# Energy Efficiency and $CO_2$ Emissions from the Global Cement Industry

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## Introduction

Cement accounts for two-thirds of total energy use in the production of non-metallic minerals. In terms of $CO_2$ emissions, cement production is by far the most important activity in this category. Global cement production grew from 594 Mt in 1970 to 2 284 Mt in 2005, with the vast majority of the growth occurring in developing countries, especially China. In 2005, China produced 1 064 Mt (47% of world cement production), while India, Thailand, Brazil, Turkey Indonesia, Iran, Egypt, Vietnam and Saudi Arabia accounted for another 394 Mt (17%) (Table 1).

**Table 1: Cement production, 2005 (USGS, 2006)**

| | Production [Mt/yr] | Share [%] | Cumulative [%] |
|---|---|---|---|
| China | 1064 | 46.6 | 46.6 |
| India | 130 | 5.7 | 52.3 |
| United States | 99 | 4.3 | 56.6 |
| Japan | 66 | 2.9 | 59.5 |
| Korea | 50 | 2.2 | 61.7 |
| Spain | 48 | 2.1 | 63.8 |
| Russia | 45 | 2.0 | 65.8 |
| Thailand | 40 | 1.8 | 67.5 |
| Brazil | 39 | 1.7 | 69.2 |
| Italy | 38 | 1.7 | 70.9 |
| Turkey | 38 | 1.7 | 72.6 |
| Indonesia | 37 | 1.6 | 74.2 |
| Mexico | 36 | 1.6 | 75.7 |
| Germany | 32 | 1.4 | 77.1 |
| Iran | 32 | 1.4 | 78.6 |
| Egypt | 27 | 1.2 | 79.7 |
| Vietnam | 27 | 1.2 | 80.9 |
| Saudi Arabia | 24 | 1.1 | 82.0 |
| France | 20 | 0.9 | 82.8 |
| Other | 392 | 17.2 | 100.0 |
| World | 2284 | 100.0 | |

The production of cement clinker from limestone and chalk is the main energy consuming process in this industry. The most widely used cement type is Portland cement, which contains 95% cement clinker. Clinker is produced by heating limestone to temperatures above 950° Celsius. Cement production is an energy-intensive process in which energy represents 20 to 40% of total production costs. Most of the energy used is in the form of fuel for the production of cement clinker and electricity for grinding the raw materials and finished cement. Since cement production consumes on average between 4 to 5 GJ per tonne of cement, this industry uses 8 to 10 EJ of energy annually.

In early 2007 the IEA will publish an in-depth analysis of the energy demand, $CO_2$ emissions and $CO_2$ emission reduction opportunities in industry. For each industrial sub-sector the goal is to conduct an in-depth analysis of individual countries that account for at least 80% of total production in that sub-sector. This paper sets out some of the initial data collected for the analysis that will be conducted in the cement industry for this publication. Next steps are to discuss this data and potential analysis with stakeholders to further refine the data and fill in missing information. This analysis will also be an essential input into the IEAs ongoing energy indicators programme of work, which hopes to engage developing countries as well as IEA member countries.

