The Cement Industry

This portion of the case study focuses on Mexico's cement industry and the potential for, as well as the implications of, implementing a sector-based approach to reducing the sector's carbon footprint under a post-2012 international agreement to limit greenhouse gas (GHG) emissions. In addition to providing historical context on cement production in Mexico, the sections below provide an overview of the sector, present and discuss the data available for conducting a thorough analysis of sectoral approaches, and present preliminary findings with regard to the effects and effectiveness of alternative agreements that could be negotiated to address GHG emissions from Mexico's cement industry.

A. Sector Overview

This section presents a brief history of cement production and use in Mexico, a synopsis of the current structure of the sector, and some background on technologies and emissions at the sector level.

1. Background

The first cement plant was constructed in Mexico in 1906, just four years after cement was first authorized for use by the country's construction industry (Orta, 2005; CEMEX, 2008). From the time of its introduction through the early 1940s, Mexico's cement industry evolved at a moderate pace providing an increasingly important input for the nation's construction industry. Starting in 1944, spending on public infrastructure in Mexico increased significantly and the cement industry entered into a period of rapid and sustained growth. By 1990, annual output reached nearly 24 million metric tons of gray cement (Heydari, 1995).

The sector continued to grow through the early 1990s achieving a total annual output of nearly 30 million metric tons of product by the close of 1994. However, by 1995, the financial crisis that enveloped the Mexican economy late in the previous year along with the application of antidumping duties imposed by the United States on cement imported from Mexico (Orta, 2005) took a heavy toll on the sector and annual production fell some 19% to just under 24 million metric tons (Doan, 1996).

In pace with the macroeconomic recovery of the Mexican economy, the cement industry also gradually recovered and by the end of the decade, production levels had nearly returned to pre-recessions levels reaching 29.4 million metric tons by the close of 1999 (see table A1.1 below).

Cement Production in Mexico	
Millions of metric tons	
Year	Output
1990	23.8
1991	25.1
1992	26.9
1993	27.1
1994	29.7
1995	23.9
1996	25.4
1997	27.5
1998	27.7
1999	29.4

Sources: USGS 1996, 2000 and 2002

2. Current Industry Structure and Outlook

Mexico is home to a modern and highly efficient cement industry that is on a par with those found in the leading countries around the world. This section provides an introduction to the key industry players in Mexico's cement sector, a discussion of their domestic and international markets, recent data on production and capacity levels, and a summary of the major domestic and international drivers shaping the industry's outlook.

a. Manufacturers

Six manufacturers comprise Mexico's cement industry. In 2006, this group of firms operated 31 cement plants located in 15 states, had an operating capacity of 56.5 million metric tons of output per year, and had a projected capacity for 2010 of 63.7 million metric tons annually. In 2007, Mexico's cement producers had a combined output of 38.8 million tons of cement valued at approximately €3.8 billion (IBS, 2008).[1]

Mexico's leading cement company is international giant CEMEX, which is the direct owner of 15 plants and has a minority ownership interest in 3 others. Headquartered in the state of Nuevo Leon, CEMEX supplies a 48% share of Mexico's domestic cement market. CEMEX also owns 211 concrete plants, 67 land distribution centers, and 8 maritime centers in Mexico (Orta, 2005).

The second largest producer in Mexico is Holcim-Apasco. Prior to its acquisition by Holcim, Apasco was an independent company that was founded in 1928 in the state of Mexico (Orta, 2005). Holcim-Apasco currently owns 6 cement plants with an installed capacity of 11.3 million metric tons per year. The firm also owns 23 distribution centers,

[1] Note that the value expressed is in terms of 50 kilo bags—the typical form in which cement is sold in Mexico.

4 maritime terminals, and has a network of roughly two thousand distributors (Holcim-Apasco, 2008).

Cooperativa La Cruz Azul, which is also known as Cementos Cruz Azul, is Mexico's third largest manufacturer of cement. As its name suggests the company is organized as a cooperative society. It began operations in 1934 (Orta, 2005). Today it owns 3 cement plants and supplies 16% of the domestic market. Installed capacity in 2007 was 8.3 million metric tons per annum (IBS, 2008).

The fourth largest cement producer in Mexico is Cementos Moctezuma. Headquartered in the state of Morelos, the firm owns two cement plants with a combined annual capacity of 5.1 million metric tons (IBS, 2008).

Grupo Cementos Chihuahua (GCC Cemento) supplies 4% of the domestic market from production at the firm's three plants, all of which are located in the state of Chihuahua. GCC Cemento has a total capacity of 4 million metric tons per annum (IBS, 2008).

LaFarge Cementos is the sixth and final manufacturer in the Mexican cement industry. The company entered the market in 1999 with the acquisition of a cement plant in Vito. In 2003, LaFarge Cementos announced plans to construct a new €78.9 million state of the art plant in Tula, near Mexico City. The plant began production in the spring of 2006. Their two plants give LaFarge Cemento a 0.6 million ton annual capacity (LaFarge, 2006).

The following table summarizes some of the basic data available on each company.[2]

Mexico's Cement Manufacturers				
Company Name	Domestic Market Share	Number of Plants	Current Capacity 2008	Expected Capacity 2010
CEMEX Mexico	48%	15	27.2 MMT	33.1 MMT
Holcim-Apasco	22%	6	11.3 MMT	11.3 MMT
Cementos Cruz Azul	16%	3	8.3 MMT	8.3 MMT
Cementos Moctezuma	9%	2	5.1 MMT	6.4 MMT
GCC Cemento	4%	3	4.0 MMT	4.0 MMT
LaFarge Cementos	1%	2	0.6 MMT	0.6 MMT
Totals	100%	31	56.5 MMT	63.7 MMT

Source: IBS, 2008

[2] In March of 2007, Cruz Azul completed construction of their Pueblo plant. It is estimated that cement production capacity is 1 million tons per year; no information is available on this facility at this time.

b. Domestic and International Markets

Approximately 80% of the cement consumed in Mexico is purchased in 50 kilo bags. The formal residential construction sector accounts for around 48% of all cement purchases, the informal (do-it-yourself) sector consumes 32%, and the remaining 20% is sold in bulk to large construction companies (Orta, 2005). Grey cement accounts for the overwhelming majority of sales with a 94% share of the market. Mortar cement (5%) and white cement (1%) are much less favored in Mexico.

The northern region of the country has traditionally been the largest consumer of cement, accounting for 48% of sales mainly for use in infrastructure construction projects, housing and office complexes, and other construction activities. Central Mexico is also a relatively strong market for domestic producers. However, the primary use differs somewhat in that the main source of demand is from construction of new buildings such as hotels and office complexes. The relatively slower pace of economic growth in southern Mexico accounts for the lower share (17%) of domestic cement sales in the south (Orta, 2005).

c. Outlook

According to a May 2008 assessment by International Business Strategies, demand for cement produced in Mexico is expected to grow at an above average annual rate over the next 4 to 5 years. One of the main sources of this growth is expected to be increased exports, especially to the United States and Canada. The table below shows destinations for Mexico's cement exports in 2007.

Mexico's Cement Exports – 2007		
Destination Country	Share	Volume
United States	59.4 %	1.3 MMT
Dominican Republic	22.6%	0.5 MMT
Spain	7.7%	0.17 MMT
Guatemala	2.9%	0.06 MMT
El Salvador	2.1%	0.05 MMT
Venezuela	1.3%	0.03 MMT
Belize	1.1%	0.02 MMT
Other	2.9%	0.06 MMT

Source: IBS, 2008

A second and more important potential source of growth for the cement industry is Mexico's recently announced National Infrastructure Program (NIP). The NIP is a national program initiated by President Felipe Calderón's administration in July 2007. The program includes plans for upgrades to a wide range of existing structures as well as for construction of new facilities. Planned projects include 100 roadway construction projects, further development and new investments in 13 marine facilities, 3 new airports, and expansion of 31 that are already in place (DOC, 2008a). All of these projects are expected to require significant inputs from the cement industry. In anticipation of additional demand associated with the NIP, Mexico's cement manufacturers have announced plans to invest more than €1.32 billion in new plants and upgrades to existing plants (DOC, 2008b).

The table below presents recent data on production of cement from 2000 through 2005.

Cement Production 2000-2005 Million metric tons	
Year	Output
2000	31.7
2001	30.0
2002	31.1
2003	33.4
2004	35.0
2005	37.5

Sources: USGS 2002 and 2006

3. Technologies in Place

Mexico's cement industry is among the most modern and efficient in the world today. All of the 50 kilns operating in the country's 31 cement plants are dry-process. The last of the less efficient wet process kilns was taken out of service within the past two years. Mexico's cement manufacturers are also using energy efficiency enhancing technologies such as preheaters and precalciners in many of their facilities. Moreover, a number of plants make use of some forms of low carbon alternative fuels.

4. GHG Emissions

Carbon dioxide is released during the production of cement from three sources—process emissions related to the conversion of raw materials into clinker, combustion related emissions caused by burning fuels in cement kilns, and indirect emissions associated with electric power used to operate equipment such as grinders and electric motors. Between 1992 and 2003, emissions of CO_2 by the cement industry in Mexico increased roughly 25% (Marland et al, 2006). This compares with a nearly 108% increase in cement sector emissions from all developing countries during that same time frame and a 34% increase in U.S. cement industry emissions. The relatively slow growth of emissions from Mexico's cement sector is an indication of the high overall efficiency of the sector.

B. Data Collection and Related Issues

Data collection efforts undertaken for this analysis are described below. For purposes of this analysis, ICF first identified the ideal set of data that would be required for developing plant level energy and emissions estimates for the Mexican cement industry for the latest historical year and for future years. However, due to a severe time constraint coupled with limited access to proprietary information, ICF was able to obtain only a subset of the desired data. Sources and data that were available are described below in Subsection 2. ICF's approach to addressing data gaps is presented in Subsection 3 and Subsection 4 provides a summary of the approaches ICF used to address missing data.

1. Ideal Data Inputs

A key activity in developing the results presented in this section involved developing sufficient pertinent data to construct the analyses. The first activity undertaken was to define the "ideal" set of data for conducting an analysis of a sector-based approach. The ideal set of data are sub-plant level (i.e., unit-level) data both on actual historical and on planned future estimates. The list of data elements that comprises this "ideal" set is provided in Table B.1.1 below.

