedrate – DDC (tons/hr (gpm))	3.3 (15.3) ⁽¹⁾	HRA	May 6-12, 2011 CPT RM Off	Dioxins/Furans (D/F), DRE
Maximum LVM Hazardous Waste Thermal Concentration (lb input attributable to HWF/MMBtu HWF)	0.08g ⁽²⁾	Fuel Limit ⁽³⁾	May 6-12, 2011 CPT RM Off and Approved Extrapolation ⁽⁶⁾	LVMs
Maximum SVM Hazardous Waste Thermal Concentration (lb input attributable to HWF/MMBtu HWF)	0.18g ⁽²⁾	Fuel Limit ⁽³⁾	May 6-12, 2011 CPT RM Off and Approved Extrapolation ⁽⁶⁾	SVMs
Maximum Flue Gas Flow Rate (acfm)	361,900	HRA ⁽²⁾	May 6-12, 2011 CPT RM Off	Particulate Matter, LVMs SVMs, HCl/Cl ₂ , D/F, DRE
Minimum Flue Gas Flow Rate (discfm @ 7% O ₂)	67,421	HRA	Engineering Calculation	Hg (MTEC) ⁽⁵⁾
Minimum Kiln Combustion Zone Temperature (°F)	1,881.4	HRA	May 6-12, 2011 CPT RM Off	DRE
Minimum DDC Combustion Zone Temperature (°F)	1,570.6	HRA	May 6-12, 2011 CPT RM Off	DRE
Maximum Bypass APCD Inlet Temperature (°F)	359.2	HRA	May 6-12, 2011 CPT RM Off	D/F, SVMs, LVMs
Maximum Main APCD Inlet Temperature (°F)	393.9	HRA	May 6-12, 2011 CPT RM Off	D/F, SVMs, LVMs
Minimum Kiln Combustion Zone Pressure (in. w.c.)	≤ 0.0	Inst. ⁽³⁾	Regulatory Limit	Combustion System Leaks
Minimum DDC Combustion Zone Pressure (in. w.c.)	≤ 0.0	Inst. ⁽³⁾	Regulatory Limit	Combustion System Leaks
Minimum Kiln Atomization Air Pressure (psig)	(10)	Inst.	Engineering Judgment	DRE
Minimum DDC Atomization Air Pressure (psig)	(10)	Inst.	Engineering Judgment	DRE
Maximum LVM Feedrates (g/hr total (lb/hr total))	69,493 (153.2)	HRA ⁽⁴⁾	May 6-12, 2011 CPT RM Off and Approved Extrapolation ⁽⁶⁾	LVMs
Maximum SVM Feedrates (g/hr total (lb/hr total))	117,016 (258)	HRA ⁽⁴⁾	May 6-12, 2011 CPT RM Off and Approved Extrapolation ⁽⁶⁾	SVMs
Maximum Mercury Hazardous Waste Feedrate (g/hr total (lb/hr total)) ⁽⁵⁾⁽⁶⁾	13.6 (0.030)	HRA ⁽⁴⁾	Engineering Calculation	Hg (MTEC)
Maximum Chloride Feedrate (g/hr total (lb/hr total))	435,610 (960.3)	HRA ⁽⁴⁾	May 6-12, 2011 CPT RM Off	HCl/Cl ₂ , LVMs, SVMs
THC Concentration – Main Stack (ppmv @ 7% O ₂)	20	HRA	Regulatory Limit	THC

