Reducing Greenhouse Gas Emissions in the B.C. Road Building and Maintenance Industry

MAY 2011

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Ministry of Transportation and Infrastructure

B.C. Road Builders & Heavy Construction Association

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REDUCING GREENHOUSE GAS EMISSIONS IN B.C. ROAD BUILDING AND HIGHWAY MAINTENANCE

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Foreword from the B.C. Road Builders and Heavy Construction Association

I'm pleased to share this document which details a wide range of best practices guidelines to assist our industry in further reducing greenhouse gas (GHG) emissions. These guidelines are the result of a collaborative effort between the B.C. Road Builders and Heavy Construction Association and the Ministry of Transportation and Infrastructure.

As reflected in our 2010 Business Plan, the Association is committed to supporting the development of strategies to reduce GHG's in each of the road building, maintenance and service sectors. A number of our member companies have already incorporated some of these strategies into their day to day operations. With continued effort and the growing participation of other firms, I am confident our industry will again demonstrate leadership in addressing this significant environmental challenge.

The efforts of the B.C. road building and heavy construction industries to reduce GHG emissions are good for the environment and good for business. By reducing the emissions, fuel consumption is reduced, and that contributes to financial savings. The Best Practices Guidelines will be a living document that will be updated as required. I encourage everyone to become familiar with these Guidelines, and to look for ways to incorporate appropriate practices into your operations.

I'd like to thank both those Association members and the respective staff at the Ministry of Transportation and Infrastructure who contributed to the development of these important Guidelines. I encourage Association members to continue offering your suggestions regarding the refinement of these Guidelines and as well as other strategies to reduce GHG emissions in your work.

Jack Davidson
President
B.C. Road Builders and Heavy Construction Association

Foreword from Ministry of Transportation and Infrastructure Staff

Taking action on climate change is a top priority for the Ministry of Transportation and Infrastructure. The Province of British Columbia has committed to reducing greenhouse gases by 33 percent by 2020 and 80 percent by 2050. As the transportation sector accounts for almost 40 percent of B.C.'s greenhouse gas emissions, the Ministry is committed to working with all our transportation partners to reduce our carbon footprint. In addition to reducing future emissions, we also continue to work on adaptation strategies to address the impacts of earlier emissions on changes in temperature, storm events, and sea levels.

Our partnership with the British Columbia Road Builders and Heavy Construction Association on reducing emissions from road building activities is a key piece of the climate action solution. It also has many benefits in addition to the reduced greenhouse gas emissions. Many of the best practices in this manual also reduce the amount of fossil fuels being used, saving money on both fuel and maintenance. Through this partnership, we've also explored innovative new techniques, such as alternate fuels, aggregate tarping and warm-mix asphalt, making B.C. a leader in green technology.

One of the greatest benefits has been the opportunity to work collaboratively with the BCRHCA on developing practical strategies that can be used right away on job sites and roads across the province. Applying these guidelines to our projects will no doubt lead to new ideas and innovations, which can be added to future editions of this manual.

We encourage all Ministry staff to read these guidelines and apply them to their work, and to continue to think of new strategies and ideas that should be included. Please feel free to contact us with any questions on these guidelines, or with new ideas that you would like included in the manual.

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1. INTRODUCTION

An efficient, intermodal transportation system is vital to B.C.'s continued economic growth. A key part of this system is our network of highways and side roads that provide access to our communities, forests, mines, ports, and to the rest of North America.

British Columbia is committed not only to building the safest and most efficient transportation system, but also to addressing climate change through aggressive greenhouse gas (GHG) emission reduction targets. To support the province's climate action objectives, the Ministry of Transportation and Infrastructure (MoTI) and the B.C. Road Builders and Heavy Construction Association (BCRBHCA) have partnered to publish these best practices to reduce greenhouse gas emissions for the construction, rehabilitation, and maintenance of B.C.'s highway system.

1.1 BACKGROUND

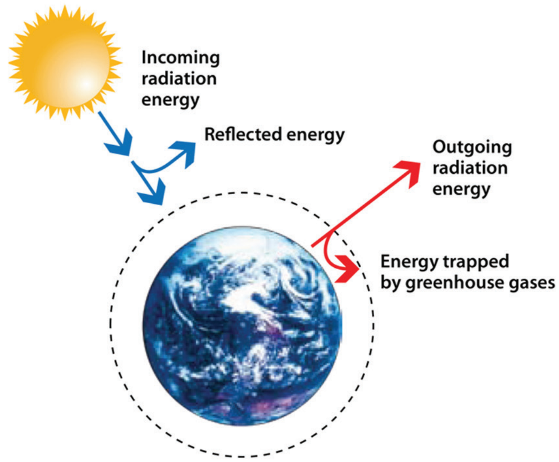
Climate Change

An international panel of respected scientists has concluded that climate change is real.[1] The warming observed over the past century is in part due to the burning of fossil fuels, which release higher levels of carbon dioxide, methane and nitrous oxide—all greenhouse gases. These gases trap solar heat within the atmosphere, like a greenhouse, leading to an overall rise in global temperatures.

