The Cement and Concrete Industry in Puerto Rico:

An Industry Overview and Analysis

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FOREWORD

Industrial Ecology (IE) is “the study of the metabolisms of technological organisms, their potential environmental impacts, and the ways in which their interactions with the natural world can be restructured to enable global sustainability” (Graedel, 2006). Professor Marian Chertow directs the project “Puerto Rico: An Island of Sustainability,” which studies the industrial interactions among firms and companies in an island setting. The primary research objectives of the industrial ecology project include:

- *Providing practical recommendations for improving environmental sustainability of industrial activities in Puerto Rico*
- *Collaborating with Puerto Rican professionals and students to augment their understanding of industrial ecology concepts and usefulness*
- *Improving theoretical understanding of how industrial symbiosis is related to economic development*
- *Identifying potential symbiotic relationships*
- *Developing a methodology for studying industrial ecosystems (Ashton, 2006).*

As of 2001, Yale University and the School of Forestry and Environmental Studies Industrial Environmental Management Program have been trying to answer the question *Can industrial ecology be a useful tool in Puerto Rico’s economic development?* (Ashton, 2006). This project applies the tools, and key concepts of the IE field in the context of analyzing the diverse industrial sectors in the island of Puerto Rico, and examines the cement and concrete industries in the context of these goals.

I. INTRODUCTION

Background

Cement and concrete products comprise the largest share of construction materials worldwide. The widespread usage of cement and concrete in construction can be attributed to their abundance, durability, and relatively low price. Demand for these products has grown in tandem with world population and development. From 1995 until 2003, global cement production increased 500 million tonnes per year. The annual concrete production worldwide is estimated at 6 billion tons, or more than 1 tonne per person (SDC, 2001). As current population growth trends continue, demand will continue to rise (BGS, 2003). China, India, and the United States currently produce most of the world's cement producing 45 percent, 5.85 percent, and 4.46 percent respectively (van Oss, 2006).

The cement and concrete industry in Puerto Rico is relatively young compared with the U.S. mainland. The first cement facility was founded in the U.S. in 1876 by David O. Saylor under the name of Coplay Cement Company in Pennsylvania (Essroc, 2004). The first large-scale cement production did not begin in Puerto Rico until the 1950s, when Luis Ferré and Empresas Ferré bought Puerto Rico Cement and Ponce Cement (ARR, 2006). By 1955, Ponce Cement produced approximately 30,000 bags of cement per day (ENDI, 2006). In recent years, Puerto Rico Cement and Ponce cement have been bought by the international cement companies Essroc Italicementi and CEMEX.

An increasing population density over the years has generated a greater demand more infrastructure and inputs necessary for its construction such as cement and concrete (Evans, pers. comm.). Today, the demand for cement in Puerto Rico is about 1.9 million tons per year, or 500 kilograms per person per year (kg pp/yr). This is significantly higher than the global average of about 272 kg pp/yr, which is largely a function of Puerto Rico's location in a hurricane prone area. The demand for ready-mix concrete in Puerto Rico is estimated at about 6.5 million cubic meter ($Mm^{3)}$ per year calculated based on the amount of cement sold in Puerto Rico using the conversion rate of van Oss 2005 report.

Both the cement and concrete industries are important in the Puerto Rican economy and contribute significantly to the manufacturing, construction, industrial transportation, utility and residential employment sectors (SDC, 2001).

Objectives

The objective of this research is to examine the cement and concrete industries in Puerto Rico in terms of material flows, market interactions, environmental and industrial challenges.

Methodology

Research for this project include literature review, interviews with key companies in the Puerto Rican cement, concrete and demolition industries, as well as personal communications with governmental officials (Appendix A). The material flow diagram is constructed from a synthesis of this information; where exact agreement was not possible, numbers published by government agencies, and data from other significant research papers, are included.

I. CEMENT INDUSTRY

Overview of Cement Production

Cement making is a material intensive process, which requires the daily input of thousands of tons of materials at a given facility and consists primarily of limestone, clay, sand or shale, and gypsum. Millscale, iron ores, bauxite and other minerals are also utilized in small quantities in order to obtain the desired chemical composition. Due to their high volumes and low per ton value, limestone and clay are usually mined in close proximity to the cement factories. The quality of the limestone deposits and their estimated lifetime are some of the important factors in determining where to locate a cement plant. Other materials are used in relatively small quantities and local availability is not crucial.

After the limestone and clay are transported from the quarries, they pass through a series of crushers, which gradually reduce the size of the particles to about 3 inches in diameter. Once crushed, the materials are either ground into fine particles in large mills, mixed with compressed air and fed into the kiln as dry powder in the dry process; in the wet process, fine particles are mixed and ground with water and fed to the kiln as a slurry. Due to the excess energy needed to evaporate the added water, there has been a historical shift away from the wet process. In Puerto Rico, the change from wet to dry process began in 1991.

The kiln is the heart of each cement plant. It is a slowly rotating, slightly tilted horizontal steel tube, lined with special firebricks. Its length and the diameter vary depending on the capacity of the plant and the type of feeding process. The temperature in the kiln gradually increases along its length and reaches about 1450°C at the lower end. As the materials pass through the kiln, they undergo series of chemical changes. The first of these changes is the calcination of limestone before becoming clinker, an intermediate product. After the clinker is cooled with cold air, it is mixed with additives and ground into particles smaller than 45 micrometers. Gypsum is then added to the clinker usually accounting for 3 to 7 percent of the finished cement. Depending on the desired qualities of the final product, fly ash, granulated blast furnace slag, limestone or natural pozollans are also used as additives. (see Appendix B for the main types of cement and their main characteristics). The finished product is stored in silos and transported out of the plants either in bulk in specialized trucks, or is first packaged in paper bags and then transported on wooden pallets covered with plastic wrap. See Appendix C for main steps of cement production (PCA, 2006; Evans, pers. comm.).

Cement Market in Puerto Rico

Cement production in Puerto Rico is one of the major industries on the island and is comprised of CEMEX Puerto Rico and Essroc San Juan, two local manufacturers, and Antilles Cement, an importer. Cemex dominates the industry, with a market share of 50 percent. Essroc San Juan and Antilles Cement control about 35 percent and 15 percent of the market respectively. Below are brief profiles of the three companies:

***CEMEX Puerto Rico*:** The factory was founded in 1941 in the outskirts of the city of Ponce under the name Puerto Rico Cement Company. At that time, the company was owned by a local family, had production capacity of 31,000 tonnes per day and used the wet process. Driven by rising energy prices, the company switched in 1991 from the wet to the dry process. In 1997 the plant increased its capacity to 41,000 tonnes per day in response to increased demand. International cement giant CEMEX acquired the plant in 2002. CEMEX Puerto Rico produces 0.95 million tonnes per year of Type I Portland. Seventy percent of cement is sold in bulk and 30 percent is sold in bags.

