Road Rehabilitation Energy Reduction Guide for Canadian Road Builders

In collaboration with the Canadian Construction Association

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For more information or to receive additional copies of this publication, contact:

Canadian Industry Program for Energy Conservation
c/o Natural Resources Canada
580 Booth Street, 18th Floor
Ottawa ON K1A 0E4

Tel.: (613) 995-6839 Fax: (613) 992-3161
E-mail: cipec.peeic@nrcan.gc.ca
Web site: oee.nrcan.gc.ca/cipec

Or

Canadian Construction Association
75 Albert Street, Suite 400
Ottawa ON K1P 5E7

Tel.: (613) 236-9455 Fax: (613) 236-9526
E-mail: cca@cca-acc.com
Web site: www.cca-acc.com

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Disclaimer

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Leading Canadians to Energy Efficiency at Home, at Work and on the Road

The Office of Energy Efficiency of Natural Resources Canada
strengthens and expands Canada's commitment to energy efficiency
in order to help address the challenges of climate change.

Contents

1 INTRODUCTION

1.1 THE ROAD BUILDING AND HEAVY CONSTRUCTION INDUSTRY

The road building and heavy construction industry in Canada employs tens of thousands of Canadians and accounted for more than $5 billion in economic activity in 2003. Road builders are responsible for all forms of road work, from construction and rehabilitation, to site work on other types of construction projects. The industry is dominated by small businesses – approximately 90 percent of the road building companies in Canada employ 20 or fewer people. It is also an extremely seasonal industry, with the bulk of activity occurring during the summer and fall. Road building companies are heavy users of various types of fuel, including diesel and heavy fuel oil. They also use natural gas to a lesser extent.

1.2 THE ENERGY REDUCTION GUIDE

Canada's road building industry is represented by the Roadbuilders and Heavy Construction Council of the Canadian Construction Association (CCA). CCA represents the non-residential construction sector in Canada, with some 20 000 firms as members.

Since joining the Canadian Industry Program for Energy Conservation (CIPEC) in 2002, CCA has focused on encouraging sustainable building and construction practices, including reducing energy use.

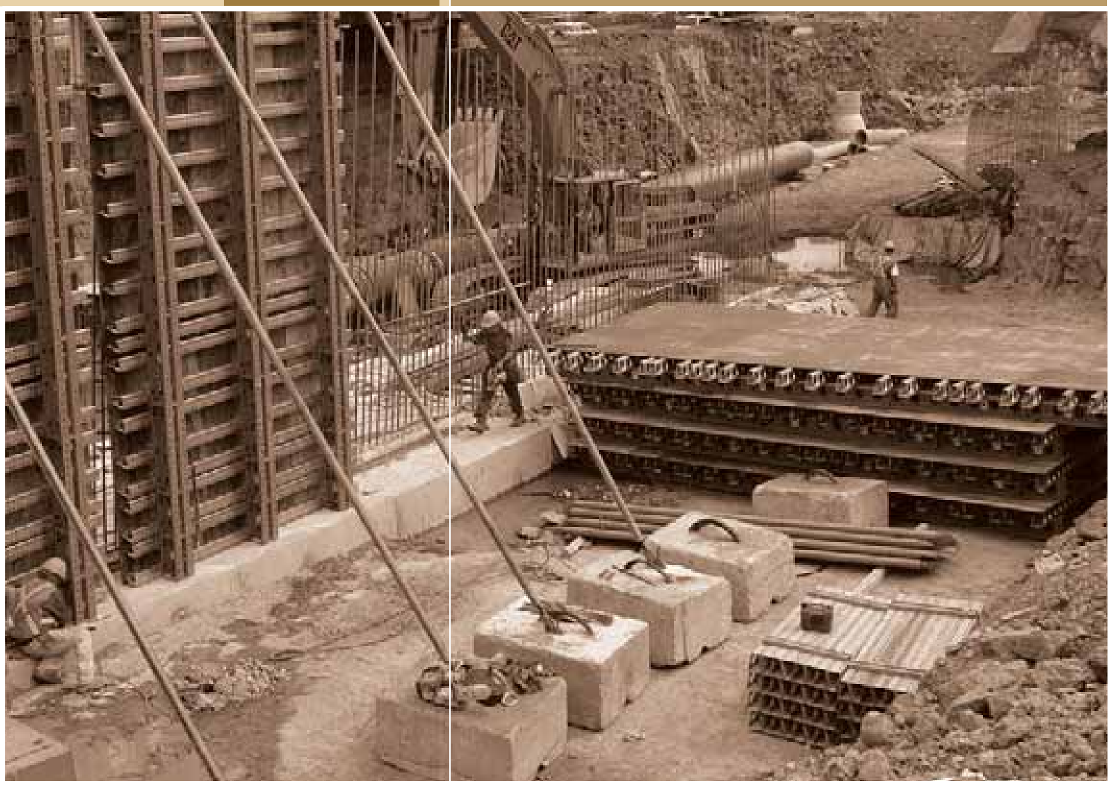
Until recently, energy costs, although significant, have not been a major cost driver for the road building industry. As a result, the industry has typically done little monitoring of its energy use. In fact, the industry practice for factoring energy costs into a contract bid has traditionally been to assume a set price for fuels and to absorb any additional fuel costs brought about by a rise in fuel prices between the time a bid is accepted and the completion of the construction.[1]

In April 2004, the CCA Roadbuilders and Heavy Construction Council made energy reduction a priority for the road building industry. With funding from CIPEC, CCA contracted the Athena Sustainable Materials Institute to work with its members on a road rehabilitation energy-reduction guide for Canadian road builders. The recommendations in this guide are based in part on an energy use survey conducted by the Institute.

Section 2 of this guide describes the survey methodology, Section 3 summarizes the survey results and discusses the significance of the results relative to other studies, and Section 4 outlines measures for reducing energy use. Appendix A lists the survey participants, and a sample survey form can be found in Appendix B.