- (1) The PADEP limitation on the total maximum hazardous waste feedrate to the kiln system (i.e., to the kiln and DDC combined) is 50.2 gpm based on the CPT. The HWC MACT limit of 11.2 tons/hr is a mass input limit based on the CPT.
- (2) Maximum flue gas flow rate is required to be established on an hourly rolling average for LVMs, SVMs, and HCl/Cl₂. Therefore, as a conservative measure, Keystone is maintaining an hourly rolling average for maximum flue gas flow rate to demonstrate compliance for all standards.
- (3) The kiln and DDC combustion zone pressures are monitored continuously, and the PLC system selectively interrogates the sensors every 15 seconds.
- (4) Keystone may elect to comply with the 12-hour rolling average values using an hourly rolling average as a conservative measure.
- (5) Keystone will comply with the maximum theoretical emission concentration (MTEC) approach for mercury by establishing a maximum mercury HWF feedrate and a minimum airflow (see note (6)).
- (6) The minimum airflow is based on a maximum Hg concentration in the HWF of 1.34 ppmw; therefore, the maximum as-fired Hg concentration in the HWF will be limited to 1.34 ppmw.
- (7) These are the calculated OPLs using: the LVM HWF thermal concentration standard (1.5E-05 lbs emitted attributable to HWF/MMBtu HWF) divided by one minus the measured LVM system removal efficiency (SRE) during the RM Off operating scenario of 99.983%; and the SVM HWF thermal concentration standard (6.2E-05 lbs emitted attributable to HWF/MMBtu HWF) divided by one minus the measured SVM SRE during the RM Off operating scenario of 99.966%.
- (8) The extrapolation methodology was provided in the CPT Plan, which was approved by PADEP on February 9, 2009.
- (9) Keystone intends to demonstrate compliance with these limits in the fuels lab prior to releasing the HWF for combustion.
- (10) The kiln and DDC atomization air is monitored by the data acquisition and handling system as a discrete signal, i.e., the air pressure is "OK" or "Not OK." A "Not OK" signal results in an AWFCO at both the kiln and DDC burner locations.

Table 2-6
Operating Parameter Limits and Compliance Methodologies After the HWF Residence Time Has Transpired
Kiln No. 1, Scenario A – Raw Mill Off
Keystone Cement Company
Bath, Pennsylvania

Operating Parameters/ Compliance Methodologies	Operating Parameter Limits, Kiln No. 1	Averaging Period	Basis of Limit	Associated Emission Standard(s)
Maximum Hazardous Waste Fuel (HWF) Feedrate – Kiln (g/hr (tons/hr)(gpm))	0 (Monitor Only)	HRA	Self-Evident Non-Applicability	Dioxins/Furans (D/F), DRE
Maximum Hazardous Waste Fuel (HWF) Feedrate – DDC (g/hr (tons/hr)(gpm))	0 (Monitor Only)	HRA	Self-Evident Non-Applicability	Dioxins/Furans (D/F), DRE
Maximum LVM Hazardous Waste Thermal Concentration (lb input attributable to HWF/MMBtu HWF)	0	HWF Fuel Limit	Self-Evident Non-Applicability	LVMs
Maximum SVM Hazardous Waste Thermal Concentration (lb input attributable to HWF/MMBtu HWF)	0	HWF Fuel Limit	Self-Evident Non-Applicability	SVMs
Maximum Flue Gas Flow Rate (acfm)	361,900	HRA ⁽²⁾	May 6-12, 2011 CPT RM Off	Particulate Matter, LVMs SVMs, HCl/Cl ₂ , D/F, DRE
Minimum Flue Gas Flow Rate (dscfm @ 7% O ₂)	N/A (Monitor Only)	HRA	Self-Evident Non-Applicability	Hg (MTEC)
Minimum Kiln Combustion Zone Temperature (°F)	N/A (Monitor Only)	HRA	Self-Evident Non-Applicability	DRE
Minimum DDC Combustion Zone Temperature (°F)	N/A (Monitor Only)	HRA	Self-Evident Non-Applicability	DRE
Maximum Bypass APCD Inlet Temperature (°F)	359.2	HRA	May 6-12, 2011 CPT RM Off	D/F, SVMs, LVMs
Maximum Main APCD Inlet Temperature (°F)	393.9	HRA	May 6-12, 2011 CPT RM Off	D/F, SVMs, LVMs
Minimum Kiln Combustion Zone Pressure (in. w.c.)	N/A (Monitor Only)	Inst.	Self-Evident Non-Applicability	Combustion System Leaks
Minimum DDC Combustion Zone Pressure (in. w.c.)	N/A (Monitor Only)	Inst.	Self-Evident Non-Applicability	Combustion System Leaks
Minimum Kiln Atomization Air Pressure (psig)	N/A (Monitor Only)	Inst.	Self-Evident Non-Applicability	DRE
Minimum DDC Atomization Air Pressure (psig)	N/A (Monitor Only)	Inst.	Self-Evident Non-Applicability	DRE
Maximum LVM Feedrates (g/hr total (lb/hr total))	69,493 (153.2)	HRA ⁽⁴⁾	May 6-12, 2011 CPT RM Off and Approved Extrapolation ⁽⁶⁾	LVMs
Maximum SVM Feedrates (g/hr total (lb/hr total))	117,016 (258)	HRA ⁽⁴⁾	May 6-12, 2011 CPT RM Off and Approved Extrapolation ⁽⁶⁾	SVMs
Maximum Mercury Hazardous Waste Feedrate (g/hr total (lb/hr total))	0	HRA	Self-Evident Non-Applicability	Hg (MTEC)
Maximum Chloride Feedrate (g/hr total (lb/hr total))	435,610 (960.3)	HRA ⁽⁴⁾	May 6-12, 2011 CPT RM Off	HCl/Cl ₂ , LVMs, SVMs
THC Concentration – Main Stack (ppmv @ 7% O ₂)	20	HRA	Regulatory Limit	THC

