Cement and Concrete Industries Contribution to Climate Change Mitigation

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Paper prepared for presentation
at the
Economic Implications of Climate Change

of the 2009 Annual Conference of the
Transportation Association of Canada
Vancouver, British Columbia

Abstract

The Cement Industry is continuously trying to find ways to reduce its environmental foot print through development of a comprehensive strategy for reducing emissions and energy use. Another way the Cement Industry can assist with climate change mitigation is to encourage the use of concrete based products in Canada's Infrastructure.

This paper gives a brief overview on the Canadian Cement and Concrete Industry and how cement is made. In addition, a brief introduction is provided on Canada's Cement Sustainability Initiative (CSI) which identifies an action plan addressing performance related to six key issues. The main focus of the paper is to identifying the Cement Industry's climate change mitigation initiatives and several concrete based applications that help mitigate climate change. Cement based initiatives focus on use of alternate and renewable fuels, Portland limestone cement and use of supplementary cementing materials. Discussions on concrete based initiatives focus on concrete pavements, concrete as a potential CO_2 sink, high performance concrete for bridges, and energy efficiency of concrete buildings. Details are provided on research showing the advantages of concrete such as the updated Athena study looking at pavement structures' energy use and global warming potential, NRC's truck fuel usage studies and research on concrete as a CO_2 sink. Other topics such as optimized concrete mixes and ultra high strength concrete are also discussed. An example of the potential fuel savings and associated CO_2, NOx and SO_2 reductions when operating on concrete pavement is also provided.

1.0 Introduction

1.1 Canadian Cement and Concrete Industry Overview
The Cement Association of Canada (CAC) has eight member companies who operate one white and 15 grey Portland cement manufacturing facilities across Canada and produce over 98 % of the cement consumed in Canada. As shown in Figure 1, Portland cement is manufactured in 5 different provinces across Canada and there are several cement distribution centres located in all ten provinces. The cement industry is a key contributor to Canada's economic and social development from the Statistics Canada reports that the industry produced over 14.3 million tonnes of cement worth more than $1.7 billion in 2006. This translated into over 2,000 direct, stable and high-quality jobs. Total production rises to more than 16.7 million tonnes of cement when supplementary cementing materials (SCM) such as fly ash and slag cement are included. Traditionally over one third of the total annual cement production in Canada is exported to the United States but this amount has been lower over the past few years due to economic conditions and Asian competition. [CAC 2008] According to Environment Canada's, "Sources of Canadian GHG Emissions 2005, National Inventory Report 1990-2005" released in April 2007 the Cement Industry produces only 1.58 % of all the GHG in Canada. [Environment Canada 2007]

Figure 1 Cement Plants and Distribution Terminals in Canada

Source: Cement Association of Canada, "Canadian Cement Industry – 2008 Sustainability Report"

Concrete products, on the other hand, are produced in many villages, towns and cities across Canada and in 2006 employed more than 25,000 Canadians in the production of ready mixed concrete and concrete construction products. [CAC 2008] Numerous infrastructure products are created by these groups such as: box culverts, bridges, buildings, concrete pavements, interlocking concrete pavers, concrete pipe, precast walls, retaining and sounds walls, and traffic barriers. Factoring in both cement and concrete product sales in 2006 the Cement and

Concrete Industry was responsible for more then $8.0 billion in sales and contributed over $3.3 billion to Canada's Gross Domestic Product. [CAC 2008]

Concrete has been an important building material since Romans times when they used natural cementing materials mined from local volcanic areas to make concrete. Many examples of Roman buildings and public works are still with us today showing concrete truly is a sustainable long lasting material.

Modern cement kilns are like "mini-volcanoes" using very high temperatures, almost 1500 °C, to reduce raw materials (primarily crushed limestone) into a clinker that is finely ground to produce Portland cement. Figure 2 is a simplified schematic of the four-step process on how cement is made. Concrete made from Portland cement is stronger and even more durable than its earlier form used by Romans and has the potential to last much longer. Concrete is an ideal building material for durable, sustainable buildings, bridges, pipes and roads.

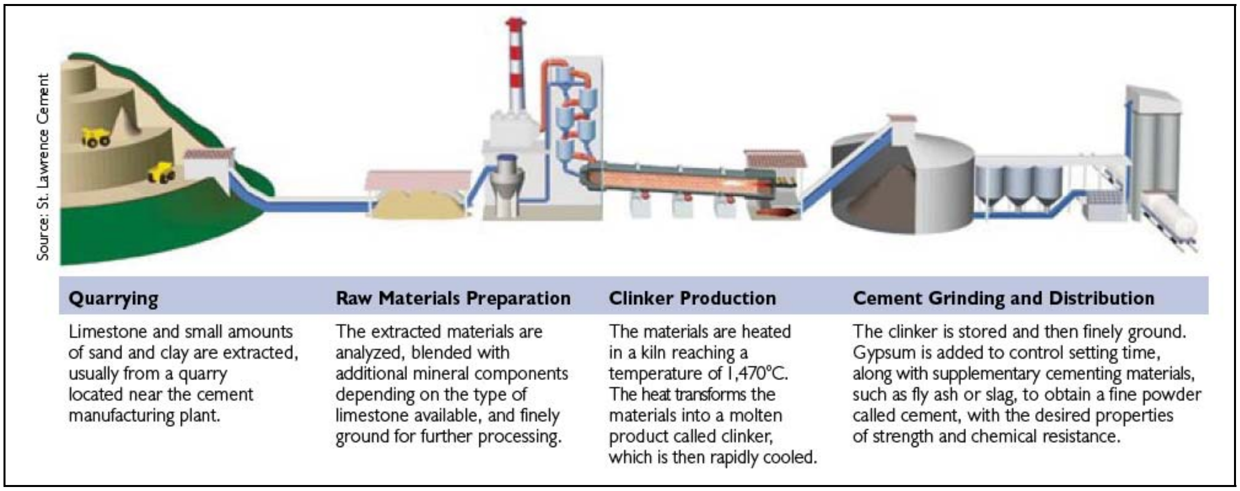


Figure 2 How Cement is Made

Source: Cement Association of Canada, "Canadian Cement Industry – 2008 Sustainability Report"

1.2 Cement Sustainability Initiative

The global cement manufacturers, through the Cement Sustainability Initiative (CSI), have committed to an Action Plan addressing the following issues:

1) **Climate protection and CO2 management** – using tools set out in the World Business Council for Sustainable Development (WBCSD) CSI reporting protocol to define and make public baseline emissions, report annually on CO2 emissions in line with protocol and develop a climate change mitigation strategy and publish targets by 2006.
2) **Responsible use of fuels and materials** – actions include applying the WBCSD CSI guidelines for fuel and raw material use.
3) **Employee health and safety** – responding to the recommendations of the WBCSD CSI Health and Safety Task Force on systems, measurements and public reporting.
4) **Emissions monitoring and reporting** – using tools set out in the WBCSD CSI reporting protocol for measurement, monitoring, and reporting of emissions; making emissions data publicly available and accessible to stakeholders by 2006; and setting emissions targets on relevant materials and report publicly on progress.