[1] In the United States, many state road departments compensate contractors for significant price changes in fuel costs from the time of the winning bid to completion of the work.

2 METHODOLOGY



This survey-based study asked five Canadian road builders about their energy use and energy conservation practices. The five companies (see Appendix A) also helped develop the methodology for the study. This section describes the process, tools and assumptions used in the gathering of information about the energy use for road rehabilitation. It describes the types of roads included in the study and the types and quantities of materials used and their hauling distances.

2.1 ROAD SPECIFICATIONS AND REHABILITATION SCENARIOS

Canadian roadways range from gravel county side roads to major expressways. This guide examines only two roadway types – one rural, one urban – both with flexible asphalt concrete surfaces. Table 1 shows the as-constructed road material quantities per lane-kilometre[2] (lane-km[2]) for each of the road classes, assuming a California Bearing Ratio of 3[3].

TABLE 1 AS-CONSTRUCTED PAVEMENT MATERIAL QUANTITIES (per lane-km)

Pavement Structure	Class 1 Roadway Rural Secondary Highway	Class 2 Roadway Urban Arterial Road
Asphalt (m^3)	413	863
Asphalt (tonnes) @ 2.42 t/m^3	998	2087
Asphalt Cement (tonnes)	50	104
Aggregate (tonnes)	949	1984
Granular Base (m^3)	563	563
Granular Base (tonnes) @ 2.2 t/m^3	1238	1238
Granular Sub-base (m^3)	2250	2813
Granular Sub-base (tonnes) @ 2.2 t/m^3	4950	6188

Note: lane width set at 3.75 m

2 A lane-kilometre is one lane in width (a width of 3.75 metres was used for the study) for a distance of 1000 metres.

3 The California Bearing Ratio (CBR) test is an empirical test first developed in California, USA, for estimating the bearing value of highway sub-bases and subgrades. The CBR scale reflects a soil's bearing capacity based on its moisture and density. A CPR of 3 indicates a poor soil classification and will affect the design of flexible pavement road structures.

2.1.1 Rehabilitation of Flexible Asphalt Pavements

Asphalt overlay is required for flexible asphalt pavements at year 25 for a Class 1 roadway and at years 18 and 35 for Class 2 roadways. The study assumed that the Class 1 roadway, a rural secondary highway, was due to receive its 25-year asphalt overlay and that the Class 2 roadway, an urban arterial road, was due to receive its 35-year asphalt overlay (see Table 2).

The rehabilitation procedure consists of grinding the entire pavement surface, applying a tack coat to the milled surface, laying a new hot-mix asphalt surface by machine, and compacting the hot-mix asphalt using smooth steel wheel rollers and pneumatic wheel rollers. The materials include tack coat and hot-mix asphalt.

In the case of the Class 1 roadway, the first 25-year overlay is assumed to involve removing 40 mm of the existing asphalt and replacing it with one 50-mm lift of hot-mix asphalt. In the case of the Class 2 roadway, the 35-year overlay involves removing 80 mm of the existing asphalt and replacing it with 100 mm of hot-mix asphalt (placed in two lifts). The rehabilitation material quantities are shown in Table 2.

The study assumed that the hot-mix asphalt used to rehabilitate rural roads (Class 1 roadways) was produced in portable plants erected in a suitable location and that the asphalt used to rehabilitate urban roads (Class 2 roadways) came from permanent manufacturing plants. Typically, raw aggregates and asphalt binder are delivered by truck to the production plant, with the asphalt binder usually delivered hot in a liquid state and used while still hot. The aggregates for the hot-mix asphalt are dried and heated prior to mixing. After the hot materials are mixed, they may be stored in an insulated silo or loaded directly into trucks for delivery to the site.

The delivery trucks discharge the hot-mix into an asphalt paver, which spreads the material on the road. The hot-mix is compacted and smoothed by steel wheel and rubber tire rollers. The number and size of the rollers depend on the weather, the material quantities and the type of hot-mix, but it is common to have two steel wheel rollers and one rubber tire roller. When a tack coat is used, the emulsion is often delivered to the site in a truck equipped with a spray bar to spread the liquid material.

TABLE 2 MATERIAL QUANTITIES FOR ASPHALT OVERLAYS (per lane-km)

	Class 1 Roadway Rural Secondary Highway	Class 2 Roadway Urban Arterial Road
Year	25	35
Asphalt Removal Thickness (mm)	40	80
Asphalt Removal (tonnes)	363	726
New Asphalt Thickness (mm)	50	100
Asphalt (m^3)	188	375
Asphalt (tonnes) @ 2.42 t/m^3	454	908
Asphalt Cement (tonnes)	23	45
Aggregate (tonnes)	431	863

2.1.2 Representative Material Hauling Distances

Hauling distances for materials can vary substantially across the country, depending on the availability and proximity of materials. To account for variations in material hauling distances and thereby standardize energy-use reporting among the participants, the survey used pre-determined material hauling distances (Table 3).

TABLE 3 MATERIAL HAULING DISTANCES

	Class 1 Roadway Rural Secondary Highway	Class 2 Roadway Urban Arterial Road
Raw asphalt to portable plant	200 km	
Raw asphalt to permanent plant		80 km
Aggregate to portable plant	0 km*	
Aggregate to permanent plant		60 km
Hot-mix asphalt concrete to road site	30 km	45 km
Asphalt lifted from road site	60 km	70 km

* The zero value reflects industry practice to reduce hauling requirements by locating the portable asphalt mixing plant next to an aggregate source.