Essroc San Juan: The Company was built as a wet cement processing facility in 1970, close to the city of Vega Alta. It was acquired in 1991 by a French company, who converted to the dry process. The current owner of the factory, Italicementi, bought the company in 1994. The plant supplies about 0.65 million tonnes of cement per year to the market. Only Type I and Type II cement are currently produced but research is underway to start the production of slag modified and pozzolan-modified Portland cement. Two thirds of the produced cement is sold in bulk.

Antilles Cement: Antilles Cement, also known as Cemento Elefante Rojo (The Red Elephant), is the only cement importer to the island. It entered the market in the 1990s and is currently supplying 0.25 to 0.30 million tonnes per year, mostly imported from China and Korea. Antilles Cement imports Type I and Type II Portland cement, 95 percent of which is sold in bulk.

Business challenges: Cement

Community-Level

Impact of Urban Encroachment

The CEMEX and Italicementi plants were initially built several decades ago close to the ports of San Juan and Ponce to take advantage of the location and to keep away from urban areas. Over time, urbanization has brought housing developments in close proximity to the cement plants. Residents are concerned about potential health effects of air-borne cement kiln dust. Both companies take caution by sprinkling water throughout their plants to reduce dust levels. Essroc collects the dust with trucks. Amongst the cement manufacturers, CEMEX is located closest to a residential area. The company is taking extra measures, such as planting trees to create a dust barrier and buffer zone between the plant and the residential areas. However, residents complain that gray cement kiln dust is visible within their homes and on the cement delivery trucks going into and out of the plants.

Impact of Cartels and Multi-National Companies

In the last decade, two large international companies control cement production in Puerto Rico. Based on our interviews, we find that locals and industry insiders are somewhat disappointed about the take over, which has made them less trusting of the industry. Subsequently, this has created more tensions between cement manufacturers and communities located on their periphery. Both companies are trying to improve community relations by inviting the general public into their plants and conducting community activities, working with local non-profit organizations, and launching environmental education campaigns. These activities are part of their efforts in improving public relations.

Industry-Level

Competition and Protectionist laws

The cement market is very competitive. Market behavior in Puerto Rico is defined by price, and not by the quality of cement. It is speculated that before Antilles Cement entered the cement market, Essroc and CEMEX had more control of cement prices, which were higher than the average on the world market. When Antilles Cement started importing cement, the price dropped by $30 (Gonzales, pers. comm.). Despite the competitive market, cooperation between the two cement manufacturers is apparent. CEMEX and Essroc occasionally share equipment and clinker. Out of mutual interest, all three cement suppliers also share information on relevant regulation and legislation that can affect their companies.

Protectionist laws make entering the Puerto Rican cement market difficult for importers. In order to protect the local manufacturers, the legislature passed Law 109 (1985), which requires the use of Puerto Rican cement in publicly funded construction projects. On September 17, 2001, a second part of the legislation, Law 132, was passed that requires special labels for cement manufactured outside of the island. These protectionist laws, which trigger the Dormant Commerce Clause, which stipulates that Congress has the authority to regulate commerce within and outside of the U.S., have been challenged in court by Antilles Cement in the last few years (U.S. Court of Appeals, 2005).

High Energy Costs and the Use of Alternative Fuels

The costs of fuels, are consequently electricity prices, are high and continue to increase in the island. Current prices range from $0.16 to $ 0.18 per kilowatt per hour (kW/h). At such high costs, it is in the interest of the companies to be energy efficient. Essroc and CEMEX have improved their energy efficiency in the last decade by switching from a wet to a dry process cement-making process.

Further, the two companies have substituted some of the low sulfur used in clinker manufacturing with used oil. The governments subsidizes the use of used oils, compensating companies $0.60 per gallon used (Riviera, 2006). Currently both plants meet less than 10 percent of their fuel needs with used oil despite having the capacity to completely switch from coal to used oil. The main reason for this underutilization is the insufficient collection of used oil; only 50 percent is collected, on the island which limits the supply of the commodity to the cement plants.

Waste tires are another substitute to the fossil fuels required in the cement kilns. CEMEX and Essroc have both considered burning tires for energy, but there are two main constraints to advancing this effort. First, the permitting process is onerous and lengthy. Second, the public is strongly opposed to tire-burning due to perceptions that it results in significant air pollution. As a result, both companies are willing to burn waste tires for energy only under a government mandate which would ease the permitting process and potentially reduce public (Evans, pers. comm.). Technically, 15 to 20 percent of the total coal input into the plants can be substituted with either whole tires or shredded tires.

Sewage sludge is another alternative source of fuel to coal, but neither of the plants has looked into this possibility. The value of sludge is about 5,500 kcal/kilogram of dry volatile solid. Coal has a fuel value of 7,750 kcal/kilogram suggesting that sludge can provide tremendous potential for energy (Outwater, 1994). In addition, most of sludge waste amassed on the island is landfilled (22,410 tonnes were landfilled in 1999), and considering existing landfill constraints, there are advantages to exploring the energy potential of sludge (PR, 1999). The main limitations in using sewage sludge in cement kilns are related to its physical composition. If sludge has a high value of phosphate, the quality of cement can be affected. A high content of mercury content in sewage sludge can affect both cement quality and production process. These limitations can be overcome by testing the chemical composition and combustion potential of sludge to find the appropriate conditions for its use. Sludge has the capability to substitute up to 15 percent of coal input in cement manufacturing (Colon; Evans, pers. comm.).

Environmental Challenges: Cement Companies

The main environmental challenges of cement companies in Puerto Rico are similar to the hurdles cement companies face worldwide. These challenges stem mainly from the intensive extraction of raw materials, significant energy consumption, ambient emissions, and solid wastes associated with clinker production.

***Carbon Dioxide* (CO_2)**

The world cement industry contributes about 5 percent of global anthropogenic CO_2 emissions (Worrell, 2001). The main sources of CO_2 in cement manufacturing are the calcination of limestone (52 percent), the combustion of fuels in the kiln (41 percent), and the indirect emissions related to the electricity used in the cement plant (7 percent) (Choate, 2003). Therefore, the main opportunities for emission reductions are: improved process energy efficiency, decarbonization of fuels, use of alternative fuels, and waste fuels, and increased use of additives in cement making.

Improved Energy Efficiency

Cement production is a very energy intensive process. Most of the energy, fossil fuels, is used to reach high temperatures in the kiln. Coal, oil and natural gas can be used as fuels. With the dry cement-making process, about 4.2 to 4.4 million Btu of fuel is required to produce a ton of clinker. Grinding input materials and clinker in mills and operating equipment in the factory also consume a considerable amount of electricity. About 146 to 148 kWh of electricity is required per tonne of cement produced by the dry method (van Oss, 2005).