5) **Local impacts on land and communities** – applying the WBCSD CSI Environmental and Social Impact Assessment guidelines, and development tools to integrate them into decision-making processes; drawing up rehabilitation plans for operating quarries and plant sites, and communicating them to local stakeholders by 2006.
6) **Reporting and communications** – integrating sustainable development programs into existing management, monitoring, and reporting systems; publishing a statement of business ethics by 2006; establishing a systematic dialogue processing with stakeholders to understand and address their expectations; reporting progress on developing stakeholder engagement programs; and developing documented and auditable environment management systems at all plants. [CAC 2008]

The Cement Association of Canada's 2008 Sustainability Report provides summarizes the performance of the 15 Canadian grey Portland cement manufacturers for the six issues noted above. Several key CSI indicators for each issue are identified, as well as, the number of cement plants met the indicator requirements in 2005 and 2007. This shows the progress the Canadian Cement Industry has been making in its sustainability initiatives.

2.0 Cement Based Climate Change Mitigation Initiatives

Climate change and clean air are important concerns for the Canadian Cement Industry. The industry is continuously looking for ways to reduce its environmental footprint. Between 2003 and 2006 the grey Portland cement industry reduced its total SO_2 and NO_X emissions by 14 % and 23 % respectively even though Portland cement production increased by 10 % during this period. Between 1990 and 2006, Canada's cement manufacturers improved the energy efficiency of their production operations by 11 % per tonne of Portland cement, and reduced the greenhouse gas emissions (GHG) intensity of their production by 6.4 % per tonne of Portland cement. Improvements are largely due to modernization of two cement plants in the 1990's, closure of the Industry's least efficient plants and the increased use of supplementary cementing materials (SCM). [CAC 2008]

The Cement Industry has been researching and implementing ways to reduce its CO_2 footprint. Approximately 60 % of the CO_2 produced by the cement industry results from the heating of the raw material in the kiln to transform it into clinker. The clinker is then rapidly cooled and finely ground with Gypsum and possibly SCMs to create the product known as Portland cement. Currently no alternative processes are commercially available to reduce the amount of CO_2 produced during the transformation process. Therefore, Industry's focus has centered on the reduction in thermal energy required to heat up the raw materials to produce clinker.

The fuels used to obtain the temperature necessary to breakdown the limestone in the kilns are currently high-emissions intensity fuels such as coal and petroleum coke because they are relatively inexpensive. Although there is not a great deal more that can be done to economically increase the energy efficiency of the kilns, there is a possibility of decreasing the amount of fossil fuels used in kilns and reducing the amount of raw material that needs to be heated and transformed to make each tonne of cement. The following four methods are being pursued to reduce the Cement Industry's energy and CO_2 footprints:

1) Improving the energy efficiency of manufacturing operations;
2) Substituting alternative (waste derived) and renewable (biomass) energy sources for fossil fuels utilized in the manufacturing process;
3) Substituting SCM for clinker in the production of blended cements and other cement products;

4) Undertaking long-term research and development on less CO_2 – intensive cementing materials and manufacturing operations.

2.1 Alternative and Renewable Energy Sources

Alternate and renewable energy sources are replacements for traditional fossil fuels. They have been used as fuel in kilns in European countries for many years. Alternate fuel sources include items such as scrap tires, used oil, recovered solvents, recovered asphalt shingles, oily water, oil shales, plastics and certain hazardous wastes. Renewable fuels include sources such as fibre residue from forest products manufacturing, meat and bone meal, municipal solid waste, agricultural waste, post-consumer paper and packing, recovered wooden utility poles, and residue wood biomass from forestry operations.

Figure 3, shows the percentage of alternate fuel used per kJ used in various countries. The graph shows that alternate fuels account for only 6.9 of the fuel used in Canadian cement kilns. Netherlands and Switzerland, on the other hand, use 83 and 47.8 percent alternate and renewable fuels. Using these alternate energy sources contributes to emission reductions including CO_2 emissions. The more these fuels are utilized, as in Europe, the greater the reductions will be. The global cement industry has been very active in developing substitute fuels – almost any material of organic composition can be used – and because of the high combustion temperature in the kiln, consumed safely. In fact, environmental and public health authorities from the US Environmental Protection Agency to the UK Health Protection Agency have supported use of alternative energies. They have concluded that, when the materials are processed properly, the use of some alternative energy sources in cement kilns can contribute to improved environmental performance without increasing risks to human health and the environment. [CAC2008]

