COMPARATIVE LIFE CYCLE ANALYSIS

OF CEMENT MADE WITH COAL VS.

HAZARDOUS WASTE AS FUEL

PRESENTED AT THE AIR & WASTE MANAGEMENT ASSOCIATION SPECIALTY CONFERENCE ON WASTE COMBUSTION IN BOILERS AND INDUSTRIAL FURNACES

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KATHRYN E. KELLY, DR.P.H.
DELTA TOXICOLOGY
Crystal Bay, Nevada

ABSTRACT

The purpose of this life cycle analysis (LCA) is to compare the life cycle of cement made with coal, the standard fuel used in a cement kiln, versus cement made with hazardous waste-derived fuels. The intent of the study is to determine whether the use of hazardous waste as a fuel in the production of cement could result in an increase in detrimental effects to either health or environment. Those evaluated for potential adverse effect include cement kiln workers, waste transporters, and consumers using the final product for private use. The LCA stages included all the processes involved with cement, including raw materials acquisition, transportation, manufacturing, packaging, distribution, use, recycling, and disposal.

The overall conclusions of the LCA are that use of waste fuels instead of coal to make cement: 1) does not increase, and may reduce, the concentration of contaminants in the cement product due to the reduction or elimination of the use of coal; 2) reduces or eliminates use of non-renewable fossil fuels, such as coal, as well as the environmental damage and impacts associated with coal mining; 3) provides a more environmentally beneficial means of destroying many types of wastes than alternative treatment methods, including incineration, thus decreasing the need for waste treatment facilities and capacity; 4) decreases overall emissions during transportation but may increase the overall consequences of accidents or spills; 5) results in cement product which may be packaged, transported, distributed and used in the same manner as cement product made with coal; 6) lowers the cost of cement production; and 7) overall appears to result in less health and environmental impacts.

INTRODUCTION

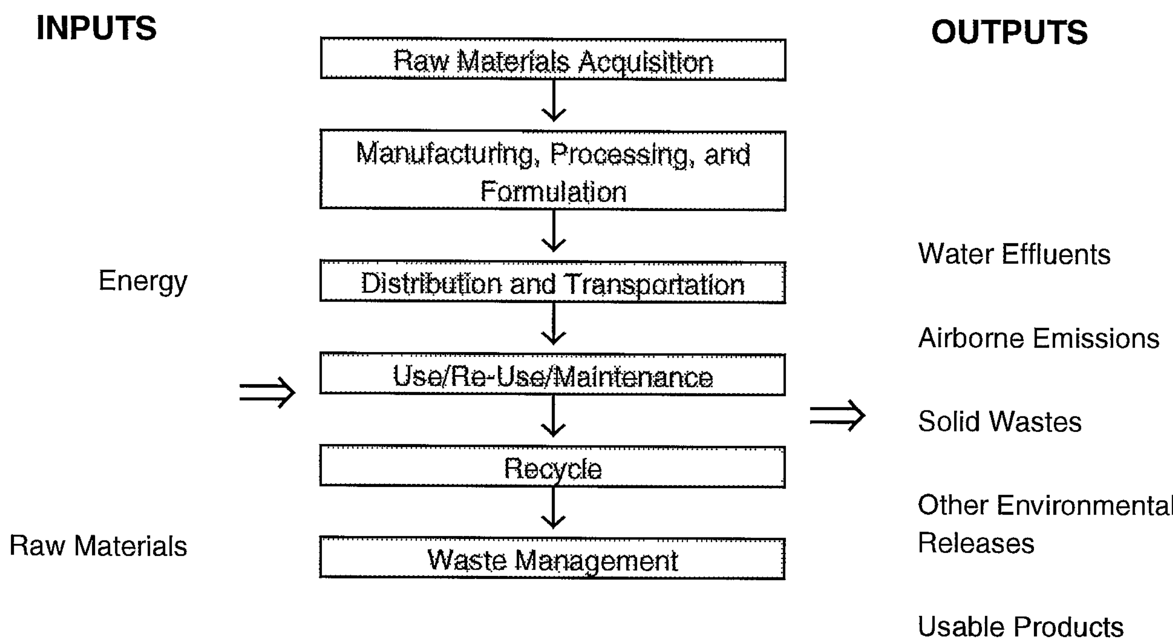
A life cycle analysis describes the stages that a product goes through from the time the raw materials for that product are obtained until the final disposal of the product (see Figure 1). An LCA examines the materials and energy used and the effects to public health and the environment in each stage of the product's life. It allows manufacturers to revise their process in ways that reduce environmental impacts, and allows consumers to make more informed decisions about which products to buy that meet those goals.

The purpose of this LCA study is to compare the life cycle of cement made with coal, the standard fuel used in a cement kiln, versus cement made with hazardous waste-derived fuels. The primary reason to burn waste instead of coal in a cement kiln is to re-use the heat value in the ignitable waste to produce cement, which conserves non-renewable fossil fuels such as coal. Hazardous wastes used as fuel in kilns are typically ignitable solvents collected from industries that clean tools, tune cars, dry-clean clothes, etc., which have a high energy value needed by the kiln to make cement. The high temperatures within a cement kiln also results in virtually total destruction of the organic compounds in the fuels, whether in the ignitable waste or the coal. This LCA also assessed whether the use of hazardous waste as a fuel in the production of cement could result in an increase in detrimental effects to either health or to the environment.