2.2 SURVEY

The survey was limited to elements of road building over which the participants exercised a certain amount of control (e.g. the survey did not look at energy use in the manufacture of bitumen). As a result, the survey design had to break down the process of road rehabilitation into discernable parts to determine the energy used for different activities. The survey focused on the three main road rehabilitation activities:

- mixing aggregates and hot asphalt emulsion (bitumen) at the asphalt plant
- hauling materials and transporting personnel to the site
- using heavy machinery at the site

It sought to gather data on participants' energy use, as well as information on their energy conservation practices.

The survey was mailed to each of the five participating road building companies. The Institute summarized the data received and returned the individual summary, as well as the complete results, to all participants for their review. Therefore, participants were able to compare their data with the group average to see where they stood. This process made it easier to spot data outliers and to correct inaccurate data.

A copy of the survey appears in Appendix B.

3

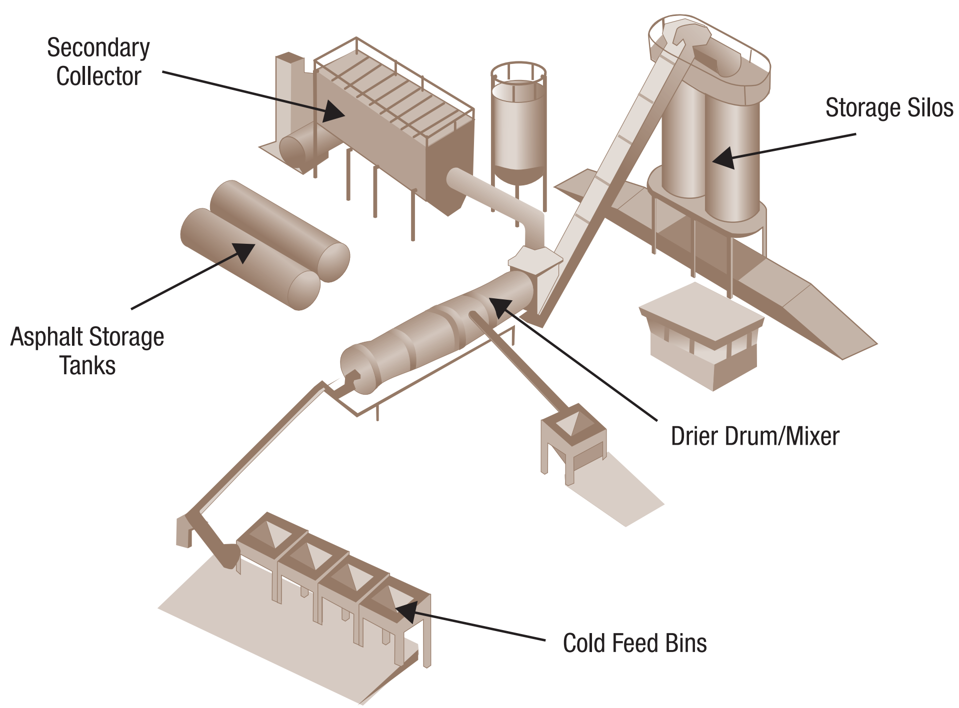
RESULTS

This section summarizes the survey findings relating to energy use in the production and hauling of road building materials and the transport of maintenance personnel for Class 1 and Class 2 roadways. It also summarizes data on the on-site consumption of energy by the heavy machinery used to grind down the old road surface and re-lay and compact the new one. Hot-mix asphalt concrete production is identified as the primary energy consumer in the road rehabilitation process.

3.1 HOT-MIX ASPHALT PLANT

Hot-mix asphalt concrete is a mixture of aggregate (crushed stone, gravel and sand) and asphalt binder. The asphalt binder percentage of the mix can vary, but typically is in the range of 4 to 6 percent by weight (the material quantities used in this study assume a 5 percent binder portion). Plants can be either portable or permanent and may use a batch or drum mixer. Figure 1 provides a schematic of a typical permanent asphalt mixing plant.

FIGURE 1 TYPICAL PERMANENT HOT-MIX ASPHALT PLANT CONFIGURATION



Source: National Asphalt Pavement Association

The five survey participants provided energy use information on a total of seven hot-mix asphalt plants (five portable and two permanent plants). To maintain confidentiality, it was necessary to aggregate all seven plants into a single group, which precludes reporting on a plant type basis.

Plant production varied from a low of 12 000 tonnes to a high of 250 000 tonnes on an annual basis. Table 4 sets out the average fuel use per tonne of hot-mix asphalt, as well as the energy use by fuel type. Natural gas and waste oil are the prevalent fuels used in the production of hot-mix asphalt and make up almost 75 percent of the total energy used at the plant. Note that although purchased electricity use is reportedly small, all the portable plants surveyed use diesel-fuelled generators to provide their on-site electricity needs. A small portion of the total energy used in the surveyed plants was consumed by mobile equipment at the plant (e.g. loaders). Although the average energy use for the seven plants was calculated to be 406 megajoules (MJ) per tonne of hot-mix asphalt, energy use ranged between a low of 356 MJ per tonne and a high of 443 MJ per tonne.

TABLE 4 AVERAGE ENERGY USE PER TONNE OF HOT-MIX ASPHALT

	Physical Units	Physical Quantity	Energy Equivalent (MJ)
Liquid Propane Gas	L	0.52	13.85
Heavy Fuel Oil	L	0.72	30.12
Diesel Fuel	L	1.24	48.07
Waste (used) Oil	L	2.95	123.43
Purchased Electricity	kWh	2.12	12.98
Natural Gas	m^3	4.66	177.21
		Total	405.66

Note: Higher heating values for fuel physical quantity conversions to MJ: Natural Gas (38.03 MJ/m^3), Diesel (38.77 MJ/L), Heavy Fuel Oil and Waste Oil (41.84 MJ/L), Liquid Propane Gas (26.64 MJ/L), and Electricity Primary Energy (6.12 MJ/kWh).