Table B.1.1. Ideal Set of Data Inputs

Plant-level Data
Plant name, plant identification (ID) Number (if applicable), plant Location (city and region), parent company, type of plant (integrated plant or only grinding mill), plant production capacity by product type (i.e., clinker and cement), types of cement produced (e.g., Portland cement, white cement, and masonry cement) and their relative shares (latest year for which the data are available), average annual capacity utilization factor, types and amounts of fuels used by fuel type, amount of clinker produced annually (or for the latest year), amount of cement kiln dust (CKD) generated annually, amount of CKD recycled and discarded, amount of conventional and alternative fuels consumed by fuel type, annual production; quantities of raw materials used by type of raw material and their carbon contents, carbon contents of fuels used by type of fuel.
Unit-level (sub-plant level) Data
Number of production units in a plant, unit name (if given and if this corresponds to one of multiple units in a plant), Unit ID, type of production unit (kiln or grinding mill), the last year of modernization, the unit operating status, production capacity (i.e., clinker production and mill grinding capacity), the type of technology (i.e., dry kiln, wet kiln, dry kiln with preheater, dry kiln with calciner, etc.), amount of clinker produced annually, amount of cement kiln dust (CKD) generated, amount of CKD recycled and discarded, type of grinding technology used, amount of conventional and alternative fuels consumed by fuel type, average annual capacity utilization factor by production unit (typical or for the latest year), annual production by production unit (i.e., amount of clinker and cement produced, by type of unit, for the latest year), quantities of raw materials used by type of raw material and their carbon contents, carbon contents of fuels used by type of fuel

Regional and National Data
Clinker and cement production capacity, by technology type, and by region; amount of clinker and cement produced by technology type and by region; amount of fuels consumed in the cement industry by fuel type, by technology type and by region; average annual capacity utilization factor, by technology type and by region; carbon contents of fuels used.
Other Data
Data on all the relevant variables of interest from other studies; historic and future and plant level / unit level estimates; projections at the regional and national level for cement industry variables; national data on reported emissions; national and sectoral programs for cement industry; cement industry standards and regulatory requirements

2. Available Data and Sources

Data and information for the cement industry in Mexico are available from a wide variety of sources including cement companies, industry groups, public agencies, and private research firms. Generally, sector-wide information is provided by the industry groups and public agencies while company and plant-specific information is provided by cement companies and private research firms. Company-level CO_2 emissions, and in some cases plant-level CO_2 emissions, are available for some years through public/private greenhouse gas reporting partnerships.

Data collection activities for this project were focused on gathering plant-specific information from both public and private sources. There is no universal database that provides detailed plant-level information. There are two cement directories available for purchase that provide limited plant-level information such as plant location, fuel type, number of kilns, clinker capacity, and cement capacity.

Plant-level information for CEMEX plants was obtained from a data file that CEMEX submitted to the United Nations Framework Convention on Climate Change (UNFCCC) CDM Executive Board for a CDM project (#1356) CEMEX proposed for its fifteen plants (CEMEX, 2008). The data are very detailed and include clinker production, cement production, and fuel consumption for producing 30-R Type of blended cement.

National and sector-wide information was also collected. Sectoral fuel consumption data by fuel type were collected for the cement sector and for the electric power sector. National and sector-wide information was used in some cases as reference to ensure that bottom-up calculations were consistent and, in some cases, to estimate plant level data.

Sources of Data

The data for this work were collected from a variety of sources. The following provides a brief description of all of the key information sources from which ICF developed inputs.

(i) Cámara Nacional del Cemento (CANACEM)

The National Cement Chamber is an industry group comprised of the six cement companies that currently operate in Mexico. The Chamber's Web site offers some sector-wide data.

Relevant data include:

- Number of plants operating in Mexico, by company (current)
- Total cement production in Mexico (2000-2007)
- Total cement consumption in Mexico (2000-2005)

(ii) Secretaría de Energía (SENER)

The Secretary of Energy is an agency within the Mexican government that regulates and monitors energy production in Mexico. The agency's Web site offers a wide range of statistics related to energy use, including comprehensive data on electricity generation and distribution.

Relevant data include:

- Fuel consumption for electricity generation in Mexico sorted by quantities of fuel oil, diesel, coal, and natural gas consumed (1999 to 2007).

(iii) United States Geological Survey – Mexico 2006

Each year the USGS publishes a Minerals Yearbook for Mexico that contains a qualitative information section as well as overall production and capacity information for metals, minerals, and related products.

Relevant data obtained from this source include:

- Total cement production (2002-2006)
- Structure of cement industry (2006)
- Location of main cement facilities (2006)
- Total production capacity for each cement company (2006)

(iv) Cement Americas' North American Cement Directory – 2008

Each year the Cement Americas magazine publishes a North American Cement Directory that lists all cement plants in North America along with key information for each plant. The level of detail provided varies based on the company, and there is very little plant-specific information for CEMEX plants.

Relevant data included plant level data for the following variables for 2007:

- Type of process (wet vs. dry)
- Number of kilns
- Type of fuel burned
- Type of cement produced
- Clinker capacity
- Cement capacity

(v) Programa GEI Mexico

GEI Mexico is a voluntary program that encourages companies in Mexico to report their greenhouse gas emissions to the Mexican government in return for technical support with monitoring and reporting emissions.

The program is coordinated by the Secretary of Environment and Natural Resources (SEMARNAT) and the Commission of Studies of the Private Sector for Sustainable Development (CESPEDES). Technical support is provided by the World-Resources Institute (WRI) and World Business Council for Sustainable Development (WBCSD).

Every cement company in Mexico other than Lafarge participates in the program and each reported both direct and indirect emissions for 2005 and 2006. Most companies also reported historical emissions and production data.

(vi) Secretaría de Medio Ambiente y Recursos Naturales (SEMARNAT)

The Secretary of Environment and National Resources maintains the Pollutant Release and Transfer Database, which provides 2004 CO_2 emissions for 21 cement plants in Mexico.

Relevant data included:

- Plant-level CO_2 emissions for 21 plants

(vii) CEMEX Project Design Document for Clean Development Mechanism

In 2007, CEMEX submitted a Project Design Document to the Clean Development Mechanism Executive Board for project 1356: "Reducing the Average Clinker Content in

Cement at CEMEX Mexico Operations." A spreadsheet accompanied the Project Design Document that included a plethora of detailed plant-level information for all CEMEX plants. There was also clinker factor information for cement plants in Mexico owned by other cement companies.

Relevant information included:

- Estimated clinker factor and production of type 30 cement for cement companies other than CEMEX (2007)
- Actual clinker factor and type 30 production for CEMEX plants (2006)
- Forecasts for type 30 cement production at CEMEX plants (2008-2017)
- Emission factors for electricity consumption, fossil fuel consumption, calcinations, clinker production, and cement production for each CEMEX plant
- Fuel consumption for CEMEX plants by fuel type (2006)

3. Data Gaps and Implications

Plant and unit-level data were unavailable for several variables of interest, including annual clinker and cement production or capacity utilization factor, and number of production units, by their unit type and the type and amount of fuels used, by technology and/or unit type. These data gaps required ICF to develop average plant level estimates, based on historic regional and known plant-level information. A variety of assumptions about specific plants, their fuel use, and emissions were made by the analysts developing the emission estimates and the marginal abatement cost analysis.

4. Efforts to Address Data Gaps

As noted above, for many variables, plant level data were not available. Therefore, ICF estimated plant level data using information that was available. For example, to allocate company-level production estimates to plants, ICF used the available data on plant level production capacity to allocate the production level proportionately. Underlying this methodology is the implicit assumption that the capacity utilization factor is the same for all plants owned by a company. For 2006, and for the future years, energy consumption and CO_2 emissions were calculated by applying the national energy intensity and the national fuel mix in Mexico's cement industry for 2006. Alternative fuel consumption was assumed to be 1.5 percent of national fuel consumption in the cement industry in 2006 and beyond.

Direct and indirect CO_2 emissions and other data reported by individual cement companies to the *Programa GEI Mexico* for 2006 were used to adjust plant level production, fuel consumption, and emissions.

These assumptions led to development of plant-level estimates that are representative, rather than plant-specific. Therefore, these estimates must be used cautiously. Also, these data estimates require additional benchmarking and quality assurance.

C. BAU Estimates of Key Parameters to 2025

In Mexico, there were 31 cement plants,[3] owned by six cement companies in 2006, the base-historical year used for these projections. ICF developed draft estimates of production, energy consumption, and CO_2 emissions at the plant level for the Mexican cement industry through 2025. The national level estimates for 2006 and for the forecast years 2010, 2015, 2020 and 2025 are presented in Tables C.1.1 through C.4.1 below.

1. Production Estimates

National cement production data for 2006 and 2007 were obtained from CANACEM, Mexico's national chamber of cement industry.[4] For the years 2008 through 2025, the cement production was assumed to grow at the average annual growth rate of 2.89 percent, which was the average annual growth rate in cement production in Mexico between 2000 and 2007 based on CANACEM estimates. Table C.1.1 presents national cement projections estimates through 2025.

Table C.1.1. Draft Estimates of Cement Production in Mexico (2006-2025)

Year	Cement Production (million tonnes)
2006	37.90
2010	42.31
2015	48.88
2020	56.47
2025	65.24

Notes:
(1) 2006 datum correspond to the actual historic estimate for the same year and the estimates for the remainder of the years in this table were developed based on average annual historic growth rates between 2000 and 2007. 2010 projection was developed based on 2.89 percent annual growth over 2007 historic production estimate.
Source:
(a) CANACEM (official industry group), http://www.canacem.org.mx/canacem_eng/la_industria_del_cemento.htm
(b) ICF calculations

[3] In March of 2007, CYCNA completed construction of their Pueblo plant. It is estimated that cement production capacity is 1 million tons per year, but there is no actual production data available. Therefore information on this facility was not used in developing projections presented in this section.

[4] Camara Nacional del Cimento (CANACEM), http://www.canacem.org.mx/canacem_eng/la_industria_del_cemento.htm

2. Energy Consumption by Type

Energy consumption in the cement industry includes fuel combustion related energy consumption and electricity consumption. Fuel combustion includes both fossil fuels and alternative fuels.

In the cement industry, fuels are consumed by the kilns for clinker production. Quantity of fuels consumed for clinker production was calculated for each year (from 2006 through 2025) by multiplying clinker production and the fuel consumption intensity per ton of clinker estimate of 3,515 MJ per ton of clinker. This fuel consumption intensity for clinker production was the weighted average 2006-average fuel consumption intensity reported by CEMEX for all its 15 plants in its CDM project description for project number 1356.

Clinker production was estimated based on cement production by assuming that the national average clinker to cement ratio in 2006 was 79.2 percent, which was the weighted average clinker factor (i.e.. clinker to cement ratio) reported by CEMEX for all its 15 plants in 2006 in their CDM project description for project number 1356.

The clinker to cement ratio as well as the fuel consumption intensity was assumed to remain unchanged at 2006-level throughout the forecast period ending in 2025.

Electricity consumption was calculated by multiplying the cement production and the average electricity consumption per unit of cement production estimate for CEMEX plants in 2006. The electricity consumed by the 15 CEMEX-cement plants were calculated by dividing the total indirect emissions for the 15 cement plants in 2006 reported the CDM project #1356 by the average CO2 intensity of grid electricity reported by one or more cement companies to the Mexico's voluntary GHG reporting program, *Programa GEI Mexico*.[5] The average electricity consumption per unit of cement in 2006 was calculated for CEMEX by dividing the total electricity consumption for the 15 cement plants by the 15 plants' total cement production. The electricity consumption intensity (i.e., electricity consumed per unit of cement production) was assumed to remain constant from 2006 through 2025.

Table C.2.1 illustrates the draft estimates of the total fuel and electricity energy consumption in the Mexican cement industry from 2006 through 2025. The table indicates that electricity consumption accounts for about 13 percent of the total annual energy consumption in the Mexico's cement industry.

[5] The Mexico's voluntary GHG reporting program, *Programa GEI Mexico*, is jointly sponsored by Ministry of Environment and Natural Resources, the World Resources Institute (WRI), the World Business Council for Sustainable Development (WBCSD) and the Business Coordinating Council (CCE).