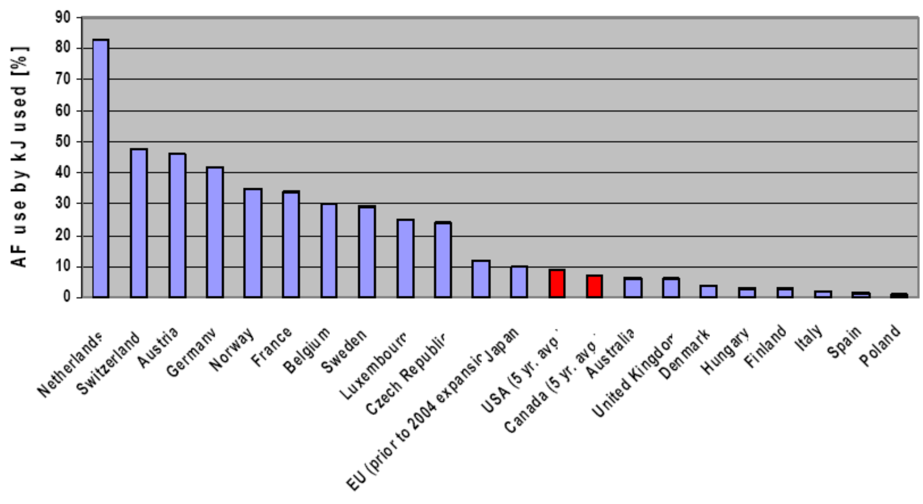


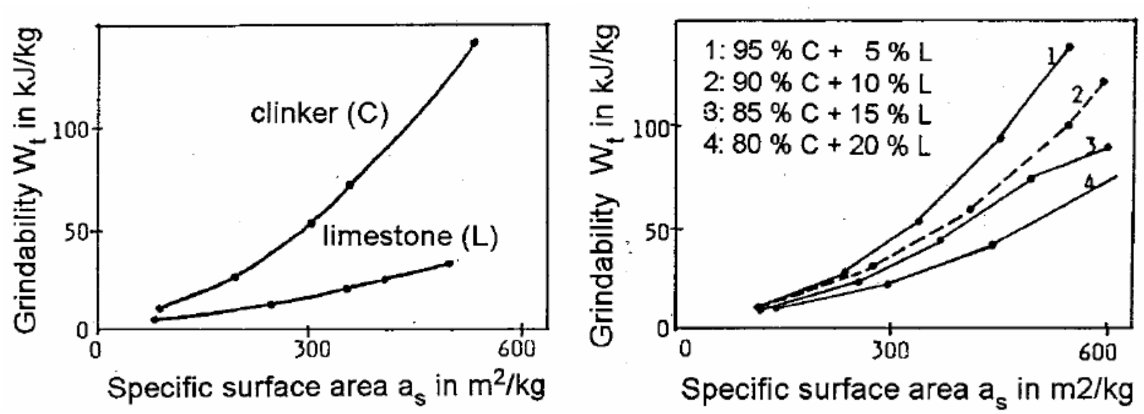
Figure 3 Alternate and Renewable Energy Use in Global Cement Manufacturing

Source: Cement Association of Canada, “Canadian Cement Industry – 2008 Sustainability Report”

Using alternate and renewable fuels also provides sustainable benefits such as minimizing natural resources utilized and diverting industrial by-products and residue away from landfill sites. The Canadian cement industry is pursuing this alternate and renewable fuel strategy, with biomass as a possible long term solution. However, there are two main challenges to their use: economic and supply barriers and government policy barriers.

2.2 Portland Limestone Cement (PLC)

Portland-limestone Cement (PLC) is a type of cement which reduces the clinker to cement ratio by intergrinding the cement with up to 15 % limestone. Increasing the allowable limestone content from the existing 5 % reduces the CO_2 created in the production of PLC by a corresponding 10 %. In addition to this large reduction in CO_2, PLC also expends less energy in the grinding process as limestone is a softer material than clinker. Figure 4a clearly illustrates the difference in energy required to grind both clinker and limestone. As illustrated in Figure 4b as the limestone content increases so to does the energy savings in grinding the combined product.



(a) Limestone vs Clinker b) PLC

Figure 4 Grindability of Limestone and Portland-limestone Cement

Source: Richard McGrath, "The Canadian Cement Industry and Innovation Towards Sustainable Development

Research on PLC has also revealed some unexpected bonuses. The limestone was first thought to be inert filler but recent research has concluded that, when ground +fine enough, the limestone does have some cementitious properties that contribute to the properties of the concrete. The finer the limestone particles are ground the more likely it is to have reactive properties. [McGrath 2008]

European countries have been using PLC for a over 40 years. It first appeared in Germany in 1965 where PLCs were used for specialty applications. French Standards first included provisions for the new PLC product in 1979. Limestone additions of up to 5 % were first introduced into Canada's Canadian Standards Association (CSA) A5 Standard in 1983. It was not until 2004 that ASTM C150 cements would allow similar limestone additions. By 1990, PLCs at 20 % limestone additions were widely used in Germany and Britain adopted similar provisions for PLC two years later. The most commonly used portland-limestone cement in Europe is CEM II/A L Cements with 6-20% limestone. Figure 5 illustrates how the usage of PLCs has increased in Europe since 1999. To date, there have been no adverse durability effects identified with this type of cement, with the one provision it should not be used in sulphate environments. [McGrath 2008]

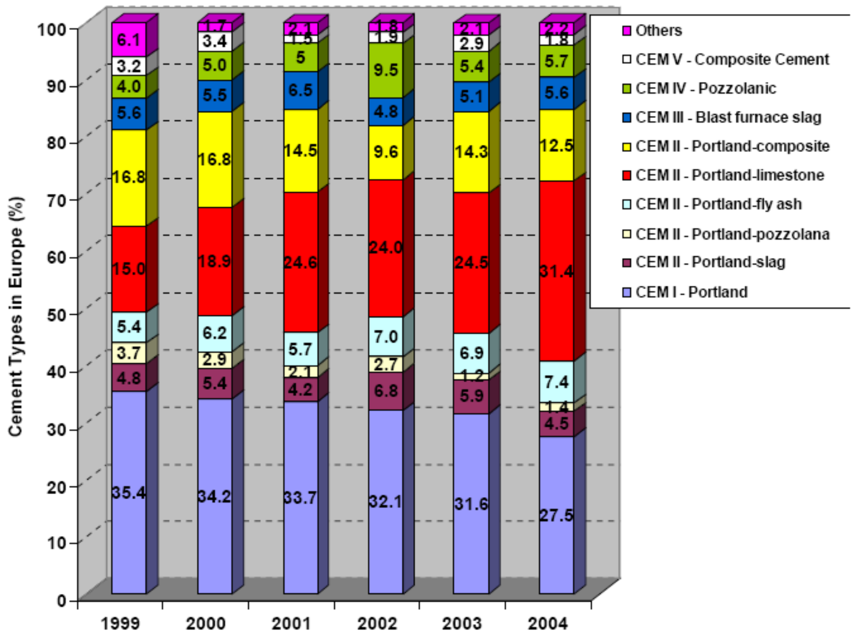


Figure 5 European Portland-limestone Cements

Source: Richard McGrath, "The Canadian Cement Industry and Innovation Towards Sustainable Development"

The CSA A3000-08 Compendium of Cement Standards now includes a new Portland-limestone cement (PLC) classification. The upcoming CSA A23.1-09 Concrete Materials and Methods of Concrete Construction Standard to be released in September of 2009 will also reference the new class Portland-limestone cements. The end result is cement with a much lower energy and CO_2 footprint. PLCs will reduce the CO_2 emissions per tonne of cement produced.