It is estimated that there are just over 500 hot-mix asphalt plants across Canada, producing 30 to 31 million tonnes annually. The province of Ontario has the greatest concentration of plants (28 percent) and produces about 40 percent of all hot-mix asphalt concrete in the country. In Canada, most asphalt production plants are over 30 years old and are predominately batch plants producing between 180 and 240 tonnes per hour (tph). New portable plants in the 400-tph range have a fuel consumption of about 7.4 L/tonne (approximately 300 MJ/tonne) when processing aggregates with 5 percent moisture content[4].

Data for portable plants provided in this survey indicated a fuel consumption range of between 7 L (280 MJ) and 11 L (440 MJ) with an average of 9.2 L (368 MJ). Liquid fuels used included heavy fuel oil, diesel and waste oil.

[4] *Multi-pollutant Emission Reduction Analysis Foundation (MERAF) for the Hot-Mix Asphalt Sector* (Final Report) by Canadian ORTECH Environmental Inc. and John Emery Geotechnical Engineering Limited (JEGEL). March 2000. p. 67

3.2 TRANSPORTATION OF MATERIALS AND PERSONNEL

Table 5 summarizes fuel use for the transportation of material and site workers by road type, assuming the same material quantities defined in Table 2 and the distances defined in Table 3.

The survey results for the Class 1 roadway (rural secondary highway) indicate that a total of 1222 L of diesel and 156 L of gasoline would be consumed in transporting the materials and workers to and from the road site. Transporting the milled asphalt from the original roadway was the primary energy consumption activity (38 percent), followed closely by transporting hot-mix asphalt concrete to the road site (31 percent) and worker transportation (20 percent). Transporting liquid asphalt binder to the plant accounted for the smallest portion (11 percent) of all the energy consumed in rehabilitating one lane-kilometre of Class 1 road. Aggregate transportation was estimated to be negligible as it is industry practice for portable asphalt plants to be located next to the aggregate source, thereby minimizing transportation of this component.

The final column of Table 5 shows the ratio of the high and low values for each of the transportation activities involved in rehabilitating one lane-kilometre of Class 1 road. It is evident that there is some variability in transportation energy use. This may be a function of the small sample size (five participants) and the variable nature of the climate and geography, as well as varying vehicle hauling capacity and vintage.

TABLE 5 TRANSPORTATION ENERGY USE BY ROAD TYPE (per lane-km)

Class 1 Roadway (Rural Secondary Highway)	Units	Fuel Type	Quantity Average	Range		High/Low Ratio
				Low	High	
Liquid asphalt transport	L	Diesel	149	83	225	2.7
Aggregate transport	L	Diesel	0	0	0	–
Hot-mix asphalt transport	L	Diesel	434	213	500	2.3
Milled asphalt from road site	L	Diesel	519	323	870	2.7
Site worker transport	L	Gasoline	156	90	270	3.0
Site worker transport	L	Diesel	120	120	120	1.0
Total Diesel	**L**		**1222**	**837**	**1370**	**1.6**
Total Gasoline	**L**		**156**	**90**	**270**	**3.0**

Class 2 Roadway (Urban Arterial Roadway)	Units	Fuel Type	Quantity Average	Range		High/Low Ratio
				Low	High	
Liquid asphalt transport	L	Diesel	72	41	116	2.8
Aggregate transport	L	Diesel	884	729	1140	1.6
Hot-mix asphalt transport	L	Diesel	1298	1100	2014	1.8
Milled asphalt from road site	L	Diesel	1214	713	2496	3.5
Site worker transport	L	Gasoline	72	46	110	2.4
Site worker transport	L	Diesel	100	100	100	1.0
Total Diesel	**L**		**3568**	**2751**	**4655**	**1.7**
Total Gasoline	**L**		**72**	**46**	**110**	**2.4**

For the Class 2 roadway (urban arterial road), the survey results revealed that a total of 3568 L of diesel and 72 L of gasoline would be consumed in transporting the materials and workers to and from the road site. Transporting hot-mix asphalt concrete to the road site was the primary energy consumption activity (36 percent), followed closely by transport of the milled asphalt from the original roadway (33 percent). Aggregate transportation was the third most significant energy consumption activity (24 percent), displacing site worker transportation, which dropped to fourth in importance at 5 percent. Liquid asphalt transport to the asphalt plant again contributed the smallest amount (2 percent) of all the energy consumed in rehabilitating one lane-kilometre of Class 2 road.

3.3 ON-SITE HEAVY EQUIPMENT ENERGY CONSUMPTION

The rehabilitation procedure consists of grinding the entire pavement surface, followed by the application of a tack coat to the milled surface, machine placement of a new hot-mix asphalt surface, and compaction of the hot-mix asphalt using smooth steel wheel and pneumatic wheel rollers. The survey asked each participant to document various heavy machinery fuel uses (diesel) per hour, as well as to estimate the machine hours necessary to complete each machine activity of the rehabilitation procedure for a lane-kilometre of each road type. By combining hourly fuel use with the time required by each machine type, the total energy consumed by heavy machinery used at the road site was estimated. Table 6 summarizes the total heavy equipment energy use by road type.

TABLE 6 HEAVY EQUIPMENT ENERGY USE BY ROAD TYPE (per lane-km)

	Units	Quantity Average	Range		High/Low Ratio
			Low	High	
Class 1 Roadway	L	484	326	601	1.8
Class 2 Roadway	L	819	622	1293	2.1

As expected, the Class 2 road exhibited the higher heavy machinery energy use of the two roads; it was not twice that of the Class 1 road, however, as the material quantities alone would suggest. Therefore it appears that certain scale economies are achieved with the lift depth of asphalt concrete.

3.4 ENERGY CONSUMPTION SURVEY SUMMARY

Table 7 summarizes the total road rehabilitation energy use survey results by activity component for each road type. It takes about 247 gigajoules (GJ) and 538 GJ, respectively, to rehabilitate one lane-km of Class 1 and 2 roads. To put this energy use into perspective, the energy used to rehabilitate a Class 1 or 2 road is equivalent to an average car[5] travelling 80 620 km or 175 280 km, respectively. Assuming the average car is driven 20 000 km per year, then rehabilitating a lane-km of Class 1 or 2 roadway is equivalent to about four or nine years of car operation, respectively.

