Concrete Pavement
A Truly Sustainable Choice

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ABSTRACT

Portland cement concrete pavement (PCCP) has long been known as a longer lasting pavement surface with low maintenance costs over the life of the pavement. This paper, however, looks at the sustainability side of PCCP by identifying its many environmental advantages over asphalt concrete pavement (ACP) pavement such as: use of industry by-products in the mix design, truck fuel savings when operating on PCCP, recyclable pavement material, reduced usage of nonrenewable resources over 50 year life cycle period, reduced energy consumption and reduced heat island effect.

Several studies have shown that trucks traveling on concrete pavement compared to asphalt pavement save fuel. This paper identifies these studies and shows how these fuel savings translate into reduced greenhouse gas (GHG) and smug emissions, thereby providing a cleaner environment to live in. Use of supplementary cementing materials (SCM) is also discussed to show how industry by-products such as fly ash, blast furnace slag and silica fume, which are normally being disposed of in landfill sites, can be used in the concrete to improve the PCCP characteristics. The recyclable nature of PCCP is discussed including using PCCP as base for a new pavement or aggregate for a new concrete pavement. Reuse of the asphalt pavements as a base for a new concrete pavement options such as Whitetopping and Ultra-Thin Whitetopping is also provided. Research by the Athena Sustainable Materials Institute on the Life Cycle Embodied Primary Energy and Global Warming emissions for PCCP and asphalt roadways is presented, as well as, research on the "urban heat island" effect and how PCCP can help with this problem.

1.0 **Introduction**

Portland cement concrete pavement (PCCP) has long enjoyed the reputation as a longer lasting, durable pavement surface with low maintenance costs. Cities such as Winnipeg and Windsor have been using PCCP for some time and have extensive PCCP networks. In addition, the Ministère des Transport du Quebec (MTQ) and Ministry of Transportation of Ontario (MTO) and have constructed several PCCP on high truck traffic routes over the last several years. Many other 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.

Even though there is an increased usage of PCCP in Canada, most Provincial and Municipal Governments choose pavement type on an initial cost bases and have traditionally tendered only asphalt pavements. However, with continually decreasing funding some government agencies are beginning to look at the longer term to increase the life of their assets. This has lead government Agencies to consider the life cycle cost of a project rather than just the initial cost when tendering projects. Some departments of Transportation are tendering projects with equivalent concrete and asphalt pavement designs, also known as Alternate bid tenders, and are including a Life cycle cost analysis (LCCA) component for each pavement type to reflect the long term cost of each option. Since 2000 eight of the nine alternate bid tenders with a LCCA component called across Canada have went PCCP.

Although alternate bid tenders with a LCCA component are a step in the right direction in helping government agencies to determine the best pavement option for a particular job they do not provide the real cost of a paving project. To have a complete understanding of the cost of one pavement type compared to another one must consider the sustainability of each product. Governments must consider the impact of the triple bottom line – the effect on Social, Environmental and Economic (SEE) impacts of their decision.

There are many Social and Economic advantages of concrete pavement including: decreased potential for hydroplaning, superior night time visibility, improved stopping distance, reduced lighting requirements and economy of having a two-pavement system and lower life cycle cost. This paper focuses on the many environmental benefits of constructing a roadway network of Portland cement concrete pavement including: reduced energy consumption; reduced greenhouse gas emissions (GHG) and smog; reusable and recyclable paving material; decrease in granular requirements; use of industrial by-products in product; use of pervious pavements; and reduced heat island effect. Government agencies considering the sustainable benefits of the different pavement types will be better equipped to make informed decisions related to the impact new and rehabilitated roadways have on the general public.

2.0 **Environmental Benefits**

Concrete pavements provide many environmental advantages compared to other pavement structures. This section of the report looks at the many environmental benefits identified in the introduction.

2.1 **PCCP Reduces Energy Consumption**

The Athena Institute was commissioned by the Cement and Concrete Industry to undertake a review and update the research it completed 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 various road construction materials such as cement, concrete, steel and asphalt. This change, as well as, the decision to evaluate different roadway sections in the second study means the results of the two different reports can not be compared.