Table C.2.1. Draft Estimates of Energy Consumption in the Cement Industry in Mexico (2006-2025)

Year	Total Fuel Consumption (TJ)	Electricity Consumption (TJ)	Total Energy Consumption, including Electricity (TJ)
2006	105,451	15,928	121,379
2010	117,722	17,782	135,504
2015	136,004	20,543	156,548
2020	157,126	23,734	180,860
2025	181,528	27,419	208,947

Notes:
(1) Total Fuel Consumption includes consumption of conventional and alternative fuels combusted on-site.
(2) Fuel consumption includes 1.5% of alternative fuel share, which was assumed based on available data.
Source:
(a) CEMEX spreadsheet that accompanied CEMEX's Clean Development Mechanism (CDM) Project Description submission for project #1356
(b) ICF International Calculations

In calculating the fuel projections through 2025, it was assumed that the future fuel mix in the Mexican cement industry through 2025 will remain the same as the 2006-fuel mix. Table C.2.2 illustrates the 2006-fuel mix for the entire Mexican cement industry and for the 15 CEMEX plants in Mexico. The table indicates that petroleum coke accounts for most of the energy consumed by the CEMEX plants in 2006. The alternative fuels share for the entire Mexican cement industry was assumed to be 1.5 percent based on nearly the same share of alternative fuels consumed by the 15 CEMEX-cement plants in 2006.

Table C.2.2. 2006-Fuel Mix in Cement Industry in Mexico

Fuel Type	Fuel Share-CEMEX plants	Fuel Share-Mexican Cement Industry
Coal	0.0%	4.7%
Petroleum Coke	90.6%	61.5%
Diesel Oil	0.1%	0.2%
Residual Fuel Oil	5.2%	26.3%
Dry Natural Gas	1.8%	5.8%
Other Liquid Fuels	0.9%	0.0%
Alternative Fuels	1.4%	1.5%
Total	**100.0%**	**100.0%**

Notes:
(i) The alternative fuels share of 1.5% for the cement industry has been assumed. The other fuel share estimates were calculated from Mexico's Secretariat of Energy's (SENER's) estimates of fuel consumption for the cement industry in 2006, after including the 1.5 percent of alternative fuels.
Source:
(a) CEMEX spreadsheet that accompanied CEMEX's Clean Development Mechanism (CDM) Project Description submission for project #1356
(b) "Balance National De Energia 2006," Secretariat of Energy (SENER), Mexico.

3. CO_2 Emissions

CO_2 emissions from cement manufacturing comprises (i) direct emissions from on-site fuel consumption and chemical reactions during the manufacturing process, and (ii) indirect emissions from electricity consumption for operating machinery, such as for finish grinding of cement using clinker and other additives. Methodologies adopted for estimating these emissions are described below.

Process-related CO2 emissions were estimated for each year (from 2006 through 2025) by multiplying the respective years' clinker production estimates by the CO2 intensity for clinker production (i.e., 0.5283 tonne of CO2 per tonne of clinker) reported by CEMEX for all its 15 plants for 2006 in their CDM project description for project number 1356. CEMEX calculated its process-related CO2 intensity per ton of clinker based on the methodology prescribed by the WBSCD and it is slightly higher than the IPCC Tier 2 default CO2 emission factor of 0.5203 per tonne of clinker.

Combustion related CO2 emissions were calculated for each year from 2006 through 2025 by multiplying the fuel consumption estimate for the respective year and the CO2 intensity per unit of fuel consumption.

CO2 intensity of fuel consumption was calculated for CEMEX plants and for non-CEMEX plants separately. For CEMEX plants, the weighted average 2006-CO2 intensity was calculated using the plant level fuel consumption by fuel type and the associated CO2 emissions reported by CEMEX for all its 15 plants in 2006 in its description of the CDM project # 1356. For the non-CEMEX plants' fuel consumption, Mexico's cement sector's average CO2 intensity in 2006 was assumed.

The average sector-wide CO2 intensity for 2006 was calculated as follows: CO2 emissions were calculated for the entire cement industry in 2006 based on the Mexico's Secretariat of Energy (SENER)-reported fuel consumption, by fuel type, data for 2006, after adding consumption of tires to account for alternative fuel consumption. It was assumed that consumption of tires (as alternative fuel) accounted for 1.5 percent of the total traditional fuel consumption in 2006. The CO2 intensity per ton of cement was calculated by dividing the total CO2 emissions from cement sector fuel consumption in 2006 by the total national cement production in 2006. The fuel consumption intensity estimates were assumed to remain unchanged for CEMEX and non-CEMEX fuel consumption from 2006 through 2025.

Direct CO2 emissions were calculated as the sum of process and combustion related CO2 emissions.

Indirect CO2 emissions were calculated by multiplying the electricity consumption by the CO2 intensity of purchased electricity, which was reported by cement companies to the Mexico's voluntary GHG reporting program, *Programa GEI Mexico*, as the CO2 intensity of grid electricity in 2006. The CO2 intensity of grid electricity (0.5283 tonne of CO2 per MWh) was assumed to remain constant from 2006 through 2025.

Total CO2 emissions were calculated by adding direct and indirect CO2 emissions. Table C.3.1 indicates that, as expected, the total CO_2 emissions from cement manufacturing in Mexico are also projected to grow at the same rate as cement production.

Table C.3.1. Draft Estimates of CO_2 Emissions from the Cement Industry in Mexico (2006-2025)

Year	Total Process Emissions (million tonnes of CO2)	Total Combustion Emissions (million tonnes of CO2)	Indirect Emissions (million tonnes of CO2)	Total Emissions (million tonnes of CO2)
2006	15.85	9.80	2.34	27.99
2010	17.69	10.94	2.61	31.25
2015	20.44	12.64	3.01	36.10
2020	23.62	14.61	3.48	41.71
2025	27.28	16.87	4.02	48.18

Source:
(a) CANACEM, http://www.canacem.org.mx/canacem_eng/la_industria_del_cemento.htm
(b) CEMEX spreadsheet that accompanied CEMEX's Clean Development Mechanism (CDM) Project Description submission for project #1356
(c) CO2 intensity of grid electricity estimate for 2006 submitted by Mexico's cement companies to Mexico's voluntary GHG Reporting Program, *Programa GEI Mexico*.
(d) ICF International Calculations

4. Energy and Emissions Intensity

Table C.4.1 presents the estimates of energy and emissions intensity in the Mexican cement industry. During the period, 2006 through 2025, however, as noted above, both the energy intensity and the fuel mix are assumed to remain unchanged during the forecast years.

Table C.4.1 Draft Estimates of Energy and Emissions Intensity in the Mexican Cement Industry (2006-2025)

Year	Direct Energy Intensity (MJ per tonne of cement)	Total Energy Intensity (MJ per tonne of cement)	Direct Emission Intensity (tonne CO2 per tonne of cement)	Total Emission Intensity (tonne CO2 per tonne of cement)
2006-2025	2,782	3,203	0.677	0.739

Notes:
(1) Total Energy Intensity includes emissions from calcinations (i.e., process-related) and fuel combustion and the emissions attributable to generation of electricity consumed in the cement industry.
Source:

(a) CANACEM (official industry group), http://www.canacem.org.mx/canacem_eng/la_industria_del_cemento.htm
(b) CEMEX spreadsheet that accompanied CEMEX's Clean Development Mechanism (CDM) Project Description submission for project #1356
(c) CO2 intensity of grid electricity data for 2006 submitted by Mexico's cement companies to Mexico's voluntary GHG Reporting Program, Programa GEI Mexico.
(d) ICF International Calculations

5. Changes in Industry Structure

Mexican cement industry has relatively low energy consumption per ton of clinker produced compared to other regions of the world with the exception of Europe and Japan (IEA 2007).[6] However, energy and emission intensities per ton of cement produced have increased in Mexico during recent years. While higher energy intensity can be attributed to higher than the required proportion of clinker used in cement production, higher emission intensity can also be attributed to fuel switching to higher carbon petroleum coke consumption from residual oil and other lower carbon fuel consumption. In the BAU scenario calculations, it is assumed that the fuel mix as well as clinker to cement factor will remain constant at the 2006-level through 2025. Similarly, the Mexican electricity sector's fuel mix and energy intensity (which together influence the CO2 intensity of purchased electricity in the cement sector) are also assumed to remain unchanged during the forecast years.

D. Analysis of Potential Mitigation Options

1. Methodology

This section presents the methodology used to construct the marginal abatement cost curve for the cement industry in Mexico.

a. Analytical Approach to Developing Abatement Supply Curves

Once baselines emissions were projected, commercially available and emerging technologies, processes, and other options for reducing GHG emissions within Mexico were evaluated. These options were examined in terms of their costs and GHG emission reduction potential, as well as the feasibility for and barriers to implementation.
The focus of ICF's efforts to develop the abatement supply curve was on technologies and measures that could be applied directly to cement production within Mexico. Thus, the measures assessed were limited to cement-specific technology options. For example, installation of electricity-saving technologies is examined; however, the option of constructing a renewable energy power plant (e.g., a wind farm) to reduce emissions at Mexican plants was not considered.

The GHG emission reduction benefit of any reduction technology or practice depends on several factors, including the level of abatement already in place (e.g., residual emissions cannot be abated using the same technology), the stream of emissions addressed by the

[6] "Tracking Industrial Energy Efficiency and CO2 Emissions," International Energy Agency, 2007.

option as a portion of total emissions from the source, the efficiency of the option, the adoption of the option by the industry, other options that might be in place, and the option's impacts on other GHG emissions from the source. For each mitigation option identified, it was necessary to determine:

- the fraction of total source category emissions that could be addressed by the option, or the option's applicability, for the most recent year for which emissions data are available; and
- the reduction efficiency, or technical effectiveness, of the option, defined as the percent of applicable emissions that can be abated.

The total abatement potential of any particular GHG emission abatement practice or technology is calculated as the product of its applicability and its effectiveness. However, for this analysis it is assumed that each option is mutually exclusive, and thus costs are evaluated assuming that a particular mitigation option does not overlap with any other options. For example, while cement plants could implement both energy saving process changes and use alternative fuels to reduce the carbon intensity of clinker production, the effect of the interaction of these two options is too complex to model in this analysis. Table D.1.1 summarizes the key parametric data that was collected to characterize each mitigation option.

Table D.1.1: Technical and Economic Characteristics of Abatement Options

Characteristics of Abatement Options	Unit	Definition
Applicability (A)	%	Percent of the total emissions from a particular emission source (e.g., a cement kiln) to which a given option can be potentially applied.
Technical Effectiveness (E)	%	Percent of emissions that can be abated by a given option relative to the total emissions to which this option can be applied.
Abatement Potential (AP)	%	Percent of emissions that can be reduced at the source by a given option (i.e., the product of A and E).
Option Lifetime (T)	Years	Average technical lifetime of an option.
Depreciation Period (DP)	Years	The period over which capital is depreciated.
Lag Time (N)	Years	The amount of time before an option is operational (i.e., no emission reductions, recurring costs, or revenue are incurred).
Emission Reduction (ER)	$tCO_2Eq.$	Absolute amount of emissions reduced by an option (as modeled) in a given year. ER is estimated for each source by multiplying the baseline emissions in a selected year by the abatement potential, AP.
Capital Cost (CC)	€	Total fixed capital cost of an abatement option.
Recurring Cost (RC)	€	Annual operating and maintenance costs (including reductions in costs resulting from the option).
Revenue (R)	€	Revenues generated from abatement option activities and savings, such as reduced fuel costs that are associated with the option.