- (1) Reserved.
- (2) Maximum flue gas flow rate is required to be established on an hourly rolling average for dioxins/furans and DRE and a 12-hour rolling average for LVMs, SVMs, and HC/Cl₂. Therefore, as a conservative measure, Keystone is maintaining an hourly rolling average for maximum flue gas flow rate to demonstrate compliance for all standards.
- (3) Reserved.
- (4) Keystone may elect to comply with the 12-hour rolling average values using an hourly rolling average as a conservative measure.
- (5) Reserved.
- (6) Reserved.
- (7) Reserved.
- (8) The extrapolation methodology was provided in the CPT Plan, which was approved by PADEP on February 9, 2009.
- (9) Reserved.
- (10) Reserved.

Table 2-7
HAP Major Source Summary⁽¹⁾
Keystone Cement Company
Bath, Pennsylvania

	HAP	Emission Rate (lbs/hr)	May 6-12, 2011	Hours of Operation/ Year ⁽³⁾	TPY
Kiln No. 1	HCl	15.04	Average of RM On and RM Off ⁽²⁾	7,920	59.6

⁽¹⁾ The potential to emit for the facility is the MACT concentration limit of 86 ppmv HCl/Cl₂ at 7% O₂.

⁽²⁾ The emission rate of 15.04 lbs/hr is based on the sum of the average emission rate measured during the raw mill on condition (4.27 lbs/hr) multiplied by an assumed raw mill on time of 65% and the average emission rate measured during the raw mill off condition (35.04 lbs/hr) multiplied by an assumed raw mill off time of 35%.

⁽³⁾ The hours of operation/year is based on a kiln uptime of 330 days/year.

Table 2-8
System Removal Efficiencies for HAPs
Keystone Cement Company
Bath, Pennsylvania

Subpart EEE Regulated HAP	HWC MACT Metal Family	Kiln No. 1 Raw Mill On	Kiln No. 1 Raw Mill Off
Arsenic	Low-volatile Metals (LVMs)	99.991%	99.983%
Beryllium			
Chromium ⁽¹⁾			
Cadmium	Semi-volatile Metals (SVMs)	99.995%	99.966%
Lead ⁽¹⁾			
Hydrochloric Acid/Chlorine Gas ⁽¹⁾	HCl/Cl ₂	99.475%	96.268%
Mercury	Hg	NA ⁽²⁾	NA ⁽²⁾

⁽¹⁾ Constituents for which spiking occurred during the May 6-12, 2011 CPT.

⁽²⁾ Keystone is demonstrating compliance with the mercury emission standard using the hazardous waste fuel MTEC approach.

Table 3-1
Hazardous Waste Residence Time Calculations
Keystone Cement Company
Bath, Pennsylvania

Location	Design Flowrate ⁽¹⁾ (acfm)	Design Temperature (°F)	Design Flowrate ⁽¹⁾ (scfm)	Dimensions		Combustion		Total HWF Residence Time ⁽³⁾ (sec)
				Diameter (ft)	Length (ft)	Zone Volume ⁽²⁾ (ft³)	Residence Time (sec)	
DDC	183,912	1,571	47,812	10.80	51.8	4,747	1.5	
DDC/ILC Connector	183,912	1,571	47,812	7.03	47.0	1,822	0.6	
ILC	298,751	1,571	77,666	21.20	99.7	35,204	7.1	
Bypass	22,247	2,102	4,881	N/A	N/A	N/A	N/A	
Entire Precalciner (DDC/ILC/Connector)	N/A	N/A	125,478	N/A	N/A	41,773	9.2	10.5
Kiln	168,549	2,102	34,736	12.56	184	21,170	7.5	8.8

Locations in **Bold** represent the different combustion zone residence times.