B.C. has experienced warming more than twice the global average in many areas. Already, we are facing impacts such as more frequent storms, warmer winters, and longer summer droughts. One specific example of the impacts of climate change has been the pine beetle epidemic. Historically controlled by cold winters, the beetles now survive the warmer winters, which allowed them to spread in greater numbers and devastate our mountain pine forests.[2]

1 Intergovernmental Panel on Climate Change (2007), *Summary for Policymakers, p.5.*

2 Province of B.C. (2008), British Columbia's Climate Action Plan, pp. 6-8.



The Greenhouse Effect

When the sun's energy reaches earth most of the energy warms the atmosphere and the earth's surface. The earth then radiates some of this energy back into space as infrared rays. Greenhouse gases in the atmosphere trap some of the infrared rays before they escape resulting in additional warming of the earth.

Burning fossil fuels, and other human activities, have increased levels of greenhouse gases in the atmosphere. This has increased the atmosphere's capacity to trap energy by accentuating the greenhouse effect and raising global temperatures.

B.C.'s Greenhouse Gas Emissions and Targets

Every year, Environment Canada produces an inventory of greenhouse gas emissions in Canada, broken down by province and by source. As of 2010, the most recent Environment Canada inventory provided data up to 2008.

In 2008, 68 million tonnes (Mt) carbon-equivalent (CO_2e) of greenhouse gases were emitted in British Columbia, of which 25 Mt came from the transportation sector.[3]

The Province has committed to reducing the amount of greenhouse gas emissions by establishing emission reduction targets for 2020 and 2050, and by enshrining these targets in provincial legislation.

Many transportation-related actions will be in place by 2020 to contribute to these targets, including stricter vehicle emission standards, renewable and low carbon fuel standards, and an aggressive expansion of the public transit system.

LEGISLATED TARGETS

The November 2007 Greenhouse Gas Reduction Targets Act entrenched the following committments in law:

- By 2020, B.C. will reduce its greenhouse gas emissions by 33 per cent, compared to 2007 levels.
- By 2050, GHG emissions in the Province will be reduced by at least 80 per cent below 2007 levels.
- By 2010, the B.C. public sector will be carbon neutral. In other words, the government is setting an example and keeping its own carbon footprint as small as possible.

3 Environment Canada (2010), *National Inventory Report 1990-2008: Greenhouse Gas Sources and Sinks in Canada*

A Government-Industry Partnership

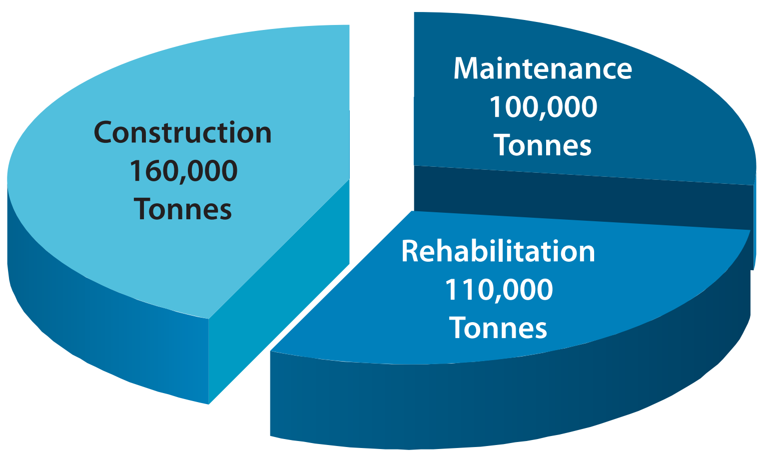
The provincial highway system has been identified as a key area where the Ministry and its partners can take effective action on climate change. How B.C.'s roads and highways are designed, built, operated and maintained can have a significant impact on GHG emissions.

The Ministry and the B.C. Road Builders and Heavy Construction Association (BCRBHCA) have therefore partnered to produce this best practices document, drawing on the collective expertise of four road building sectors —construction, paving, maintenance and service and supply.

The Carbon Footprint of Road Building

In 2008, an analysis of 17 construction and rehabilitation projects around B.C. found that an estimated 370,000 tonnes CO_2e of GHG emissions were emitted through the construction, rehabilitation, and maintenance of the provincial road network. These numbers will vary year-by-year, depending on the amount of work done.

Annual Emissions from
Ministry of Transportation and Infrastructure Road Building Activities



Opportunities for GHG Reduction in the Road Building Sector

This best practices document presents a broad range of strategies available for lowering road building emissions, most of which have the added benefit of reduced fuel use. As a result, many of these emission reduction opportunities result in both financial and GHG emission savings.