As cement plants vary in their use of fuels, as reflected in their permits, this evaluation was designed specifically to evaluate cement made at the Texas Industries cement plant in Midlothian, TX. Only information and data specific to TXI were used in this study, and conclusions apply only to the cement produced at that plant.

This paper presents the highlights of the original study (1).

FIGURE 1. STAGES OF THE INVENTORY COMPONENT OF A LIFE CYCLE ANALYSIS (Source: Ref. 2)



OVERVIEW OF LIFE CYCLE ANALYSIS

Interest in LCA began in the 1960s because of concerns about the finite amount of natural resources that could be used to produce energy. During the 1960s, approximately a dozen LCAs were conducted to evaluate the environmental effects of different types of energy used in industrial processes (2). The use of LCAs continued through the early 1970s due to the oil shortage as well as increased attention from public interest groups that focused on the environmental effects of industry. LCAs were useful because they provided a way to quantify energy consumption for individual products and to anticipate future resource supplies (3).

Around 1975, once the urgency of the oil crisis had passed, interest in LCAs waned through the early 1980s. Throughout that period, about two LCAs were published per year, primarily focusing on the energy requirements of packaging materials. Several of these studies were comparative analyses, which attempted to show which product caused the least environmental burden. Some examples are comparisons between cloth and plastic diapers, between paper and plastic grocery bags, and between paper and Styrofoam containers at McDonalds. Approximately 100 LCAs have been performed to date for a variety of consumer products (3).

Interest in LCAs have increased again in the last several years, in large part due to increasing concerns about the impacts of solid waste on the environment. Today, LCAs are primarily performed for two different reasons. First, they are used to help consumers make purchasing decisions by providing them with a way to compare the environmental effects of different products. Second, they are used to help industry make decisions about product manufacturing. For example, an LCA can help to assess whether proposed changes in the way a product is manufactured are actual improvements, or merely a shift of environmental burden from one area to another. An example is a change in production which decreases the amount of air pollution that is emitted, but increases the amount of pollution to water or land.

Why Perform an LCA for Cement Made Using Hazardous Waste Fuels?

Increasingly, consumers wish to make informed decisions regarding the products they purchase by comparing the differences in environmental impacts between product choices. In choosing among various options, cement is the world's most widely used construction material; in 1990, the U.S. cement industry manufactured 79.7 million tons of cement (4). It is commonly used to build roads, buildings, foundations, sidewalks, pipes, bridges, reservoirs, etc. It is also used by individuals at home for numerous purposes, such as putting in a patio, driveway, fish pond, or setting fence posts.

It is becoming more widely known that cement production is also an increasingly common means of destroying many types of wastes. Each year, the United States generates approximately 200 million tons of hazardous waste which must be disposed of properly. An estimated one million tons of this hazardous waste is burned in cement kilns each year (5).

As with all manufacturing processes, there are risks associated with using hazardous wastes as fuel in cement kilns which need to be evaluated and managed to ensure safety. Transportation of wastes to the kilns, the health and safety of workers handling the wastes, possible effects to persons living near the facility, and the impacts to consumers of using cement made with waste-derived fuels are all issues unique to burning hazardous waste-derived fuels that need to be addressed in comparing the risks of cement made with and without these fuels.

How Does This Life Cycle Analysis Differ From Other Published LCAs?

This life cycle analysis differs from other published LCAs in two major ways. First, most LCAs are inevitably comparisons of two (or more) different products that are made in an entirely different way, but used for the same purpose. One example is the comparison between paper and plastic cups. An LCA of two altogether different products leads to difficult but unavoidable "apples-and-oranges" comparisons, such as how to assess the impacts of a reduction in trees vs. a reduction in petroleum resources. This type of comparison often requires an exhaustive amount of research to be able to fully evaluate and quantify the differing impacts.

In contrast, this study evaluates one product, cement, made in two different ways (i.e., with two different types of fuel). Because many of the variables are the same for cement made with or without waste fuels, it is a much more straightforward comparison. The cement raw materials, the method of production, the way the final product is packaged, distributed, used, and disposed is the same whether hazardous waste or coal was used as fuel. This greatly reduces the amount of information required to evaluate the relative impacts.

Some of the variables in this LCA, however, cannot be accurately quantified. For example, it may not be possible to quantify the value to society of destroying a gallon of hazardous waste and thereby avoiding future exposure to it. In these cases, relative comparisons are given so that an impact can be identified as greater or lesser between the two products. Some LCA comparisons are therefore more qualitative than quantitative.

The second way in which this LCA differs from others is that it focuses solely on the product of one plant: the Texas Industries (TXI) cement plant in Midlothian, Texas. This is an important difference because the types and quantities of waste vary significantly within the cement production industry. Without specific data from each plant, it would be impossible to fully describe the life cycle analysis of cement made throughout the industry without making assumptions about the process and conditions at each plant, whose results may vary.

Much of the specific data required for this study were provided by Texas Industries, which increases the confidence of the conclusions of the report with regard to Texas Industries-produced cement and limits the conclusions to conditions assumed at the plant as described below. Extrapolating the conclusions of this focused LCA to other facilities and other products should be done only after careful review of these assumptions and data relevant to those products.