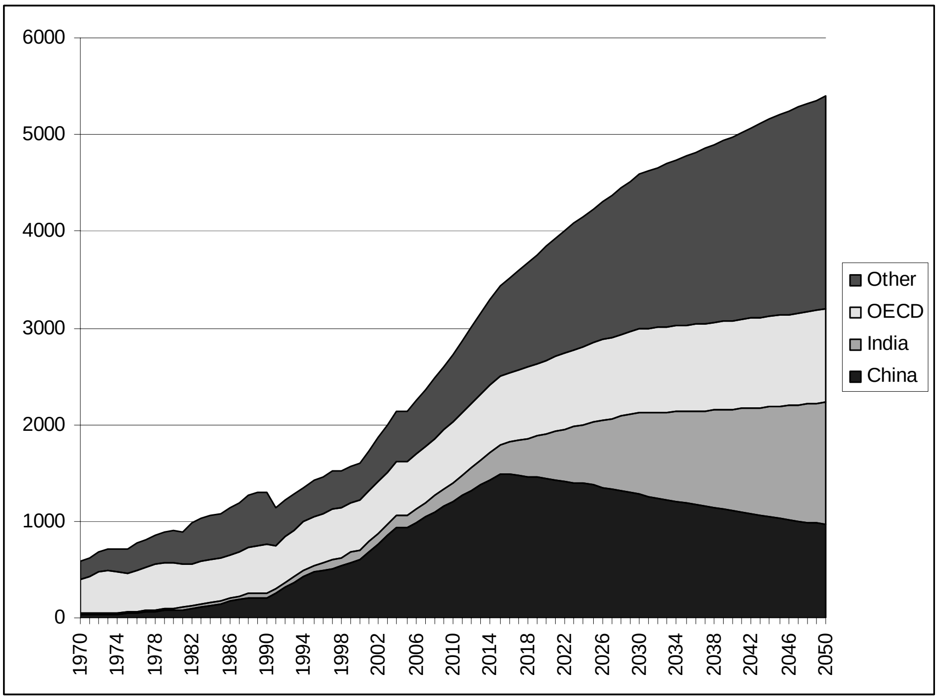
## Cement Production and Demand Drivers

Global GDP is assumed to grow by 2.9% per year between 2003 and 2050 in the ETP scenarios. That is to say the global economy will be around 3.6 times larger in 2050 than it is today. In the past, the global economy has experienced a relatively stable cement intensity per unit of GDP. The cement intensity of the global economy remained within a relatively narrow band around 40 kg of cement per US$ 1000 of GDP (1995 dollars at PPP) since the 1970s.

However, this relatively stable trend at a global level hides some quite dramatic differences between countries and regions. There has been little change in the absolute demand in Europe and North America since 1970, with virtually all of the growth in cement demand coming from developing countries. More specifically, China's demand for cement has exploded,and between 1998 and 2004 it accounted for around two-thirds of the global growth in cement demand (USGS).

Chateau *et al.* (2005) show that the intensity of cement use, after initially rising, declines with increasing GDP per capita, although this is not the case for all materials. The intensity of cement demand per unit of GDP has declined in developed countries, at the same time as it has increased in many developing countries. However, as their economies mature, the demand for cement per unit of GDP is likely to decline in a similar manner to that experienced by developed countries. However, given the different economic structure, natural resources available, levels of industrialization, infrastructure development etc of developing countries no hard and fast rule can be applied to identify when the intensity might peak. Our cement demand projections have been developed at a detailed country, or regional, level. They assume a peak in the intensity of cement demand per unit of GDP between 2015 and 2045 for developing countries, the resulting cement demand is shown in Figure 1. China and India account for around half of global cement production.

**Figure 1: Global Cement Demand by Region and Country (1970-2050)**




Source: USGS and IEA.

## The Clinker-to-Cement Ratio

Clinker production is the most energy intensive component of cement production, ordinary Portland cement contains around 95% clinker (Table 2).

Certain cement types contain other feedstocks, such as pozzolana (volcanic ash), fly ash or granulated blast-furnace slag. Producing these alternative cement types is far less energy intensive, due to the lower clinker requirements per tonne of cement. This therefore reduces emissions from energy consumption in the kiln and avoids the process emissions that stem from clinker production. However, the availability of waste slag is limited, and pozzolana can be obtained only in certain locations. Long-distance transportation of cement or cement feedstocks would result in significant additional energy use, which is not an attractive option given the low value of the product. Nonetheless, there is an appreciable potential for clinker substitutes, even in OECD countries.

**Table 2: Composition of Different Cement Types**

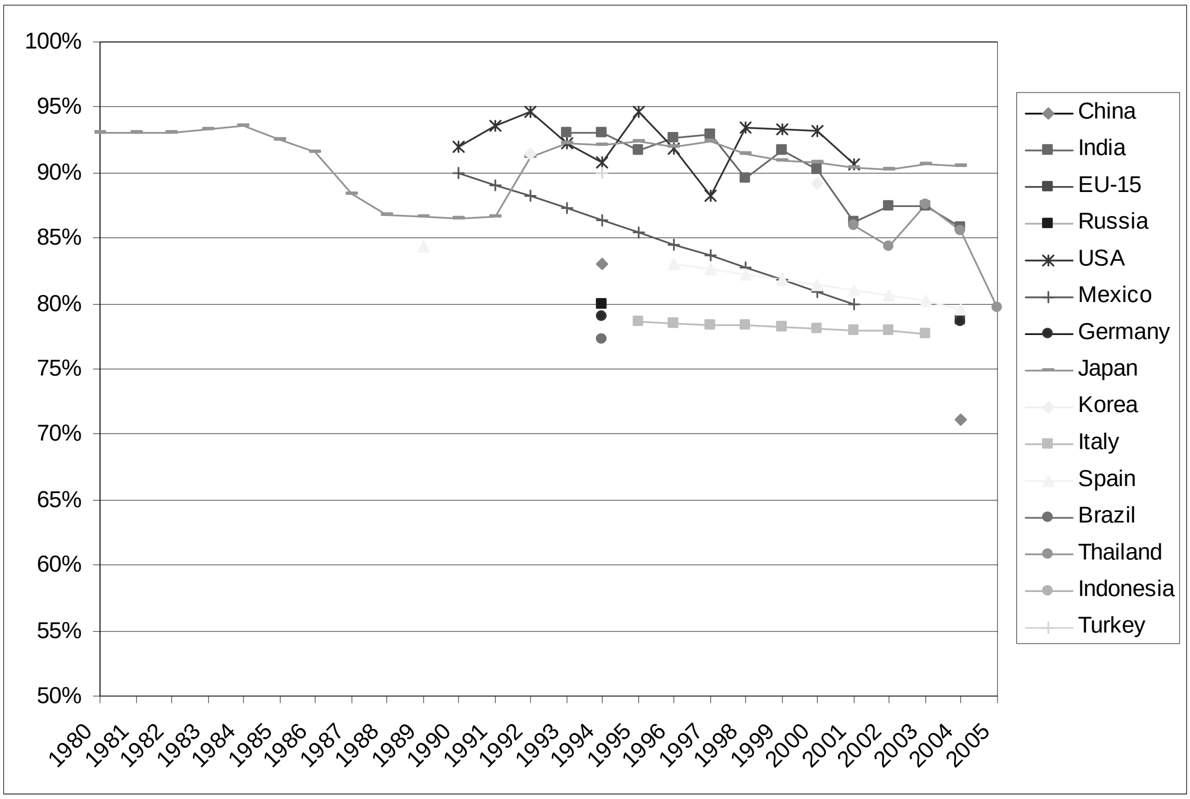
| Cement type | Portland cement (%) | Portland fly-ash cement (%) | Blast-furnace cement (%) | Activated slag cement (%) |
|---|---|---|---|---|
| Clinker | 95 | 75 | 30 | - |
| Fly ash | - | 25 | - | 45 |
| Blast-furnace slag | - | - | 65 | - |
| Synthetic slag | - | - | - | 45 |
| Quicklime | - | - | - | - |
| Water glass | - | - | - | 10 |
| Sodium sulphate | - | - | - | - |
| Gypsum | 5 | - | 5 | - |