Aside from these financial savings, emission reduction activities also provide an opportunity to develop B.C.-based technologies for the road building industry, benefiting both local businesses and communities. Moreover, most GHG-reducing measures provide other important benefits, such as fewer air pollutants and improved worker comfort and public safety.

1.2 PURPOSE OF THIS DOCUMENT

This guideline document presents a series of best practices, developed together by government and industry, to reduce GHG emissions in B.C.'s road building sectors. The practices have been selected to help industry participants cut costs and improve their efficiency, while lowering emissions and other environmental impacts.

The document is intended as a primer for Ministry contractors and internal staff to learn more about the sources of GHG emissions in road building and how to address these emissions most effectively. While focused on the provincial highway system, the best practices are also useful for B.C. municipalities and other road building organizations.

The Ministry and the BCRBHCA have initiated pilot projects to test these best practices. As information becomes available from the pilots and other best practice implementation, these guidelines will be updated and expanded. Where possible, estimates of the cost and greenhouse gas emission savings for the best practices are also included.

Chapter 2 of this document contains an overview of best practices that apply to all areas of road building—these include the purchase, upgrading, and maintenance of vehicles and equipment, anti-idling, and alternate power sources.

Chapter 3 provides a more detailed description of actions that can be taken in the paving sector. These include equipment maintenance techniques that are unique to the paving sector, and a review of the different paving technologies.

2. ROAD BUILDING – CROSS-SECTOR BEST PRACTICES

Some emission reduction strategies apply to all sectors of road building, and are explored in this chapter. These strategies cover the purchase and maintenance of vehicles and equipment, operator behaviour, alternate power and fuels, and the use of weather data.

2.1 RIGHT SIZING ON-ROAD FLEETS

Equipment comes in all sizes, and, ideally, the most efficient piece of equipment is matched to each task. While options may sometimes be limited for specialised equipment, on-road fleets are one area where "right-sizing" can result in fuel savings.

For a pickup truck that travels 50,000 highway kilometres per year, the difference between a 3 litre engine (9.4 litres per 100 km) and a 4 litre engine (10.6 litres/100 km) is 600 litres of fuel per year. At $1.20 per litre, the difference in fuel costs would be $720. The fuel savings also cut greenhouse gas emissions by 1.4 to 1.6 tonnes, depending on the fuel type.

Light Duty Trucks (Pickups)

Depending on the type of road building activity, the largest-sized vehicle may not always be necessary. The cost of fuel should be taken into consideration when selecting a vehicle, along with carrying capacity, winter driving needs and other factors.

In general, larger vehicles have lower (poorer) fuel efficiency ratings than smaller vehicles. However, most jobsite and maintenance activities require the versatility, power, and traction of a truck. Natural Resources Canada (NRCan) maintains an on-line database of the fuel economy of all new vehicles, including pickup trucks. For the 2011 model year, 94 pickup truck models were reviewed. Tables 1 and 2 show that, in general, engine size is linked to fuel efficiency.

The only area where this trend does not hold true is for 5 to 6 litre engines, which are reported to be more fuel efficient than 4 to 5 litre engines.
One theory is that the 4 litre engine has to operate at a higher RPM and lower gear than the 5 litre engine to maintain the truck's speed.

Table 1: Fuel Consumption Ratings for 2011 Pickup Trucks – Highway Driving

Engine Size (L)	Number of Cylinders				
	4 cylinders	5 cylinders	6 cylinders	8 cylinders	Total
2.0–2.9 Litres	8.2 L/100 km				8.2 L/100 km
3.0–3.9 Litres		9.2 L/100 km	9.8 L/100 km		9.4 L/ 100 km
4.0–4.9 Litres			10.4 L/100 km	10.8 L/100 km	10.6 L/100 km
5.0–5.9 Litres				10.1 L/100 km	10.1 L/100 km
6.0–6.9 Litres				12.8 L/100 km	12.8 L/100 km

Table 2: Fuel Consumption Ratings for 2011 Pickup Trucks – City Driving

Engine Size (L)	Number of Cylinders				
	4 cylinders	5 cylinders	6 cylinders	8 cylinders	Total
2.0–2.9 Litres	11.3 L/100 km				11.3 L/100 km
3.0–3.9 Litres		13.1 L/100 km	13.9 L/100 km		13.4 L/ 100 km
4.0–4.9 Litres			14.2 L/100 km	15.4 L/100 km	14.7 L/100 km
5.0–5.9 Litres				14.9 L/100 km	14.9 L/100 km
6.0–6.9 Litres				18.1 L/100 km	18.1 L/100 km

Source: Natural Resources Canada, Office of Energy Efficiency (2010).

http://oee.nrcan.gc.ca/transportation/tools/fuelratings/ratings-results.cfm

Other factors affect fuel economy as well. Vehicles with automatic transmissions typically consume 0.2 to 0.3 L/100 km more fuel than those with a manual transmission. Four-wheel drive vehicles consume, on average, 0.4 L/100 km more fuel than two-wheel drive vehicles.