In the new study, concrete and asphalt roadway structures were analyzed for four different roadway examples including the following:

1) Canadian (average) arterial roadway
2) Canadian (average) high volume highway
3) Ontario freeway (401) section
4) Quebec urban freeway section

The first two designs are equivalent concrete and asphalt pavement designs prepared by ERES consultants, now known as Applied Research Associates, Inc. ERES Consultants Division. These designs were prepare for subgrade strengths of California bearing ratio (CBR) 3 and 8. Table 1 below gives the design material quantities by roadway type and subgrade support for the equivalent concrete and asphalt structures prepared by ERES consultants. Table 2 below 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.

The Athena study determines the embodied primary energy and global warming potential (GWP) estimates for the construction and maintenance of PCCP and ACP structures for the four examples identified above over a 50 year period. The analysis took into account material use and construction 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 [1].

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

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	

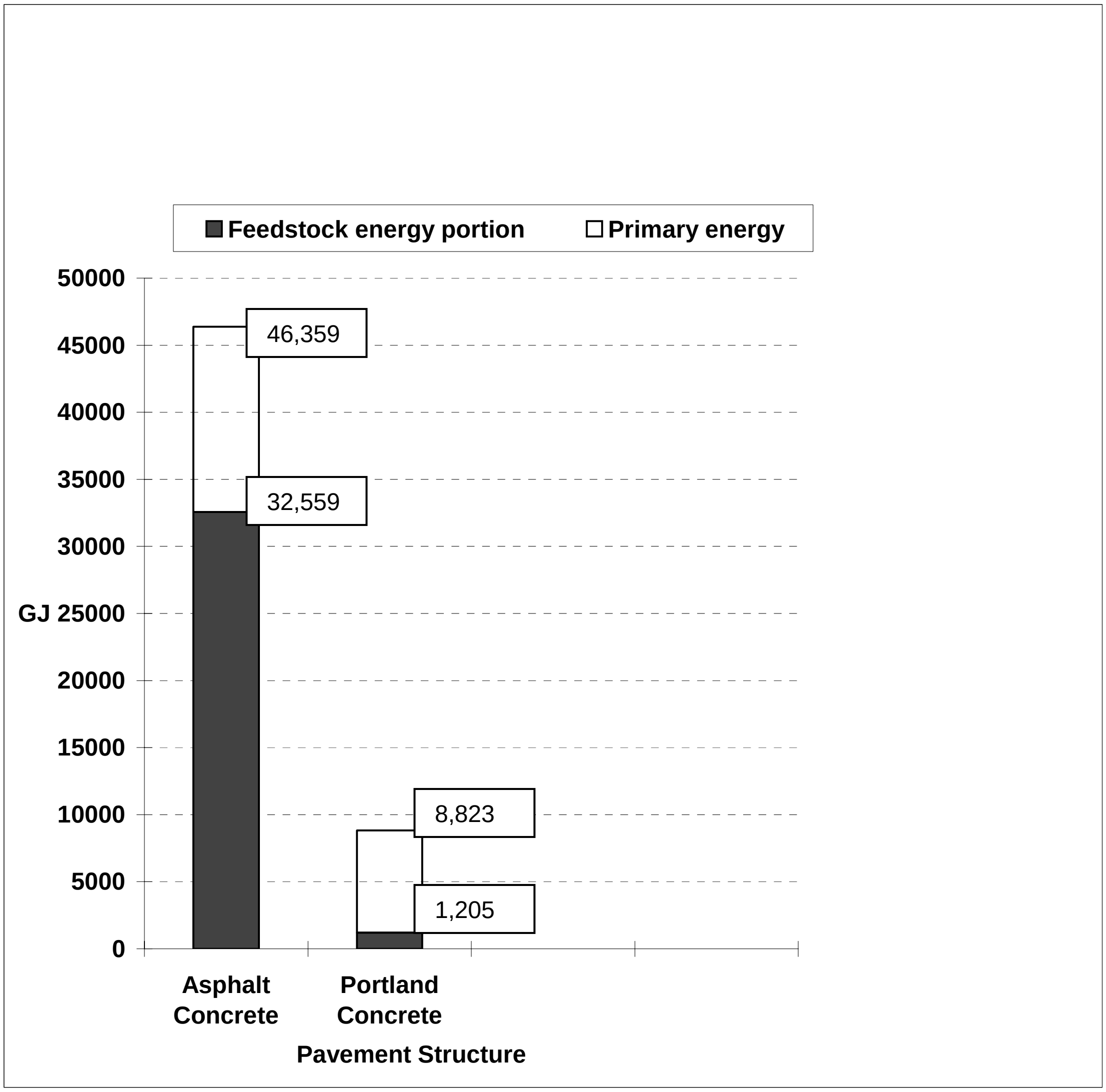
HMA Surface (mm)		300		300
HMA Surface (tonnes)		7986		7986
Shoulders				
Concrete Surface (mm)			150	
HMA Surface (mm)	90	90		90
Concrete Surface (mm^3)			645	
HMA Surface (tonnes)	1243	1307		1307
Granular OGDL				
OGDL Base (mm)	100	100		
OGDL Base (tonnes)	2926	2684		
Granular Base				
Base (mm)			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