Across both road types, the production of hot-mix asphalt concrete was the most energy intensive activity in the road rehabilitation process, accounting for about 70 percent of the total energy use. Transportation accounted for between 20 and 25 percent of the total energy consumed, and heavy equipment use accounted for less than 10 percent of all energy consumed. Both transportation and heavy machinery exhibited greater variability in their energy use values than the asphalt plant values; this fact may indicate that the industry is cognizant of the greater significance of the asphalt plant's energy use and hence pays more attention to monitoring energy use at the plant. In addition, although the high energy use at the asphalt plant would tend to suggest that an energy-use-reduction program would be advised to target this particular activity, the higher variability in the reported energy consumption of transportation and machinery use may signal better and easier opportunities to save energy.

TABLE 7 TOTAL REHABILITATION ENERGY USE BY ROAD TYPE (per lane-km)

Class 1 Roadway (Rural Secondary Highway)	Units	Quantity Average	(%)	Range Low	Range High	High/Low Ratio
Asphalt Plant	MJ	180 728	73	161 637	194 744	1.2
Transportation	MJ	48 031	19	26 443	66 166	2.5
On-Site Heavy Equipment Use	MJ	18 756	8	14 713	23 301	1.6
Total	**MJ**	**247 516**	**100**	**239 178**	**252 792**	**1.1**

Class 2 Roadway (Urban Arterial Road)	Units	Quantity Average	(%)	Range Low	Range High	High/Low Ratio
Asphalt Plant	MJ	369 620	69	323 275	389 488	1.2
Transportation	MJ	136 735	25	104 867	213 094	2.0
On-Site Heavy Equipment Use	MJ	31 765	6	24 099	50 110	2.1
Total	**MJ**	**538 120**	**100**	**520 243**	**586 479**	**1.1**

5 Consuming 8.8 L of gasoline per 100 km (8.8 L x 34.87 MJ/L of gasoline = 307 MJ)

4 ENERGY CONSERVATION OPPORTUNITIES

This section briefly discusses alternatives to hot-mix asphalt and recommends ways to reduce energy use in the three main road building processes: preparing hot-mix asphalt, transporting materials and personnel, and operating on-site heavy equipment. The recommendations are drawn from the energy use survey, a Web site review and suggestions from the survey participants.

4.1 ENERGY-SAVING ALTERNATIVES TO HOT-MIX ASPHALT

As shown in the previous section, the asphalt plant is the single largest contributor to the road rehabilitation industry's energy use. Before delving into possible energy-saving practices and technologies that can be applied at the asphalt plant, it is worthwhile to consider whether there are alternatives to hot-mix asphalt concrete that may offer more immediate and substantial energy savings.

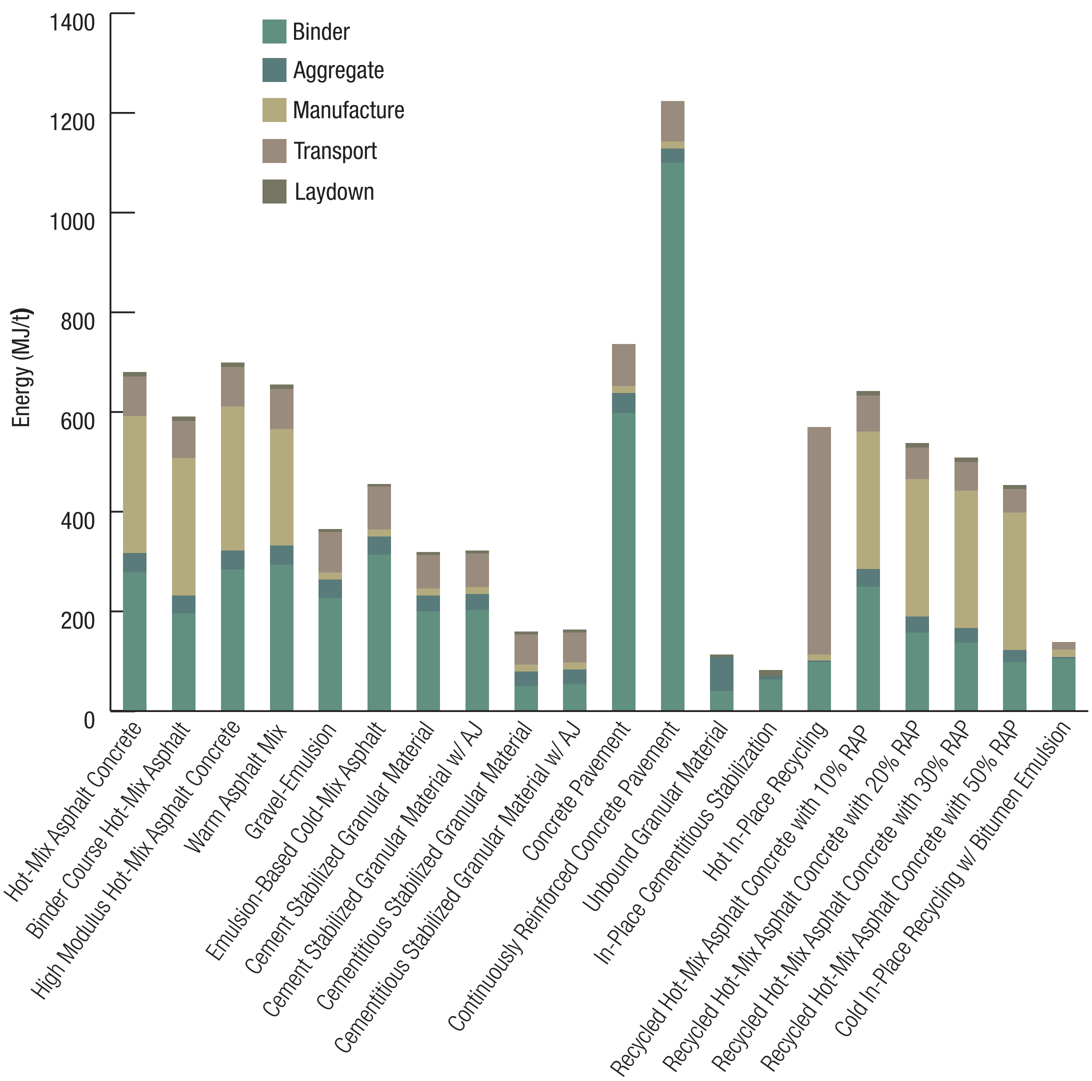
To this end, the Colas Group (September 2003) reviewed two life-cycle assessment studies (one completed by the Swedish Environmental Research Institute and the other by the Athena Sustainable Materials Institute), added their own engineering expertise and completed a report entitled *The Environmental Road of the Future*. Figure 2 (on p. 16 of this guide), from the report, summarizes the 30-year life cycle energy use per tonne of various road materials, from natural gravel to concrete pavements. The figure provides a breakdown of energy use by activity: to manufacture the binder material; to produce the aggregates; material manufacturing (combining aggregates and binder); transportation of the road material; and its on-site installation (laydown). Table 8 (on p. 17 of this guide) provides the point estimate data underlying Figure 2.