2.3 Increase Use of Supplementary Cementing Materials (SCM)

Concrete is a mixture of fine and coarse aggregate, cement, water and admixtures. However, it is possible to replace a portion of cement with a variety of industry by-products often referred to as supplementary cementing materials or SCMs. These materials, if used in the proper proportions, will enhance the properties of the concrete mix, as well as, stabilize any by-product material in the concrete structure rather than dumping them at local landfill sites. The three most commonly used SCMs are fly ash (by-product of coal burning), blast furnace slag (by-product of steel manufacturing) and silica fume (by-product of manufacture of silicon or ferrosilicon alloy). Ternary blends (i.e. cement combined with two of the three most common SCMs) are also being used in Canada. In fact, a few of the Portland cement concrete pavement (PCCP) installations in Québec have used ternary cements. Using SCMs can enhance the concrete properties including improved durability, permeability and strength. Fly ash, blast furnace slag and silica fume can also help control alkali - silica reactivity also known as ASR (a chemical reaction that occurs when free alkalis in the concrete combine with certain siliceous aggregates to form an alkali-silica gel. As the gel forms, it absorbs water and expands, which cracks the surrounding concrete) [Kosmatka 2002]. Fly ash and blast furnace slag also improve workability of the concrete mixtures.

Another important benefit of utilizing SCMs in concrete pavement is the reduction of CO_2 emissions and energy use associated with the concrete structure. The SCMs replace a portion of the cement in the concrete mixture and thereby decreases the total amount of CO_2 and its embodied energy total. The amount of CO_2 and energy reduction is directly related to the percentage of the SCM used in the mix design. Details on what is done on the use of SCMs in pavements across Canada and in the Northern States can be found in a report completed in March 2005 by Norman MacLeod entitled, “A Synthesis of Data on the Use of Supplementary Cementing Materials (SCMs) In Concrete Pavement Applications Exposed too Freeze / Thaw and De-icing Chemicals”. The use of SCMs in concrete mix designs is recognised by the Leadership in Energy and Environmental Design (LEED) Green Building Rating system as an effective measure in mitigating CO_2 emissions.

3.0 Concrete Based Climate Change Mitigation Initiatives

While the cement industry is working hard to reduce the energy and materials used to produce Portland cement, it is important to note that its primary use is to make concrete. Concrete itself has low levels of energy use and CO_2 associated with it as its other components (water, fine and coarse aggregates) are abundant local materials with low energy and CO_2 footprints. Portland cement comprises only a small portion of a concrete mix normally ranging from 8 to 15 percent, depending on strength requirements and amount of SCMs used. The environmental costs of obtaining aggregate for the concrete mixes can be reduced even further by using recycled concrete.

3.1 Portland Cement Concrete Pavement

Portland cement concrete pavement (PCCP) has long enjoyed a reputation as a longer lasting, durable pavement surface with low maintenance costs. Cities such as Winnipeg, Windsor, Montreal and Toronto have been using PCCP and composite pavement for some time and have extensive networks of PCCP. In addition, many cities are also using PCCP at high traffic and high wear areas such as intersections and bus stops where turning movements and static loading are rutting and showing asphalt pavements. Although concrete pavement has many sustainable benefits which could be discussed this section of the paper focuses on concrete pavement and how it helps with Climate Change mitigation.

3.1.1 PCCP Reduces Energy Consumption

The Athena Institute was commissioned by the Cement and Concrete Industry to update work it completed for it in 1999 on the Life Cycle Embodied Primary Energy and Global Warming Emissions for PCCP and ACP Roadways. A key component of the new study was to update the life cycle inventory data for construction materials such as cement, concrete, steel and asphalt. The new study also analyzes four different concrete and asphalt roadway structures including: Canadian (average) arterial roadway; Canadian (average) high volume highway; Ontario freeway (401) section; Quebec urban freeway section. Therefore, the results of the two studies cannot be compared.

The first two designs are equivalent concrete and asphalt pavement designs by ERES consultants, now known as Applied Research Associates, Inc. These designs were prepare for subgrade strengths of California bearing ratio (CBR) 3 and 8. Table 1 gives the design material quantities by roadway type and subgrade support for the equivalent concrete and asphalt structures prepared by ERES consultants. [ERES 2003] Table 2 gives the actual thickness designs and quantities for the 401 Ontario freeway and Quebec urban freeway examples. Note, the Quebec concrete and asphalt pavement structures are not equivalent designs like the Canadian Highway and MTO examples because Quebec design's their pavement structures for frost depth. Therefore, the PCCP option has substantially more aggregate than is required in an equivalent concrete pavement design.

Table 1
Design Material Arterial Quantities by
Roadway Type and Sub-grade Support

Roadway Type	**Arterial Roadway/Highway**				**High Volume Highways**			
Sub-grade Support	Low-CBR 3		Medium-CBR 8		Low-CBR 3		Medium-CBR 8	
Pavement Type	PC	AC	PC	AC	PC	AC	PC	AC
Lanes								
Thickness (mm)	200		190		225		215	
Quantity (m^3)	1600		1520		1800		1720	
Dowel Bars (tonnes)	21		21		21		21	
HMA Surface (mm)		50		50		50		50
HMA Binder (mm)		120		120		155		155
HMA Surface (tonnes)		919		919		919		919
HMA Binder (tonnes)		2205		2205		2848		2848
Shoulders								
HMA Surface (mm)	40	40	40	40	40	40	40	40
HMA Binder (mm)	50	50	50	50	50	50	50	50
Gran A Shoulder (tonnes)	886	1564	805	1564	1087	1886	1006.	1886
HMA Surface (tonnes)	343	392	343	392	343	392	343	392
HMA Binder (tonnes)	429	490	429	490	429	490	429	490
Granular Base								
Base (mm)	150	150	150	150	150	150	150	150
Base (tonnes)	3968	3968	3968	3968	3968	3968	3968	3968
Granular Sub-base								
Sub-base (mm)	150	585	0	165	150	700	0	225
Sub-base (tonnes)	3300	12870	0	3630	3300	15400	0	4950

AC – Asphalt Concrete PC – Portland Cement Concrete
CBR – California Bearing Ratio HMA – Hot Mix Asphalt

Source: A Life Cycle Perspective on Concrete and Asphalt Roadways: Embodied Primary Energy and Global and Global Warming Potential, Athena Institute

The Athena study estimates the embodied primary energy and global warming potential (GWP) for the construction and maintenance of the four pavement structures examples over a 50 year period. The analysis took into account material extraction and production, construction / maintenance of the granular subbase, base and finished surface for both PCCP and ACP roadways, but eliminated items common to both pavement structures such as right-of-way clearing. The report shows the PCCP pavement has lower embodied primary energy results for each roadway examples analyzed. The additional embodied primary energy used by the asphalt pavement structures ranged from 2.3 for the Ontario Highway 401 example to 5.3 times more for the Quebec urban freeway example. [Athena 2006]