The report shows the PCCP pavement has lower total primary energy results for all roadway examples analyzed. The absolute primary energy advantage gained from the use of PCCP ranges from 131% for the Ontario Highway 401 example to 425% for the Quebec urban freeway example. Figures 1 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 feedstock portion and primary energy use portion. 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 [1]. 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 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 [1].

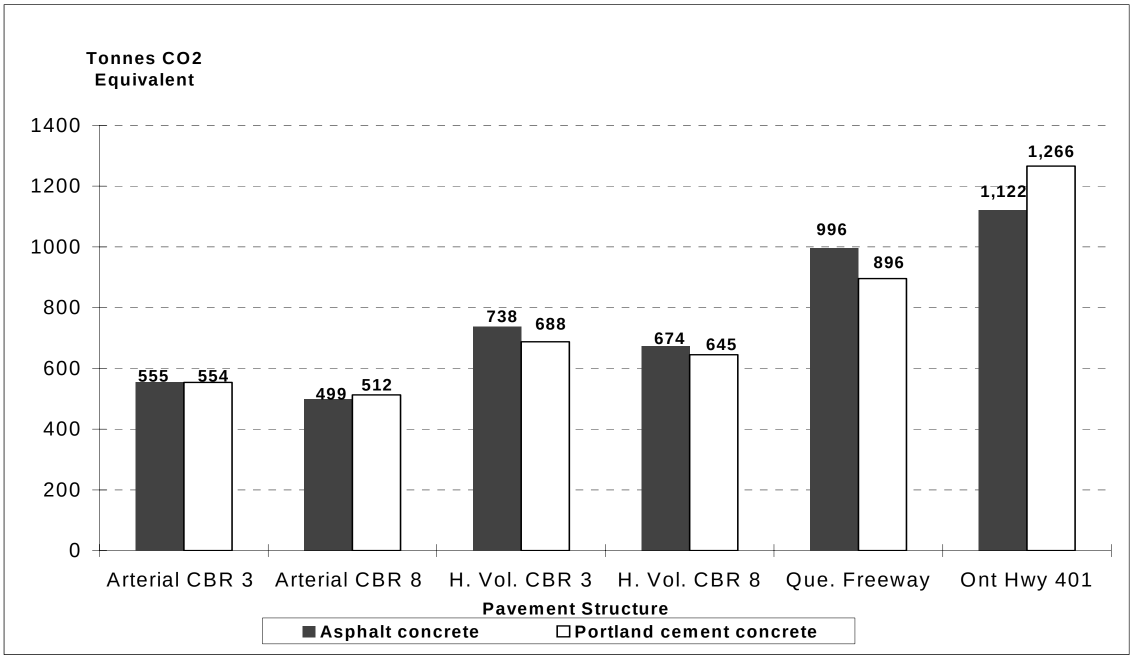


AC – Asphalt Concrete   PC – Portland Cement Concrete
Source: A Life Cycle Perspective on Concrete and Asphalt Roadways: Embodied Primary Energy and Global Warming Potential, Athena Institute