Source: IEA, 2006.

The use of blended cement varies widely from country to country. It is high in continental Europe, but low in the United States and the United Kingdom. In the long term, new cement types may be developed that do not use limestone as a primary resource. The technological feasibility, economics and energy effects of such alternative cements remain speculative and they will not be considered in this analysis.

Figure 2 presents estimates of the clinker-to-cement ratio in a number of different countries and regions. Significant uncertainty surrounds some of these estimates, and in many cases only a snapshot of the industry is available from the 1990s. More accurate data for the current clinker-to-cement ratio is needed if accurate projections of the clinker production to meet cement demand are to be made.

**Figure 2: Clinker-to-Cement Ratio by Country and Region (1980-2004)**




Sources: Brazil - SNIC Soares, Centre for Clean Air Policy. China, Indonesia, Turkey and Russia - Worrell, *et al.* 2001. Thailand – Siam Cement Company Ltd. Germany and EU15 – CEMBUREAU and EC. Italy – AITEC. India – Coal Statistics. Mexico – IEA estimate. US – US Bureau of Mines and USGS. Canada – NRCAN and USGS. Japan – Japanese Cement Association. Korea – Inha University.

An additional complicating factor is that in some countries, notably the US, significant blending of clinker substitutes occurs when the concrete is mixed, rather than at the time of cement production. This obviously has important implications for any analysis of the role that clinker substitutes can play in reducing clinker production and hence $CO_2$ emissions.

Clinker substitutes are not only used in cement production. Significant amounts of pozzolanic materials are directly used for road bases etc., where they substitute cement and concrete. Also in a few countries, notably the US and China, clinker substitutes are directly used in conceret production. This is important because such practice reduces energy use and $CO_2$ emissions in cement production, but it does not show up when the energy use and $CO_2$ emissions per tonnen of cement are compared.

In the US, 9 Mt of fly ash were directly used for concrete making in 1999. This represents about 17% of all fly-ash. It should be compared to 86 Mt cement production, so this is equivalent to a lowering of the clinker/cement ratio by 10 percentage points (NAHM, 2006). Also 2 million tonnes of blast furnace slag were used in concrete. This is equivalent to the lowering of the cement/clinker ratio by 2 percentage points. In total this is equivalent to a reduction of the clinker/cement ratio by 12 percentage points. This results in important energy savings and $CO_2$ reductions. This type of measures must be considered when country energy efficiency and $CO_2$ emission indicators are compared.

## Technology and Energy Consumption in Cement Production

The technology used in the cement industry in developing countries (notably in China) differs from the one used in industrialised countries. While small-scale vertical kilns predominate in China, large-scale rotary kilns are most common in industrialised countries. Large-scale kilns are considerably more energy efficient. The most widely used production process for Portland cement clinker is the relatively energy efficient dry process, which is gradually replacing the wet process. In the last few decades, pre-calcination technology has also been introduced as an energy-saving measure. Pre-heating also helps to reduce the energy needed in the kiln.

Process types and fuel shares differ considerably by region (Table 3), which explains to a large extent the regional differences in $CO_2$ emissions per tonne of cement.