Both cement factories in Puerto Rico have followed the world trends and have switched to the more energy efficient dry process of clinker production. At both facilities the hot air from cooling clinker is used as combustion air in the kiln and for preheating the input materials. This practice is widespread in the cement industry. Neither of the facilities uses the residual heat of the exhaust gases for co-generation.

Use of lower carbon fuels

Oil and natural gas are less carbon intensive than coal. A shift from coal to oil or natural gas would directly translate into a reduction of carbon dioxide emissions. However, coal is much cheaper than oil or natural gas, and in an industry with low margins and high fuel consumption, a shift to a more expensive fuel is not economically attractive. A carbon tax would theoretically make a switch away from coal more feasible.

Use of alternative fuels

Use of alternative fuels such as waste tires, used oil, impregnated saw dust, or sewage sludge is another way to lower carbon dioxide emissions from cement production. High temperatures in the cement kiln guarantees full combustion of these materials. The natural scrubbing properties of calcium oxide, which forms inside the kiln, significantly reduces the amount of emissions from combustion hence ensuring a safe way to dispose of these wastes. Used oil, waste tires and sewage sludge have high caloric values and by incinerating them in the kilns, fossil fuels are conserved. Accounting for the carbon dioxide emissions from these alternative fuels is slightly complex and depends on the type of waste. According to a recent publication by the World Business Council for Sustainable Development, bio-fuels, such as sewage sludge for example, should be considered carbon neutral. Carbon dioxide emissions from burning used oil or tires however, have to be accounted for (WBCSD, 2005). Improving the efficiency of used oil collection, for example, will not only lead to reduced CO_2 emissions for the cement industry but will ensure that that oil does not pollute the water sources of Puerto Rico.

Increased use of cement additives

As mentioned earlier, the main source of carbon dioxide emissions from cement manufacturing is the calcination of limestone to calcium oxide. One way to reduce these emissions is to use alternative materials already containing calcium oxide in the clinker manufacturing. Granulated blast furnace slag, fly ash and bottom ash are the materials most commonly used for limestone substitution. A tonne of furnace slag substituted for a tonne of limestone creates a 0.5 tonnes reduction in CO_2 emissions (van Oss, 2005). Another strategy to reduce CO_2 emissions is to reduce the clinker content of finished cement through the use of additives such as fly ash, slag or limestone. When making blended cements, CO_2 emissions are also decreased by reduced fuel use. However, the extent to which these alternative materials can be used in the clinker making or in blending the cement is somewhat limited. Use of alternative materials is tightly linked to the desirable cement qualities and is very dependent on the demand and acceptance by concrete producers.

The cement industry of Puerto Rico has only partly taken advantage of these opportunities for energy and CO_2 emissions reductions. Small quantities of blast furnace slag are blended in the cement produced by Essroc. The company is also looking into making both slag modified and pozzolan modified cements in the future. Fly ash is not used by either company due to the lack of a local supply of fly ash with the desirable qualities and because of high transportation costs from the mainland United States. Additionally, the concrete and construction industry in Puerto Rico is quite conservative and slow to adopt new products, which further diminishes the motivation of Essroc and CEMEX to explore potential use of fly ash (Evans; Rivera, pers. comm.).

NOx and SOx

NOx and SOx are two of the main air pollutants released by cement plants. The high temperature in the kiln stimulates the formation of nitrogen oxides. Sulfur from the fuels and input materials used in the kiln is also oxidized to SO_2. Due to the scrubbing properties of the calcium oxide, most of the SO_2 is bound into gypsum in the kiln. The SO_2 releases are further minimized due to the Puerto Rican law which requires the sulfur content of fuels imported to Puerto Rico to be under 2.5 percent. Both cement plants in Puerto Rico are monitoring these emissions and are usually below the regulatory limits.

Another source of NOx and SOx at a cement plant is the equipment. These emissions can be reduced by the use of low sulfur fuels, catalytic converters and more fuel efficient equipment. However, none of these factors were mentioned during our interviews as criteria for purchasing decisions.

Particulate Matter (PM)

Releases of particulate matter to the atmosphere are a serious environmental and social concern for the cement industry in Puerto Rico. Some dust is generated at the quarries, around the plant from transportation and spillage of materials and from milling. The main source of particulate matter (PM) however, is the exhaust gas coming from the cement kiln. The CEMEX plant has installed electrostatic filters, which while properly functioning reduce the particulate matter releases to within regulatory standards. However, malfunctions are common and results in short but massive releases of dust. These dust releases are one of the main reasons for the low popularity of the plant among the local community. Essroc uses bag filters, which have far fewer malfunctions than electrostatic filters. The remote location of the plant additionally reduces the impact of particulate matter releases.

Solid Waste

The only substantial solid residue generated at cement plants is cement kiln dust (CKD), which is captured at the dust control equipment, the electrostatic or bag filters. CKD includes particulates representing the raw mix at various stages of burning, particles of clinker, and even particles eroded from the refractory bricks (van Oss, 2005). The fate of the CKD is determined by its composition. The presence of alkalis usually prevents its recycling and this CKD is commonly landfilled. The CKD captured at the bag filters of Essroc is very similar in composition to the finished cement and is completely recycled. At CEMEX, only part of the CKD is suitable for recycling. The rest is sold to a waste management company, which collects liquid wastes from other industries and mixes them with the CKD to form solids that can be landfilled.

Water use and disposal

The cement industry is not a major water consumer. Water is consumed primarily for cooling and dust control. Neither of the cement plants in Puerto Rico experiences water shortages. Both Essroc and CEMEX partially recirculate cooling water. Currently, the high levels of total suspended solids and lack of proper water treatment prevent from more complete water circulation.

Land disruption

Quarrying of raw materials is from surface quarries and is associated with the disruption of large land areas. There are two main approaches to mitigate this impact: use of alternative materials and minimizing the need for raw materials; and the rehabilitation of the quarries once they are exhausted. The limestone quarries of the two cement manufacturers in Puerto Rico are still in use but both companies have expressed a commitment to rehabilitation once the quarries are closed. Essroc is making an attempt to reduce raw materials usage. Annually Essroc utilizes about 300,000 tonnes of limestone slurry generated from washing limestone sand during aggregate production. The use of limestone slurry reduces the amount of quarried limestone by 25 percent. Full substitution of the input limestone would require a shift back to the wet process, which is more energy intensive and thus not desirable (Cartagena, pers. comm.). Blended cements utilize alternative materials and translate into less clinker per ton of cement, which reduces both energy and raw material input.