Last, most LCAs do not focus on the actual health and environmental effects of different products, focusing more on the relative inventory of process inputs and outputs. In contrast, this life cycle analysis examines the potential health effects associated with the use of this product, independent of which type of fuel is used to make the products (bagged concrete mix, mortar mix, etc.). This LCA clarifies whether there are any additional risks to human health from using cement made with hazardous waste as fuel.

DATA USED FOR THE LCA

Energy Requirements to Operate a Cement Kiln

Cement production is an extremely energy-intensive process. The average energy requirement to produce one ton of cement is approximately 4.4 million Btu (6); this amount of energy is roughly equivalent to 400 pounds of coal. In 1990, the U.S. cement industry manufactured 79.7 million tons of cement (4). The energy equivalent of 16 million tons of coal was required to produce this quantity of cement.

Fossil fuels (coal, natural gas, or oil) and ignitable wastes are common sources of energy to make cement. Of the fossil fuels, coal is often preferred to gas or oil because of cost and availability. Most operations use a combination of fuel types. This section discusses the constituents of coal and waste fuels.

Constituents of Fuel

Coal is a combustible solid produced from the accumulation and burial of partially decomposed vegetable matter in the absence of air and under varying degrees of high temperature and great pressure over a period of millions of years (7). The three major types of coal are bituminous, lignite, and anthracite. Approximately 95% of coal used in the United States is bituminous (8). Coal comes from the earth mixed with other natural minerals which are considered impurities. For example, coal naturally contains trace elements such as arsenic, beryllium, cadmium, chromium, copper, mercury, manganese, nickel, and lead (8). It almost always contains sulfur as well as radionuclides such as thorium-232 and uranium-235. The concentration of these impurities depends on the type of coal and the geographic region in which it was mined. The inorganic content of coal may vary considerably.

A *hazardous waste* is a material that no longer has commercial value, requires disposal, and meets criteria established by the U.S. Environmental Protection Agency (U.S. EPA) for being considered a hazardous waste. The specific guidelines established by the U.S. EPA as to which wastes are considered hazardous are in Title 40 of the U.S. Code of Federal Regulations, Part 261 (40 CFR 261). Hazardous wastes may either be "listed", which means a component of that waste appears on a list of specific chemicals considered hazardous, or a waste may meet any of the four criteria (ignitability, corrosivity, reactivity, and toxicity) to be classified as a hazardous waste.

Ignitable wastes with a high Btu content are of greatest value in supplying the fuel needs of a cement kiln. The types of waste that are used as fuels are primarily solvents collected from industries that clean tools, lubricate machines, dry-clean clothes, tune cars, etc. Other wastes with valuable energy content may include waste oils, spent organic solvents, and discarded tires. (Note: Texas Industries does not use discarded tires in its process.)

Key Assumptions and Limitations of the Report

Fuel practices vary considerably between cement plants, including the types, volumes used, storage facilities, transportation modes, etc. A comprehensive LCA of all cement made using different fuel types would need to reflect these different practices.

A review of waste fuel practices across the industry is beyond the scope of this report, whose purpose it is to analyze the product of one plant made under two different conditions. The results of the LCA are thus specific to the conditions and practices at the Texas Industries plant, and are based on the assumptions outlined in this section. The degree of confidence to which these conclusions can be applied to other situations depends on the degree to which conditions at other plants are consistent with the assumptions outlined below.

<u>Facility Conditions</u>: In any given year, Texas Industries has the capacity to produce 1.2 million tons of cement. To make this amount of cement requires the energy equivalent of approximately 6,150,000,000,000 Btu's of energy. This would require 250,000 tons of coal (at approximately 11,900 Btu/lb) or 241,776 tons (59.2 million gallons) of waste fuel, assuming 12,000 to 12,500 Btu/lb waste. The Btu values within the different fuel types can be quite variable; these are representative values based on data from Texas Industries.

<u>Quantities of Constituents in Waste Fuels and Coal</u>: The EPA and various state agencies regulate the types of metals in waste feed and cement products. According to TXI, the range of constituents in waste fuels they would be allowed to accept at the plant in a given year to make the maximum possible amount of cement using 100% fuel is shown in Table 1. Conversely, if the plant used 100% coal for its energy needs, the quantities of inorganic constituents being fed into the kiln each year to make 1.2 million tons of cement are also shown.

<u>Transportation</u>: Texas Industries tracks every shipment of fuels to the plant. In transporting fuels to the Texas Industries site, 100% of the 250,000 tons of *coal* is transported by rail. During a typical year, an average of 91% of the *waste fuels* have been transported by truck, and 9% by rail.

For purposes of this study, we have assumed 100% of the coal is transported by rail and 100% of the 59.2 million gallons of waste fuels are transported by truck. This is a conservative assumption as annual truck accident rates are higher than railway accident rates for hazardous waste transport (9).

Description of Scenarios

For this comparative life cycle analysis, the maximum production of 1.2 million tons of cement is considered in two scenarios. Scenario 1 assumes all the cement is made with coal as its energy source, and Scenario 2 assumes that all cement is made with waste fuels. As the maximum Btu value is defined by the plant's capacity (i.e., there is no situation where the maximum amounts of coal and the waste fuel would be used simultaneously), these scenarios offer the two logical extremes of constituents in cement made with and without hazardous waste. We assume the impacts for all other fuel combinations at the plant (e.g., 50% coal/50% waste fuels) would lie between these two extremes, although there may possibly be some undefined scenario where a combination of the two could result in higher impacts than either of the two extremes.