**Table 3: Cement Technologies and Fuel Mix by Region**

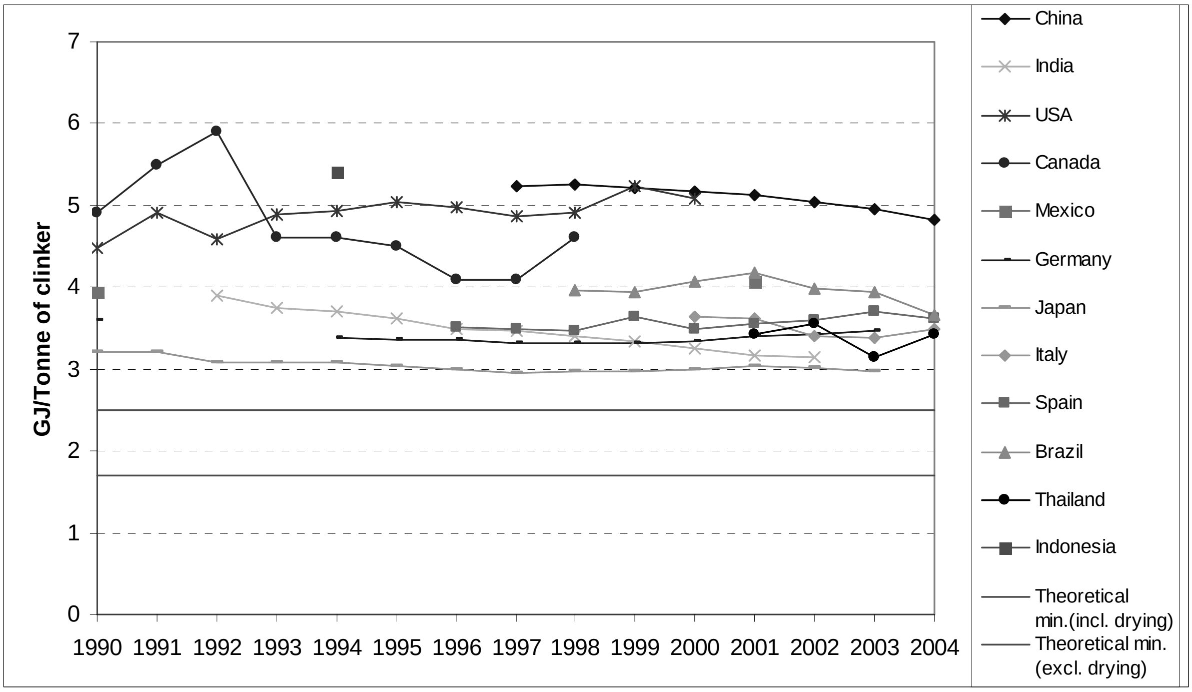
| | Process type | | | | Fuel share | | | |
|---|---|---|---|---|---|---|---|---|
| | Dry (%) | Semi-dry (%) | Wet (%) | Vertical (%) | Coal (%) | Oil (%) | Gas (%) | Other (%) |
| United States | 65 | 2 | 33 | 0 | 58 | 2 | 13 | 26 |
| Canada | 71 | 6 | 23 | 0 | 52 | 6 | 22 | 15 |
| Western Europe | 58 | 23 | 13 | 6 | 48 | 4 | 2 | 42 |
| Japan | 100 | 0 | 0 | 0 | 94 | 1 | 0 | 3 |
| Australia and New Zealand | 24 | 3 | 72 | 0 | 58 | <1 | 38 | 4 |
| China | 43 | 0 | 2 | 55 | 94 | 6 | <1 | 0 |
| Southeast Asia | 80 | 9 | 10 | 1 | 82 | 9 | 8 | 1 |
| Thailand[1] | | | | | 80 | 4 | 0 | 16 |
| Brazil | 98 | n.a. | n.a. | n.a. | 1 | 66 | 1 | 32 |
| South Korea | 93 | 0 | 7 | 0 | 87 | 11 | 0 | 2 |
| India | 50 | 9 | 25 | 16 | 96 | 1 | 1 | 2 |
| Former Soviet Union | 12 | 3 | 78 | 7 | 7 | 1 | 68 | <1 |
| Eastern Europe | 54 | 7 | 39 | 0 | 52 | 34 | 14 | <1 |
| Latin America | 67 | 9 | 23 | 1 | 20 | 36 | 24 | 12 |
| Africa | 66 | 9 | 24 | 0 | 29 | 36 | 29 | 5 |
| Middle East | 82 | 3 | 16 | 0 | 0 | 52 | 30 | 4 |

*Source*: WBCSD, 2002, IEA estimates. [1] Siam Cement Industry Company Ltd. only.