II. CONCRETE INDUSTRY

Overview of Concrete Production

Concrete is an affordable and reliable building material widely used for construction. Concrete is used as ready-mix or as concrete products such as blocks and precasts. Ready-mix concrete is most common application of concrete in Puerto Rico. Concrete generally consists of 7 to 15 percent cement, 15 to 20 percent water, 0.5 to 8 percent air, 25 to 30 percent fine aggregates such as sand, and 30 to 50 percent coarse aggregates such as gravel or crushed stone. One metric ton of cement will yield approximately 3.4 to 3.8 m^3 of concrete (van Oss, 2005). In concrete, the most widely used cements are Portland Type I and Pozzolana Portland type C-2, though is some instances Types II and IV can also be used (Choate, 2003).

Water for concrete plants is obtained from wells, the local municipal service provider, or local rivers. Aggregates are extracted locally from quarries, although sand is increasingly being imported from the Dominican Republic, due to limited local availability.

Concrete is transported in trucks, and must be used within two hours of mixing. Additives are added to prevent the hardening of the concrete while it is in transport. Appendix D contains a list with the main functions of admixtures in concrete. Each truck contains 10 to 12 cubic yards (yd^3) of concrete, which is the maximum allowable limit approved by local regulations (Joglar, pers. comm.).

In Puerto Rico the ambient temperatures are quite high ranging from 80 to 100^o F. Additional additives are used to reduce water content and ultimately reduce its shrinkage and cracking potential. This is very important characteristic demanded for structural durability in the Puerto Rican climate (Joglar, pers. comm.).

Concrete Market in Puerto Rico

There are 138 concrete product manufacturing facilities. Of the concrete producers, 77 facilities produce ready mix concrete, 31 facilities produce concrete pipes, bricks, and blocks, and other 27 facilities are listed as other concrete manufactures (Wilson et al., 2002). There are many concrete producers on the island, but the market is dominated by CEMEX, Master Concrete, and Empresas Terrassa Inc., which all together control 50 percent of the market (Figueroa, pers. comm.). The other 50 percent of the market is distributed among smaller companies and mobile concrete plants. Additives, explosives for the quarries, retardants, and dyes are imported from the U.S. mainland. The concrete industry sub-sector employs more than 50,000 people (Wilson et al., 2002). Below are brief profiles of three companies representative for the industry:

Group Carmelo Inc., known also as Ecológica Carmelo, Inc. The company started in 1955 as a masonry block plant named Bloques Carmelo (Martinez, 2002). Since then, the company has grown to include production of specialty cements, building blocks, mortars, sand, aggregates, and concrete blocks. It mines aggregate from three quarries located in Vega Baja, Alta, Bayamon, and Guayanillas. The company purchases cement from CEMEX because of the quality, color, and consistency of their product. The company's clients mostly belong to the private and business sectors (Figueroa, pers. comm.). Ecologica Carmelo, Inc. is the only company on the island that uses fly ash.

***Hormigonera del Toa*:** This company produces ready-mix concrete using cement from Antilles Cement. It mines aggregate from seven quarries in the southern part of the island. Hormigonera del Toa's client base is mainly comprised of government agencies (Joglar, pers. comm.).

***Salinas Concrete & Aggregates*:** This company has a small plant that produces concrete, aggregate and asphalt products. It has been operating for 25 years. Salinas purchases cement from CEMEX and mines aggregate from a local river. They also do some in-situ recycling of pavement and building materials. Most of Salinas' business runs on government contracts and they are currently downsizing due to a decline in contracts. Demand is expected to increase in the near future with upcoming elections (Salinas, pers. comm.).

In addition to the three managers of the ready-mix and concrete-producing plants, Eng. Antonio Joglar, President of the Asociación Productores de Hormigón Premezclado De Puerto Rico (APHPPR) (Association of Concrete Ready-mix Producers) in Puerto Rico, was interviewed. It was interesting to get his insight on the concrete market, as the owner of a small ready-mix facility. He also stressed the importance of the APHPR, an active association of ready-mix companies that are working together to have a stronger voice and influence government policies. For example, the association is advocating an increase in the quantity of ready-mix concrete that can be transported by truck. Members share best practices and technology, meet regularly and provide training for workers. Only 13 ready-mix companies are APHPPR members, and together they weave a social network (Joglar, pers. comm.).

Business challenges: Concrete

Community-level

Industry Image

The cement and concrete industries share a problem with the "not-in-my-backyard syndrome" approach to handling environmental and social issues (SDC, 2001). However, in Puerto Rico the major players in both industries take these issues seriously and are working actively with communities and concerned citizens to improve their environmental responsibilities and their overall image. On the other hand, smaller companies are difficult to account for, but some attempt to monitor their operations should be encouraged.

Industry-level

Fragmentation

The concrete industry in Puerto Rico is predominantly comprised of local ready-mix producers but the nature is quite fragmented. Producers are dispersed geographically and their operations are at various scales. In general, companies work independently from each other, which is consistent with findings in other countries (SCD, 2001). This fragmentation can deter companies from adopting promising, yet untested technologies. Reluctance to shift to new processes can be attributed to the competitive market. Experts on the cement industry note that it can take more than 15 years from conception of a new technology to its adoption (SDC, 2001). Aside from Ecologica Carmelo Inc., this trend was evident on the island.

Prescriptive rather than performance-based operating environment

Concrete is the cheapest and most common building material. Price is the most important factor for consumers. There is therefore little incentive for the industry to invest in research on technology, even though what little research has been done suggests that new technologies can improve performance and durability, reduce service costs and premature repairs, and require less energy to produce cement (SDC, 2001). Concrete companies also need to ensure that their product is durable because of safety considerations. New technologies cannot provide this assurance until they have adequately tested and proved successful (SDC, 2001). Additionally, in Puerto Rico restricted landfill capacity is requiring a particular focus on the end-of-life disposal treatment.

High Transportation Costs

Transportation accounts for 20 to 50 percent of the final costs of ready mix concrete (SDC 2001). This problem is exacerbated in Puerto Rico due to vehicular congestion on the highways. While there is no alternative solution for ready-mix concrete, development public transportation could reduce highway traffic and ease the transportation of ready-mix.

Another transportation challenge for concrete makers involves the *Jones Act*. This U.S. government provision, created in 1920, mandates the use of U.S. manufactured and operated transport vessels to and from Puerto Rico, Alaska and Hawaii. The Jones Act is a challenge for concrete manufacturers because it inflates transportation costs, making high volume, low value products like fly ash uneconomical to import. Puerto Rico is in the process of requesting an exclusion from this provision, although at this time it is unclear whether this appeal will be successful (Martinez, 2001).