TABLE 1. MAXIMUM HYPOTHETICAL AMOUNT OF CONSTITUENTS BEING FED TO THE KILN ANNUALLY (LBS/YR)

	Scenario 1		Scenario 2
Coal	100% Coal		0% Coal
Waste Fuel	0% Waste Fuel		100% Waste Fuel
	TEXAS INDUSTRIES	U.S.	TEXAS INDUSTRIES
Antimony	5	595	72,450
Arsenic	5	10,150	967
Barium	112,500	12,250	1,934,400
Beryllium	1.5	1,110	484
Cadmium	5	455	48,360
Chromium	5	10,250	967,200
Lead	1,695	5,500 - 135,000	725,400
Mercury	5	105	484
Silver	5	30	33,852
Thallium	10	100 - 2,000	14,508

Source: See Tables 4-1 and 4-2 of original report (1). For waste fuel, the top value in the range in Table 4-1 was used to calculate mass being fed to the kiln each year.

The assumption of 100% hazardous waste fuel replacement is not an overly conservative assumption as the TXI plant is legally permitted to replace 100% of its fossil fuels with hazardous waste fuels. We are also assuming that 100% use of coal is not overly conservative as this is the primary fuel used at the plant. The raw materials used to make the cement are assumed to be identical for each scenario; only the fuels used to make the cement differ. We also assume that the system removal efficiency or SRE (the percent of metals that go into the kiln system that don't come out the stack) for each metal is the same whether waste fuel or coal is used.

On the basis of the above analyses of both fuels, the maximum amount of constituents being fed into the kiln in each scenario is shown in Table 1. For comparative purposes, the amount of constituents from coal containing the average concentration of metals in the U.S. is also listed (for use of 250,000 tons).

The reason for the large discrepancy in waste fuel vs. coal is that the coal tested for this study is particularly "clean" coal, i.e., the concentrations of metals and sulfur in this coal are very low compared with most coal. This can be seen by comparing the amount of constituents in coal used at TXI with the amount in coal if a more typical variety were used. The concentrations of metals in the hazardous waste are consistent with other waste feed data reported in the literature.

STAGES OF LIFE CYCLE ANALYSIS

The use of coal as fuel is compared with the use of waste fuel in all of the processes involved with cement. In some life cycle processes, such as raw materials acquisition, there are distinct differences between coal and hazardous waste. For example, the coal and waste fuel are obtained, loaded, transported, unloaded, and stored in different ways, which results in different health or environmental impacts.

In manufacturing, on the other hand, cement is produced in basically the same way for each fuel type. Differences in the composition of the clinker, cement kiln dust (CKD), or in air emissions produced may occur during this step because of differences in coal and waste fuel. The cement itself is packaged, transported, distributed, used, maintained, recycled, and disposed of in the same way regardless of which type of fuel is used. Finally, the inputs into cement are cement raw materials and fuel. Because the raw materials of cement are virtually the same regardless of which type of fuel is used (i.e., limestone, sand, shale, and other compounds), a complete analysis of the impacts of these raw materials in cement is not given here.)

For each of these processes, the relevant literature was summarized to provide background information. The summary of the literature included general information about the process, as well as how this process may affect public health, the environment, or persons working in an occupation related to that process. Next, all available site-specific information related to TXI was described. These data were then evaluated in the form of an inventory specific to TXI, with a list of inputs of raw materials and energy vs. outputs to the environment. Data were given as quantitatively as possible. Last, impacts from the outputs to public health, the environment, and workers were examined. The key differences are highlighted in the following section.

Raw Materials Acquisition - Obtaining the Fuel

The raw materials acquisition stage begins with all activities needed for and resulting from the acquisition of a raw material and ends at the first manufacturing or processing stage that refines that raw material (10). Because of the distinct differences between coal and hazardous waste in this process, the steps are divided into two parts: 1) obtaining the fuel and 2) loading, transport, unloading and storage of the fuels at the cement plant.

Obtaining Coal: If only coal were used in cement production at Texas Industries, approximately 250,000 tons would be needed each year to meet full capacity. The coal used at this facility is bituminous coal and is mined near Raton, New Mexico, by surface and underground mining. Bulldozers, front-end loaders, scrapers, haul trucks, and graders are used in the mining process. The volumes of fuel consumption per year to obtain this coal were calculated to be 139,272 gallons, based on AP-42 data (11) for the mining of 250,000 tons of coal to produce the fuel requirements for the Texas Industries plant at maximum capacity for one year.

Air emissions from combustion of fuel used in heavy equipment at the mine site were calculated, based on AP-42 emission factors and York Canyon Mining Complex equipment usage and production rates, including mass of pollutants produced per hour of equipment usage, average number of hours of operation per year, and the number of each type of equipment in use.