Figure 1: Comparative Embodied Primary Energy Quebec Urban Freeway Designs

2.2 **Global Warming Potential of PCCP and ACP Structures**

As noted in Section 2.1, the Athena Institute was commissioned by the Cement and Concrete Industry to undertake a review and update the research on both the Life Cycle Embodied Primary Energy and Global Warming Potential (GWP) for comparative PCCP and ACP roadway structures. Figure 2 illustrates the comparative FWP estimates for the pavement structures identified in section 2.1 with 0% RAP over the 50-year life cycle. The bar chart is organized by road class design and CBR (where applicable) to facilitate direct comparisons between the PCCP and ACP alternatives. The figure shows no distinct advantage in terms of GWP between the Canadian arterial and high volume highways concrete and asphalt design examples. The difference in GWP based on the bar chart below ranges from less than 1% to as much as 7%, which according to the author of the Athena report, is generally regarded to be within the 10% acceptable error or confidence interval of the supporting life cycle inventory study and should be considered insignificant [1]. Of the two-lane kilometer designs, only the Quebec urban freeway design shows a marginally significant difference between the two alternative material designs. Here, the flexible asphalt concrete design’s global warming potential emissions are some 11% higher than that of the rigid, PCCP design. This higher GWP result for the flexible asphalt concrete is primarily a function of two factors: the need to resurface the asphalt concrete road more frequently and the requirement to reconstruct the flexible asphalt concrete roadway some 17 years earlier than the rigid Portland cement concrete roadway [1].



Note: Based on using 0% recycled asphalt pavement
Source: A Life Cycle Perspective on Concrete and Asphalt Roadways: Embodied Primary Energy and Global Warming Potential, Athena Institute

Figure 2: Comparative Global Warming Potential by Pavement Structure

Unlike the other pavement structure examples the Ontario Highway 401 example is a 3-lane kilometer roadway rather than a 2-lane km example. This example also demonstrates a marginally significant difference in GWP between the PCCP and ACP designs, with the ACP design showing an 11% lower GWP over the 50-year planning cycle. The result is a function of the greater use of materials in the initial road construction (three lanes rather than two) and the greater use of Portland cement concrete relative to the asphalt concrete in the initial designs. The Ontario Highway 401 road design difference in direct energy use for the PCCP and ACP alternatives is the lowest for the all the example pavement structures [1].

2.3 **Reduced Carbon Dioxide (CO_2) Emissions from Operating on PCCP**

Differences in fuel consumption 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 [2]. Dr. Zaniewski's hypothesis is supported by the findings of a larger study he was part of in 1989 that looked at updating vehicle operating costing tables on data collected by the World Bank and Brazilian government in the late 1970's. The vehicle operating costs were separated into several components of which one was fuel consumption. From this data Dr. Zaniewski found that the savings in fuel consumption for heavy vehicles traveling on concrete versus asphalt pavements was up to 20% [2]. This data was not, however, analyzed with detailed statistical programs to determine the data's statistical significance.

Based on the findings by Dr. Zaniewski, the Cement Association of Canada (CAC) contracted the National Research Council of Canada (NRC) to initiate its own series of studies 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 to verify the validity of Dr. Zaniewski's findings. This small scale test showed there was fuel savings in the order of 15 percent in concrete pavements favour. Based on this result CAC contracted NRC to perform a second and much more detailed study 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 [3]

The Government of Canada Action Plan 2000 on Climate Change, Concrete Roads Advisory Committee (CRAC), decided to fund a third Fuel Study to be undertaken 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 various 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.*

* This excludes summer night data which was not statistically significant. [4]

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.

Based on the evidence identified above it is conservative to say that there are significant GHG savings when operating tractor-trailers on PCCP versus ACP, which also means less pollutants being emitted into the environment. Furthermore, the reduced fuel consumption decreases trucking firms' operating costs, thereby, possibly reducing cost of goods to consumers.

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

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

2.4 **Reusable and Recyclable Paving Material**

Another key environmental advantage of PCCP is its reusable and recyclable nature. Concrete pavement provides owners several options in this area including:

1) Concrete pavement restoration
2) Bonded concrete overlay
3) Composite pavement structure
4) 100 % recyclable material

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. 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. This is a much better option than placing an asphalt overlay on the deteriorated concrete pavement. Asphalt overlays will not have the same environmental benefits as the exposed concrete and the PCCP transverse joints will eventually reflect through the asphalt and become a maintenance issue. In addition, other benefits such as brighter surface for night time driving, less potential for hydroplaning and reduced heat island effect would be eliminated. In cases when the PCCP is in a more advanced state of deterioration the old PCCP may be able to be left in tack and used as a base for a new PCCP. In these cases a thin layer of asphalt of 25 to 50 mm is placed over the old PCCP and then over laid by a new PCCP.