Figure 3 presents the data for the average energy consumption per tonne of clinker in some of the largest cement producing countries. The theoretical minimum energy use is 1.76 GJ per tonne of cement clinker. Efficient pre-heater and pre-calciner kilns use approximately 3.06 GJ of energy per tonne of clinker, while a wet kiln uses 5.3 to 7.1 GJ per tonne of clinker (WBCSD, 2002). In the European Union, the average energy consumption per tonne of Portland cement is currently 3.7 GJ per tonne. China, Canada and the US all require around 5 GJ/tonne of clinker. Together these three countries accounted for around half of total cement production. For most of the other countries presented the range is between around 3.15 GJ/tonne of clinker and 3.65 GJ/tonne of clinker.

The rapid economic development and demand growth for cement in many developing countries has provided an opportunity, in some cases, for developing countries to achieve relatively high levels of energy efficiency by building efficient dry-process plants to meet demand. Until recently, this wasn’t the case in China, where small-scale kilns and shaft kilns dominated production. For instance, in 1995 the output from NSP kilns in China was only 6% of the total and large and medium-scale kilns accounted for only 33% of total output (Cui, 2006). However, the situation is changing rapidly and by 2004 large and medium-scale plants accounted for 63% of production and that from NSP kilns for around 45% of total output. Plans are that cement from large-scale NSP kilns should reach 80% of total cement production by 2010 and 95% by 2030, reducing the contribution from shaft kilns to just 5%.

**Figure 3: Energy Requirement per tonne of Clinker by Country including Alternative Fuels**

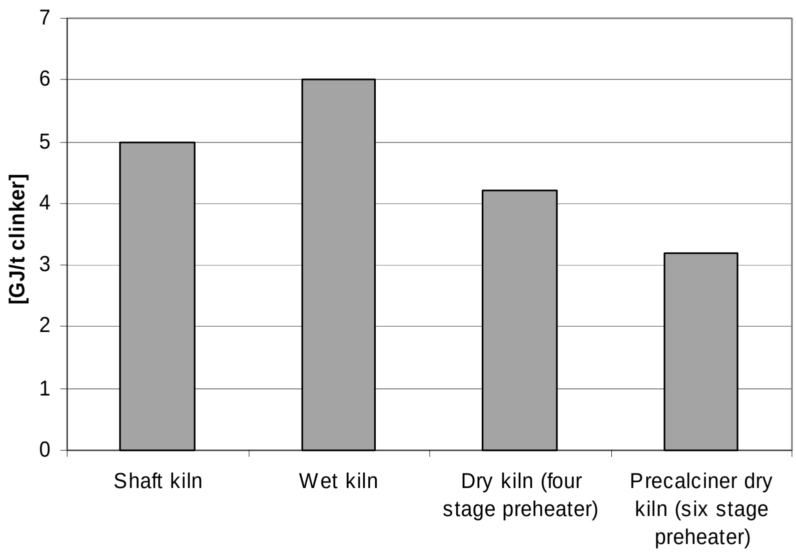



Sources: Brazil – SNIC Soares, Centre For Clean Air Policy and IEA estimate. Canada – NRCAN and Cement Association of Canada. China – LBNL and IEA estimate. Germany – VDZ and CEMBUREAU. India - NCB. Italy - AITEC. Japan – JCA and IEA estimate. Mexico – Jacott, et al. 2003. Thailand - Siam Cement Company Ltd. US - Jacott, et al. 2003.

Note: The theoretical minimum energy requirement including drying is an upper limit, based on a very wet feedstock. Most feedstock tends to be less wet than this, meaning that the actual theoretical minimum can be below this.

Today's state-of-the-art dry-rotary clinker kilns are fairly fuel efficient, consuming about 3.0 GJ/tonne of clinker (Figure 4). The thermodynamic minimum to drive the endothermic reactions is approximately 1.8 GJ/tonne. The superior performance of rotary kilns makes them the likely technology for the next decades.