Environmental Challenges: Concrete Companies

Air pollution

Combustion of diesel fuel is the main source of carbon dioxide produced by the concrete industry. Blending and mixing, and transportation generate 5.65 *10^6 and 4.53 *10^6 tonnes of CO_2 per year, respectively (Choate, 2003). Depending on engine type, diesel trucks can emit exhaust contributing various types of air pollution gases including smog-forming oxides of nitrogen (NOx) and fine particles (PM2.5) (NRDC, 1998).

Water use and disposal

In 1995, water use by the concrete industry was estimated at 4.17 Mega gallons per day (Mgal/day) of which 1.35 Mgal/day was surface water and 2.82 Mgal/day was ground water. Main water sources are concentrated in the northeastern part of Puerto Rico. The largest ground water extraction occurs in Manatí and Vega Baja (Molina-Rivera, 1995). Water is mainly used for dust control, concrete manufacturing, and washing trucks. There is some concern about discharge laced with additives, retardants, and other chemicals or admixtures, which can cause high alkali content. This type of wastewater comes from truck-washing and is not treated prior to discharge.

Solid Waste

Solid waste produced by the concrete industry is limited to municipal waste, dust, and minimal solid material by-product.

Land disturbance

The U.S. Geological Survey reported in 1995 that the principal mining activity in Puerto Rico is the production of sand and gravel for the construction industry (Molina-Rivera, 1995). The concrete industry mines rock, sand and other aggregates, mostly from bedrock but sometimes from local rivers.

In general, companies select quarries with reserves that are expected to last a long time and therefore do not prepare rehabilitation plans. Once again, the larger international companies are the exception as they do have tangible plans.

III. DEMOLITION AND DEMOLITION WASTE DISPOSAL

Overview of Demolition in Puerto Rico

The end of the cement and concrete lifecycle is demolition and disposal. Construction debris accounts for 17.1 percent by volume of all the waste that is produced in Puerto Rico (Soto, 2004). All of the concrete produced in the island is used for construction. Because concrete is extremely durable, buildings get torn down before their lifetime is through. In Puerto Rico the average life span of a building is between 50 and 60 years (Medina, pers. comm.). Recent economic and tourism growth has accelerated demolition and new construction. Hurricane damage also accounts for a share of the construction and demolition industry.

Demolition on the island is accomplished by two processes: implosion and mechanical demolition with heavy equipment. There are many small and unregulated, and only about ten major demolition companies. Of these ten, 5 or 6 recycle concrete. Thirty percent of demolition and one hundred percent of implosions on Puerto Rico is handled by Controlled Demolition and Recycling Corp. Forty-five percent is handled by the other five big firms, and the rest by smaller companies (Medina, pers. comm.).

In 2000, it was estimated that about 1.2 Mt of demolition debris are generated every year of which only 25 percent is recycled (Medina, pers. comm.). Of this amount, 0.3 Mt is recycled (Perez, pers. comm.), 0.7 Mt is landfilled (Wehram, 2003), and 0.2 Mt is disposed of illegally by small, unregulated demolition companies.

Buildings in Puerto Rico are approximately 60 percent concrete, 30 percent steel, and 10 percent other materials (Medina, pers. comm.). Of this, about 25 percent mostly steel is commonly recycled. In order to recycle concrete, the debris has to be relatively clean and can be accomplished in two steps: 1) before demolition, the buildings are stripped of all non-concrete items, such as wooden doorways, metal frames, and ceramic sinks; and 2) after demolition cranes are brought to pick up the debris which is later separated into concrete, steel, and other materials. This operation is time and labor intensive. All recycled products, with the exception of steel, remain in Puerto Rico. Recycled steel is exported to China. Recycled concrete is then crushed for use as aggregate. Government regulations prohibit the use of recycled concrete as a substitute for virgin aggregate in public projects, but it is popular in the private market.

Recycling concrete is an economically viable procedure. Landfill costs are $100 per m^3, and recycling concrete costs $5/ m^3. Recycled concrete sells on the market for $12 to 13/$m^3$, while virgin aggregate costs $14/$m^3$. The biggest obstacle to entering the concrete recycling market is the $250,000 cost of each portable recycling plant (Medina, pers. comm.). In addition to equipment, recycling concrete requires about 450 gallons per day of water for dust control and about 100 gal/day of diesel to run each portable recycling plant (Medina, pers. comm.).

Business Challenges: Demolition Companies

The demolition industry must comply with local regulations and acquire permits for air emissions, diesel motors, noise pollution, and NOx emissions. The Fire Department must be notified prior to each demolition project. Air emissions consist mainly of CO_2 and particulate matter from diesel combustion.

Concrete recycling offers important solution to the construction industry in Puerto Rico and seems to hold promising future. Currently, the government of Puerto Rico provides tax incentives for purchasing equipment for concrete recycling and also contacts for governmental demolition projects are granted with preference to companies intending to recycle the concrete (Medina, pers. comm.). However, currently illegal landfilling is widespread, which acts as a disincentive to concrete recycling companies. Additionally, the government prohibits the use of recycled aggregate in governmental projects, which seems to be conflicting with its overall intention to promote concrete recycling (Figueroa, pers. comm.).

The government has proposed mining landfills for construction debris, and a pilot program will be beginning in Carolina. The goal of this project is to recover landfill space. More incentives should be given to companies to start working on similar landfill cleaning operations.

IV. QUANTIFICATION OF MATERIAL FLOWS

A material flow diagram encompassing cement manufacturing, concrete making, construction and demolition is presented in Appendix E along with technical notes on the calculations.

V. DISCUSSION AND RECOMMENDATIONS

Rules and environmental regulations are essential to ensure environmental quality but formulating legislation that meets all stakeholder demands is a challenge. In the case of Puerto Rico, certain legislation prevents the cement industry on the island to take full advantage current technological advances in terms of energy efficiency and waste management. Among the regulations that this report finds are hindering various interesting opportunities of the industry are the issuance of permits to use alternative fuels, the protectionist laws, and the *Jones Act*. The industry would also benefit from initiatives that streamline the permit issuing process from the various regulatory entities. Additionally, discouraging the illegal dumping of construction and demolition debris could be prevented by providing additional incentives for proper demolition and disposal. Further, Puerto Rico could benefit from exploring opportunities that could help to address the end-of-life fate of concrete products. Currently, buildings are designed and built only with ensuring durability in mind and no attempts are made to incorporate end-of-life construction and demolition management.

The perception of the communities on the hazard of burning tires in the cement kiln seems to be a constraint for cement companies though they are working to educate the communities on their plant operations. The concrete industry could benefit from the transfer of technology and from cooperation to learn best practices. The work of the APHPPR is important in helping to attract the interest of a larger membership network of other ready-mix companies in Puerto Rico.