Another possible reuse option for PCCP is a bonded overlay. When traffic patterns change and a roadway is receiving substantially more traffic than originally designed for, a bonded concrete overlay can be used to increase the pavement life. To use this technique the underlying pavement must be in good condition so a new layer of concrete can be placed over the existing PCCP and have no reflective cracks. The new layer of concrete is bonded to the old surface of the PCCP and the joint locations are matched to prevent reflective cracks. This process effectively increasing the thickness of pavement, thereby, increasing the amount of traffic the pavement structure can handle and increases the pavements expected life.

Concrete pavement can also be placed over existing asphalt pavements to create a new composite pavement structure. This type of paving process is known as “whitetopping” and utilizes the existing asphalt pavement structure as 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 and becomes part of the new composite PCCP structure.

Concrete pavement is also a 100 percent recyclable material and provides government agencies an attractive option at reconstruction time. If subgrade or pavement condition does not allow the older PCCP to be reused in its existing state it can be rubblized and used as granular fill, base course for new pavement and / or as an aggregate for new concrete pavement. In addition, the steel in the PCCP such as dowels and tie bars can be recycled [5]. In fact, a company in the United States is developing a prototype machine called Paradigm which is an in-place recycling system for concrete pavements. This machine breaks and crushes the concrete into the desired aggregate sizes and collects the reinforcing steel. However, this system is still in the experimental stage of development.

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.

2.5 **Utilize Less Granular Material**

The essential difference between flexible and rigid pavements is the manner in which they distribute the load over the pavement foundation (i.e. subbase and subgrade). Due to 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 [6]. In fact, in many cases there is approximately twice as much granular material used in typical asphalt structures. 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. This increases the fuel consumed by the gravel haul trucks and the CO_2 emitted by them. Therefore, a concrete pavement structure provides a more sustainable pavement when considering aggregate use.

2.6 **Use of Industrial by-products**

Concrete pavement 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 the by-product material in the pavement 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 PCCP installations in Québec have used ternary cements. Using SCMs can enhance the concrete properties including improved concrete pavement 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) [8]. 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 associated with the PCCP structure. The SCMs replace a portion of the cement in the concrete mixture and thereby decreases the total amount of CO_2 associated with the construction of PCCP structure. The amount of CO_2 reduction is related to the percentage of the SCM used in the mix design. Details on what is done on the use of SCMs 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 Deicing Chemicals”.

2.7 **Use of pervious pavements**

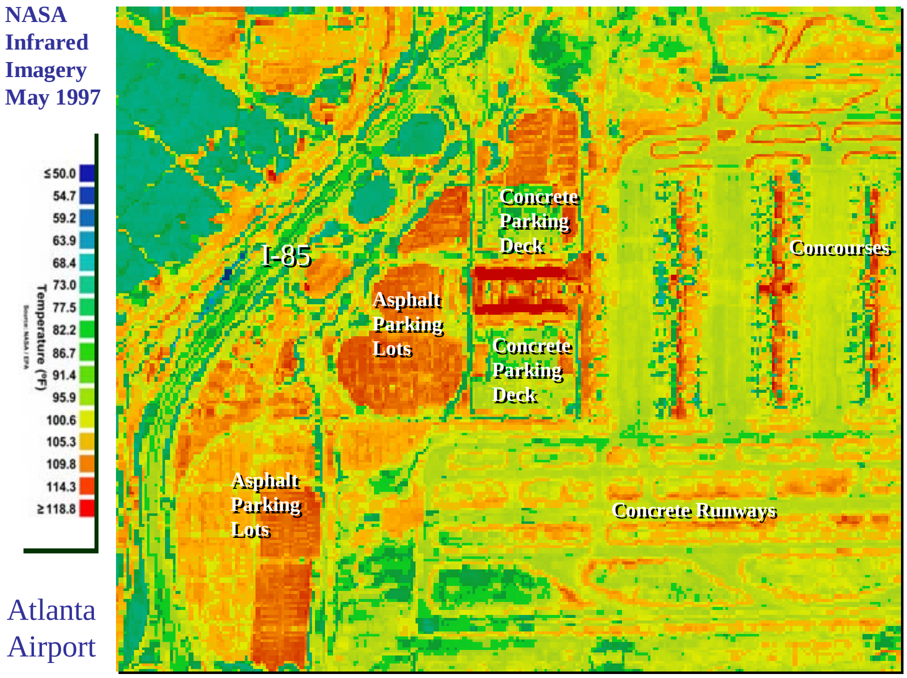
Pervious pavements have been around for some time and can be constructed of concrete or asphalt surfaces. The Green Building movement, however, has brought more of a focus on this technology as an environmentally friendly product. Pervious concrete pavements also known as “no fines concrete” or “porous concrete” are comprised of specially graded coarse aggregates, cementitious materials, admixtures, water, possibly fibres and little or no fines. Mixing these products in a carefully controlled process creates a paste that forms a thick coating around aggregate particles and creates a pavement with interconnected voids in the order of 12 to 35 percent. This provides a pavement that is highly permeable with drainage rates in the range of 100 to 750 litres per minute per square meter, thereby, reducing storm runoff and minimizing the amount of pollutants (car oil, anti-freeze and other automobile fluids) contained in captured storm water. By allowing the rainfall to percolate into the ground, soil chemistry and biology are allowed to naturally “treat” the polluted water [9]. This also allows for reduction in storm water retention areas, thereby, saving in land acquisition and construction costs. These pavements also recharge groundwater thereby, reducing the need to water trees and shrubs in the paved areas. The light coloured pavement surface is also a solution to the heat island effect.