**Figure 4: Energy Efficiency of Various Cement-Clinker Production Technologies**

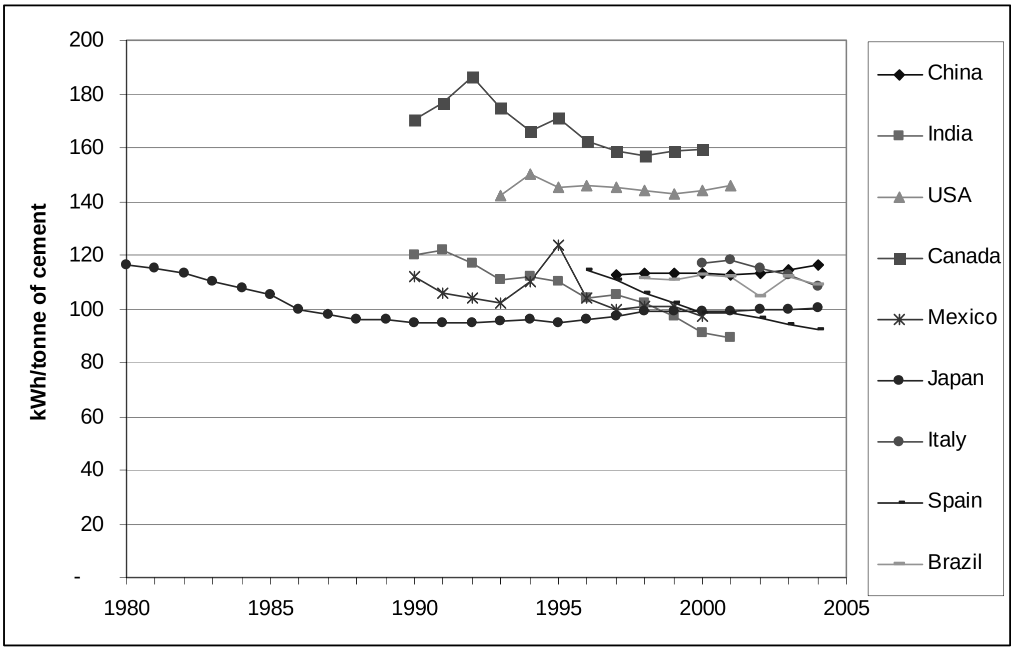



Source: WBCSD, 2002.

## Electricity Consumption in the Cement Industry

Grinding is the largest electricity consumer in the cement industry. Currently around 100 kWh per tonne of clinker is consumed in rotary kilns for grinding raw materials, at the kiln, and for grinding the cement.[1] The current state-of-the-art technologies, using roller presses and high-efficiency classifiers, are much more efficient than previous ones. Current best practice is around 75 to 80 kWh per tonne of clinker (Sathaye, J. *et al*, 2005). Still, the energy efficiency of grinding is typically only 5 to 10%, with the remainder converted to heat. There can be an enormous variation in the consumption of electricity per plant, for example cement plants in Brazil were found to consume between 90 kWh/tonne of clinker and 200 kWh/tonne of clinker (Soares and Tolmasquim, 2000). Figure 5 presents electricity consumption for cement production by country.

**Figure 5: Electricity Consumption per tonne of Cement by Country (1980-2005)**




## Alternative Fuel Use in the Cement Industry

Another way to reduce emissions and fossil fuel use is to burn waste or biomass as fuel. Cement kilns are well-suited for waste combustion because of their high process temperature and because the clinker product and limestone feedstock act as gas-cleaning agents. Used tires, wood, plastics, chemicals and other types of waste are co-combusted in cement kilns in large quantities. Providers in Belgium, France, Germany, the Netherlands and Switzerland have reached average substitution rates from 35% to more than 70% of the total energy used. Some individual plants have even achieved 100% substitution using appropriate waste materials. However, very high substitution rates can only be accomplished if a tailored pre-treatment and surveillance system is in place. Municipal solid waste, for example, needs to be pre-treated to obtain homogeneous calorific values and feed characteristics.

The cement industry in the United States burns 53 million used tyres per year, which is 41% of all tyres that are burnt and equivalent to 0.387 Mt or about 15 PJ. About 50 million tires, or 20% of the total, are still land filled. Another potential source of energy is carpets, the equivalent of about 100 PJ per year are dumped in landfills and could instead be burnt in cement kilns.

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[1] A small amount is also used for miscellaneous utilities on site and in packing.

In Japan, around 200 kilo tonnes (kt) of used tyres were burnt in 2005, 450 kt of waste oil, 340 kt of wood chips and 300 kt of waste plastic (JCA, 2006). This is equivalent to around 42 PJ of energy from alternative sources assuming 426 GJ/tonne for waste oil, 166 GJ/tonne of wood chips and 356 GJ/tonne of waste plastic.[2]

Although these alternative materials are widely used, their use is still controversial, because cement kilns are not subject to the same tight emission controls as waste incineration installations. According to IEA statistics, the OECD cement industry used 66 PJ of combustible renewables and waste in 2003, around half of it industrial waste and half wood waste. Worldwide, the sector consumed 112 PJ of biomass and 34 PJ of waste. There is apparently little use of alternative fuels outside the OECD, although the comparison of country data from various sources with IEA statistics tends to imply that alternative fuel use is under-reported. From a technical perspective, the use of alternative fuels could be raised to 1 to 2 EJ, although there would be differences among regions due to the varying availability of such fuels.