Note that this European study uses a considerable amount of process engineering data in its life-cycle approach, as well as lower heating values for fuels; these factors make direct comparison with the survey results in this guide problematic. Even so, the review is instructive in terms of relative difference between the various road material technology types.

The first bar on Figure 2 is traditional hot-mix asphalt concrete. An emerging technology alternative is the "cold-mix method" (sixth bar on graph), which all but eliminates the traditional asphalt plant and affords a 30 percent energy saving over traditional hot-mix asphalt concrete. Another rehabilitation technology that is gaining popularity in North America is the "hot in-situ" recycling of the existing road surface (bar 15) by way of a production train. Essentially, the existing roadway is milled to a specified depth, and the same material is reheated with the addition of some more binder and aggregate and then re-laid in place. This method can not only lead to a 15 percent reduction in overall energy use per tonne laid down, but also save a considerable quantity of resources. Combining in-situ recycling with a cold-mix technology can provide further energy savings of up to 80 percent over traditional hot-mix asphalt.

These material technologies are but examples of what may be possible. Portland concrete, as a rehabilitation material, would not be an option for an existing asphalt concrete roadway. Its use is more likely considered when building new roadways where its advantages – reduced use of aggregates in the sub-base and base structure and its reduced maintenance level – can be better realized. While showing promise, all of these alternative road material technologies require significant investment in new equipment as well as changes in practices. In addition, they may not always meet the rehabilitation standards for all roadway types. A closer examination of these technologies is warranted in order to better understand their respective characteristics and road class applicability.

FIGURE 2 ENERGY USE PER TONNE OF MATERIAL LAID DOWN



Notes: AJ = Active Joint, RAP = Reclaimed Asphalt Pavement, w/ = with

Source: *The Environmental Road of the Future, Life Cycle Analysis* by Groupe Chappat, M. and Julian Bilal. Colas Group, 2003, p. 34

TABLE 8 ENERGY USE BY ROAD MATERIAL TYPE (MJ/tonne)

Product	Binder	Aggregate	Manufacture	Transport	Laydown	Total
Hot-Mix Asphalt Concrete	279	38	275	79	9	68
Binder Course Hot-Mix Asphalt	196	36	275	75	9	591
High Modulus Hot-Mix Asphalt Concrete	284	38	289	79	9	699
Warm Asphalt Mix	294	38	234	80	9	654
Gravel-Emulsion	227	37	14	81	6	365
Emulsion-Based Cold-Mix Asphalt	314	36	14	86	6	457
Cement Stabilized Granular Material	200	32	14	67	6	319
Cement Stabilized Granular Material w/ AJ	203	32	14	67	6	323
Cementitious Stabilized Granular Material	50	29	14	61	6	160
Cementitious Stabilized Granular Material w/ AJ	54	29	14	61	6	164
Concrete Pavement	598	40	14	84	2.2	738
Continuously Reinforced Concrete Pavement	1100	29	14	81	2.2	1226
Unbound Granular Material	0	40	0	68	6	113
In-Place Cementitious Stabilization	63	0	0	7	12	81
Hot In-Place Recycling	98	4	0	12	456	570
Recycled Hot-Mix Asphalt Concrete with 10% RAP	250	35	275	73	9	642
Recycled Hot-Mix Asphalt Concrete with 20% RAP	157	33	275	64	9	538
Recycled Hot-Mix Asphalt Concrete with 30% RAP	137	30	275	58	9	510
Recycled Hot-Mix Asphalt Concrete with 50% RAP	98	25	275	47	9	454
Cold In-Place Recycling w/ Bitumen Emulsion	105	4	0	15	15	139

Notes: AJ = Active Joint, RAP = Reclaimed Asphalt Pavement, w/ = with

Source: *The Environmental Road of the Future, Life Cycle Analysis* by Chappat, M. and Julian Bilal. Colas Group, 2003, p. 34

4.2 ASPHALT PLANT ENERGY CONSERVATION OPPORTUNITIES

The energy use at the asphalt plant is governed by many variables, from the ambient temperature and moisture content of aggregates to the efficiency of the combustion system itself. The goal is to control all of these to the greatest degree possible to achieve efficient use of all fuels.