The most common uses of this pavement are parking lots, low traffic pavements, and pedestrian walkways. Pervious concrete pavements have been used mainly in areas with minimal freeze-thaw (F/T) issues. However, a number of installations have been completed in Northern US states and experimental sections of pervious pavement have been placed in a variety of municipalities throughout Canada such as, Halifax, Saint John and Toronto and appear to be performing well. The National Concrete Pavement Technology Center at Iowa State University in the United States has produced a document on pervious pavement entitled “The Freeze-Thaw Durability of Pervious Concrete”. This document can be obtained at the following URL: http://www.ctre.iastate.edu/reports/mix_design_pervious.pdf . Other studies are also underway to investigate the use of pervious pavements in F/T climates.

2.8 **Heat Island Effect**

Dark, heat – absorbing surfaces, such as asphalt pavements and black roofs create a phenomenon known as “urban heat islands effect”. According to the article, Keeping Things Cooler, the average U.S. urban temperatures have risen an estimated 2° to 4° F in the past 4 decades. Downtown areas register readings up to 10° F warmer than suburban and rural surroundings, where natural vegetation cools the air through evapotranspiration [10]. Furthering the problem is the turning up of air conditioning in urban areas to counteract higher temperatures which not only increases energy costs but also increases emissions of GHG, accelerating pollution and ozone deletion. It is estimated that smog increases 3% for every degree of temperature [10].

Concrete's light color reflects light; therefore, it heats up less and reduces the Heat Island Effect. The exact effect of pavements on heat retention and resulting air quality issues is complicated by several factors, including: shadows from vehicles, trees and nearby buildings; change in pavement colour over time and absorption of reflected solar radiation by nearby buildings. However, as the NASA infrared imagery of the Atlanta Airport in Figure 8 below shows, the reduction in heat retention can be significant. This figure shows the black asphalt surfaces are in the light to dark orange area while the concrete runway is in the light green to yellow area and concrete parking deck is in the green to light green area. Based on this information it is easy to see concrete surfaces provide a cooler surface than asphalt pavements and a potential solution in combination with natural vegetation for reducing urban heat island affects.



Source: NASA Infrared Imagery Atlanta Airport May 1997

Figure 3: NASA Infrared Imagery Atlanta Airport May 1997

3.0 **Conclusion**

For the general public to get the most cost effective pavement structure Government agencies must look at more than just the initial cost of the pavement when analyzing pavement alternatives in their pavement selection process. It is clear from the preceding sections of this paper that concrete pavement has many environmental benefits which should be considered by roadway decision makers when trying to compare the overall cost of one type of pavement alternative to another. These benefits include reduction in: energy consumption, carbon dioxide / smog emissions, and aggregate consumption. In addition, PCCP provides a reusable / recyclable construction material that can stabilize industrial by-products in it rather than sending them to landfill sites. Concrete pavement has many social and economic benefits which should also be considered in any comparative analysis including the following: decreased potential for hydroplaning, superior night time visibility, improved stopping distance, reduced lighting requirements, lower life cycle cost, two- pavement system, and truck fuel savings.

4.0 **References**

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