## Cement Industry Scenarios: Building on the IEA Publication *Energy Technology Perspectives: Scenarios and Strategies to 2050*

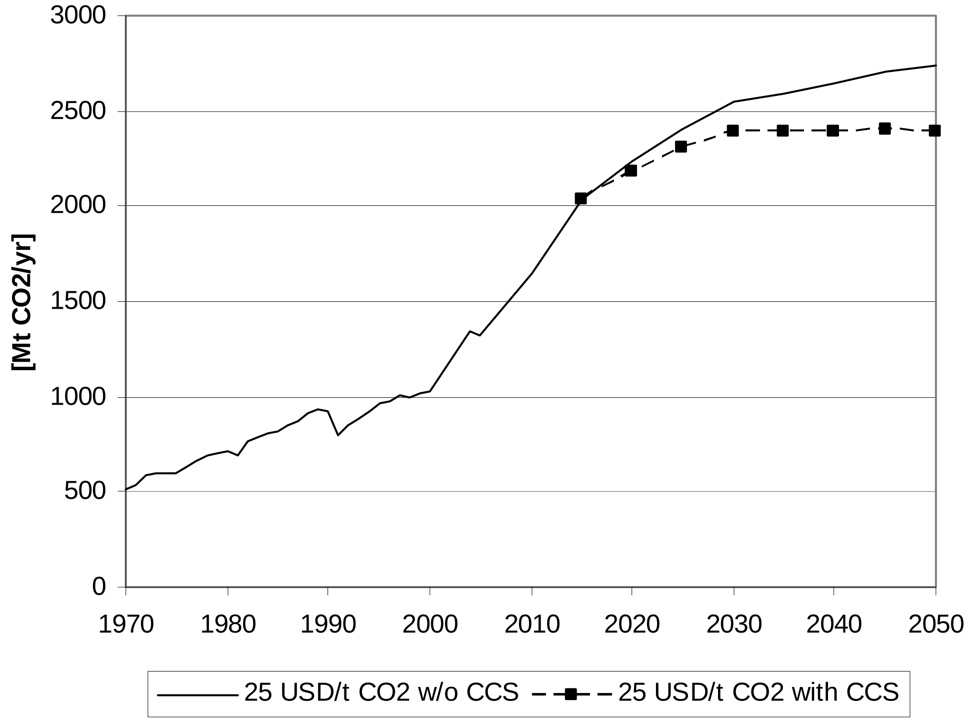
The scenarios in this analysis build on the IEAs ACT MAP scenario, which assumes an incentive of 25 USD/t $CO_2$ worldwide (IEA, 2006). The energy use and $CO_2$ emissions can be calculated if the cement production volume, the energy intensity of production, the energy mix, the clinker/cement ratio and the use of CCS are known. Two scenarios have been analysed, one without CCS and one with CCS. In the scenario with CCS, 350 Mt $CO_2$ is captured by 2050. This equals the emission of about 350 modern kilns, or 10% of all cement kilns in 2050. While more $CO_2$ could be captured, this would require a higher incentive level, unless new low-cost capture technologies are developed.

The general assumptions are that the world average clinker production fuel intensity declines to 3 GJ/t clinker, the electricity use declines to 100 kWh/t cement, the shares of coal, gas and alternative fuels are 70%, 5% and 25% by 2050, and the clinker/cement ratio declines to 0.7. This clinker/cement ratio implies the use of about 1 500 Mt clinker substitutes in 2050. At that time between 200 and 250 Mt blast furnace slag will be available and about 100 Mt steel slag, based on (Gielen and Podkanski, 2006). Also about 80 EJ of coal is used for power generation in the IEA ACT MAP scenario (IEA, 2006), resulting in about 300-400 Mt fly-ash. Especially in China and India, this could become a key clinker substitute. However its use potential is limited as Portland fly-ash cement contains only 25% fly ash. Certain other slag materials such as waste incineration bottom slag could also be used, but the quantities are limited. Natural pozzolans are not widely available but their transportation over longer distances may become an option once a $CO_2$ incentive is introduced. In conclusion, the 1 500 Mt clinker substitutes in these scenarios should be considered an upper limit.

The $CO_2$ emissions almost double from today's level to 2.4-2.7 Gt $CO_2$/yr (Figure 6). This compares to total world $CO_2$ emissions in the IEA ACT MAP scenario of about 28 Gt by 2050[3]. So 9-10% of the world $CO_2$ emissions in the ACT MAP scenario can be attributed to cement production. This puts the cement industry in the category of key sources. Almost 2 Gt of $CO_2$ (70% of the total cement industry $CO_2$ emission in ACT MAP) is process emission which can not be reduced through energy efficiency measures. Therefore effective $CO_2$ reduction policies must not only focus on energy efficiency and fuel substitution, but also include process emissions.

[2] These energy values for alternative fuels may be too high, as other data from JCA implies that 10% of energy needs come from alternative fuels (incl. tires), or only around 20 PJ.
[3] 26 Gt energy related emissions, 2 Gt process emissions

**Figure 6: Direct $CO_2$ Emissions from Cement Production (1970-2050)**




## Conclusions

More than half of all cement production comes from countries with an energy intensity of clinker production significantly higher than today's most efficient dry cement kilns with pre-heaters and pre-calciners. There is significant variation in the amount of electricity used to produce cement, ranging from around 100 kWh in Japan, Spain, India, Thailand and Italy to 160 kWh in Canada.