⁽¹⁾ Airflow information from *FLSmith Process Flow Sheet* for the Pyroprocess System. Flowrates were all corrected to a standard temperature of 68 degrees Fahrenheit.

The Bypass was also corrected to a standard pressure of 14.696 psi.

⁽²⁾ Assumes that the clinker/kiln feed occupies 7% of the kiln volume.

⁽³⁾ Total HWF Residence Time represents the time that has elapsed from cutoff of the flow of HWF into the combustion chamber, including the time required for the HWF to evacuate the pipeline from the AWFCI valve to the combustion chamber.

APPENDIX E

**Extrapolation Calculations and Proposed Feedrate Determinations
Maximum Theoretical Emission Concentration (MTEC) Calculation
LVM and SVM Hazardous Waste Thermal Limit Concentrations**

LVM and SVM Feedrate Extrapolation Calculations⁽³⁾ and Proposed Feedrate Determinations
LVM and SVM Hazardous Waste Thermal Concentration Extrapolation Calculations⁽³⁾
 Keystone Cement Company, May 6-12, 2011 CPT
 Bath, Pennsylvania

RAW MILL ON

LVM, SVM, and Hg Extrapolated and Proposed Feedrate Determinations

	HWC MACT Emission Rate (ug/dscm)	Avg. Stack Flow ⁽¹⁾ (dscm/min)	60 (min/hr)	SRE (%)	1-SRE	1,000,000 (ug/g)	Feedrate Limit (g/hr)	Feedrate Limit (lb/hr)	Proposed Internal Feedrate Limit (g/hr) ⁽²⁾	Proposed Internal Feedrate Limit (lb/hr) ⁽²⁾
LVM	54.00	3,702.3	60	99.991	0.000090	1,000,000	132,860.8	292.90	69,492.7	153.20
SVM	180.00	3,702.3	60	99.995	0.000049	1,000,000	819,398.9	1,806.43	117,016.0	257.97

HCl/Cl₂ Proposed Feedrate Determinations

				SRE (%)	1-SRE		Feedrate Limit (g/hr)	Feedrate Limit (lb/hr)	Proposed Internal Feedrate Limit (g/hr) ⁽²⁾	Proposed Internal Feedrate Limit (lb/hr) ⁽²⁾
HCl/Cl ₂				99.475	0.005249		419,564.5	924.97	419,564.5	924.97

LVM and SVM Extrapolated and Proposed Thermal Limit Determinations

	HWC MACT Thermal Std. (lb/MMBtu)			SRE (%)	1-SRE		OPL (lb/MMBtu)	Proposed Internal OPL (lb/MMBtu)
LVM	0.000015			99.991	0.000090		0.1661	0.0883
SVM	0.000062			99.995	0.000049		1.2706	0.1843

RAW MILL OFF

LVM, SVM, and Hg Extrapolated and Proposed Feedrate Determinations

	HWC MACT Emission Rate (ug/dscm)	Avg. Stack Flow ⁽¹⁾ (dscm/min)	60 (min/hr)	SRE (%)	1-SRE	1,000,000 (ug/g)	Feedrate Limit (g/hr)	Feedrate Limit (lb/hr)	Proposed Internal Feedrate Limit (g/hr) ⁽²⁾	Proposed Internal Feedrate Limit (lb/hr) ⁽²⁾
LVM	54.00	3,645.1	60	99.983	0.000170	1,000,000	69,492.7	153.20	69,492.7	153.20
SVM	180.00	3,645.1	60	99.966	0.000336	1,000,000	117,016.0	257.97	117,016.0	257.97