In terms of energy, more extensive use of alternative fuels by the cement plants in Puerto Rico is an area hiding many opportunities for both cost savings for the cement industry and for safe management of certain problematic waste streams, such as used oil, used tires and sewage sludge. To a big extent the underutilization of alternative fuels in the cement industry is due to lack of governmental support.

It has been estimated that annually between 12 and16 million gallons of used oil are generated on the island (Evans, Rivera, pers. comm.). More accurate number could not be obtained (Cammis, pers. comm.). Despite the fact that there is a comprehensive governmental regulation in Puerto Rico, mandating collection and recovery of used oil (P.R. Gov., 1998), only 3 million gallons were collected in 2004 (Camis, pers. comm.). The fate of the rest of the used oil, between 9-13 million gallons, is either legal or illegal dumping. Technically, the cement industry in Puerto Rico can substitute all coal used in the kilns with used oil, i.e. annually about 40 Mgallons of used lubricant oil. Due to the lack of supply, currently only 6 percent of the coal is substituted, or about 2.4 Mgallons. Therefore, if law enforcement is improved and used oil collection is more sufficient, the cement industry can burn all of the used oil which is currently wasted (9 to 13 Mgallons**)** and avoid the use of approximately 45,000 to 65,000 tonnes of coal per year.

Burning waste tires in the cement kilns is another opportunity to reduce the use of fossil fuels and dispose of a large waste stream. Both Essroc and CEMEX are currently not using waste tires as fuel due to tedious air permitting and public opposition despite their willingness to use this energy source. Annually, about 2 million tires are collected in Puerto Rico (Camis, pers. comm.). Detailed data on the fate of the tires was not available; interviews suggested that most of them are exported to be burnt in cement kilns in mainland U.S. Technically, up to 20 percent of the total coal input into the plants can be substituted with either whole or shredded tires (Evans, Rivera, per. comm.). Annually, this can save 40,000 tonnes of coal and provide safe disposal of over 3.6 million used tires of passenger cars. Therefore, the cement industry in Puerto Rico has the potential to provide an outlet for safe disposal of all the tires collected on the island.

Sewage sludge is another alternative fuel which can substitute coal but is currently not used, but potentially can be if the government can provide transportation cost incentives to the cement industry. With proper testing for the chemical composition of the sludge and combustion testing in the kilns, it is possible to find the appropriate conditions and potentially substitute up to 15 percent of the coal input. If the government is willing to initiate a program for sludge utilization and provide technical and legal support, the cement industry in Puerto Rico is willing to cooperate (Evans, per.

comm.). This means that potentially every year in Puerto Rico about 30,000 tonnes of coal can be substituted and up to 56,000 tons of dry sludge can be diverted from landfilling. As of 1999, annually 27,000 tonnes of dry sludge were generated on the island. Therefore, the two Puerto Rican cement plants can burn all the sludge generated on the island, which will be a cost saving for the industry, cost saving for the government (in 1999 the cost of landfilling sludge was 871,291 USD) and saving valuable landfill space.

VI. CONCLUSION

The cement and concrete industry plays an important role in Puerto Rico. It provides both employment sources and the materials necessary for infrastructure and urban growth. Lack of governmental support appears to be the key factor preventing improved efficiency in the cement industry, especially for the proposed use of alternative fuels. All of the large companies remain committed to decreasing their environmental footprint and are working with the community to teach them about the work they do. Success in developing a greener industry will require cooperation from both industry and government. Implementation of our recommendations will be the beginning of a feasible transition towards greater sustainability.

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APPENDIX A: Personal Communications list.
Interviews were conducted in the period March 6-10, 2006. E-mail communications were carried out in the period February - May, 2006.

Ms. Nivia Ayala Environmental Manager, Essroc Italcementi Production Manager, Essroc Italcementi Road No. 2, Km 26.7 BO Espinosa Dorado, Puerto Rico 00936 T: (787) 721-5878 Email: nivia.ayala@essroc.com **(***Personal interview)* **Mr. Angelo Cartagena** Assistant Plant Manager, Essroc Italcementi Road No. 2, Km 26.7 BO Espinosa Dorado, Puerto Rico 00936 T: (787) 721-5878 Email: angelo.cartagena@essroc.com (*Personal interview)* **Mr. Ramòn Lòpez Cepero** Vice President, Carmelo Group Carretera 866 Km. 0.7 Sabanah Seca, Puerto Rico 00952 T: (787) 251-5494 Email: rlópez@carmelo.com *(Personal Interview)* **Mr. Juan Colon Rivera** Environmental Compliance Officer, Cemex Carretera 123 Km. 8.2 Antigua #10 Ponce, Puerto Rico 00733 T: (787) 842-3000 Ext. 16960 Email: juan.colon@cemex.com.pr *(Personal interview)* **Mr. Lawie Evans** General Managemr and Vice President of Operation Essroc Italcementi Production Manager, Essroc Italcementi Road No. 2, Km 26.7 BO Espinosa Dorado, Puerto Rico 00936 T: (787) 721-5878 Ext. 216 Email: lawrie.evans@essroc.com *(Personal interview)*	**Ms. Melba Figueroa** President, Carmelo Group Carretera 866 Km. 0.7 Sabanah Seca, Puerto Rico 00952 T: (787) 448-9474 Email: mfigueroa@carmelo.com *(Personal interview)* **Mr. Victor Gonzalez** President, Antilles Cemente Corporation PO Box 1992261 San Juan, Puerto Rico 00919 T: (787) 977-5650 Email: victorluisgonzalez@yahoo.com *(Personal interview)* **Mr. Antonio Medina** Manager, Contolled Demolition and Recycling PP Box 2383 Toa Baja, Puerto Rico 00951 T: (787) 883-3695 Email: amedina@cdrcorp.net *(Personal interview)* **Mr. Antonio Joglar Moreno** President, Asociación de Productores de Hormigón Premezclado de Puerto Rico Av. Main Bloque 30, #1 Santa Rosa Bayamon, Puerto Rico T: (787) 798-9200 Email: info@hormigonerospr.org *(Personal interview)* **Vivian Pérez** Environmental Analyst Development Marketing Solid Waste Management Authority Email: vperez@ads.gobierno.pr *(E-mail communications)* **Mr. Efraín Camis Rosado** Environmental Permit Officer II Land Pollution Control Area PR Environmental Quality Board Email: EfrainCamis@jca.gobierno.pr *(E-mail communications)* **Salinas Aggregates and Recycling** Carretera #1 Km 90.9 Barrio Cano Verde, Salinas, Puerto Rico *(Personal interview)*