Total suspended particulates (TSP) is the total amount of particulates released into air. The total emissions from all operations are 7.63 tons TSP and 4.13 tons of particulates less than 10 micrometers (PM_{10}) in size per year. The volume of PM_{10} is significant because it is the particulates smaller than 10 micrometers that can be inhaled deep into the lungs and potentially cause respiratory illness or damage.

Obtaining Hazardous Waste Fuels: Hazardous waste that is used for fuel in cement kilns has already served its original purpose in industry, and does not involve the use of natural resources or mining to obtain these fuels. The waste materials (industrial solvents and other compounds) have to be collected for treatment and disposal regardless of whether or not it is to be used as fuel in a cement kiln. For wastes to be treated and disposed of offsite, the generator must collect, store, and transport the wastes from their facility whether the waste was to go to a cement kiln, an incinerator, or another type of treatment or disposal facility. In this study, the acquisition of hazardous waste fuels was conservatively assessed from the time it is collected from the generator, although this may not represent an actual net increase in impacts given that the waste has to transported offsite in any case.

Summary: Figure 2 summarizes the inventory of materials needed to obtain the necessary coal, and compares it to the resulting environmental releases that are associated with obtaining those materials. The volumes and impacts of each material input and output during this stage of raw materials acquisition could not be quantified in many cases, although the conclusions remain clear. One, acquisition of the process raw materials, such as shale, is the same regardless of fuel type, and no quantification is necessary to show there is no difference in impact. With regard to the other process input (the fuel to heat the raw materials), it is apparent from even qualitative review of the data that the impacts of acquiring coal greatly exceed the impacts of acquiring the waste fuels. In fact, use of waste fuels was shown to have a net environmental benefit over the use of coal, although the magnitude of this benefit was not quantified.

Raw Materials Management - Fuel Loading, Transport, Unloading, and Storage

This step involves loading the coal or waste fuel at the site where it is obtained, transport to Texas Industries, unloading, and storage until the fuel is used in the kiln. Significant differences between coal and hazardous waste are highlighted below.

Fuel Loading. TXI's coal is mined primarily from both strip mines and underground mines near Raton, New Mexico. The coal is loaded into the rail cars using a track loader and transported in open top hopper rail cars. The distance from Raton, New Mexico to Midlothian is approximately 600 miles per trip. The rail cars are returned to the mine empty; thus the total distance traveled for each load of coal is 1,200 miles.

Fuel Transport. *Coal*: There is an average of 95 tons of coal in each rail car and typically 25 rail cars are transported together at a time, for a total of 2,375 tons of coal which can be transported per trip. To provide the necessary 250,000 tons would require that 25 cars transport coal to TXI, or 104 trips be made each year. It takes approximately 32,000 gallons of diesel fuel per trip, or 3,328,000 gallons of diesel fuel each year for rail transport of the coal.

Figures 2 and 3. **Comparison of Inputs, Outputs & Impacts of Coal and Waste Fuel During Raw Materials Management.**

Figure 2. Obtaining Fuel.

COAL

INPUTS		OUPUTS	IMPACTS
139,272 gallons of diesel fuel for machinery Large volumes of well water for use at the wash plant	Acquisition of coal: 250,000 tons from mining	AIR: 8.92 tons TSP 8.86 tons CO 1.02 tons HC 18.71 tons NO_x 2.06 tons SO_x Waste water from plant Solid waste	Exposure to air pollutants causes a variety of adverse health effects Air pollutants cause adverse health effects to the environment at a local and global level Surface or groundwater contamination Occupational illnesses/accidents Damage to vegetation and wildlife

WASTE FUEL

INPUTS		OUPUTS	IMPACTS
None	Acquisition of waste: 241,776 tons from generators and fuel blenders	Possible release of small volume of VOCs	Incineration of waste in a cement kiln can be considered beneficial to the environment. • It results in the permanent destruction of wastes (and thereby prevents effects from other disposal options) • Use of heat value conserves fossil fuels

Figure 3: Fuel Loading, Transport, Unloading & Storage.

COAL

INPUTS		OUPUTS	IMPACTS
3,340,000 gallons of diesel fuel for equipment and locomotives	Loading by track loader Transport by rail Front end loader used at TXI	AIR:216.3 tons CO 156.4 tons HC 615.7 tons NO_x 94.8 tons SO_x 41.6 tons TSP (combustion) 250.0 tons TSP (fugitive emissions & rail car leakage)	Exposure to air pollutants can cause adverse health effects/potentially significant exposures to populations near the rail line Possible adverse environmental effects from air pollutants Possible contamination of surface water

WASTE FUEL

INPUTS		OUPUTS	IMPACTS
636,412 gallons diesel fuel for tankers • Electricity for pump operation	Load and unload by pump Transport by tanker truck	AIR:138.6 tons CO 16.8 tons HC 13.44 tons NO_x 1.4-2.15 tons SO_x (est.) TSP (unknown)	Exposure to air pollutants can cause adverse health and environmental effects

Diesel fuel is also consumed by the track loader, which loads the rail cars (542 gallons per year) and by front end loaders (9,375 gallons per year) that move coal at Texas Industries. Altogether, in loading, transport, unloading and storage, approximately 3,340,000 million gallons of diesel are used annually in this scenario.

On average, 0.1% of coal loaded into the rail cars is lost due to fugitive emissions and rail car leakage (12). If 250,000 tons per year are transported, this is a loss of 250 tons per year to the environment.