HCl/Cl₂ Proposed Feedrate Determinations

				SRE (%)	1-SRE		Feedrate Limit (g/hr)	Feedrate Limit (lb/hr)	Proposed Internal Feedrate Limit (g/hr) ⁽²⁾	Proposed Internal Feedrate Limit (lb/hr) ⁽²⁾
HCl/Cl ₂				96.268	0.037317		435,609.89	960.34	419,564.5	924.97

LVM and SVM Extrapolated and Proposed Thermal Limit Determinations

	HWC MACT Thermal Std. (lb/MMBtu)			SRE (%)	1-SRE		OPL (lb/MMBtu)	Proposed Internal OPL (lb/MMBtu)
LVM	0.000015			99.983	0.000170		0.0883	0.0883
SVM	0.000062			99.966	0.000336		0.1843	0.1843

Notes:

- ⁽¹⁾ Average stack flow is the average of the metals runs as measured/calculated by the stack testing contractor during each scenario. This flowrate has been corrected to 7% O₂.
- ⁽²⁾ The proposed feedrate limit for HCl/Cl₂ for both modes of operation (i.e., RM On/Off) is equivalent to the feedrate established for the RM On operating scenario. Compliance with this feedrate will result in compliance with the HCl/Cl₂ emission standard during both operating scenarios. Keystone does not intend to use emissions averaging for HCl/Cl₂.
- ⁽³⁾ The equations used for extrapolation are found in Section 6.6 and 6.7 of the December 2008 CPT Plan (as revised).
- ⁽⁴⁾ The proposed feedrate limits for LVMs and SVMs for both modes of operation (i.e., RM On/Off) are equivalent to the feedrates established for the RM Off operating scenario. Compliance with these feedrates will result in compliance with the LVM and SVM emission standards during both operating scenarios. Keystone does not intend to use emissions averaging for LVMs and SVMs.

Mercury (Hg) Maximum Theoretical Emission Concentration (MTEC), May 6-12, 2011 CPT
Keystone Cement Company
Bath, Pennsylvania

	HWF-Kiln			HWF-DDC			Total		Volumetric Airflow ³			Hg MTEC	
	Hg Conc. (ppm)	WDF (tph)	Hg Input (lbs/hr)	Hg Conc. (ppm)	WDF (tph)	Hg Input (lbs/hr)	Hg Input (ug/hr)		O2 Conc. (%)	(dscfm/min)	(dscm/hr) ¹	Hg MTEC (ug/dscm) ¹	Hg MTEC Emiss. Std. (ug/dscm) ²
RM On Run 1	0.073	7.35	0.00107	0.16	2.53	0.00081	0.00188	853,831	13.5	3,706	222,342	3.84	120
RM On Run 2	0.052	7.32	0.00076	0.19	2.58	0.00098	0.00174	790,678	13.7	3,704	222,235	3.56	120
RM On Run 3	0.029	7.52	0.00044	0.16	2.59	0.00083	0.00127	573,898	13.7	3,697	221,828	2.59	120
RM Off Run 1	0.032	7.66	0.00049	0.56	2.37	0.00265	0.00314	1,424,770	12.9	3,573	214,403	6.65	120
RM Off Run 2	0.034	7.37	0.00050	0.17	2.46	0.00084	0.00134	607,193	12.3	3,751	225,076	2.70	120
RM Off Run 3	0.069	7.09	0.00098	0.18	2.91	0.00105	0.00203	919,745	12.7	3,611	216,641	4.25	120

Notes:

¹ These volumetric flows and Hg MTEC calculation have been corrected to 7% O₂.

² Although not identified in the HWC MACT regulation, the Hg MTEC emission standard is assumed to be corrected to 7% O₂.

³ Volumetric Airflow information obtained from Weston Solutions summary of multi-metals test data and results.