APPENDIX B: Types of Cement

» Types of Portland Cement
Portland cements are hydraulic cements composed primarily of hydraulic calcium silicates. ASTM C 150, *Standard Specification for Portland Cement*, recognizes eight types of portland cement:

Type I and Type IA*
General purpose cements suitable for all uses where the special properties of other types are not required.
Type II and Type IIA*
Type II cements contain no more than 8% tricalcium aluminate (C_3A) for moderate sulfate resistance. Some Type II cements meet the moderate heat of hydration option of ASTM C 150.
Type III and Type IIIA*
Chemically and physically similar to Type I cements except they are ground finer to produce higher early strengths.
Type IV
Used in massive concrete structures where the rate and amount of heat generated from hydration must be minimized. It develops strength slower than other cement types.
Type V
Contains no more than 5% C_3A for high sulfate resistance.
*Air-entraining cements

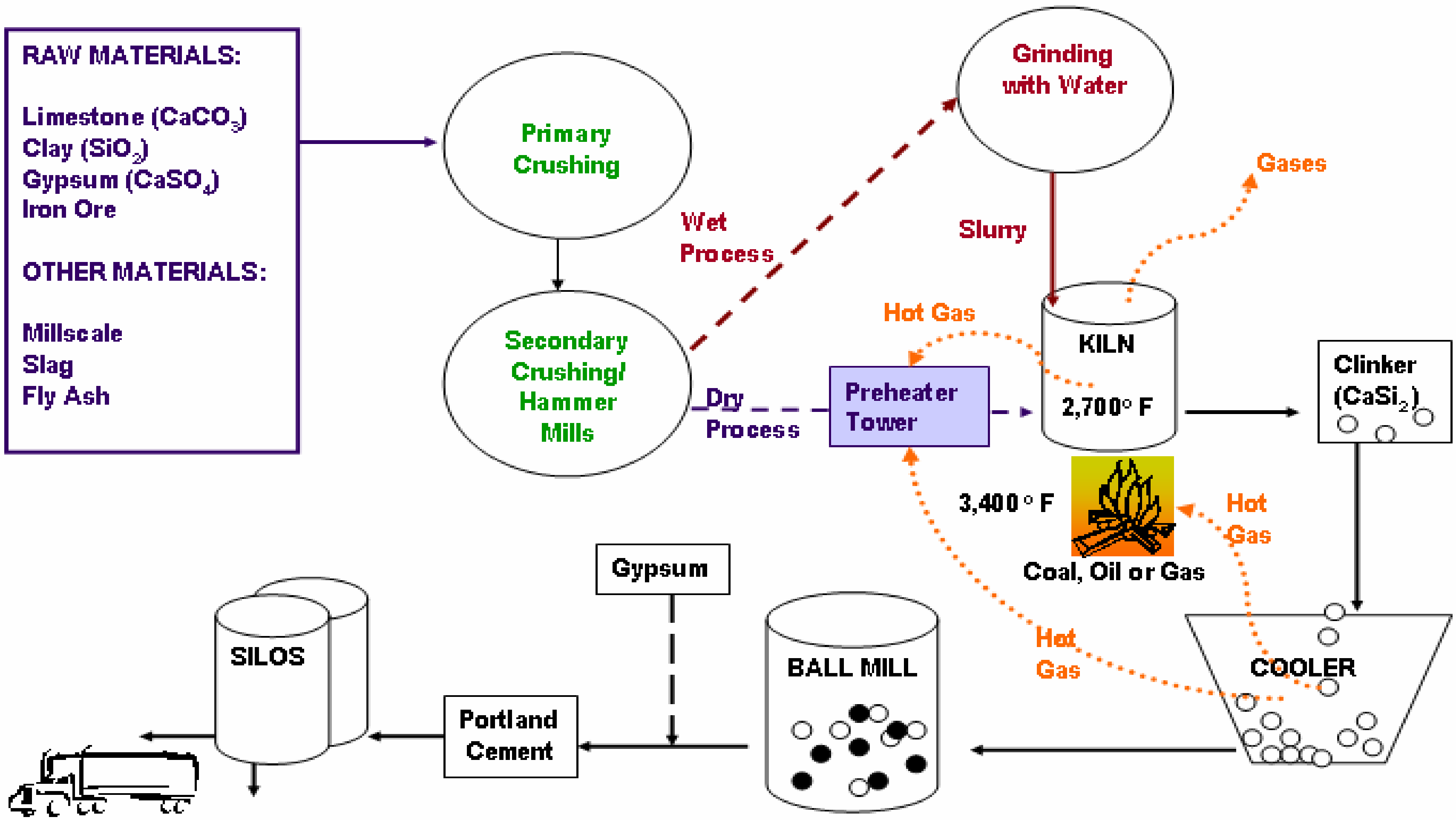
» Types of Blended Cements
Blended hydraulic cements are produced by intimately and uniformly intergrinding or blending two or more types of fine materials. The primary materials are portland cement, ground granulated blast furnace slag, fly ash, silica fume, calcined clay, other pozzolans, hydrated lime, and pre-blended combinations of these materials.

ASTM C 595, *Specification for Blended Hydraulic Cements*, recognizes five primary classes of blended cement:
Type IS-Portland blast furnace slag cement
Type IP and Type P-Portland-pozzolan cement
Type I(PM)-Pozzolan-modified portland cement
Type S-Slag cement
Type I(SM)-Slag-modified portland cement

» Types of Hydraulic Cements
All portland and blended cements are hydraulic cements. "Hydraulic cement" is merely a broader term. ASTM C 1157, *Performance Specification for Hydraulic Cements*, is a performance specification that includes portland cement, modified portland cement, and blended cements. ASTM C 1157 recognizes six types of hydraulic cements:
Type GU-general use
Type HE-high early strength
Type MS-moderate sulfate resistance
Type HS-high sulfate resistance
Type MH-moderate heat of hydration
Type LH-low heat of hydration

Source: Portland Cement Association. http://www.cement.org/tech/cct_cement_types.asp

APPENDIX C: Material flows in cement manufacturing



Source: Adapted from: "Cement and Concrete Basics. How Portland Cement is Made." Portland Cement Association. http://www.cement.org/basics/howmade.asp. 2006.