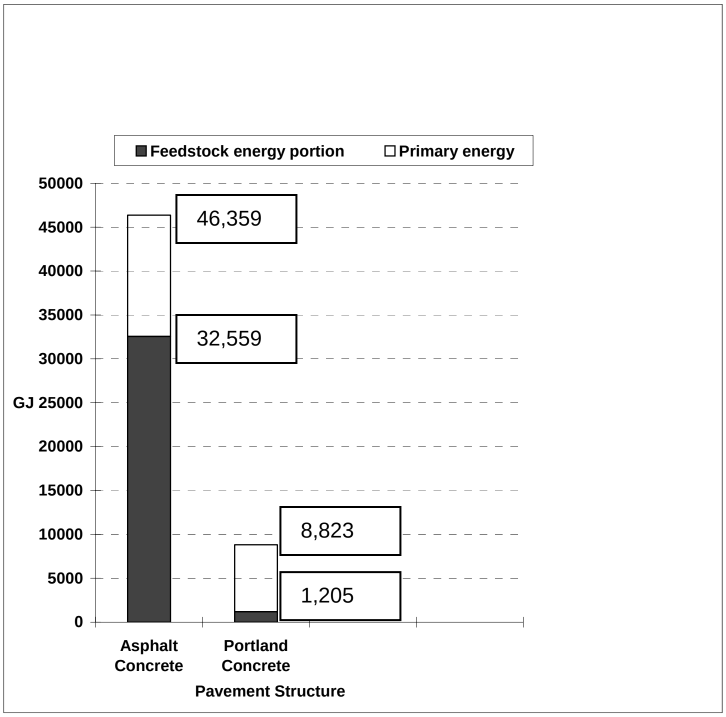
Table 2
Rigid (PC) and Flexible (AC) Design Material Quantities for Typical
401 Ontario Freeway and Quebec Urban Freeway

Roadway Type	**Ontario Freeway**		**Québec Freeway**	
Sub-grade Support	Typical		Typical	
Pavement Type	PC	AC	PC	AC
Lanes				
Thickness (mm)	260		240	
Quantity (m^3)	2990		1776	
Dowel Bars (tonnes)	29.9		22	
HMA Surface (mm)		300		300
HMA Surface (tonnes)		7986		7986
Shoulders				
Concrete Surface (mm)			150	
HMA Surface (mm)	90	90		90
Concrete Surface (mm^3)			645	
HMA Surface (tonnes)	1243	1307		1307
Granular OGDL				
OGDL Base (mm)	100	100		
OGDL Base (tonnes)	2926	2684		
Granular Base				
Base (mm)			150	286
Base (tonnes)			7121	11867
Granular Sub-base				
Sub-base (mm)	300	500	689	533
Sub-base (tonnes)	17575	27742	31277	25949

AC – Asphalt Concrete   PC – Portland Cement Concrete

Source: A Life Cycle Perspective on Concrete and Asphalt Roadways: Embodied Primary Energy and Global and Global Warming Potential, Athena Institute

Figures 6 shows the comparative embodied primary energy results for the Quebec urban freeway example noted above at 0% RAP (recycled asphalt pavement). The figure shows the embodied primary energy broken into its two components - feedstock energy and primary energy. Primary energy refers to the quantity of fossil fuel required to manufacture, supply, and maintain a product over a specified period of time, usually 50 years. Feedstock energy is the gross combustion heat value of the fossil hydrocarbon material input into the product which is a source of energy, such as liquid bitumen, but is not being used as an energy source as required by ISO standards. ISO 14040 section 4.2.3.3.2 states, "Energy inputs and outputs shall be treated as any other input or output to an LCA. The various types of energy inputs and outputs shall include inputs and outputs relevant for the production and delivery of fuels, feedstock energy and process energy used within the system being modeled." Therefore, gross combustion heat value of liquid bitumen must be included in any LCA.



AC – Asphalt Concrete   PC – Portland Cement Concrete

Figure 6: Comparative Embodied Primary Energy Quebec Urban Freeway Designs

Source: A Life Cycle Perspective on Concrete and Asphalt Roadways: Embodied Primary Energy and Global Warming Potential, Athena Institute

If feedstock energy (i.e. bitumen in the asphalt pavement) is not considered in the analysis the savings for the four examples decrease to a range of as low as 31 % for the MTO design to a high of 81 % for the MTQ design. If 20 % RAP is added in the binder course mix for the Canadian arterial and high volume highway examples the embodied primary energy estimates are reduced by 3.5 to 5 % for the PCCP option and 5 to 7.5 % for the ACP option [Athena 2006]. The reason for the reduction of embodied primary energy for the PCCP option is the use of asphalt shoulders and an asphalt overlay as part of the maintenance activities during the later stages of the pavement's maintenance and rehabilitation schedule.

It should be noted the scope of the Athena study did not include operational considerations such as truck fuel savings from operating on different pavement types and illumination energy savings due to the different light reflectance properties of the pavement types. These types of issues should, however, be taken into account in any decisions predicated on life cycle environmental effects. The report notes areas where Athena was conservative with PCCP data including ignoring the subgrade benefits of narrower PCCP structure and treating RAP as free of environmental burdens [Athena 2006]. Utilizing less energy for the concrete pavement structure means fewer emissions are associated with its use.

3.1.2 Reduced Carbon Dioxide (CO_2) Emissions from Operating on PCCP

Differences in fuel consumption of heavy vehicles as a function of pavement structure are an important consideration for users and government agencies. It is a known fact that heavy vehicles cause greater deflection on flexible pavements than on rigid pavements. This increased deflection of the pavement absorbs part of the vehicles rolling energy that would otherwise be available to propel the vehicle. Thus, the hypothesis can be made that more energy and therefore more fuel is required to drive on flexible pavements [Zaniewski 1989] Simply put driving on the asphalt is like climbing up a small hill.