LVM and SYM Hazardous Waste Thermal Concentrations, May 6-12, 2011 CPT
Keystone Cement Company
Bath, Pennsylvania

RM On

Constituent	HWF Constituent Concentration		HWF Throughput		Group SRE %	Emissions Attributable to HWF lb/hr	HWF Heat Input		Total Btu Input by HWF MMBtu/hr	Emissions Attributable to HWF lb/MMBtu	Thermal Emissions Limit lb/MMBtu	Exceed Limit?	% of Limit
	HWF-Kiln ppm	HWF-DDC ppm	HWF-Kiln tons/hr	HWF-DDC tons/hr			HWF-Kiln Btu/lb	HWF-DDC Btu/lb					
Chromium	18	25	7.35	2.53	99.89%	0.0000438	10,175	13,598	220,175	1.989E-07	1.50E-05	No	1.33%
Lead	19	27	7.35	2.53	99.99%	0.0000216	10,175	13,598	220,175	9.79942E-08	6.20E-05	No	0.16%

Constituent	HWF Constituent Concentration		HWF Throughput		Group SRE %	Emissions Attributable to HWF lb/hr	HWF Heat Input		Total Btu Input by HWF MMBtu/hr	Emissions Attributable to HWF lb/MMBtu	Thermal Emissions Limit lb/MMBtu	Exceed Limit?	% of Limit
	HWF-Kiln ppm	HWF-DDC ppm	HWF-Kiln tons/hr	HWF-DDC tons/hr			HWF-Kiln Btu/lb	HWF-DDC Btu/lb					
Chromium	32	27	7.32	2.58	99.991%	0.0000549	9,867	13,651	214,969	2.55184E-07	1.50E-05	No	1.70%
Lead	19	27	7.32	2.58	99.997%	0.0000282	9,867	13,651	214,969	1.31061E-07	6.20E-05	No	0.21%

Constituent	HWF Constituent Concentration		HWF Throughput		Group SRE %	Emissions Attributable to HWF lb/hr	HWF Heat Input		Total Btu Input by HWF MMBtu/hr	Emissions Attributable to HWF lb/MMBtu	Thermal Emissions Limit lb/MMBtu	Exceed Limit?	% of Limit
	HWF-Kiln ppm	HWF-DDC ppm	HWF-Kiln tons/hr	HWF-DDC tons/hr			HWF-Kiln Btu/lb	HWF-DDC Btu/lb					
Chromium	31	25	7.32	2.59	99.993%	0.0000409	9,351	14,422	215,334	1.89437E-07	1.50E-05	No	1.27%
Lead	18	23	7.32	2.59	99.997%	0.0000105	9,351	14,422	215,334	4.89681E-08	6.20E-05	No	0.08%

Average	Run 1		Run 2		Run 3		3-Run Average		Emission Limit lb/MMBtu	% of Limit
	lb/MMBtu	ppm	lb/MMBtu	ppm	lb/MMBtu	ppm	lb/MMBtu	ppm		
LVM	1.99E-07	2.53E-07	1.90E-07	2.15E-07	1.90E-07	2.15E-07	1.90E-07	2.15E-07	1.50E-05	1.43%
SYM	9.80E-08	1.31E-07	4.90E-08	9.27E-08	4.90E-08	9.27E-08	4.90E-08	9.27E-08	6.20E-05	0.15%

LVM and SVM Hazardous Waste Thermal Concentrations, May 6-12, 2011 CPT
Keystone Cement Company
Bath, Pennsylvania

RM Off

Run 1													
Constituent	HWF Constituent Concentration		HWF Throughput		Spike lb/hr	Group SRE %	Emissions Attributable to HWF lb/hr	HWF Heat Input		Total Btu Input by HWF MMBtu/hr	Emissions Attributable to HWF lb/MMBtu	Thermal Emissions Limit lb/MMBtu	Exceed Limit? No
	HWF-Kin ppm	HWF-DDC ppm	HWF-Kin ton/hr	HWF-DDC ton/hr				HWF-Kin Btu/lb	HWF-DDC Btu/lb				
Chromium	50	107	7.66	2.37	7.23	99.971%	0.0002802	11,673	12,762	239,195	1.178-06	1.508-05	7.81%
Lead	13	99	7.66	2.37	9.31	99.987%	0.0000862	11,673	12,762	239,195	3.60E-07	6.20E-05	0.58%