Waste: For the purposes of this analysis we have assumed that all waste fuel is transported by truck -- a conservative assumption given that truck transportation accident rates are higher than by rail, and that not all waste arrives by truck. In order to produce 1.2 million tons of cement, 59.2 million gallons of waste fuel would be needed each year by TXI. Waste fuel is typically transported in trucks that each hold 4,960 gallons of fuel. Therefore, 11,932 trips would need to be taken each year, at an average distance of 320 miles per trip, or 3.82 million miles per year. At six miles per gallon, 636,412 gallons of diesel would be needed to transport the waste fuel each year.

Fuel Unloading. *Coal*: Once the rail cars reach Texas Industries, they are unloaded inside the plant. Coal is discharged from the bottom into an undertrack hopper. It is relayed up on a conveyor, where it is unloaded by dropping it 30 feet onto ground stock piles. The coal is stored on the ground until it is needed. From the piles, it is taken by a front-end loader to another hopper which takes the coal to the conveyor belt leading to the cement kiln. Emissions from equipment were calculated based on AP-42 data for the use of one track loader, four locomotives, and three front end loaders.

Waste: Truck accidents may potentially result in spills or releases which could have detrimental effects to the environment, the truck driver, and possibly the public. All trucks must meet certain specifications to be used for the transport of hazardous waste. TXI uses trucks that have been custom-built to their specifications, which exceed national standards. TXI trucks are made of stainless steel, and they are double conical with center discharge.

It is difficult to evaluate and quantify the possibility of an accident, as national accident rates for hazardous wastes shipments per mile transported are not available. Texas Industries has taken precautions to prevent accidents by using trucks that exceed necessary standards and by assuring that drivers are trained well and maintain exemplary safety records. To date, TXI drivers have driven approximately 2.3 million miles with no spills or accidental releases of materials.

Whether or not the waste was to be used as fuel at Texas Industries, it would have to be loaded, transported (most likely by truck), unloaded, and stored at another type of disposal facility. The impacts of this step is included in this section to ensure a conservative analysis, although truck transport of hazardous waste likely does not reflect a net increase in environmental impact due to use of waste fuels in cement kilns.

Fuel Storage. A low volume of VOC emissions may be released during *waste fuel* loading, and emissions from the tankers are well controlled. Overall fugitive emissions from waste fuel handling are negligible.

There may be significant air emissions of *coal dust* that have not been quantified during several different stages after the coal has been unloaded. First, the conveyor belts are covered so they are not affected by the weather, but are not entirely enclosed, so emissions to air may occur during movement of the coal by conveyor belt. Second, when the coal is dropped from the conveyor belt to the stock piles, emissions to air may result. After the coal is within the cement kiln, it is entirely enclosed and there are no further emissions.

Summary. Figure 3 summarizes the inventory of materials needed to manage the waste fuels and coal from loading through transport, unloading, and storage, and compares it to the resulting environmental releases that are associated with managing those materials.

The volumes and impacts of each material input and output during the management of raw materials was partially quantified. Management of the process raw materials, such as shale, is the same regardless of fuel type, and no quantification is necessary to show there is no difference in impact. With regard to the other process input, the fuel to heat the raw materials, it is apparent from semi-quantitative review of the data that the impacts of managing coal exceed the impacts of managing the waste fuels.

Product Manufacturing

Product manufacturing includes processing raw materials through the kiln, grinding the clinker, and adding gypsum and other compounds to produce the desired cement. Outputs evaluated included air emissions, cement kiln dust (CKD) and clinker; if improperly managed, these outputs have the potential to result in public or occupational exposures and impact the environment.

For the most part, the manufacturing operations will be the same whether coal or hazardous waste is used as fuel. The primary difference is that if hazardous waste is used as fuel, it cannot legally be used during preheating or cooling of the kiln. This is to ensure that adequate temperatures and conditions in the kiln are maintained when hazardous waste is burned to ensure destruction of organic materials.

Packaging, Transport, and Distribution of Cement

This section of the LCA covers all stages after the cement is produced to get the product to the consumer. As it has been established in several studies and analyses that the product is essentially the same no matter what type of fuel is used, these subsequent processes are not affected by the type of fuel used. Therefore, the inputs and impacts of any outputs from these processes are equivalent and are not evaluated.

Consumer Use

This section considers the composition of the product itself and impacts that might occur from its use. As with the previous section, the product is essentially the same no matter what type of fuel is used. As these subsequent processes would not be affected by the type of fuel that was used during production of the product, the inputs and impacts of any outputs from consumer use are equivalent and are not evaluated.

Recycling and Waste Management

Based on the above information, recycling and ultimate disposal of cement products would be the same for cement produced with or without waste fuel. The lifetime of cement products is generally quite long. While cement products are in place, they have no known impact to surrounding soil, water, or living creatures that would vary by fuel type. When cement is disposed of, there are possible exposures to cement dust during removal and transportation. This potential exposure would be the same for cement made with or without hazardous waste fuels.

SUMMARY

This section summarizes the most significant differences noted throughout the life cycle. Figure 4 shows each stage in the life cycle, and depicts whether a particular output or effect is greater (>) for coal or for waste fuel (WF). The symbol ">>" means much greater than, and the symbol "$\geq$" means greater than or equal to. This is followed by a brief description of how probable or significant that output or effect might be, and whether it impacts human health, the environment, or both. In some cases, it is not quantitatively known how significant an output is or what the effects might be, and the effects are instead evaluated qualitatively.