Following the definition of each option, the marginal abatement costs in terms of cost per unit of emissions reduced (i.e., 2006 Euros per metric tonne CO_2-equivalent emission reduction) was calculated. As described above, each mitigation option is characterized by its capital and operation and maintenance costs, cost savings or revenues, efficiencies and other parameters. Using these parameters, Equation 1 was used to calculate the net specific abatement cost or “breakeven” price.

The term breakeven price represents the price of one metric ton of carbon dioxide at which an entity (i.e., plant or manufacturer) would be financially indifferent as to whether or not to implement an option. At a breakeven price of zero, an entity can install a retrofit or use an alternative gas for an amount exactly equal to the energy or other savings or revenues that would be realized. At negative breakeven prices, entities will implement mitigation options cost-effectively (i.e., realize net savings) while simultaneously reducing emissions.

At positive breakeven prices, an entity might only consider an option worthwhile if some external value were “attached” to the emission reductions. This value might be in the form of tax relief, rebates, or other government-offered incentives, or it might be associated with emission reductions through the application of regulations limiting emissions of the gases studied (for example, by a tradable allowance market).

Breakeven prices are determined using a discounted cash-flow analysis where the revenues or cost savings are equal to the costs. This relationship is demonstrated in the equation below. (All prices are in 2006 Euros.) Various discount rates (i.e., interest rate or cost of capital) and tax rate scenarios can be applied.

$$[(P \times ER)(1-TR) + R(1-TR)] \times \sum_{t=n+1}^{T} \frac{1}{(1+DR)^t} + \frac{CC \times TR}{DP} \sum_{t=1}^{DP} \left(\frac{1}{(1+DR)^t} \right) = CC + RC(1-TR) \sum_{t=n+1}^{T} \left[\frac{1}{(1+DR)^t} \right]$$

(Equation 1)

where:

P = the breakeven price of the abatement option (€/tCO_2Eq.);

ER = the emissions reduction achieved by the abatement option (tCO_2Eq.);

TR = the business tax rate (%);

R = the extra revenue generated by the abatement option, e.g., from energy savings, input savings, or extra cement production (€);

n = the time lag before the abatement option is operational (years);

t = the project lifetime (years);

DR = the selected discount rate (%);

CC = the one-time capital cost of the abatement option (€);

DP = the depreciation period (years); and

RC = the recurring (O&M) cost or saving of the option (€/year).

Assuming that the emission reduction (ER), the recurring costs (RC), and the revenue generated (R) remain constant on an annual basis, then it is possible to solve for the breakeven price as indicated below in Equation 2 (adapted from U.S. EPA (2006) by ICF International).[7] The breakeven price is for implementing the abatement technology in a given year with the cost and other characteristics (such as the operating life) as defined in Table D.1.1 above.

$$P = \frac{RC}{ER} - \frac{R}{ER} + \frac{CC}{ER(1-TR)\sum_{t=n+1}^{T} \frac{1}{(1+DR)^t}} - \left[\frac{CC \times TR}{DP} \times \sum_{t=1}^{DP} \frac{1}{(1+DR)^t} \right] \Bigg/ ER(1-TR) \sum_{t=n+1}^{T} \frac{1}{(1+DR)^t}$$

(Equation 2)

[7] Adapted from work performed by ICF International for USEPA's recent report entitled *Global Mitigation of Non-CO_2 Greenhouse Gases* (EPA Report 430-R-06-005).

An abatement supply curve or marginal abatement cost curve relates the cost per additional (or "marginal") unit of emission reductions to the total quantity of reductions. The abatement supply curve for Mexico's cement sector was compiled by rank-ordering individual options by specific abatement costs expressed in 2006Euros/tCO_2Eq. The emissions abatement supply curve was created by sorting the mitigation options from least to most cost, calculating the summation of the incremental emission reductions, and plotting the cost versus the cumulative reductions to derive the abatement supply curve. The abatement supply curves generated for this analysis are based on the use of discounted cash flow analysis from the perspective of the owner/operator of the facility (i.e., cement manufacturers). Consequently, our analysis excludes government costs for implementation of Mexican policies.

b. Conversion of Cost Data from International Estimates

The cost estimates for technologies applied in this analysis were based on published data sources and industry experts. Some of these sources incorporate price data from the United States and other international sources. Current, Mexican-specific, cost data was applied where possible, but if this data was not available, then international data was used and converted into 2006 Euros. The conversion process involved converting data to 2006 Euros, based on European Central Bank (ECB) harmonized index of consumer prices data rebased to 2006, available from the ECB (ECB 2008a). The actual conversion factors used for this analysis are shown in Table D.1.2.

Table D.1.2: Harmonized Index of Consumer Prices Conversion Factors

Year	CPI Conversion Factor
2004	0.958
2005	0.978
2006	1.000
2007	1.022
2008	1.049

Source: ECB (2008a)

In addition, some values were converted to USD from the currency of the initial cost estimates, and subsequently to Euros. Exchange rates used for this analysis are based on average 2008 daily rates through September. These were obtained from the ECB (2008b) and from the U.S. Federal Reserve (2008) for the United States, Brazil, and Mexico. The conversion factors used for this analysis are shown below.

Table D.1.3: Exchange Rate Conversion Factors

Currency	Average Exchange Rate
2008 USD to Euros	1.52[1]
2008 Real to USD	1.69[2]
2008 Pesos to USD	10.52[2]

Sources: [1]ECB (2008b) and [2]U.S. Federal Reserve (2008)

c. Data Sources and Limitations in Scope of Study

This study relies on publicly available data to characterize the mitigation options in terms of capital and operation and maintenance costs and abatement potential. ICF obtained activity data (e.g., electricity consumed, clinker production) from a variety of sources, including CDM project documents from Mexican cement companies. Where possible, ICF also obtained Mexico specific data on prices for fuels, electricity, and transportation costs. A detailed description of the inputs used in the creation of the marginal abatement cost curves is provided at the end of this case study.

Some mitigation options were not evaluated in this study due to data limitations and the complexities in modeling the underlying processes. This analysis also only focuses on technology options and does not model policy or regulatory initiatives. In addition, this study does not address life-cycle emissions, such as the emissions associated with transporting blending agents from their source to a cement plant.

2. Technologies Evaluated

The mitigation options included in this analysis fall into four main categories including process changes, alternative fuels, blended cements, and kiln conversions; individual options are described under each category. This list is not exhaustive of all types of CO_2 mitigation projects; only options that resulted in a decrease in emissions within the boundary of the plant were considered. Options specifically excluded from this analysis include alternative raw materials, renewable energy projects, and waste heat capture systems.

a. Process Changes

One of the strategies for the mitigation of GHG emissions is through the improvement of energy efficiency by reducing the consumption of electricity. There are various technologies and measures for reducing electricity intensity during the production of cement, such as opting for more efficient technologies, or making optimum use of the present equipment. The four process changes evaluated to reduce kWh per ton of cement produced include high-efficiency grinding technologies, high-efficiency motors, adjustable speed drives, and high-efficiency classifiers.

High Efficiency Grinding Technologies
In general, the energy efficiency of ball mills used in finish grinding is relatively low. Installation of roller presses and roller mills, in combination with ball mills can significantly reduce power consumption at the finish mill.

High Efficiency Motors
In a typical plant there are hundreds of electric motors of different sizes that are used to drive fans, rotate the kilns, transport materials, and propel the grinding of raw material.

Installing higher efficiency motors will increase the energy efficiency of a cement plant by decreasing the energy required to power individual motors.

Adjustable Speed Drives
During the cement production process, the drives consume a great amount of energy. To improve the energy efficiency of the drive system, a plant must increase the efficiency of the motors (see above) or reduce energy losses through decreased throttling or installation of adjustable speed drives. Since most motors are fixed speed, but often operate at partial or variable load, adjustable speed drives can optimize energy use.

High Efficiency Classifiers
Classifiers (also known as separators) sort and separate fine particles from the larger particles; large particles are sent again to the mill. Standard classifiers may not have a sophisticated sorting mechanism, sending large and some fine particles back to the mill, lengthening the grinding process and using extra power in the grinding mill. High efficiency classifiers reduce over-grinding by more cleanly separating the materials. In addition to providing an energy benefit, high efficiency classifiers improve product quality.

b. Alternative Fuels

Alternative low carbon fuels can be substituted for a portion of the fossil fuels used in cement kilns, thereby reducing direct CO_2 emissions from the plant. The reduction of CO_2 emissions is dependent upon the heat content and carbon content of the alternative fuels selected. For example: used tires have a heat content that is slightly lower than petroleum coke, but used tires emit approximately 15% less CO_2 than petroleum coke on a per-ton basis. Therefore, even though the plant will need to burn more tons of tires than petroleum coke to obtain the same amount of energy, there will be a net CO_2 emission savings. The alternative fuels considered for this analysis include scrap tires, wood waste, agricultural residues, dried sewage sludge, plastics, used oil, petroleum refinery waste, and landfill gas.

c. Blended Cements

Blending agents can replace some portion of the clinker in cement, thereby reducing the quantity of clinker needed to produce a ton of cement. The use of blended cements depends largely on the additives that are available, as well as the environmental and other regulations in force. For this option, ICF assumed the blending materials include coal fly ash and blast furnace slag. Reducing the clinker factor (percent of clinker in the final product) through the use of blending agents allows the cement plant to produce more tons of cement per ton of clinker produced. In other words, when using blending agents, a plant's production can increase while clinker production is held constant. Therefore, the use of coal fly ash and blast furnace slag reduces the CO_2 emissions intensity of a ton of cement.