From an energy reduction perspective it is of the utmost importance that the existing plant is operating efficiently. Both the Ontario Hot Mix Producers Association and the Canadian Construction Association (CCA) have published environmental best-practice guides for the hot-mix asphalt industry,[6] as has the U.S.-based Asphalt Institute. Focusing on monitoring and lowering combustion-related emissions is akin to maintaining or increasing the energy efficiency of the plant, in addition to any use of emissions control devices. The following list of operational measures can lead to either maintaining or improving energy efficiency:

- Log fuel use: maintain a plant energy use accounting system that also notes the prevailing weather conditions, or purchase a fuel meter. A meter reading at any point in time can be compared with the amount the burner should be burning.
- Minimize air leaks throughout the whole system (air leaks further away from the combustion chamber decrease energy efficiency more than those in and around the combustion chamber).
- Implement air leak detection and repair procedures.
- Consider insulating all hot pipes and tanks – an inexpensive, low technology method for saving energy (all insulation should be waterproofed).
- Regularly clean heat transfer media (coils and fins).
- Calibrate burners annually for permanent plants, and whenever a portable plant is set up at a new location (or annually, whichever occurs first).
- Ensure exhaust fans and damper controls are working in tandem to provide the correct amount of combustion air at all production rates and ambient air temperatures.
- Ensure production temperature is in accordance with asphalt production temperature charts.
- Store aggregates under cover or in a silo to reduce rewetting and, where possible, encourage air-drying of aggregates.
- Ensure the air compressor system is running at the lowest practical air pressure.
- Replace open-fired units with sealed-in 100 percent total air burners, which can achieve a 10–20 percent energy cost savings compared with open-fired units.
- When considering the replacement of a plant or its major components, make sure it is properly sized. In instances where a plant is designed to accommodate increased production at a later date, it may operate only at a partial load in the interim; when this occurs the plant is often less efficient than when operating at its full design capability.

[6] Three excellent sources of information relating to the reduction of energy use at an asphalt plant include (1) the asphalt plant environmental practices guide published by the Canadian Construction Association (forthcoming); (2) *Multi-pollutant Emission Reduction Analysis Foundation (MERAF) for the Hot-Mix Asphalt Sector* prepared by ORTECH and JEGEL for Environment Canada and the Canadian Council of Ministers of Environment in 2002; and (3) *Environmental Practices Guide for Ontario Hot-Mix Asphalt Plants*, 2nd Edition 2002 by the Ontario Hot Mix Producers Association.

4.3 TRANSPORTATION AND HEAVY EQUIPMENT ENERGY CONSERVATION OPPORTUNITIES

Transportation represents the second largest energy use component in the rehabilitation of roadways, followed by heavy equipment energy use. We have combined these two mobile equipment segments under the same heading, as they have much in common when energy conservation strategies and practices are being considered. The energy efficiency measures list has been culled from a number of different sources, including Natural Resources Canada's FleetSmart, as well as various heavy machinery manufacturers' Web sites. To get the most out of transport and heavy machinery, it is necessary to develop and continually refine appropriate maintenance schedules, operational practices and vehicle/equipment replacement schedules. Below is a list of possible energy saving guidelines for the industry to consider:

- Develop and implement a preventive maintenance schedule for all vehicles and machinery.
- Switch to synthetic lubricants, which have a demonstrated ability to increase energy efficiency through reduced friction, as well as to prolong vehicle and machinery life.
- Consider implementing a driver or operator training program to refresh operators' skills as well as to help them better understand the effect of their driving or operating habits on fuel use (see prolonged idling and speed limit measures below in this list).
- Log fuel use by vehicle and machinery to help identify fuel leaks and poor performing vehicles in a fleet.
- Where appropriate, shift more-efficient vehicles and machinery into higher duty cycles and less-efficient ones to lower duty tasks.
- Where appropriate, combine the loads of small vehicles into one larger vehicle (over the longer term, evaluate use and loading levels to help select the appropriate vehicle or machine when it comes time to replace the existing one).
- Avoid prolonged idling: develop a company policy about idling times and monitor it. Typical highway vehicles can consume 2.0 to 2.5 L of fuel per hour of idling. Studies have shown that shutting off and restarting an engine within three minutes can be cost effective.
- Institute speed limits for transport vehicles so they operate in their economic fuel range, and consider resetting the engine speed governor (can be done to heavy equipment as well, where warranted).
- Fill fuel tanks to 95 percent of capacity to allow for expansion and reduce spillage.
- When considering new equipment purchases, opt for the most efficient engine, and size the equipment so it will be used in its most efficient load or operating range.

4.4 WEB RESOURCES

Below is a table of useful Web resources that were used in the completion of this section.

Organization	Web address
Asphalt Contractor	www.asphalt.com
Asphalt Institute	www.asphaltinstitute.org
Asphalt Pavement Alliance	www.asphaltalliance.com
Canadian Construction Association	www.cca-acc.com
Canadian Technical Asphalt Association	www.ctaa.ca
Colas	www.colas.fr
National Asphalt Pavement Association	www.hotmix.org
Natural Resources Canada, Office of Energy Efficiency, FleetSmart	oee.nrcan.gc.ca/fleetsmart
Ontario Hot Mix Producers Association	www.ohmpa.org

APPENDIX A. PARTICIPANTS

Wayne Morsky
Morsky Earthmoving Ltd.
Box 4586, 299 Sherwood Road
Regina, Saskatchewan
S4P 3Y3
(306) 949-3099 (phone)
(306) 543-8077 (fax)
wayne@morsky.ca

Allan Barilla
(306) 536-3103 (phone)
allan@morsky.ca

Tom Brown, Senior Vice-President
Ledcor Alberta Limited
Edmonton, Alberta
(780) 462-4211 (phone)
(780) 437-7140 (fax)
tom.brown@ledcor.com