Manufacturers also continue to innovate and release new hybrid truck models. Hybrid vehicles are generally more expensive to purchase than conventional vehicles. While they can be more fuel efficient, the fuel cost savings of a hybrid will vary, depending on the type of work being done. For some applications, the fuel savings may justify the purchase of the hybrid. Activities in which a hybrid engine could provide the most benefit include:

- Stop-and-go traffic conditions in an urban area
- Situations where the vehicle needs to remain powered or idling on a jobsite
- Trucks that travel unloaded (i.e. low GVW) for significant periods of time

Heavy Duty Trucks

While fuel efficiency ratings do not currently exist for heavy duty trucks (see section 2.2), the selection of the properly specified engine, transmission, axle ratios for the specified load requirement, application and terrain can have a large fuel savings impact over the life of a vehicle. Each engine power setting ordered from the manufacturer has a unique torque, horsepower and fuel-consumption relationship for a defined purpose.

Transmission selection can also have a major impact on lifetime fuel consumption. The most advanced heavy-duty automatics use computer controlled shift points, based on a combination of engine speed, road speed, load and other parameters to shift at optimum engine speed points. This will save fuel and drive train wear and reduces driver fatigue.

Truck and engine manufacturers are continuing to make progress in developing diesel-electric hybrid heavy duty trucks. Some technologies are similar to passenger vehicle hybrids, with electric batteries assisting the diesel engine in providing torque to the wheels, and regenerating during braking.

An alternate technology is a parallel hybrid system which allows the diesel engine and electric motors to work independently of each other. The system allows for electric launch (ideal for creeping operation), and electrification of power steering, air compressor, and air conditioning.

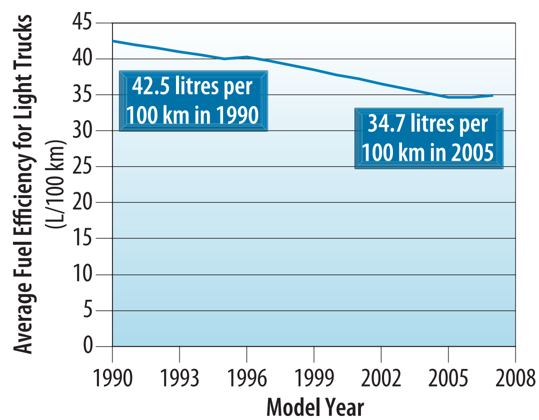
The dual power system can also be used for idle reduction. The battery system can provide the heating, air conditioning and vehicle electrical systems while the engine is off. When the idle reduction mode is active, engine operation is limited to battery charging.

2.2 MODERNIZING FLEETS AND EQUIPMENT

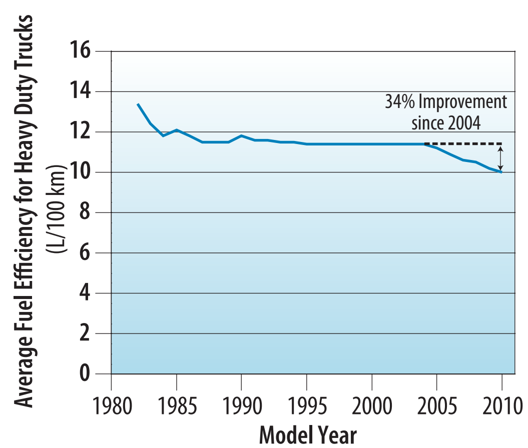
In addition to the fuel-saving benefits of right sizing vehicles, emissions are also being reduced as newer, more fuel efficient equipment replaces older equipment.

On-Road Vehicles

Emissions standards have been in place in North America for light trucks for over 30 years. The figure to the right shows the average fuel efficiency ratings that manufacturers must achieve each year. Since 2004, the fuel efficiency of new trucks sold in North America has improved by 14 percent. (Source data: Office of Energy Efficiency, Natural Resources Canada, 2011)



While no regulations are currently in place for heavy duty trucks, the average fuel efficiency of these vehicles improved by 18 percent between 1990 and 2005. Since 2005, the average fuel efficiency has remained relatively constant, with engine improvements offset by the need for trucks to carry now air quality equipment. (Source data: Office of Energy Efficiency, Natural Resources Canada, 2009)



In 2010, the Canadian and US governments announced that they will be implementing fuel efficiency standards for new heavy duty trucks. The standards will be implemented for the 2014 model year.