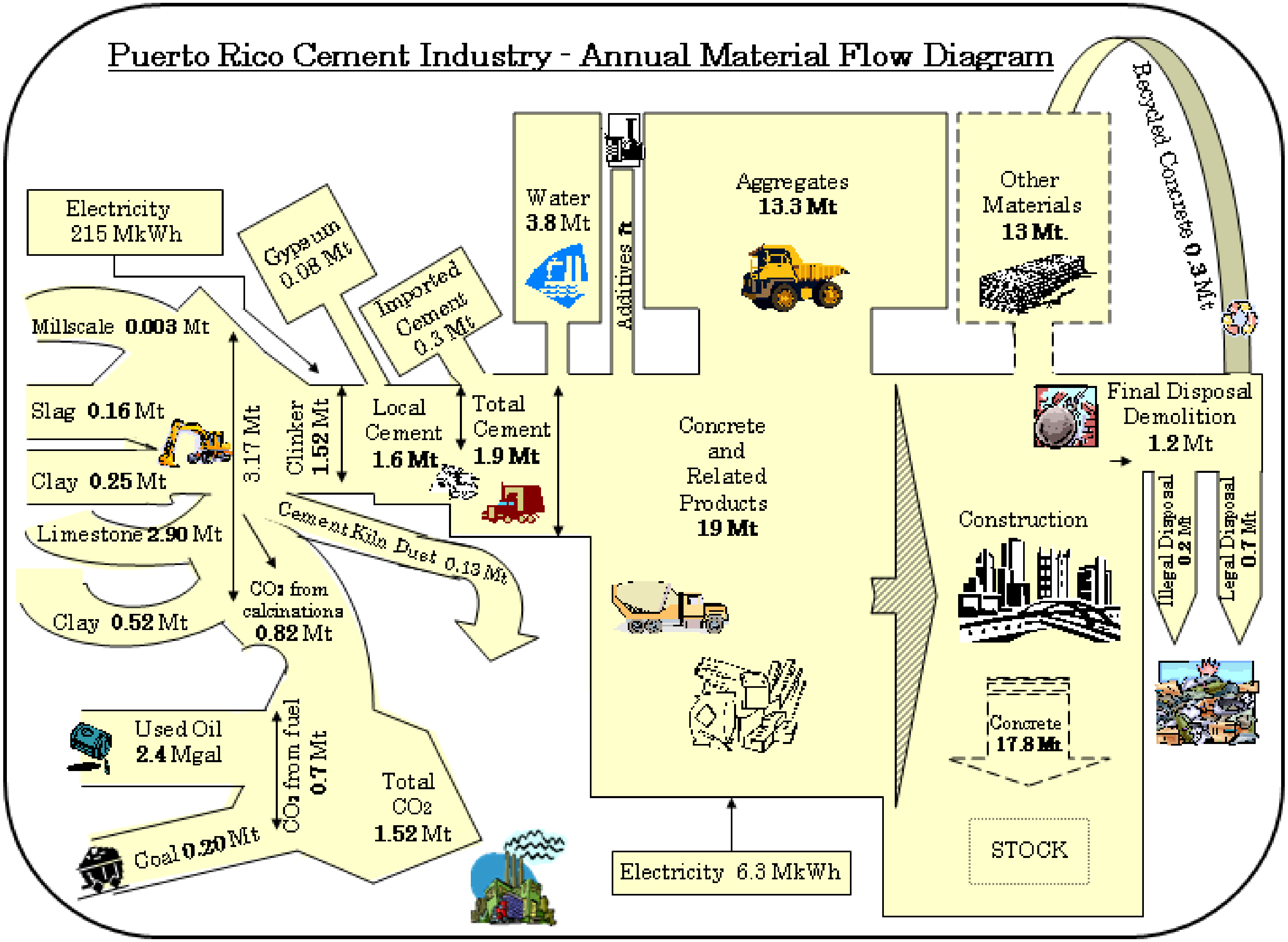
APPENDIX D: Functions of Admixtures in Concrete

Admixture: ACI 116R-00 defines the term admixture as "a material other than water, aggregates, hydraulic cement, and fiber reinforcement, used as an ingredient of a cementations mixture to modify its freshly mixed, setting, or hardened properties and that is added to the batch before or during its mixing" (ACI, 2003).

Functions of Admixtures in Concrete

- *Increase workability without increasing water content or decrease the water content at the same workability;*
- *Retard or accelerate time of initial setting;*
- *Reduce or prevent shrinkage or create slight expansion;*
- *Modify the rate or capacity for bleeding;*
- *Reduce segregation;*
- *Improve pumpability;*
- *Reduce rate of slump loss;*
- *Retard or reduce heat evolution during early hardening;*
- *Accelerate the rate of strength development at early ages;*
- *Increase strength (compressive, tensile, or flexural);*
- *Increase durability or resistance to severe conditions of exposure, including application of deicing salts and other chemicals;*
- *Decrease permeability of concrete;*
- *Control expansion caused by the reaction of alkalies with potentially reactive aggregate constituents;*
- *Increase bond of concrete to steel reinforcement;*
- *Increase bond between existing and new concrete;*
- *Improve impact and abrasion resistance;*
- *Inhibit corrosion of embedded metal; and*
- *Produce colored concrete or mortar* (ACI, 2003).

APPENDIX E: Quantification Analysis.



The numbers on the flow chart are either summations of data provided by all companies in a sub-sector such as cement, concrete ready-mix and demolition, or extrapolations from all available related data. The calculations for the CO_2 emissions are based on the estimation that in the production of 1 tonne of clinker approximately 1 tonne of CO_2 is emitted (van Oss, 2005), where 46 percent come from fuel burning and 54 percent comes from carbonate calcination (van Oss, 2005). The figure for imported cement is from Antilles Cement. The total quantity of concrete is calculated using an average density of 2200 kg/m^3. Concrete inputs were calculated using industry wide averages as reported in the text and assuming no losses during production. Figures for demolition and disposal are from the Environmental Quality Board of Puerto Rico and personal communications with a representative of a leading demolition company.

This flow chart is not comprehensive as it does not include the full life cycle of the industry e.g. emissions and wastes from transportation, mining, and construction, diesel fuel, and other concrete concrete precast and block products. However, we believe that the magnitudes are correct and that the chart provides a first order estimate of the material flows through the cement-concrete industry.

Conversion references:

i) vanOss 2005. Ratio to calculate CO2 emissions: 1 tonne CO2/ 1 tonne clinker.
ii) Boyden, 2006. 1 tonne of cement gives 3.6 m^3 of concrete or 8.07 tonnes of concrete.
iii) vanOss 2005. Concrete estimates were based on the information on 10 percent of cement is used for concrete.
iv) "Other Materials" estimate was based on 60 percent ballpark figure on the total percentage of building materials (Medina pers. comm.).
v) Water, diesel fuel, and electricity data were calculated based on the information provided by the companies interviewed on cement, concrete and demolition. It does not include numbers used in construction and transportation outside of Puerto Rico.
vi) Additives data were calculated from Ecológica Carmelo Inc. to provide a sample estimate on the use of additives, and other chemicals, in use by a single company per year.