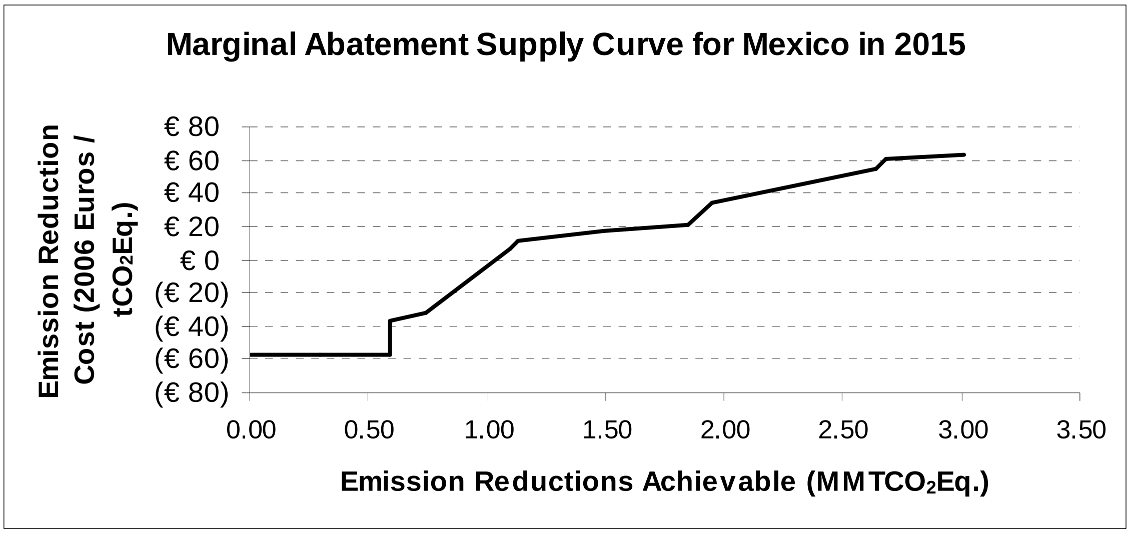
d. Kiln Conversions

One of the most significant ways to improve energy efficiency in the cement sector is upgrading to more efficient kilns. Very few (if any) wet kilns exist in the Mexican cement sector today, therefore conversion of wet to dry kilns was not considered during this analysis. There are, however, efficiency improvements available by converting dry process kilns to preheater/precalciner kilns, or converting long dry kilns to ¾ stage preheater/precalciner kilns that can also provide significant energy savings.

3. Marginal Abatement Cost Curve and Maximum Emission Reduction Potential

The graphs and tables below present the results of ICF's analysis of the marginal cost of abating cement sector emissions in Mexico.

Results for 2015 indicate that a maximum of 3.01 MMTCO2Eq could be reduced if all of the potential options are adopted.



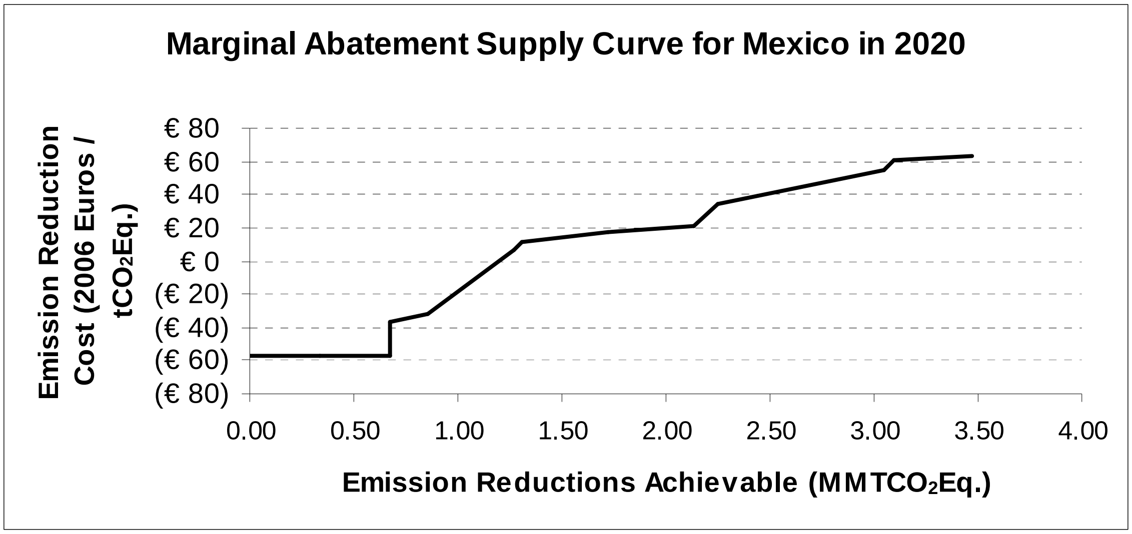
Marginal Abatement Supply Curve for Mexico in 2015

Abatement Supply Curve Schedule of Options for Mexico in 2015 (at a 10% discount rate & 30% tax rate)

Emissions Mitigation Option Name	Country	Achievable Emission Reductions (MMTCO2Eq.)	Cum. Red.	Breakeven Cost (2006€ / tCO2Eq.)
Process Change: Motors/Drivers	Mexico	0.00	0.00	(€ 57.06)
Blended Cements: Coal Fly Ash	Mexico	0.29	0.29	(€ 57.01)
Blended Cements: Blast Furnace Slag	Mexico	0.29	0.59	(€ 56.99)
Process Change: Speed Drives	Mexico	0.00	0.59	(€ 36.62)
Process Change: Grinding Technologies	Mexico	0.15	0.74	(€ 32.26)
Alternative Fuel Use: Dried Sewage Sludge	Mexico	0.36	1.10	€ 6.34
Process Change: Classifiers	Mexico	0.04	1.13	€ 11.83
Alternative Fuel Use: Wood Waste	Mexico	0.36	1.49	€ 16.95

Alternative Fuel Use: Agricultural Residues	Mexico	0.36	1.85	€ 20.84
Alternative Fuel Use: Plastics	Mexico	0.10	1.95	€ 34.36
Kiln Conversions: Conversions from Long Dry to 3/4 Stage Dry	Mexico	0.69	2.64	€ 54.47
Alternative Fuel Use: Scrap Tires	Mexico	0.04	2.68	€ 60.57
Kiln Conversions: Conversions from Dry to Preheater/Precalciner	Mexico	0.33	3.01	€ 63.38

The analysis of abatement potential for 2020 is presented in the following graph and table. The results indicate that a maximum of 3.48 MMTCO2Eq emissions could be reduced by Mexico's cement sector assuming that all available technologies are adopted.



Marginal Abatement Supply Curve for Mexico in 2020

Abatement Supply Curve Schedule of Options for Mexico in 2020 (at a 10% discount rate & 30% tax rate)

Emissions Mitigation Option Name	**Country**	**Achievable Emission Reductions** (MMTCO2Eq.)	Cum. Red.	**Breakeven Cost** (2006€ / tCO2Eq.)
Process Change: Motors/Drivers	Mexico	0.00	0.00	(€ 57.06)
Blended Cements: Coal Fly Ash	Mexico	0.34	0.34	(€ 57.01)
Blended Cements: Blast Furnace Slag	Mexico	0.34	0.68	(€ 56.99)
Process Change: Speed Drives	Mexico	0.00	0.68	(€ 36.62)
Process Change: Grinding Technologies	Mexico	0.18	0.85	(€ 32.26)
Alternative Fuel Use: Dried Sewage Sludge	Mexico	0.41	1.27	€ 6.34
Process Change: Classifiers	Mexico	0.04	1.31	€ 11.83
Alternative Fuel Use: Wood Waste	Mexico	0.41	1.72	€ 16.95
Alternative Fuel Use: Agricultural Residues	Mexico	0.41	2.14	€ 20.84
Alternative Fuel Use: Plastics	Mexico	0.12	2.25	€ 34.36
Kiln Conversions: Conversions from Long Dry to 3/4 Stage Dry	Mexico	0.80	3.05	€ 54.47
Alternative Fuel Use: Scrap Tires	Mexico	0.05	3.09	€ 60.57
Kiln Conversions: Conversions from Dry to Preheater/Precalciner	Mexico	0.38	3.48	€ 63.38

4. Barriers to Achieving Maximum Reductions

The analyses presented above have focused on the potential for reducing GHG emissions from the manufacture of cement from purely a technical perspective. The estimated emission reductions are thus the maximum achievable under ideal circumstances. In other words, the analyses were constructed under the implicit assumption that all of the underlying conditions required for full and successful deployment of the abatement options are satisfied. In reality, numerous barriers could exist that will limit the overall applicability of the abatement options described in Section D.2. The discussion below identifies four broad categories of barriers to the adoption of emission reducing technologies by the cement sector in Mexico.

a. Input Supply Barriers

Many of the mitigation options analyzed in this study have associated supply issues. Specifically, there are a number of possible supply chain barriers related to the availability of the different types of alternative fuels and the materials that are suitable for use in blended cement.

Several of the materials that can be used as alternative fuels, such as plastics, sewage sludge, and wood waste, require unique materials handling systems to make them accessible to the cement industry. That is, each type of material needs a system of collection, initial processing, delivery, and storage that is tailored specifically for that material. For example, before sewage sludge can be used as a fuel, it must first be treated for pathogens, then dried, transported to a manufacturer's facility, and stored in a manner that prevents re-hydration. With the exception of providing on-site storage facilities, these activities are not likely to be undertaken by cement manufacturers. Preparing and handling sewage sludge requires expertise and equipment that is not available to the typical cement plant. Likewise, for waste plastics to be used as a fuel by cement manufacturers the materials must first be collected from initial users (households and businesses), sorted to remove materials, such as Polyvinyl Chloride (PVC), that contain vinyl chlorine—a known carcinogen—and finally shredded to produce a material that can be fed into a cement kiln. Again the activities, equipment, and expertise needed to convert waste plastics into a viable fuel source for cement kilns are quite different from those that are accessible at the typical cement plant. These two examples illustrate the need for upstream materials handling capabilities by entities that are most likely not members of the cement sector.

Another form of supply constraint relates to the location specific nature of some types of alternative fuels. For example, used tires are really only a cost-effective alternative fuel in areas where a supply of scrap tires is found in close proximity to the plants that will use them. In Mexico, the main region where this is true is in the north near the U.S. border. For cement plants in central and especially in southern areas of Mexico, access to this potential fuel source is much more limited.

In addition to alternative fuel supply chain barriers, there are also issues associated with the quality of cement produced using alternative fuels. For example, scrap tires often contain significant amounts of zinc in the steel belts used in radial tires. If the belts are not removed during shredding, zinc can be absorbed by clinker during processing. If too much zinc is absorbed cement made from zinc contaminated clinker will harden too quickly and would not be suitable for most uses.

b. Informational Barriers

The cement industry's adoption of alternative fuels could be further stimulated by access to some basic research into the effects of using alternative fuels in the clinker production process. Determining how various substances found in alternative fuels will ultimately affect the quality of the final product and/or continuing operations at facilities that adopt alternative fuels, is a complex process that requires expert knowledge about the properties of the materials that comprise alternative fuels. This type of expertise and the associated research efforts are not readily available to the cement industry. Limited access to sound information on the impacts of alternative fuels on product quality acts as a barrier to more widespread use of these substances. As noted above, using tires as an energy source brings with it a risk that the clinker produced will be adversely affected by the absorption of zinc. What is not clear is the exact mix of scrap tires and other fuels that can be used without risking excessive amounts of zinc in the final product. Research is needed to understand the conditions under which tires can be safely used as a substitute for more traditional fuels.

Likewise, additional information is needed regarding the use of blending materials in producing cement. Blast furnace slag and fly ash are currently mixed with clinker to create blended cements. However, these materials are not available at cost-effective prices in many locations. Additional research is needed to identify other potential blending materials and to assess the implications of using these materials for the quality of the final product.

c. Financial Barriers

There is no evidence suggesting that financial barriers are inhibiting adoption of GHG mitigation options within the cement industry per se. Mexico has a flexible trade policy including NAFTA that allows imports from Canada and the United States to enter Mexico duty free. Moreover, all of the major cement companies operating in Mexico are well capitalized and have access to formal credit markets.