When considering the purchase of equipment, the operational fuel savings of the newer models should be weighed against the higher price. The following table summarises some of the operating savings that could be achieved by selecting different model years of pickup trucks. Similar analysis can be done when considering the purchase or lease of heavier-duty vehicles as well.

Year	Average Fuel Efficiency (L/100 km - Highway)	Extra Fuel Costs Compared to 2010 Model Engine		
		50,000 km/yr	75,000 km/yr	100,000 km/yr
1985	12.1	$1,232	$1,848	$2,464
1990	11.8	$1,051	$1,576	$2,102
1995	11.4	$845	$1,268	$1,691
2000	11.4	$812	$1,218	$1,625
2005	11.2	$715	$1,072	$1,430
2010	10.0	n/a	n/a	n/a

For example, a 2005 pickup truck driven 75,000 km per year will cost at least an extra $1,000 per year in fuel costs than a 2010 model. Depending on the number of years that the truck will be used for, it may make sense to consider the newer model.

Aerodynamic Improvements

Air resistance, also known as drag, can account for up to 40% of a commercial truck's fuel consumption. On a tractor trailer, 70% of drag is caused by the trailer. Most of the drag on the trailer occurs at three "hot spots": the front face, rear face, and undercarriage of the trailer. Aerodynamic devices such as rooftop (cab roof) air deflectors, trailer side skirts, boat tails and gap fairings are crucial in efforts to improve a truck's fuel.

Tractor-trailers with poor aerodynamic design and no aerodynamic devices must use more fuel to overcome aerodynamic drag, which leads to poor fuel efficiency and overall performance. Using aerodynamic devices reduces fuel use by 5% or more, per device. To achieve these savings, some of the devices must be used in combination with each other (for example, side skirts should be used with gap reducers or boat tails).

Rolling Resistance

Rolling resistance is the friction between the road and the tires of a vehicle which acts against the vehicle's forward movement. It is influenced by the tire's tread, size, and even its inflation level. A tire's rolling resistance

For a tractor trailer that travels 100,000 kilometres per year, a 5% improvement in fuel efficiency can save 2,000 litres of diesel per year. At $1.20 per litre, the difference in fuel costs would be $2,400 per year. it would also reduce GHG emissions by almost 5.4 tonnes per year.

A 3 percent improvement in a tractor trailer's rolling resistance can save 1,400 litres of fuel over 100,000 kilometres. At $1.20 per litre, the difference in fuel costs would be $1,400 per year. It would also reduce GHG emissions by over 3 tonnes per year.

represents about one-third of a truck's energy, and a significant amount of its fuel consumption.

Purchasing the right tire is important for safety, fuel efficiency, and costs. Low-rolling resistance tires are designed to create less friction and less heat, which reduces rolling resistance and makes vehicles move more smoothly along the road.

Non-GHG Emission Retrofit Technologies

There are several after-treatment exhaust opportunities that could be retrofitted to older diesel engines to upgrade their non-GHG emission standards.

Diesel oxidation catalysts (DOC) are devices that use a chemical process to break down pollutants in the exhaust stream such as volatile organic compounds (VOC) and the soluble organic fraction of the particulates. A typical DOC uses a combination of precious metals (typically platinum and palladium) and base metal oxides to oxidize particulates. Diesel oxidation catalysts are similar to catalytic converters on passenger cars.

Diesel oxidation catalysts can reduce emissions of diesel particulate matter (PM) by 20 percent, hydrocarbons by 50 percent and carbon monoxide (CO) by approximately 40 percent, based on regular diesel fuel. They can be installed on off-road equipment and on diesel equipment that must operate within enclosed spaces (e.g. mines, buildings). A DOC can operate on virtually any engine on any duty cycle, and, as a passive device, is typically maintenance free.

Diesel particulate filters (DPF) are ceramic devices that can be retrofitted in the exhaust stream of older trucks. They require low sulphur diesel, which has been available in Canada since 2006. The high temperature of the exhaust heats the ceramic structure and allows the particles inside to oxidize into less harmful components. They can be installed on new and used trucks, but must be used in conjunction with low sulphur diesel. The combination of PM filters and low sulphur can reduce emissions of PM, HC, and CO by 60 to 90 percent.[4]

A DPF requires sufficient exhaust temperature for proper regeneration. This means that the duty cycle of the vehicle must be evaluated to confirm that the vehicle has the proper duty cycle for a DPF to function properly. A DPF also requires periodic cleaning to ensure proper performance.

4 http://www.epa.gov/otaq/schoolbus/retrofit.htm#emulsified

PM filters come in kit form that includes mounting brackets and an electronic monitoring device. The kits can range in price from $5,000 to $10,000. Although installation time can vary, field experience suggests it takes about 6 to 8 hours to install the filter. PM filters work best on engines built after 1995.