The primary differences in effects to public health and the environment were seen in the first three stages of this LCA. Effects from raw materials acquisition (obtaining the fuel) for coal include equipment usage and operations for mining, which can produce extensive and in some cases permanent damage to the environment. The mining of coal can deface large tracts of land, and cause loss of vegetation and wildlife, possible contamination of surface and/or ground water, and changes in soil composition and quality.

In comparison, waste fuel is obtained either from industries that generate wastes or from fuel blenders (facilities that collect and recycle wastes). If waste fuels were not burned to produce cement, they would have to be disposed of in another manner. In addition, the use of these waste fuels reduces the need for coal to fuel the cement kilns, which results in reductions in environmental impacts from coal mining. Incineration of wastes in a cement kiln is also a means of recovering the energy value in the waste to make a product, and is thus a form of recycling the energy value of the waste. This also conserves non-renewable resources. Waste fuel use was shown to have an overall net benefit to the environment at this stage of the LCA, relative to the greater impacts of other disposal options for the same type of wastes and the ability to avoid the use of fossil fuels by replacement with waste fuels. Finally, the use of waste fuel in cement kilns results in the complete destruction of wastes which could potentially contaminate the environment or effect public health if it were disposed in an alternative manner.

Different impacts were also seen in the loading, transport, unloading and storage of fuel. In this LCA, transport of coal was conservatively assumed to be totally by rail and transport of waste fuel was assumed to be totally by truck. (Statistically, trucks are involved in more accidents per year than rail cars, which could potentially result in spills to the environment and possible public exposures. In order to prevent accidents, TXI uses trucks that exceed safety requirements and drivers are selected based on their experience and safety record.)

Coal is responsible for a higher level of release of the air pollutants of concern to human health and the environment overall, when compared to waste fuels. Specifically, the transport of coal by rail results in fugitive emissions of 250 tons of coal particulates per year. This is primarily a human health concern. The combustion of coal in the cement kilns also results in high emissions of sulfur and nitrogen oxides — nearly 6,000 tons per year.

There is a higher risk of an accident with the transport of waste fuel by truck than coal by rail. The probability of an accident is difficult to quantify. Impacts may range in severity depending on the size of the spill. TXI has attempted to reduce the likelihood and magnitude of an accident by using trucks that exceed necessary standards and by ensuring that drivers are well trained and maintain exemplary safety records. TXI drivers have driven over 2.3 million miles with no spills or accidental releases of materials.

Figure 4. Comparative Analysis of Coal and Waste Fuel at Each Life Cycle Stage.

INPUTS	Life Cycle Stage	OUTPUTS	IMPACTS
Coal > Waste Fuel (Environmental, consumption of fossil fuels)	RAW MATERIALS ACQUISITION (Obtaining the fuel)	TSP: Coal > WF	Potential health effects
		CO: Coal > WF	Effects unknown
		HC: Coal > WF	Potential health/env. effects
		NO_x/SO_x: Coal > WF	Potential health (aerosols) & env. (acid rain) effects
		Accidents: WF > Coal	Potential health/env. effects
		Groundwater: Coal > WF	Potential health/env. effects
		Surface water: Coal > WF	Potential health/env. effects
		Solid wastes: Coal > WF	Potential health/env. effects
		Occupational: Coal > WF	
		Recycling: WF > Coal	WF conserves fossil fuels
Coal >> Waste Fuel (Consumption of fossil fuels)	RAW MATERIALS MANAGEMENT (Loading, transport, unloading & storage)	TSP: Coal >> WF	Significant to health & env.
		CO: Coal > WF	Unknown
		HC: Coal > WF	Potential health/env. effects
		NO_x/SO_x: Coal > WF	Potential health (aerosols) & env. (acid rain) effects
		Accidents: WF > Coal	Potential health/env. effects
Coal = Waste Fuel	PRODUCT MANUFACTURING	TSP: Coal ≥ WF	Unknown
		CO: WF > Coal	Unknown
		HC: Coal ≥ WF	Unknown
		NO_x/SO_x: Coal >> WF	Probable health/env. effects
		Metals: WF > Coal	Potential health/env. effects
		CKD: Differences from fuel type not significant	
		Clinker: Differences from fuel type not significant	
Coal = Waste Fuel	PACKAGING TRANSPORT & DISTRIBUTION	No difference based on type of fuel used	
Coal = Waste Fuel	USE OF CEMENT	There are no detectable differences in cement made with coal or with waste fuel	
Coal = Waste Fuel	RECYCLING & WASTE MANAGEMENT	No difference based on type of fuel used	

The processes involved in the product manufacturing stage are basically the same whether coal or waste is used as fuel. In the kiln, the raw materials (limestone, shale, sand, etc.) reach temperatures of approximately 2,750°F and change composition to form a product called clinker. (Clinker is cooled and ground with gypsum to make cement). The air emissions, however, differ when coal and waste fuels are used and depend on the composition of the fuels being used relative to the inorganic content of the coal.