Financial barriers might however be an issue affecting the potential supply of alternative fuels. Many of the activities associated with generating a supply of alternative fuels, such as scrap tires, wood and agricultural waste, sewage sludge, etc., are ones that will best be done by firms other than the major cement producers. To the extent that it is difficult for small firms in these supply side industries to obtain funding to purchase equipment and/or to cover other types of costs, financial barriers will limit the ability of cement producers to achieve their maximum emission reduction potential.

d. Regulatory Barriers

Most cement plants in Mexico are currently authorized to use scrap tires and other waste materials for fuel. However, there are some potential environmental issues associated with the burning of these materials in cement kilns. For example, cement kiln dust (CKD), which is a fine matter produced during combustion and transported by the flow of hot gases within a kiln, can contain a variety of substances that are hazardous to human health. Some examples of materials found in CKD include arsenic, dioxin, furans, lead, and chlorine. The concentrations of all of these substances can be increased by the use of some types of alternative fuels. To minimize adverse impacts on human health, regulations are used to restrict the quantity of some alternative fuels that can be burned in processing clinker. The closer are manufacturing facilities to large population centers, the more likely it is that regulations are already in place and/or that restrictions could be tightened or implemented in the future.

E. Public and Private Policy Options

The research conducted for this case study and the results of the analyses suggest several opportunities for public and private sector initiatives that could stimulate additional or more rapid adoption of emission abatement options in Mexico's cement industry. The following briefly describes two types of cooperative efforts that industry and government could undertake and a public sector option that could be used to support firms that could supply alternative fuels to the cement industry.

a. Industry-Government Research Partnerships

Public-private partnerships focused on research relating specifically to materials available in Mexico could provide valuable information for the cement industry.

1. Alternative Fuels Research

Many of the materials that are recommended as alternative fuels for cement kilns have properties that are well known and materials handling procedures that are well developed. Scrap tires, sewage sludge, and wood wastes are included in this group. Less is known about other types of materials, such as many forms of agricultural wastes. A joint government-industry research program might help promote more widespread use of these materials by providing a better understanding of their properties, handling requirements, and availability.

2. Materials for Producing Blended Cements

Another potentially fruitful area of research that could be undertaken jointly by the government and cement manufacturers is identifying and testing possible alternative substances for use in blended cements. Access to fly ash and blast furnace slag, which are often used in blended cements, is very limited and highly location specific in Mexico. If suitable waste or raw materials can be identified, these might allow cement producers to increase their production of cement with lower inputs of clinker and thus lower emissions of CO_2.

In addition, research is needed to improve upon the blending process so that the clinker fraction can be decreased without compromising the structural integrity of the final cement product. Joint research efforts by industry and government could provide valuable results in this area that will allow increased use of blending materials and a related reduction in emissions associated with the production of clinker.

b. Government Policies

An area where government support could be especially productive is in providing support to the further development of a system that ensures a reliable supply of alternative fuels for use by cement manufacturers. Even if alternative fuels cost less than the fuels they are currently using, cement manufacturers will not find alternatives more attractive unless they are assured about the quality of the alternatives and reliability of supply. Moreover, because most of the activities, expertise, and capital equipment required to supply alternative fuels for cement production are not closely related to the functions, skills, and equipment needed to operate the typical cement plant, there is a role for small to medium sized firms that are not part of the cement industry to become alternative fuel suppliers. A government sponsored support program that helps small and medium sized enterprises get started could be key to encouraging new firms to enter the alternative fuels market and to encouraging cement manufacturers to contract with start-up firms to supply alternative fuels.

Other government policies that could be implemented to encourage emission reductions by the cement industry include:

1. Establishing a deposit-refund system applicable to products purchased in plastic containers. This would have the effect of increasing the quantity of scrap plastic available for use as an alternative fuel.

2. Imposing “tipping fees” at landfills that apply specifically to disposal of materials—e.g., plastics, wood waste, etc.—that can be used as alternative fuels.

3. Removing any price distorting policies, such as subsidies and concessionary taxes, that reduce the price of fossil fuel relative to alternative fuels.

F. Observations and Insights

The six manufacturers and 31 plants that comprise Mexico's cement industry have already made significant strides toward maximizing energy efficiency and thereby reducing the sector's carbon footprint. The data gathered for this preliminary assessment indicate that there are no energy intensive wet kilns operating in Mexico and that most plants are already using preheaters and precalciners. The data also indicate that cement manufacturers are producing blended cements and that at least some plants are using alternative fuels to fire their kilns.

To some extent, time constraints associated with developing this interim report, have prevented an exhaustive assessment of emission abatement opportunities in Mexico's cement sector. However, a more important constraint on the analyses is limited access to much of the data needed to produce a definitive report on emissions abatement potential and related costs. Some critical pieces of information that are needed for such a study include a variety of types of data that are treated as highly confidential by industry players because of potential competitive and antitrust implications. To further engage the industry's participation in assessing the potential for a sector-based strategy to be part of a post-Kyoto international agreement on greenhouse gas mitigation, it will be necessary for researchers and analysts to devise mechanisms that will assure industry players that the information they provide on a plant by plant basis will be protected and used only for purposes of providing analyses that are instructive for assessing and comparing different approaches to an international sector-based agreement.

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Annex Costs Associated with the Mitigation Options Evaluated

This section presents a cost analysis for achieving CO2 emission reductions through the implementation of the mitigation options described above. Since each abatement option is previously described, the remainder of this section is focused on providing a description of the economic assumptions for these abatement options. All costs reported in this document are in the units ($, R$, and €) published by each reference; these costs are converted into 2006 Euros in the MAC model.

I. Process Changes

a. Cost and Emission Reduction Analysis for High Efficiency Grinding Technologies

The following describes cost and emission inputs used to derive the final dollars per tCO_2eq for the high efficiency grinding technologies option, the results of which are presented in Table 4.

- One-Time Costs. One-time costs associated with installation of high efficiency grinding technologies are assumed to be $4.00 per ton of cement capacity, based on an estimate from Worrell and Galitsky (2004) and Worrell, *et al.*, (2008).
- Annual Costs. Operation and maintenance costs are assumed to be equal to 5% of the one-time cost associated with this technology. This assumption is based on the judgment of the ICF cement sector lead.
- Cost Savings. Cost savings are associated with the decrease in electricity used per ton of cement produced. The amount of electricity saved is multiplied by the assumed cost of electricity, $1.1429 pesos per kWh, based on the sales statistics provided online by the Mexico Comission Federal de Electridicad (CFE, 2008).
- Emission Reductions. Emission reductions for this option are associated with the decrease in electricity used per ton of cement produced. According to Worrell and Galitsky (2004) and Worrell, *et al.*, (2008), more efficient grinding technologies are associated with a reduction of electricity use of approximately 25 kWh per ton of cement. Emission reductions were calculated based on the 25 kWh/ton savings, and an assumed carbon dioxide intensity of electricity of 0.525 tCO_2/MWh (CO_2 Global Solutions International, 2007).

b. Cost and Emission Reduction Analysis for High Efficiency Grinding Technologies

The following describes cost and emission inputs used to derive the final dollars per tCO_2eq for the high efficiency motors option, the results of which are presented in Table 4. Please note that based on comments from Cemex regarding a previous report, the applicability of this option in Mexico is zero.

- One-Time Costs. One-time costs associated with installation of high efficiency motors are assumed to be $0.20 per ton of cement capacity, based on an estimate from Worrell and Galitsky (2004) and Worrell, *et al.*, (2008).

- Annual Costs. Operation and maintenance costs are assumed to be equal to 5% of the one-time cost associated with this technology. This assumption is based on the judgment of the ICF cement sector lead.

- Cost Savings. Cost savings are associated with the decrease in electricity used per ton of cement produced. The amount of electricity saved is multiplied by the assumed cost of electricity, $1.1429 pesos per kWh, based on the sales statistics provided online by the Mexico Comission Federal de Electridicad (CFE, 2008).

- Emission Reductions. Emission reductions for this option are associated with the decrease in electricity used per ton of cement produced. According to Worrell and Galitsky (2004) and Worrell, *et al.*, (2008), more efficient grinding technologies are associated with a reduction of electricity use of approximately 3.2 kWh per ton of cement. Emission reductions were calculated based on the 3.2 kWh/ton savings, and an assumed carbon dioxide intensity of electricity of 0.525 tCO_2/MWh (CO_2 Global Solutions International, 2007).

c. Cost and Emission Reduction Analysis for Adjustable Speed Drives

The following describes cost and emission inputs used to derive the final dollars per tCO_2eq for the adjustable speed drives option, the results of which are presented in Table 4. Please note that based on comments from Cemex regarding a previous report, the applicability of this option in Mexico is zero.

- One-Time Costs. One-time costs associated with installation of adjustable speed drives are assumed to be $1.00 per ton of cement capacity, based on an estimate from Worrell and Galitsky (2004) and Worrell, *et al.*, (2008).

- Annual Costs. Operation and maintenance costs are assumed to be equal to 5% of the one-time cost associated with this technology. This assumption is based on the judgment of the ICF cement sector lead.

- Cost Savings. Cost savings are associated with the decrease in electricity used per ton of cement produced. The amount of electricity saved is multiplied by the assumed cost of electricity, $1.1429 pesos per kWh, based on the sales statistics provided online by the Mexico Comission Federal de Electridicad (CFE, 2008).

- Emission Reductions. Emission reductions for this option are associated with the decrease in electricity used per ton of cement produced. According to Worrell and Galitsky (2004) and Worrell, *et al.*, (2008), more efficient grinding technologies are associated with a reduction of electricity use of approximately 7 kWh per ton of cement. Emission reductions were calculated based on the 7 kWh/ton savings, and an assumed carbon dioxide intensity of electricity of 0.525 tCO_2/MWh (CO_2 Global Solutions International, 2007).

d. Cost and Emission Reduction Analysis for High Efficiency Classifiers

The following describes cost and emission inputs used to derive the final dollars per tCO_2eq for the high efficiency classifiers option, the results of which are presented in Table 4.

- One-Time Costs. One-time costs associated with installation of adjustable speed drives are assumed to be $2.00 per ton of cement capacity, based on an estimate from Worrell and Galitsky (2004) and Worrell, *et al.*, (2008).
- Annual Costs. Operation and maintenance costs are assumed to be equal to 5% of the one-time cost associated with this technology. This assumption is based on the judgment of the ICF cement sector lead.
- Cost Savings. Cost savings are associated with the decrease in electricity used per ton of cement produced. The amount of electricity saved is multiplied by the assumed cost of electricity, $1.1429 pesos per kWh, based on the sales statistics provided online by the Mexico Comission Federal de Electridicad (CFE, 2008).
- Emission Reductions. Emission reductions for this option are associated with the decrease in electricity used per ton of cement produced. According to Worrell and Galitsky (2004) and Worrell, *et al.*, (2008), more efficient grinding technologies are associated with a reduction of electricity use of approximately 6 kWh per ton of cement. Emission reductions were calculated based on the 6 kWh/ton savings, and an assumed carbon dioxide intensity of electricity of 0.525 tCO_2/MWh (CO_2 Global Solutions International, 2007).

II. Alternative Fuels

a. Cost and Emission Reduction Analysis for Scrap Tires

The following describes cost and emission inputs used to derive the final dollars per tCO_2eq for the scrap tires as an alternative fuel option, the results of which are presented in Table 4.