Selective Catalytic Reduction (SCR) is a new technology being considered by North American engine manufacturers to meet the US Environmental Protection Agency (EPA)'s 2010 nitrogen oxides regulations. SCR injects urea through a catalyst into the exhaust stream of a diesel engine, which turns nitrogen oxides into nitrogen and water, which is then expelled through the vehicle tailpipe. SCR technology is a cost-effective and fuel-efficient technology to help reduce emissions. SCR can reduce nitrogen oxide (NOx) emissions up to 90 percent while simultaneously reducing HC and CO emissions by 50-90 percent, and PM emissions by 30-50 percent.

SCR technology may become more prevalent in the United States as both light and heavy-duty engine manufacturers work to meet tougher EPA emissions standards starting in 2009. For light-duty vehicles, urea refill intervals will occur around the time of a recommended oil change, while urea replenishment for heavy-duty vehicles will vary depending on the vehicle specifics and application requirements. Precaution must be made to prevent freezing at temperatures below -11°C.

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Non-Highway Equipment

Non-highway diesel equipment is used throughout all phases of road construction, rehabilitation and maintenance activities. This equipment includes excavators, bulldozers, bobcats, dump trucks, scrapers, loaders, pavement rollers and pavers. The fuel burned by this road building equipment is a significant source of a project's GHG emissions and air pollutants.

Diesel Emission Standards

In 1990, the US Environmental Protection Agency (EPA) introduced a tiered emission-reduction plan for all non-highway diesel engines of all sizes. The tiers are essentially deadlines for engine manufacturers to adopt technologies that achieve lower engine emissions of the NOx and PM. As diesel engines move to Tier 4, emissions will be reduced and brought in-line with highway diesel standards for 2007-2010.

The Tier level's effective dates are as follows for engines between 50 hp to 750 hp (37 kW to 560 kW):

- Tier 1 – 1996 through 2000
- Tier 2 – 2001 through 2006
- Tier 3 – 2006 through 2008
- Interim Tier 4 spans 2008 through 2012
- Final Tier 4 spans 2012 through 2015

Prior to 1999, there were no Canadian regulations applying to non-highway diesel engines. In 2000 Environment Canada began regulating off-road diesel engines to meet US EPA Tier 1 standards through voluntary agreements with engine manufacturers. In 2005, the Canadian Off-Road Compression-Ignition Engine Emission Standards were introduced for model years 2006 and later years, which approximately align themselves with the EPA Tier 2 and Tier 3 standards.

With the introduction of Tier 2 EPA emission standards, non-highway engine manufacturers have worked to improve fuel efficiency as a strategy for meeting the new emission standards. This has led to some manufacturers:

- Phasing out mechanical fuel injection systems in favour of high-pressure common rail systems, which provide electronically controlled fuel injection timing.
- Automatic low idle mode switches an idling engine to a low idle if an operator allows a machine to stand unused for a period of time.
- Advanced technology in engine cooling designs, including high-performing fan blades that use less energy than older model designs.
- Development of more sophisticated hydraulic functions through load-sensing hydraulics that automatically or manually run the engine in an 'economy' or 'power' mode. Operators claim they can use the 'economy' mode for about 30 to 40 percent of the time for light-duty work loads.

Improvements in fuel efficiency have resulted in fuel savings of 10 percent up to 20 percent (Equipment Today, July 2008). When sourcing equipment, project staff should seek information from suppliers on the fuel efficiency features of comparable pieces of equipment, and consider whether the fuel cost savings offset any differences in equipment costs.

Emerging Technologies

Diesel-electric power systems are commonly used in locomotives, submarines, ships and large mining trucks. This technology uses a diesel engine connected to a generator that powers electric motors to propel the vehicle. The diesel engine runs at an optimal speed which optimizes fuel economy and minimizes emissions. The electric motor eliminates the need for a transmission.

Diesel-hybrid power systems include a battery to store electric power, and offset some of the diesel engine's power needs. The modern hybrids available today are using newer technologies such as regenerative braking and power-on-demand controls to reduce engine size to meet peak load demands. The electric motor derives its power from an alternator or generator that is coupled to an engine and an energy storage device (batteries or super capacitors).

There are four benefits potentially found in hybrid designs:

- **Smaller Engines:** In diesel hybrids the largest gain in efficiency comes from using a smaller, more efficiently operated engine.
- **Constant Engine Speeds:** In a hybrid application, the engine can run at the engine's best power output. Emissions are reduced because the engine can be tuned to minimize emissions at that optimal speed.

If a loader burns 45 litres of diesel per hour, a hybrid engine could reduce fuel consumption by 4.5 to 9 litres per hour. At $1.20 per litre, this would translate into a savings of $540 to $1,080 per 100 hours of run time, and 1.2 to 2.4 tonnes of GHG.