Run 2													
Constituent	HWF Constituent Concentration		HWF Throughput		Spike lb/hr	Group SRE %	Emissions Attributable to HWF lb/hr	HWF Heat Input		Total Btu Input by HWF MMBtu/hr	Emissions Attributable to HWF lb/MMBtu	Thermal Emissions Limit lb/MMBtu	Exceed Limit? No
	HWF-Kin ppm	HWF-DDC ppm	HWF-Kin ton/hr	HWF-DDC ton/hr				HWF-Kin Btu/lb	HWF-DDC Btu/lb				
Chromium	7	11	7.37	2.46	7.93	99.989%	0.0000180	11,130	13,840	232,244	7.73962E-08	1.508-05	0.52%
Lead	5	12	7.37	2.46	9.94	99.934%	0.0000674	11,130	13,840	232,244	3.76463E-07	6.20E-05	0.61%

Run 3													
Constituent	HWF Constituent Concentration		HWF Throughput		Spike lb/hr	Group SRE %	Emissions Attributable to HWF lb/hr	HWF Heat Input		Total Btu Input by HWF MMBtu/hr	Emissions Attributable to HWF lb/MMBtu	Thermal Emissions Limit lb/MMBtu	Exceed Limit? No
	HWF-Kin ppm	HWF-DDC ppm	HWF-Kin ton/hr	HWF-DDC ton/hr				HWF-Kin Btu/lb	HWF-DDC Btu/lb				
Chromium	22	18	7.09	2.91	6.69	99.989%	0.0000440	9,608	15,580	227,082	1.93793E-07	1.508-05	1.29%
Lead	17	18	7.09	2.91	10.08	99.978%	0.0000768	9,608	15,580	227,082	3.38114E-07	6.20E-05	0.55%

RM Off					
Average	Run 1 lb/MMBtu	Run 2 lb/MMBtu	Run 3 lb/MMBtu	3-Run Average lb/MMBtu	Emission Limit lb/MMBtu
LVM	1.17E-06	7.74E-08	1.94E-07	4.81E-07	1.50E-05
SVM	3.60E-07	3.76E-07	3.98E-07	3.58E-07	6.20E-05
					% of Limit
					3.21%
					0.58%

Cement NOC Data Coal Only

RM On Constituent	WF Kiln ppm	WF Calciner ppm	WF Kiln ton/hr	WF Calciner ton/hr	SRE %	WF Emissions lb/hr
Chromium	27.0	25.7	7.40	2.57	99.991%	0.0000478
Lead	18.7	25.7	7.40	2.57	99.995%	0.0000204
Mercury	0.077	0.17	7.40	2.57	0.00%	0.0020118

RM Off Constituent	WF Kiln ppm	WF Calciner ppm	WF Kiln ton/hr	WF Calciner ton/hr	SRE %	WF Emissions lb/hr
Chromium	19.7	45.3	7.48	2.58	99.983%	0.0000898
Lead	11.7	43.0	7.48	2.58	99.996%	0.0000159
Mercury	0.045	0.303	7.48	2.58	0.00%	0.0022387

Note: Chromium is surrogate for As and Be.
Lead is a surrogate for Cadmium.

2013 RM On/Off Operation		
RM On	2962 hr	61.1%
Rm Off	1886 hr	38.9%
Total	4848 hr	

Hg Results	
RM On	0.000774
Rm Off	0.00244
Total	6.89

Fuel Factor to Account for Not Co-Burning		
Coal	ton/hr	5.76
Coal	ton/hr	12.94
Emission Factor		2.25
Explosives Used	285000 lb/yr 58.8 lb/hr	

Data Summary In-line Raw Mill Off		
Pollutant	Result	Units
Arsenic	0.00157	lb/hr
Beryllium	0.00024	lb/hr
Chromium	0.00240	lb/hr
Cadmium	0.00041	lb/hr
Lead	0.00522	lb/hr
Mercury	0.00244	lb/hr
Chloride	45.0	lb/hr
PM	0.00320	gr/dscf (7% O ₂)
PM	3.59	lb/hr
O ₂	12.6	%
Q	218,113	dscf/min
Q corr. 7% O ₂	130,868	dscf/min

Data Summary In-line Raw Mill On		
Pollutant	Result	Units
Arsenic	0.00080	lb/hr
Beryllium	0.00012	lb/hr
Chromium	0.00358	lb/hr
Cadmium	0.00018	lb/hr
Lead	0.00090	lb/hr
Mercury	0.00077	lb/hr
Chloride	2.0	lb/hr
PM	0.00220	gr/dscf (7% O ₂)
PM	2.48	lb/hr
O ₂	13.6	%
Q	248,513	dscf/min
Q corr. 7% O ₂	131,357	dscf/min