- One-Time Costs. In order to use scrap tires for alternative fuels, modifications to the cement plant must be made, and permits must be obtained prior to use. According to Blue Circle Southern Cement (J D Court and Associates Pty Ltd., 2005) the cost of modifying a cement plant for the use of scrap tires is approximately $4 million. Additionally, another $100,000 is assumed for expenses related to permits; $50,000 to obtain the permits, and $50,000 for initial performance testing. This assumption is based on the judgment of the ICF cement sector lead.
- Annual Costs. Annual costs for using scrap tires as alternative fuels are made up of maintenance costs, alternative fuel costs, and transport costs. Maintenance costs are assumed to be equal to 5% of the one-time cost associated with this technology. This assumption is based on the judgment of the ICF cement sector lead. Scrap tires are assumed to cost €15.50 per ton,

based on the cost of other alternative fuels (Brazil Biomass and Renewable Energy, 2006). It is also assumed that the cement plant will incur the cost of transporting the alternative fuel at an average distance of 501.44 kilometers, at a cost of R$0.12 per ton. The distance traveled is based upon a weighted average for the transport capacity and trip distance of blending agents for blended cements in Mexico (CO_2 Global Solutions International, 2007). The cost is based on the cost associated with transporting steel slag in Brazil; R$35.00 per ton to transport 290 km (Ecoinvest Carbon, 2007).

- Cost Savings. Cost savings from this option are associated with replacing the traditional fuel (petroleum coke) with the alternative fuel. As stated above, the cost of scrap tires is assumed to be €15.50 per ton. The cost for petroleum coke is assumed to be $58 per ton ($CO_2$ Global Solutions International, 2007).
- Emission Reductions. Emission reductions for this option are associated with the use of alternative fuels with lower carbon content than traditional fuels. The carbon content of petroleum coke is assumed to be 90%, and the carbon content of scrap tires is assumed to be 73% (SGS Climate Change Programme, 2008). Since the alternative fuel has a lower carbon content than the traditional fuel it should produce an emission reduction. However, the heat content of the fuels is also taken into account, since in most cases, additional quantities of the alternative fuel must be consumed in order to heat at the same level as the traditional fuel. The heat content for petroleum coke is assumed to be 7,775 kcal/kg and the heat content for scrap tires is assumed to be 7,500 kcal/kg (SGS Climate Change Programme, 2008). Finally, a replacement rate of 20% is assumed, meaning up to 20% of the current fuel could be replaced by scrap tire consumption. This assumption is based on the penetration of scrap tire use in the United States where some kilns have already achieved a 20% replacement rate.

b. Cost and Emission Reduction Analysis for Wood Waste

The following describes cost and emission inputs used to derive the final dollars per tCO_2eq for the wood waste as an alternative fuel option, the results of which are presented in Table 4.

- One-Time Costs. In order to use wood waste as an alternative fuel, modifications to the cement plant must be made including a materials handling system and storage area for the alternative fuel supply. According to a Lafarge Uganda case study (Lafarge, 2008) a plant spends approximately $1.2 million for a 2000 ton capacity storage and conveyer system.
- Annual Costs. Annual costs for using wood waste as an alternative fuel are made up of maintenance costs, alternative fuel costs, and transport costs. Maintenance costs are assumed to be equal to 5% of the one-time cost associated with this technology. This assumption is based on the judgment of the ICF cement sector lead. Wood waste is assumed to cost €15.50 per ton (Brazil Biomass and Renewable Energy, 2006). It is also assumed that the cement plant will incur the cost of transporting the alternative fuel at an

average distance of 501.44 kilometers, at a cost of R$0.12 per ton. The distance traveled is based upon a weighted average for the transport capacity and trip distance of blending agents for blended cements in Mexico (CO_2 Global Solutions International, 2007). The cost is based on the cost associated with transporting steel slag in Brazil; R$35.00 per ton to transport 290 km (Ecoinvest Carbon, 2007).

- Cost Savings. Cost savings from this option are associated with replacing the traditional fuel (petroleum coke) with the alternative fuel. As stated above, the cost of wood waste is assumed to be €15.50 per ton. The cost for petroleum coke is assumed to be $58 per ton ($CO_2$ Global Solutions International, 2007).

- Emission Reductions. Emission reductions for this option are associated with the use of alternative fuels with lower carbon content than traditional fuels. The carbon content of petroleum coke is assumed to be 90% (SGS Climate Change Programme, 2008), and the carbon content of wood waste is assumed to be 0%, based on the CSI Protocol (CSI, 2005). Since the alternative fuel has a lower carbon content than the traditional fuel it should produce an emission reduction. However, the heat content of the fuels is also taken into account, since in most cases, additional quantities of the alternative fuel must be consumed in order to heat at the same level as the traditional fuel. The heat content for petroleum coke is assumed to be 7,775 kcal/kg and the heat content for wood waste is assumed to be 4,000 kcal/kg (SGS Climate Change Programme, 2008). Finally, a replacement rate of up to 27% is assumed, meaning up to 27% of the petroleum coke could be replaced by alternative fuels (SGS Climate Change Programme, 2008).

c. Cost and Emission Reduction Analysis for Agricultural Residues

The following describes cost and emission inputs used to derive the final dollars per tCO_2eq for the agricultural residues as an alternative fuel option, the results of which are presented in Table 4.

- One-Time Costs. In order to use agricultural residues as an alternative fuel, modifications to the cement plant must be made including a materials handling system and storage area for the alternative fuel supply. According to a Lafarge Uganda case study (Lafarge, 2008) a plant spends approximately $1.2 million for a 2000 ton capacity storage and conveyer system.

- Annual Costs. Annual costs for using agricultural residues as an alternative fuel are made up of maintenance costs, alternative fuel costs, and transport costs. Maintenance costs are assumed to be equal to 5% of the one-time cost associated with this technology. This assumption is based on the judgment of the ICF cement sector lead. Agricultural residue is assumed to cost €15.50 per ton, based on the price of wood waste (Brazil Biomass and Renewable Energy, 2006). It is also assumed that the cement plant will incur the cost of transporting the alternative fuel at an average distance of 501.44 kilometers, at a cost of R$0.12 per ton. The distance traveled is based upon a weighted average for the transport capacity and trip distance of blending agents for blended cements in Mexico (CO_2 Global Solutions International, 2007). The cost is based on the cost associated with transporting steel slag in Brazil; R$35.00 per ton to transport 290 km (Ecoinvest Carbon, 2007).

- Cost Savings. Cost savings from this option are associated with replacing the traditional fuel (petroleum coke) with the alternative fuel. As stated above, the cost of agricultural residue is assumed to be €15.50 per ton. The cost for petroleum coke is assumed to be $58 per ton ($CO_2$ Global Solutions International, 2007).

- Emission Reductions. Emission reductions for this option are associated with the use of alternative fuels with lower carbon content than traditional fuels. The carbon content of petroleum coke is assumed to be 90% (SGS Climate Change Programme, 2008), and the carbon content of agricultural residue is assumed to be 0%, based on the CSI Protocol (CSI, 2005). Since the alternative fuel has a lower carbon content than the traditional fuel it should produce an emission reduction. However, the heat content of the fuels is also taken into account, since in most cases, additional quantities of the alternative fuel must be consumed in order to heat at the same level as the traditional fuel. The heat content for petroleum coke is assumed to be 7,775 kcal/kg and the heat content for agricultural residue is assumed to be 3,500 kcal/kg (SGS Climate Change Programme, 2008). Finally, a replacement rate of up to 27% is assumed, meaning up to 27% of the petroleum coke could be replaced by alternative fuels (SGS Climate Change Programme, 2008).

d. Cost and Emission Reduction Analysis for Dried Sewage Sludge

The following describes cost and emission inputs used to derive the final dollars per tCO_2eq for the dried sewage sludge as an alternative fuel option, the results of which are presented in Table 4.

- One-Time Costs. In order to use dried sewage sludge as an alternative fuel, modifications to the cement plant must be made including a materials handling system and storage area for the alternative fuel supply. According to Blue Circle Southern Cement (J D Court and Associates Pty Ltd., 2005) the cost of modifying a cement plant for the use of scrap tires is approximately $4 million. It is assumed that modifying a plant to accommodate dried sewage sludge would be half as expensive as scrap tires, thus a $2 million capitol cost is assumed.

- Annual Costs. Annual costs for using dried sewage sludge as an alternative fuel are made up of maintenance costs, alternative fuel costs, and transport costs. Maintenance costs are assumed to be equal to 5% of the one-time cost associated with this technology. This assumption is based on the judgment of the ICF cement sector lead. Dried sewage sludge is assumed to cost €15.50 per ton, based on the price of wood waste (Brazil Biomass and Renewable Energy, 2006). It is also assumed that the cement plant will incur the cost of transporting the alternative fuel at an average distance of 501.44 kilometers, at a cost of R$0.12 per ton. The distance traveled is based upon a weighted average for the transport capacity and trip distance of blending agents for blended cements in Mexico (CO_2 Global Solutions International, 2007). The cost is based on the cost associated with transporting steel slag in Brazil; R$35.00 per ton to transport 290 km (Ecoinvest Carbon, 2007).

- Cost Savings. Cost savings from this option are associated with replacing the traditional fuel (petroleum coke) with the alternative fuel. As stated above, the cost of dried sewage sludge is assumed to be €15.50 per ton. The cost for petroleum coke is assumed to be $58 per ton ($CO_2$ Global Solutions International, 2007).
- Emission Reductions. Emission reductions for this option are associated with the use of alternative fuels with lower carbon content than traditional fuels. The carbon content of petroleum coke is assumed to be 90% (SGS Climate Change Programme, 2008), and the carbon content of dried sewage sludge is assumed to be 0%, based on the CSI Protocol (CSI, 2005). Since the alternative fuel has a lower carbon content than the traditional fuel it should produce an emission reduction. However, the heat content of the fuels is also taken into account, since in most cases, additional quantities of the alternative fuel must be consumed in order to heat at the same level as the traditional fuel. The heat content for petroleum coke is assumed to be 7,775 kcal/kg and the heat content for dried sewage sludge is assumed to be 7,000 kcal/kg (SGS Climate Change Programme, 2008). Finally, a replacement rate of up to 27% is assumed, meaning up to 27% of the petroleum coke could be replaced by alternative fuels (SGS Climate Change Programme, 2008).

e. Cost and Emission Reduction Analysis for Plastics

The following describes cost and emission inputs used to derive the final dollars per tCO_2eq for the plastics as an alternative fuel option, the results of which are presented in Table 4.

- One-Time Costs. In order to use plastic as an alternative fuel, modifications to the cement plant must be made including a materials handling system and storage area for the alternative fuel supply. According to Blue Circle Southern Cement (J D Court and Associates Pty Ltd., 2005) the cost of modifying a cement plant for the use of scrap tires is approximately $4 million. It is assumed that modifying a plant to accommodate plastic would be half as expensive as scrap tires, thus a $2 million capitol cost is assumed.
- Annual Costs. Annual costs for using plastic as an alternative fuel are made up of maintenance costs, alternative fuel costs, and transport costs. Maintenance costs are assumed to be equal to 5% of the one-time cost associated with this technology. This assumption is based on the judgment of the ICF cement sector lead. Plastic is assumed to cost €15.50 per ton, based on the price of wood waste (Brazil Biomass and Renewable Energy, 2006). It is also assumed that the cement plant will incur the cost of transporting the alternative fuel at an average distance of 501.44 kilometers, at a cost of

R$0.12 per ton. The distance traveled is based upon a weighted average for the transport capacity and trip distance of blending agents for blended cements in Mexico (CO_2 Global Solutions International, 2007). The cost is based on the cost associated with transporting steel slag in Brazil; R$35.00 per ton to transport 290 km (Ecoinvest Carbon, 2007).