- **Regenerative Braking:** Regenerative braking recovers energy normally lost as heat during braking, and stores the energy in batteries or capacitors. The engine-powered generator is used to produce electric energy only when the stored electrical energy does not provide enough power on demand.
- **Power-On-Demand:** Another feature that reduces emissions is the ability to temporarily shut off the engine during idle, yet still allow low-speed travel by the electric motor.

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2.3 ALTERNATE FUELS

There are several options for transportation fuels to power vehicles and equipment. Four of the most popular are gasoline, diesel, propane and compressed natural gas (CNG). All of these fuels are available in British Columbia, with supply, quality, and price varying by region.

Gasoline and Diesel

Gasoline and diesel are the most widely used fuels, with gasoline being used for passenger cars, and diesel being used for larger and heavier-duty engines. However, there are many classes of vehicles where fleet managers have a choice between the two fuels. One example is medium-duty ¾ and 1 tonne pickup trucks. The Ministry of Transportation and Infrastructure uses this type of vehicle for avalanche control and communications. Since 2004, the Ministry has been replacing gasoline powered trucks with diesel-powers models. As diesel engines are generally more efficient than gasoline engines per unit of fuel, both fuel consumption and GHG emissions per kilometre have been reduced. The use of low-sulphur diesel and emission filters has also alleviated many of the pollution concerns from previous years.

Propane and Compressed Natural Gas (CNG)

Two other fuels—propane and CNG—are also available and in use in British Columbia. The boxes below summarise some of the key facts about these fuels.

Propane

- When compared to gasoline, emits roughly 65 percent of GHGs per unit of volume, and 89 percent of GHGs per unit of energy
- One litre of propane has only 73 percent of the energy content of a litre of gasoline, resulting in larger tanks or shorter range
- Propane is non-toxic and does not contaminate the environment when spilled
- The price of propane is typically two-thirds the price of gasoline.
- Vehicles can be purchased from manufacturers with propane system factory installed.
- Vehicles can also be retrofitted to "bi-fuel" vehicles to run on both propane and diesel gas.

Compressed Natural Gas (CNG)

- CNG has been shown to reduce GHG emissions in US tests by 21 to 26 percent, compared to gasoline
- CNG has a lower energy content than gasoline or diesel, resulting in larger fuel tanks or a shorter range.
- CNG is frequently used in shorter-range fleets that "return to base" such as transit or sanitation, where a single fuelling station is used for all vehicles.
- CNG vehicles typically cost more than comparable gasoline vehicles, but have been shown to have lower maintenance costs.

Summary

With a wide variety of fuels available, it can be advantageous for fleet and equipment managers to consider what might work best for their purposes. Gasoline and diesel vehicles have the longest range and are the most widely available, while propane and natural gas have lower fuel and maintenance costs, and also have lower greenhouse gas emissions.

For some applications, such as medium duty pickup trucks, all four fuels are an option. Many agencies, such as the Ministry of Transportation and Infrastructure, are purchasing bi-fuel vehicles that provide the flexibility to use both conventional and alternate fuels, depending on availability and price in the field.

2.4 MAINTAINING TRUCKS AND EQUIPMENT

Diligent maintenance of excavators, loaders, pavers, rollers, haul trucks and other vehicles and equipment will help reduce fuel use, while improving worker comfort, performance and productivity. Developing and implementing a comprehensive maintenance schedule for trucks and equipment can be one of the most cost-effective ways to control GHG emissions.

Proper maintenance consists of regular tune-ups of vehicles and equipment and checking and replacement of worn or damaged parts. Daily maintenance is also a priority, such as a truck walk-around and greasing of equipment prior to the shift start.

All trucks and equipment should be maintained to manufacturers' standards for their required load and specific use. A detailed maintenance schedule and checklist are important tools for ensuring thorough maintenance.[5]

Key maintenance areas for fuel efficiency are outlined below.

Proper tire inflation and axle alignment alone can improve fuel efficiency by 3 to 4 percent. This would translate into a fuel saving of up to $1,900 per 100,000 km driven, and a 4.3 tonne reduction in GHGs.

IMPROVING FUEL EFFICIENCY THROUGH VEHICLE MAINTENANCE

Filter replacement – For all engines, clean air and fuel are essential to efficient operation and fuel combustion, as well as engine performance and long life. In addition, energy and fuel are wasted as the engine pushes the air of fuel through clogged filters. Air and fuel filters should be replaced at appropriate intervals. In the dusty environment of road construction and maintenance, air filters need to be checked more frequently than in highway applications.

Air leak detection – A reduction in truck engine power or boost could indicate a leak in the charge air system, which affects fuel economy. Charge air hoses and clamps and air intake manifolds should be inspected for leaks, cracks and chafing damage. Ideally, this should be done on a daily basis at time of shift start-up.