During the production of clinker in the kilns, high levels of nitrogen and sulfur oxides are released when coal is burned. If improperly managed, exposure to these compounds may result in adverse health effects to persons that are exposed and can also cause environmental damage. Emissions of these compounds are approximately three times higher when coal is used than when waste fuels are used in the kiln.

During manufacturing at TXI, total metals emissions were higher when waste fuel was used and emissions of 4 of 5 of the air pollutants evaluated in this study were higher when coal was used. The TXI plant has achieved a destruction and removal efficiency of 99.9999% for organic compounds and high System Removal Efficiencies for metals. Emissions at the TXI plant were below known national averages for all metals when coal was burned, and below average for all metals except lead when waste fuel was burned. No differences in the composition of CKD or clinker related to fuel type were reported in the literature or seen at the TXI plant.

After cement is produced, it is packaged, transported, distributed, used, and disposed in the same manner whether coal or waste fuel was used. This is because the cement product is basically the same, physically and chemically, regardless of which type of fuel is used. Three studies have compared samples of cement produced with coal and with waste fuel to determine whether there were any differences that could affect persons using that cement. The studies all showed that there were no discernible differences in the composition of the cement. In addition, one sample of cement produced at Texas Industries using waste fuels was compared with a sample of cement produced using fossil fuels. Again, no chemical differences were found.

Overall, the cement product made with waste fuels and with fossil fuels appear to be indistinguishable based on all studies available, and there are no known increased effects to public health or the environment from the use of waste as fuel in the production of cement. In fact, potential effects to health and the environment appear to be less throughout the life cycle of cement when waste fuel is used. This is important information for consumers wishing to purchase cement based on the environmental impact and public health effects of this product.

CONCLUSIONS

This LCA has been produced to comprehensively compare the environmental and public health effects of producing cement made with coal and with waste fuel, in part so that persons that buy and use cement can make an informed decision regarding this product. The overall conclusions of the LCA are that use of waste fuels at the Texas Industries plant:

1. Does not increase, and may in fact reduce, the concentration of contaminants in the cement product due to the reduction or elimination of the use of coal;
2. Reduces or eliminates use of non-renewable fossil fuels, such as coal, as well as the environmental damage and impacts associated with coal mining;

3. Provides a more environmentally beneficial means of destroying many types of hazardous wastes than alternative treatment methods, including hazardous waste incineration, thus decreasing the need for waste treatment facilities and capacity;
4. Decreases overall emissions during transportation but may increase the overall consequences of accidents and spills;
5. Results in cement product which may be packaged, transported, distributed, and used in the same manner as cement product made with coal;
6. Lowers the cost of cement production; and
7. Overall, appears to result in less health and environmental impacts than the use of coal.

As cement plants vary in their use of fuels, as reflected in their permits, this evaluation was designed specifically to evaluate cement made at the Texas Industries cement plant in Midlothian, Texas. Only information and data specific to TXI were used in this study, and conclusions apply only to the cement produced at that plant. Extrapolating the conclusions of this focused LCA to other facilities and other products should be done only after careful review of these assumptions and data relevant to those products.

REFERENCES

1. Environmental Toxicology International, Inc. (ETI). 1993. *Comparative Life Cycle Analysis of Cement Made With Coal vs. Hazardous Waste As Fuel at Texas Industries, Midlothian, Texas.* November. Available from D.R. Jones, Texas Industries, 7610 Stemmons Freeway, Dallas, TX 75247. Tel. (214) 647-3946.
2. U.S. EPA. 1992. *Life cycle assessment: Inventory guidelines and principles.* EPA 600/R-92-245. U.S. Environmental Protection Agency, Office of Research and Development, Washington, DC.
3. Curran, M.A. 1993. Broad-based environmental life cycle assessment. Environmental Science and Technology 27(3):430-436.
4. Huhta, R.S. 1991. International cement review. *Rock Products* April:55-80.
5. Valenti, M. 1993. Tougher standards for burning hazardous waste. *Mechanical Engineering* Aug.:68-72.
6. Ullman, F. 1991. The Japanese cement industry. *Rock Products* April: 47-51.
7. Vorres, K.S. 1979. Coal. In *Kirk-Othmer Encyclopedia of Chemical Technology*. 3rd Ed. Vol. 6. pp. 224. Wiley-Interscience, NY.
8. U.S. EPA. 1989. *Estimating air toxic emissions from coal and oil combustion sources.* EPA 450/2-89-001. U.S. Environmental Protection Agency, Office of Air and Radiation, Research Triangle Park, NC.
9. U.S. Department of Transportation. 1991a. Hazardous materials releases (by year and mode). 29 March.
10. SETAC (Society of Environmental Toxicology and Chemistry). 1991. *A Technical Framework for Life-Cycle Assessments.* SETAC and SETAC Foundation for Environmental Education, Inc., Washington DC.
11. U.S. EPA. 1985. Air Pollution Emission Factors (AP-42), 4th Edition. U.S. Environmental Protection Agency, Office of Air and Radiation, Research Triangle Park, North Carolina.
12. Texas Industries. 1993a. Personal Communication. (Telefacsimile to J.Beeh, Environmental Toxicology International, Inc., Seattle, WA regarding transportation of coal and hazardous waste used at Texas Industries.) Midlothian, TX. 5 October.