The Cement Association of Canada (CAC) contracted the National Research Council of Canada (NRC) to investigate the potential truck fuel savings when operating on concrete pavement compared to asphalt pavement. In the fall of 1998 a small test study was undertaken that showed there was fuel savings in the order of 15 percent in concrete pavements favour. A second and more detailed study was then performed during 1999 and 2000 comparing several PCCP, ACP and composite pavements roadways in Quebec and Ontario. This Phase II study also included several other variables in the analysis including:

- Pavement roughness (IRI<1.5, IRI>2)
- Vehicle type (Tanker semi-trailer, Straight, B-train)
- Load (Empty, Half, Full)
- Speed (100, 75, 60 km/h)
- Seasons (Spring, Summer, Fall and Winter)
- Temperature (<-5,-5 to 10, 10 to 25, >25 ° C)
- Grade < 0.5%
- Ambient wind (< 10km/h average)

In-cab state-of-the-art real time computerized data collection equipment along with Cummins supplied in-site software was used in the tractor trailer unit to collect and calculate instantaneous fuel flow while traveling over the desired pavement locations. The tanker semi-trailer data was analyzed using a multivariate linear regression analysis tool to determine the potential savings and the statistical significance of the results. The results of the Phase II MVA Study entitled, “Additional Analysis of the Effect of Pavement Structure on Truck Fuel Consumption” showed statistically significant fuel savings for heavy vehicles operating on PCCP versus ACP as follows:

- 4.1 to 4.9 % compared to ACP at 100 km/hr
- 5.4 to 6.9 % compared to ACP at 60 km/hr [Taylor 2002]

The Government of Canada Action Plan 2000 on Climate Change, Concrete Roads Advisory Committee (CRAC), funded a third Fuel Study by the NRC to verify the Phase II study findings. This study, however, was funded by the CRAC with only a small portion of the project cost coming from the Cement and Concrete Industry. Terms of reference for the study were set by the CRAC which included people form several organizations including Natural Resources Canada, the Ministry of Transportation of Ontario (MTO), Ministère des Transport du Québec (MTQ) and others. Like the Phase II study this was a year long study comparing fuel consumption data for ACP, PCCP and composite pavements. The main difference with this Phase III study from the Phase II study was the test vehicle was a van semi-trailer instead of a tanker semi-trailer and the DOTs chose the sections of pavements (PCCP, ACP and composite pavement) to be tested in Ontario and Québec.

The results of the Phase III Fuel Study show statistically significant fuel savings for heavy vehicles traveling on PCCP compared ACP ranging as follows:

- 0.8 to 1.8 % savings compared to ACP pavement at 100 km/h.*
- 1.3 to 3.9 % savings compared to ACP pavement at 60 km/h.* [Taylor 2006]

* This excludes summer night data which was not statistically significant.

Based on the finding of these two detailed studies one can confidently say there is statistically significant fuel savings from operating on PCCP compared to ACP ranging from 0.8 to 6.9 %. Table 3 identifies the yearly potential fuel saving and associated $, CO_2 Equivalent, NOx, SO_2 savings over a year period if a 100 km section of a typical major urban arterial highway was PCCP. The savings are based on the following assumptions: heavy truck fuel efficiency of 43 litres / 100 km; diesel fuel cost of $0.8964 / litres; and highway section carrying 20,000 vehicles per day at 15% heavy truck traffic.

Table 3: Yearly Potential Savings in $, CO_2 Equivalent, NO_X, SO_2
For Typical Major Urban Arterial Highway

% Fuel Savings	Fuel Saved (litres)	Fuel Savings ($)	CO_2 Eq (tonnes)	NO_X (kg)	SO_2 (kg)
0.8 min.	376,680	$337,656	1039	11,758	1,486
3.85 avg.	1,812,772	$1,624,969	5000	56,585	7,152
6.9 max.	3,248,865	$2,912,282	8960	101,413	12,818

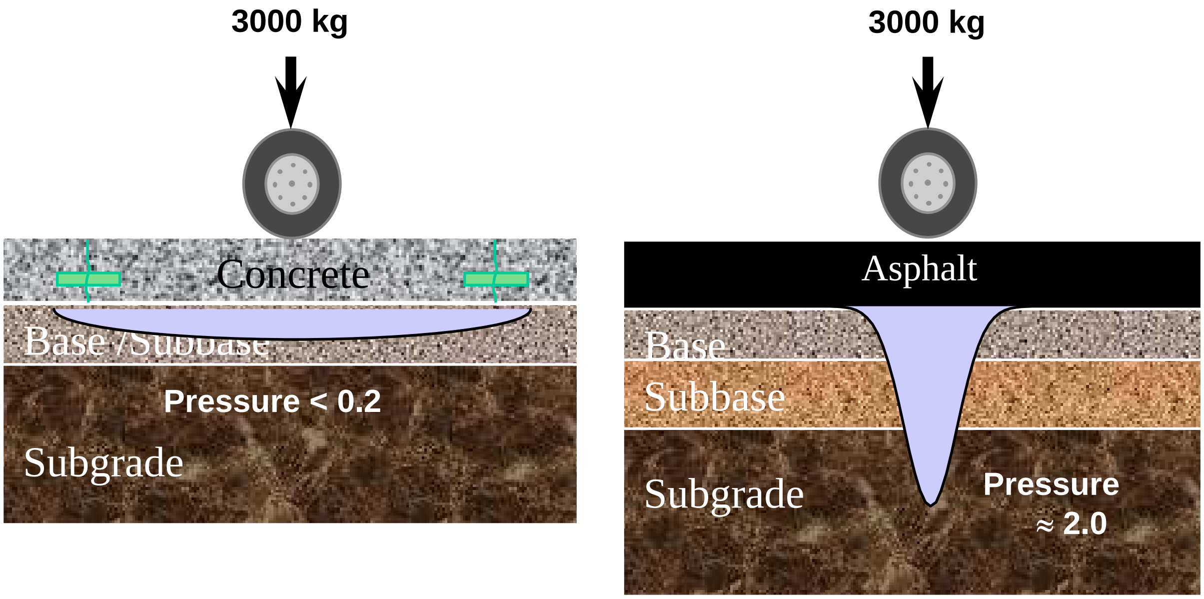
CO_2 Equivalent calculations include carbon dioxide, methane and nitrous oxide.
CO_2 = carbon dioxide, NO_X = nitrogen oxides, SO_2 = sulphur dioxide

In conclusion there are significant CO_2, NO_X and SO_2 savings when operating tractor-trailers on PCCP versus ACP. This means less pollutants being emitted into the environment, reduced fuel consumption, decreased trucking firms' operating costs, and possibly reduction in cost of goods to consumers.