The scope for utilising clinker substitutes is large in some countries, but many large producers already have quite low clinker-to-cement ratios. There could be an emerging constraint in terms of feedstock availability for some of these clinker substitutes in some countries over. Significant uncertainty surrounds some of the data and further investigation is merited.

$CO_2$ emissions in the cement industry will continue to rise, even if new ambitious $CO_2$ policies are put in place. In the IEA ACT MAP scenario where global $CO_2$ emissions in 2050 are at today's level, between 9 and 10% of the world $CO_2$ emissions can be attributed to cement production. This makes cement production a key emissions source.

Almost 2 Gt of $CO_2$ (70% of the total cement industry $CO_2$ emissions in ACT MAP) are process emissions which can not be reduced through energy efficiency measures. Therefore effective $CO_2$ reduction policies must not only focus on energy efficiency and fuel substitution, but also address process emissions.

Options exist to reduce $CO_2$ emissions further, such as a wider application of CCS and the production of new clinker substitutes or pozzolan transportation. However, the feasibility and economics need to be analysed in more detail.

## References


Anand, S., Vrat, P. and Dahiya, R.P. (2006), *Application of a system dynamics approach for assessment and mitigation of $CO_2$ emissions from the cement industry*, Journal of Environment Management 79, pp. 383-398.

Cement Association of Canada (CAC) (2006), *2006 Sustainability Report*, CAC, Ottawa, ON.

Chateau, B., et al. (2005), VLEEM 2 (Very Long Term Energy Model), Study prepared for the European Commission, EC/DG Research, ENERDATA.

Cui Yuan-Sheng and Wang Xiao (2006), *The state of the Chinese cement industry in 2005 and its future prospects*, Cement International 4/2006, pp. 36-43.

European Commission (EC) (2006), *Annual European Community Greenhouse Gas Inventory 1990–2004 and Inventory Report 2006*, EEA Technical report No 6/2006, EC DG Environment, European Environment Authority, Brussels.

Gielen, D.J., Podkanski, J. (2006), *Technological potentials for $CO_2$ emission reduction in the global iron and steel industry*, Proceedings Ishii symposium on sustainable ironmaking, 2-3 March, 2006, Sydney. Cooperative Research Centre for Coal in Sustainable Development CCSD, Brisbane, Australia.

IEA (2006), *Energy Technology Perspectives. Scenarios & Strategies to 2050*, IEA/OECD, Paris.

Jacott, M., *et al.* (2003), *Energy Use in the Cement Industry in North America: Emissions, Waste Generation and Pollution Control*, *1990-2001*, paper prepared for the 2nd North American Symposium on Assessing the Environmental Effects of Trade, May 30, 2003.

Japanese Cement Association (2006), *Cement Industry's Status and Activities for GHG Emissions Reduction in Japan,* presentation to the IEA-WBCSD Workshop "Energy Efficiency and $CO_2$ Emission Reduction Potentials and Policies in the Cement Industry", IEA, Paris, 4-5 September 2006.

NAHB (2006), Technical Information Resource, http://www.toolbase.org/index.aspx, NAHB Research Center, Upper Marlboro, MD.

Natural Resources Canada (NRCAN) (2001), *Energy Consumption Benchmark Guide: Cement Clinker Production,* Office of Energy Efficiency, NRCAN, Ottawa, ON.

Raina, S. J. (2002), Energy Efficiency Improvement in Indian Cement Industry, National Council for Cement & Building Materials, paper prepapred for IIPEC Programme.

Sathaye, J., *et al.* (2005), *Assessment of Energy Use and Energy Savings Potential in Selected Industrial Sectors in India*, Lawrence Berkeley National Laboratory, Berkeley, CA.

Siam Cement Company Ltd (2005), *Sustainable Development Report 2005*, Siam Cement Company Ltd, Bangkok.

Soares, J.B. and Tolmasquim, M. T. (2000), *Energy Efficiency and Reduction of $CO_2$ Emissions Through 2015: The Brazilian Cement Industry*, Mitigation and Adaptation Strategies for Global Change 5, pp. 297–318, The Netherlands.

United States Geological Survey (USGS), *Minerals Yearbook*, various years, USGS, Reston, VA.

WBCSD ( 2002), *Toward a Sustainable Cement Industry. Climate Change,* WBCSD, Geneva, http://ww.wbcsd.org.

Worrell, E., *et al.* (2001), *Carbon Dioxide Emissions from the Global Cement Industry*, Annual Review of Energy and Environment, Vol 26, 2001.