Annualized Emissions for Two Conditions		
Pollutant	Result	Units
Arsenic	5.31	lb/yr
Beryllium	0.81	lb/yr
Chromium	15.13	lb/yr
Cadmium	1.30	lb/yr
Lead	12.52	lb/yr
Mercury	6.89	lb/yr
Chloride as (HCl)	45.39	ton/yr
PM	7.05	ton/yr
O ₂	13.21	%

Hourly Emission for Two Conditions		
Pollutant	Result	Units
Arsenic	0.001095	lb/hr
Beryllium	0.000167	lb/hr
Chromium	0.003121	lb/hr
Cadmium	0.000269	lb/hr
Lead	0.002582	lb/hr
Mercury	0.001422	lb/hr
Chloride as (HCl)	0.009363	lb/hr
PM	2.91	lb/hr
O ₂	13.21	%

Data Summary			
In-line Raw Mill Off			
Coal & Waste Fuel			
Pollutant	Result	Units	
Arsenic	0.0000	lb/yr	
Beryllium	0.0000	lb/yr	
Chromium	0.0018	lb/yr	
Cadmium	0.0020	lb/yr	
Lead	0.0024	lb/yr	
Mercury	0.0020	lb/yr	
Chloride	46.0	lb/yr	
PM	0.00300	grained (7% O ₂)	
PM	3.59	lb/yr	
O ₂	12.6	%	
Q	218,113	acfm/min	
Q corr. 7% O ₂	130,688	acfm/min	

Data Summary			
In-line Raw Mill On			
Coal & Waste Fuel			
Pollutant	Result	Units	
Arsenic	0.0000	lb/yr	
Beryllium	0.0000	lb/yr	
Chromium	0.0018	lb/yr	
Cadmium	0.0020	lb/yr	
Lead	0.0024	lb/yr	
Mercury	0.0020	lb/yr	
Chloride	2.0	lb/yr	
PM	0.00220	grained (7% O ₂)	
PM	2.48	lb/yr	
O ₂	13.8	%	
Q	248,513	acfm/min	
Q corr. 7% O ₂	131,357	acfm/min	

Annualized Emissions for Two Conditions			
Pollutant	Result	Units	
Arsenic	2.88	lb/yr	
Beryllium	0.87	lb/yr	
Chromium	7.05	lb/yr	
Cadmium	0.87	lb/yr	
Lead	5.86	lb/yr	
Mercury	8.84	lb/yr	
Chloride as (HCl)	45.39	lb/yr	
PM	7.05	lb/yr	
O ₂	13.21	%	

Hourly Emission for Two Conditions			
Pollutant	Result	Units	
Arsenic	0.00052	lb/hr	
Beryllium	0.00138	lb/hr	
Chromium	0.00143	lb/hr	
Cadmium	0.00138	lb/hr	
Lead	0.00143	lb/hr	
Mercury	0.00143	lb/hr	
Chloride as (HCl)	18.728478	lb/hr	
PM	2.81	lb/hr	
O ₂	13.21	%	

2013 RM On/Off Operation			
RM On	2862 hr	61.1%	
RM Off	1886 hr	38.9%	
Total	4848 hr		
RM On			
Constituent	WF Kiln	WF Calciner	WF Emissions
Chromium	27.0	25.7	0.000478
Lead	18.7	25.7	0.000204
Mercury	0.071	0.17	0.000118
RM Off			
Constituent	WF Kiln	WF Calciner	WF Emissions
Chromium	19.7	43	0.000988
Lead	11.7	43	0.000139
Mercury	0.643	0.303	0.000287

RM On/Off			
Constituent	WF Emissions	WF Emissions	WF Emissions
Chromium	30.230467	0.000541	0.000541
Lead	30.230467	0.000186	0.000186
Mercury	30.230467	0.000100	0.000100

RM On/Off			
Constituent	WF Emissions	WF Emissions	WF Emissions
Chromium	30.230467	0.000541	0.000541
Lead	30.230467	0.000186	0.000186
Mercury	30.230467	0.000100	0.000100