3.1.3 Utilize Less Granular Material

The essential difference between flexible and rigid pavements is the manner in which they distribute the load over the subgrade. Figure 7 below illustrates how PCCP and ACP carry heavy vehicles loads. Because of concrete's rigidity and stiffness, the slab itself supplies the major portion of a rigid pavement's structural capacity and distributes the heavy vehicle loads over a relatively wide area of the subgrade. On the other hand, flexible pavement which is built with weaker and less stiff material does not spread loads as well as concrete. Therefore, more of the heavy vehicle's load is distributed into the base and subbase layers of the flexible pavement structure. This results in the flexible structure usually requiring more layers and greater thickness to the layers for optimal transmission of the vehicle load to the subgrade [ACPA 2004]. An exception to this is when government agencies specify granular thicknesses based solely of frost protection.

As noted earlier in the paper Applied Research Associates (ARA) Inc. prepared an analysis on equivalent pavement designs for flexible and rigid pavements for CAC. In this paper ARA identifies the amount of granular material required in the base, subbase and shoulders for the PCCP and ACP structures. For arterial roads on low strength subgrade the report recommends the following pavement structures: PCCP (200 mm, 150 mm base and 150 mm subbase) and ACP (175 mm ACP, 150 mm base and 585 mm subbase) [ERES 2003]. Based on these structures there is approximately twice as much granular material used in the asphalt structure. The environmental effect of this increased usage of granular material is magnified as the hauling distance to job sites increases due to depletion of suitable aggregate sources, thereby, increasing the fuel consumed by the gravel haul trucks and the CO_2 emitted from them.



Concrete acts more like a bridge over the subgrade. cm for cm much less pressure is placed on materials below concrete than on asphalt pavements

Figure 7: Typical Load Distribution for Flexible and Rigid Pavement Layers [ACPA 2004]

3.1.4 Reusable and Recyclable Paving Material

Another key environmental advantage of PCCP is its reusable and recyclable nature. Reusing and recycling the PCCP minimizes the amount of non-renewable resources required for a new pavement structure and eliminates potential material going to landfill sites. In addition, the short hauling distance for the aggregate reduces aggregate hauling costs, as well as, reduces fuel consumption and truck emissions associated with the aggregate supply. Concrete pavement provides owners several options in this area including:

1) Concrete pavement restoration
2) Composite pavement structure
3) 100 % recyclable material

All these options provide a climate change friendly solution to upgrading the condition of the highway.

Concrete pavement can be reused by performing concrete pavement restoration (CPR) techniques on the damaged areas. Repair techniques such as full depth / partial depth repairs, load transfer restoration, slab stitching, slab jacking and diamond grinding can be used to restore the pavement to an almost new condition. All these repair activities have low energy use and CO_2 footprints while restoring an older concrete pavement to an almost new condition. The final product is a smooth concrete pavement that will provide a long lasting surface with all the sustainable benefits of a new concrete pavement.

Concrete pavement can also be placed over existing asphalt pavements to create a new composite pavement structure. The existing asphalt pavement structure becomes a strong base for the new concrete overlay. In fact, the known performance of the asphalt pavement will minimize the potential for pumping, faulting and loss of support in the new concrete pavement.

No repairs are required to the existing ACP unless there are large areas of soft spots or the pavement ruts are over 50 mm. The key point is that the asphalt pavement is reused, therefore, minimizing the amount of reconstruction required and the associated emissions with it.

3.2 Optimized Concrete Mix Design

Optimized concrete mix designs are another key method of reducing concrete's CO_2 footprint. Three key issues to consider are as follows:

1) Minimize the amount of cement used for the desired strength requirements
2) Use well grade aggregate
3) Use SCMs in the mix.

Architects and engineers specifying the concrete properties must consider the usage of the concrete to ensure they are not over specifying the concrete strength for the intended use of the concrete product. This is a simple yet effective method of reducing the amount of cement required and reducing the CO_2 footprint.

Use of well-graded aggregates is also important to minimize cement usage. Well-graded concrete mixtures provide a balanced variety of aggregate sizes with the smaller particles filling the voids between the larger aggregates. This maximizes the aggregate volume and minimizes the amount of cement paste required to provide a workable and durable concrete mixture. Optimized mix designs with well- graded aggregates will require less cement and will generally have less shrinkage and permeability, as well as, be easier to handle / finish and be more economical. Gap-graded mixes, on the other hand, can result in segregation, require more cement paste and require more water for the same workability. [NCPTC 2007]

As noted in section 2.3, replacement of cement with SCMs also plays an important role in reducing the CO_2 footprint of concrete related products. The key is to ensure the SCMs are used in the appropriate amounts to ensure the concrete durability is not compromised.

3.3 Concrete as Potential CO_2 Sink

Carbon dioxide sequestration is another climate change mitigation advantage of concrete. It has long been known concrete absorbs CO_2 over its life but little was known about this potential. The Portland Cement Association contracted Construction Technology Laboratories, Inc., to investigate the current state of understanding of the absorption of CO_2 by concrete (also known as carbonation) and estimate the amount of CO_2 removed from the atmosphere by the carbonation of concrete. Sixteen literature references were reviewed and summaries of the documents were provided. The report estimates 200,000 metric tons of CO_2 would be absorbed the first year after construction assuming a typical U.S. concrete production year and 13.6% fly ash in the mix. The concrete will continue to absorb CO_2 throughout its life and over 100 years this concrete would absorb nearly 2.1 million metric tons of CO_2. If no fly ash is used in the mix the amount of CO_2 absorbed by the concrete would increase by 32% [Gajda 00].

Research by Caijun Shi and Yanzhong of CJS Technology noted in the February 2009 publication of Concrete International states that one way to sequester CO_2 is to use it to cure concrete blocks. The article notes concrete block manufactures could potentially sequester CO_2, reduce energy consumption and reduce the associated generation of CO_2 by switching from the current steam curing method to a CO_2 curing process. A number of advantages of CO_2 curing are identified in including:

1) Water absorption of CO_2 - cured blocks is lower than that of steam-cured blocks
2) Total energy consumption for CO_2 curing is about 1/10 of the energy consumption required for steam curing.
3) Assuming 8,000 blocks produced per day, CO_2 curing could save about 4×10^9 kJ and consume about 930 tonnes of CO_2 per year [Caijun 2009]

Two issues which need to be addressed are the price of CO_2 curing compared to steam curing and slower strength gain for CO_2 curing. However, if the concrete blocks are preconditioned properly the CO_2 curing time can be reduced.

Once this CO_2 curing process gets perfected it could potentially be used to cure other precast concrete products such as, concrete pavements and concrete median barriers.