Allan Mills
allan.mills@ledcor.com

Barry Brown, President
Maple Leaf Construction Ltd.
Winnipeg, Manitoba
(204) 783-7091 (phone)
(204) 786-3106 (fax)
barry@mapleleafconstruction.mb.ca

Jean-Martin Croteau, Technical Director
Miller Paving Ltd.
Markham, Ontario
(905) 475-6660 (phone)
(416) 505-7916 (cell)
(905) 475-7160 (fax)
jmcroteau@millergroup.ca

Fred J. Penney, Vice President
Penney Paving Ltd.
P.O. Box 806
Grand Falls-Windsor, Newfoundland and Labrador
A2A 2M4
(709) 489-3072
fjpenney@nf.sympatico.ca

APPENDIX B. SURVEY TOOL

GENERAL INFORMATION – PAGE 1 OF 4

CANADIAN ROAD CONSTRUCTION ENERGY USE SURVEY FORM

Company Name		
Contact Person		
Contact Information	Phone	
	Facsimile	
	E-mail	

This survey is requesting energy use information applicable to three road construction processes used in the course of rehabilitating two roadway types. The three processes are hot-mix asphalt mixing (permanent and/or portable); material hauling activities; and heavy equipment use. The two roadway designs are as follows:

1. Class 1 rural secondary highway
2. Class 2 urban arterial roadway

For each road type, the basic metric unit is a lane-kilometre with a width of 3.75 m. The rehabilitation scenario is limited to resurfacing the two roadway types.

This survey workbook is divided into four worksheets – one sheet per process and this general information sheet. The asphalt mixing plant sheet is structured independently of the two roadway designs – here we are looking to determine average fuel used in the production of a tonne of hot-mix asphalt. The other two sheets are to be completed with the two roadway designs' material quantity requirements in mind.

Please complete all information shaded in yellow. Please indicate any departures from the information requested on the sheet(s) directly.

For questions concerning the completion of the survey, please contact Jamie Meil at (613) 523-1020 (phone) or by e-mail at jkmeil@sympatico.ca.

ASPHALT MIXING PLANT ENERGY USE – PAGE 2 OF 4

This sheet is used to calculate fuel use per tonne of mixed asphalt

Type of plant (please check one X)	Permanent	Portable

Plant production		
annual for permanent facility	(tonnes/yr)	
any job specific quantity for portable*		(tonnes/job)

* can be for a previously completed job of not less than 5000 tonnes

Plant energy use			
	Permanent Annual	**Portable** specific qty(**)	**Units**
Annual specific qty			
Purchased Electricity			kWh
Natural Gas			ft^3 or m^3
Heavy Fuel Oil			gal. or litres
Medium Fuel Oil			gal. or litres
Diesel Fuel			gal. or litres
Other (Specify)			

(**) as per quantity indicated in cell C9

Plant air emission abatement technology Specify (e.g., baghouse, scrubber)

NOTES Any comments here

HAULING EQUIPMENT ENERGY USE – PAGE 3 OF 4

	Units	Class 1 Roadway	Class 2 Roadway	
Typical haul distance				
Liquid asphalt to portable plant	km – oneway	200		Given these one-way haul distances …
Liquid asphalt to permanent plant	km – oneway		80	
Aggregate to portable plant	km – oneway	0		
Aggregate to permanent plant	km – oneway		60	
Hot mixed asphalt to road site	km – oneway	30	45	
Milled asphalt lifted from road site	km – oneway	60	70	
Material quantities				
Liquid asphalt to portable plant	tonnes	23		and material quantities by road type …
Liquid asphalt to permanent plant	tonnes		45	
Aggregate to portable plant	tonnes	431		
Aggregate to permanent plant	tonnes		863	
Hot mixed asphalt to road site	tonnes	454	908	
Milled asphalt lifted from road site	tonnes	363	726	
Typical diesel fuel use				estimate fuel usage by process, including empty backhaul and truck idling.
Liquid asphalt transport vehicle	litres			
Aggregate transport vehicle	litres			
Hot mixed asphalt transport vehicle	litres			
Milled asphalt from road site	litres			
Personnel transportation				
Movement of site workers to and from site:				
Diesel	litres			
Gasoline	litres			

Note: One way of estimating site worker / supervisor transportation is to determine the average daily fuel usage of pick-up vehicles and then estimate the number of days it would take to complete each lane-km of roadway.

Site workers would also include portable asphalt mix plant.

HEAVY EQUIPMENT ENERGY USE – PAGE 4 OF 4

Equipment Use	Units	Class 1 Roadway secondary hwy	Class 2 Roadway urban arterial	Class 1 Roadway	Class 2 Roadway
		per lane-km (l-km) requirements		per lane-km	
scarifier/milling machine	hrs	to remove 363 t	to remove 726 t		
tack coat spray truck	hrs	one l-km	two l-km		
mobile pick-up machine	hrs	pick-up & transfer 454 t	pick-up & transfer 908 t		
material transfer vehicle	hrs	transfer 454 t	transfer 908 t		
paver	hrs	lay 454 t	lay 908 t		
steel roller	hrs	roll a 50-mm l-km	roll two 50-mm lifts l-km		
rubber wheel roller	hrs	roll a 50-mm l-km	roll two 50-mm lifts l-km		
float trucks	hrs	travel time (hrs)	travel time (hrs)		
other (specify)	hrs				

Note: The above table is asking you to estimate scarifier/milling machine hours required to lift 363 tonnes of asphalt from the Class 1 roadway (or 726 tonnes from the Class 2 roadway) and to place your estimate in the yellow shaded columns for each roadway type.

Fuel Use

scarifier/milling machine	L/hr
tack coat spray truck	L/hr
mobile pick-up machine	L/hr
material transfer vehicle	L/hr
paver	L/hr
steel roller	L/hr
rubber wheel roller	L/hr
float trucks	L/hr
other (specify)	L/hr

NOTES Please insert comments where your practice differs from the above process descriptions.