- Cost Savings. Cost savings from this option are associated with replacing the traditional fuel (petroleum coke) with the alternative fuel. As stated above, the cost of plastic is assumed to be €15.50 per ton. The cost for petroleum coke is assumed to be $58 per ton ($CO_2$ Global Solutions International, 2007).
- Emission Reductions. Emission reductions for this option are associated with the use of alternative fuels with lower carbon content than traditional fuels. The carbon content of petroleum coke is assumed to be 90%, and the carbon content of plastic is assumed to be 48% (SGS Climate Change Programme, 2008). Since the alternative fuel has a lower carbon content than the traditional fuel it should produce an emission reduction. However, the heat content of the fuels is also taken into account, since in most cases, additional quantities of the alternative fuel must be consumed in order to heat at the same level as the traditional fuel. The heat content for petroleum coke is assumed to be 7,775 kcal/kg and the heat content for dried sewage sludge is assumed to be 5,800 kcal/kg (SGS Climate Change Programme, 2008). Finally, a replacement rate of up to 27% is assumed, meaning up to 27% of the petroleum coke could be replaced by alternative fuels (SGS Climate Change Programme, 2008).

III Blended Cements

a. Cost and Emission Reduction Analysis for Coal Fly Ash

The following describes cost and emission inputs used to derive the final dollars per tCO_2eq for the coal fly ash blending agent option, the results of which are presented in Table 4.

- One-Time Costs. One-time costs to initiate the production of blended cements include material storage and handling facilities for the blending agents. It is assumed that a one-time cost of $1.5 million will be required to initiate blending, based on the average cost reported by Cemex (CO_2 Global Solutions International, 2007).
- Annual Costs. Annual costs for using coal fly ash as an alternative fuel are made up of maintenance costs, fly ash costs, and ash transport costs. Maintenance costs are assumed to be equal to 5% of the one-time cost associated with this technology. This assumption is based on the judgment of the ICF cement sector lead. Coal fly ash is assumed to cost $22.50 per ton based on the range of $15-30 by Worrell *et al.* (2001). It is also assumed that the cement plant will incur the cost of transporting the alternative fuel at an

average distance of 501.44 kilometers, at a cost of R$0.12 per ton. The distance traveled is based upon a weighted average for the transport capacity and trip distance of blending agents for blended cements in Mexico (CO_2 Global Solutions International, 2007). The cost is based on the cost associated with transporting steel slag in Brazil; R$35.00 per ton to transport 290 km (Ecoinvest Carbon, 2007).

- Cost Savings. Cost savings are associated with an increase in cement production despite a lack of change in clinker production. The baseline clinker factor for Mexico is assumed to be 82.23% and the assumed clinker factor with blending agents is 72.13%, based on the supporting spreadsheets provided by Cemex with their CDM application for blended cements (CO_2 Global Solutions International., 2007). The lower the clinker factor, the less clinker is required per ton of cement. Finally, the sale price for one ton of cement is assumed to be $110 (SNIC, 2008). The increase in tons of cement produced along with the price per ton of cement is used to calculate cost savings.

- Emission Reductions. Emission reductions for this option are associated with the decrease in clinker needed to produce a ton of cement. The specific emission factor associated with a ton of cement is assumed to be 0.676 tons CO_2/ton of blended cement. This is based on the supporting spreadsheets submitted with CDM project 1356 (CO_2 Global Solutions International, 2007). In order to calculate emission reductions, the emission factor is multiplied by the additional tons of cement produced due to the use of blending agents.

b. Cost and Emission Reduction Analysis for Blast Furnace Slag

The following describes cost and emission inputs used to derive the final dollars per tCO_2eq for the blast furnace slag blending agent option, the results of which are presented in Table 4.

- One-Time Costs. One-time costs to initiate the production of blended cements include material storage and handling facilities for the blending agents. It is assumed that a One-time cost of $1.5 million will be required to initiate blending, based on the average cost reported by Cemex (CO_2 Global Solutions International, 2007).

- Annual Costs. Annual costs for using blast furnace slag as an alternative fuel are made up of maintenance costs, slag costs, and slag transport costs. Maintenance costs are assumed to be equal to 5% of the one-time cost associated with this technology. This assumption is based on the judgment of the ICF cement sector lead. Blast furnace slag is assumed to cost $22.59 per ton per ton based on the cost of SICARTSA's slag (Det Norske Veritas Certification, 2007). It is also assumed that the cement plant will incur the cost of transporting the alternative fuel at an average distance of 501.44 kilometers, at a cost of R$0.12 per ton. The distance traveled is based upon a weighted average for the transport capacity and trip distance of blending agents for blended cements in Mexico (CO_2 Global Solutions International, 2007). The cost is based on the cost associated with transporting steel slag in Brazil; R$35.00 per ton to transport 290 km (Ecoinvest Carbon, 2007).

- Cost Savings. Cost savings are associated with an increase in cement production despite a lack of change in clinker production. The baseline clinker factor for Mexico is assumed to be 82.23% and the assumed clinker factor with blending agents is 72.13%, based on the supporting spreadsheets provided by Cemex with their CDM application for blended cements (CO_2 Global Solutions International., 2007). The lower the clinker factor, the less clinker is required per ton of cement. Finally, the sale price for one ton of cement is assumed to be $110 (SNIC, 2008). The increase in tons of cement produced along with the price per ton of cement is used to calculate cost savings.
- Emission Reductions. Emission reductions for this option are associated with the decrease in clinker needed to produce a ton of cement. The specific emission factor associated with a ton of cement is assumed to be 0.676 tons CO_2/ton of blended cement. This is based on the supporting spreadsheets submitted with CDM project 1356 (CO_2 Global Solutions International, 2007). In order to calculate emission reductions, the emission factor is multiplied by the additional tons of cement produced due to the use of blending agents.

IV. Kiln Conversions

a. Cost and Emission Reduction Analysis for Converting Dry Process Kilns to Preheater/Precalciner Kilns

The following describes cost and emission inputs used to derive the final dollars per tCO_2eq for the converting dry process kilns to preheater/precalciner kilns option, the results of which are presented in Table 4.

- One-Time Costs. One-time costs associated with conversion to a dry process preheater/precalciner kiln is assumed to be $18.70 per ton of cement capacity, based on an estimate from Worrell and Galitsky (2004) and Worrell, *et al.*, (2008).
- Annual Costs. Operation and maintenance costs are assumed to be equal to 5% of the one-time cost associated with this technology. This assumption is based on the judgment of the ICF cement sector lead.
- Cost Savings. Cost savings are associated with the decrease in fuel consumption per ton of cement produced. The amount of fuel saved is multiplied by the assumed cost of the fuel, $58 per ton ($CO_2$ Global Solutions International, 2007), to obtain the total savings.

- Emission Reductions. Emission reductions for this option are associated with the decrease in fuel consumption per ton of clinker. According to Worrell and Galitsky (2004) and Worrell, *et al.*, (2008), conversion to a preheater/precalciner kiln will provide a fuel savings of 0.43 GJ/ton of clinker. For this calculation it is assumed that the kiln is using petroleum coke, with a carbon content of 90%, and a heat content of 7,775 kcal/kg (SGS Climate Change Programme, 2008).

b. Cost and Emission Reduction Analysis for Converting Long Dry Kilns to ¾ Stage Dry Kilns

The following describes cost and emission inputs used to derive the final dollars per tCO_2eq for the converting long dry kilns to ¾ stage dry kilns option, the results of which are presented in Table 4.

- One-Time Costs. One-time costs associated with conversion of a long dry kiln to a ¾ stage dry kiln is assumed to be $34.50 per ton of cement capacity, based on an estimate from Worrell and Galitsky (2004) and Worrell, *et al.*, (2008).
- Annual Costs. Operation and maintenance costs are assumed to be equal to 5% of the one-time cost associated with this technology. This assumption is based on the judgment of the ICF cement sector lead.
- Cost Savings. Cost savings are associated with the decrease in fuel consumption per ton of cement produced. The amount of fuel saved is multiplied by the assumed cost of the fuel, $58 per ton ($CO_2$ Global Solutions International, 2007), to obtain the total savings.
- Emission Reductions. Emission reductions for this option are associated with the decrease in fuel consumption per ton of clinker. According to Worrell and Galitsky (2004) and Worrell, *et al.*, (2008), conversion to a preheater/precalciner kiln will provide a fuel savings of 0.9 GJ/ton of clinker. For this calculation it is assumed that the kiln is using petroleum coke, with a carbon content of 90%, and a heat content of 7,775 kcal/kg (SGS Climate Change Programme, 2008).

Table 4: Characteristics of Mitigation Options for Reducing CO_2 Emissions from the Cement Sector

Abatement Option	Technical Effectiveness (%)	Applicability (%)	Capital Cost (2006€)	Recurring Annual Cost (2006€)	Annual Revenue (2006€)	PE Price (2006€/ $tCO_2Eq.$)
Process Changes						
Grinding Technologies	19.8%	2.1%	€ 2,631,578	€ 136,006	€ 1,001,039	(€ 32.26)
Motors/Drivers	2.5%	0.0%	€ 130,428	€ 6,800	€ 128,133	(€ 57.06)
Speed Drives	5.5%	0.0%	€ 1,304,283	€ 34,001	€ 280,291	(€ 36.62)
Classifiers	4.8%	2.1%	€ 986,842	€ 68,003	€ 240,249	€ 11.83
Alternative Fuels						
Scrap Tires	3.3%	3.3%	€ 22,498,887	€ 306,420	€ 919,853	(€ 60.57)
Wood Waste	27.0%	3.7%	€ 1,315,789	€ 981,200	€ 732,647	€ 16.95
Agricultural Residues	27.0%	3.7%	€ 713,667	€ 1,116,167	€ 659,911	€ 20.84
Dried Sewage Sludge	27.0%	3.7%	€ 986,842	€ 607,032	€ 950,857	(€ 6.34)
Plastics	7.5%	3.7%	€ 789,473	€ 718,729	€ 890,661	€ 34.36
Blended Cement						
Coal Fly Ash	14.0%	5.8%	€ 652,141	€ 2,837,704	€ 3,852,083	(€ 57.01)
Blast Furnace Slag	14.0%	5.8%	€ 2,608,566	€ 2,837,704	€ 3,852,083	(€ 56.99)
Kiln Conversion						
Long Dry to 3/4 Stage Dry	26.2%	7.3%	€ 789,473	€ 1,173,050	€ 1,496,355	€ 54.47
Dry to Preheater/Precalciner	12.5%	7.3%	€ 12,195,048	€ 635,827	€ 714,925	€ 63.38

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