3.4 High Performance Concrete Bridge Structures

High Performance Concrete (HPC) is widely used to extend the service life of bridges in Canada. Increasing the time between reconstructing the structure minimizes the material and energy used over the life of the bridge. This means less CO_2 will be created over the same period of time as structures designed for a shorter life. The increased durability of the concrete should also mean less maintenance on the bridge over time.

The most well known HPC Bridge in Canada is the 12.9 kilometre Confederation Bridge between New Brunswick and Prince Edward Island. The world's longest bridge over ice-covered water was designed for a 100 year life span. This is 33 % more than the required 75 years noted in the Canadian Highway Bridge Design Code.

New types of concrete like material, which are predominately used in precast concrete applications, provide extremely strong concrete with increased structural and durability performance. When using this new product known as Ultra High Performance Concrete (UHPC) bridges can be completely redesigned to reduce the amount of material needed for the bridge by potentially using fewer members, increasing span lengths and, in some cases, reducing the number of piers needed to support the bridge.

Self consolidating concrete (SCC) is used to place concrete with less energy input, and provides superior concrete consolidation in congested reinforced structural sections. This produces more durable structural elements therefore, contributing to a more sustainable bridge structure.

3.5 Building Energy Efficiency

One of the lowest cost/highest benefit actions we can take is to increase the energy efficiency of buildings. Utilizing less energy means a decrease in emissions such as CO_2. A building's maintenance and operation costs can amount to 80% of its environmental footprint over its life time. Initial investments in energy efficiency will definitely produce significant long-term benefits. The thermal mass potential of concrete has significant potential for "load leveling" in both heating and cooling regimes and offers long term payback. Thermal Mass is any mass that is used to absorb, retain, and gradually release heat. Concrete products such as cast-in-place, tilt-up, precast concrete, insulating concrete forms (ICF), or masonry have this attribute. This ability allows concrete products to help moderate indoor temperature extremes and reduces peak heating and cooling loads. In many climates, these buildings have lower energy consumption than non-massive buildings with walls of similar thermal resistance. When buildings are properly designed and optimized, incorporating thermal mass can lead to a reduction in heating, ventilating, and air-conditioning equipment capacity. Reduced equipment capacity can represent energy and related emission savings. [PCA 2009]

Figure 8 below illustrates how thermal mass affects energy performance. Concrete mass moderates indoor temperature fluctuations by reducing spikes in temperature. Mass wall and roof elements slow the transfer of heat through the building envelope. Mass can store energy thus shifting demand to off-peak time periods. It acts as a heat sink, absorbing and retaining heat, then releases heat back into the interior space in delay effect (time lag) up to 6 hours for peak temperature and up to 6-8 degree C difference between peak external / internal temperatures (damping), thus reducing and delaying peak load demands, resulting in reduction of heating and cooling energy consumption. [Ashley 2008]

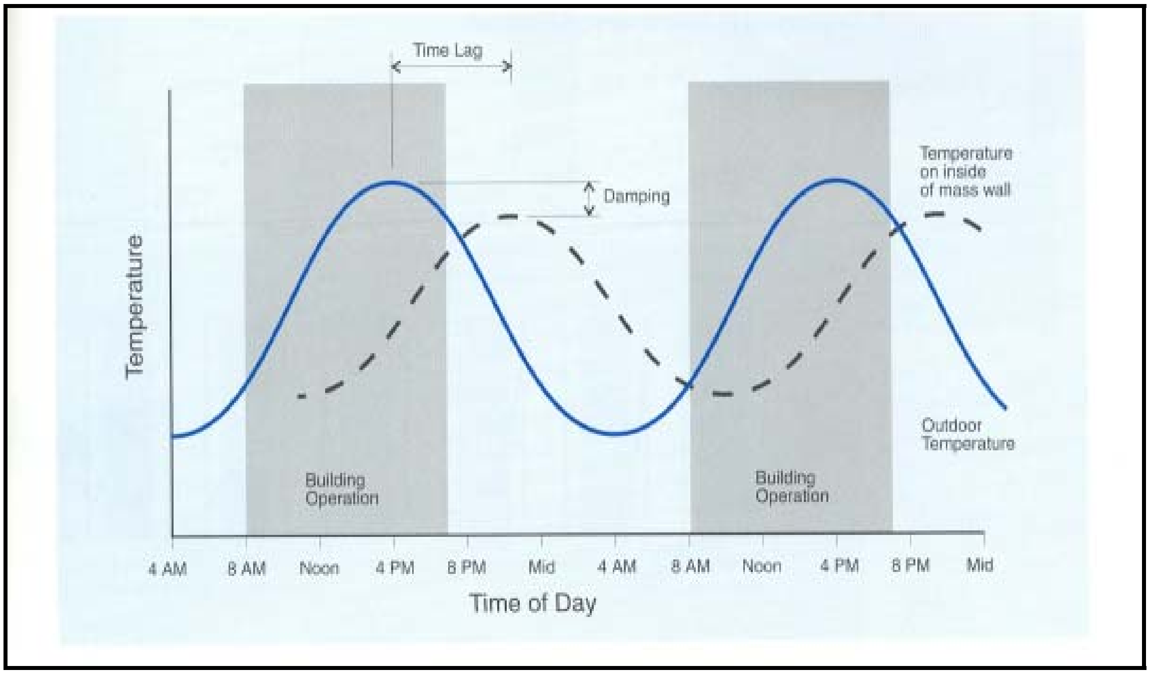


Figure 8 Damping and Lag Effect of Thermal Mass

Source: Erin Ashley, Concrete's Contribution to Sustainable Development

4.0 Conclusion

Like the general public, Climate Change and clean air are important concerns of the Cement and Concrete Industry. Through the Cement Sustainability Initiative the Industry has undertaken an Action Plan to address climate change and other issues. Several steps have already been taken to reduce the Industries CO_2 footprint including modernization of cement plants and energy efficiency improvements in operations. Additional methods are being pursued to further reduce the Cement CO_2 footprint including: use of alternate and renewable energies for use in cement kilns, use of Portland limestone cement and increased use of SCMs, improving the energy efficiency of manufacturing operations and undertaking long-term research and development on less CO_2 – intensive cementing materials and manufacturing operations. Concrete products can also assist with climate change mitigation. These include the use of concrete pavements, optimized concrete mix designs, concrete as potential CO_2 sink, high performance concrete bridges, ultra high performance concrete, and building energy efficiency. The Cement and Concrete Industry will continue to work with the Federal and Provincial Governments to reduce emissions and save energy. Combined with the many other sustainable advantages of concrete it is easy to see why concrete is considered such a sustainable product.

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