Switching to synthetic lubricants – A wide range of synthetic oils, fluids and greases can be used in diesel engines, transmissions, gears, hydraulics, compressors and other machinery. Compared to petroleum-based lubricants, these products have shown that they can increase fuel efficiency through reduced friction, and provide other benefits such as less engine wear and longer vehicle and machinery life. Based on the manufacturer's recommendations

5 See an example of a safety and maintenance checklist for a truck walk-around in "Making Haul Truck Maintenance Routine."

and the operating conditions, the lowest appropriate viscosity should be selected. There have been some concerns that the lower friction characteristics may make them unsuitable for initial engine break-in and older transmissions. However, many new engines now come with synthetic oil as a factory fill and specialty synthetic transmission fluids are available for non-synchromesh transmissions.

Tire inflation – Under-inflated tires on trucks and equipment mean greater rolling resistance, harder work for the engine and more fuel burned. Over-inflated tires bounce equipment upward and increase wheel spin, both of which waste energy. Tire pressure should be measured at least once a week where trucks or equipment are in regular use. Tires should be inflated to the manufacturer's recommended pressure and checked daily for wear and damage. To get the most accurate pressure readings, tires should be inflated cold, first thing in the morning, rather than after the truck has been driven and the air in the tires has expanded.

Proper axle alignment – Misaligned axles (front and rear) can also increase rolling resistance, fuel use and tire wear. The more time a heavy truck spends at highway speed, the greater the impact of axle alignment on fuel economy. All haul trucks should have their axle alignment checked and adjusted periodically or when any abnormal tire wear appears.

Fuelling practices – For trucks, the quality and quantity of diesel fuel can also have an impact on fuel efficiency. Fuel quality should be monitored, as dirty fuel causes the fuel injectors to clog or exhibit improper spray pattern. Fuel tanks should be filled to 95 percent of capacity to reduce spillage and allow for expansion.

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2.5 IDLE REDUCTION EQUIPMENT

If idle reduction equipment is properly selected for the vehicle's operating characteristics, it can save fuel and GHG emissions from reducing the idling time of the main engine. There is range of technologies available that may be suitable for use in on-highway vehicles and off-highway equipment.

Automatic Shut-Down/Start-Up Systems

Electronic diesel engines can be programmed to shut down after a preset time period. This requires changes to the engine control module, which can be done at little cost by the truck dealer, engine manufacturer, or truck fleet manager. The system automatically controls the engine starting and stopping on a set time interval, ambient temperature and state of battery charge. These devices are available from some of the engine manufacturers and according the EPA cost in the order of $900 – $1,200.[6]

Battery Powered/Engine-Off Systems

These systems can keep the vehicle cab warm for up to several hours by continuing to circulate the heated coolant from the engine to the cab heater operating on a separate battery system. However most of these systems provide heating and evaporative or condensing air conditioning capability and are relatively large and are designed to be installed under the sleeper bunk.[7] Some of these systems have refrigeration connections with the trailer (reefer units). With the addition of air conditioning, which requires twice as much power than for cab heating, most of these systems are in the $3,500 to $7,800 range.

Diesel Fired Heaters

Diesel-fired heaters are small, lightweight heating devices that burn diesel fuel from the vehicle tank or from a separate tank. These units cost $1,000 to $3,000 and are available at the vehicle manufacturer level. The heaters are thermostatic controlled and burn fuel at a rate of 1 US gallon every 20 hours. The more expensive systems have separate auxiliary battery systems.[8] Larger models can keep the engine coolant warm in cold climates and also work as cold starting assists. These units burn more fuel, about 1 US gallon every 4 to 6 hours.

6 BBW, Inc., Cummins Engine Company, TAS Distributing, Inc.

7 Autotherm Division Enthal Systems, Bergstrom Inc., Driver Comfort System, Idle Free Systems, LLC, Safer Corporation, Sun Power Technologies

8 Automotive Climate Control (ACC), Espar Heater Systems, Webasto Product North America, Inc.

Auxiliary Power Units

Auxiliary power systems (APUs) are essentially small generator sets (5-10 hp) which produce greater amounts of stand-alone heat and power. APUs can provide enough power to run air conditioners, heaters, and appliances.[9] There are many models available, including some with air compressors, air-driven engine starters, oil pump for pre-lubricating the engine and inverters for AC 120 power. Most units can produce between 3.0 and 6.0 kW, enough to power intensive air conditioners and other accessories.

External Electrification Systems

External electrification refers to a technology that provides the truck driver with climate control and other needs from an external 120 VAC power supply. This technology can be combined with the above systems. The external electrification system is usually used at a truck stop that has electrification facilities.

9 Auxiliary Power Dynamics, LLC, Black Rock Systems, Idlebuster, Kohler, Pony Pack, Inc, to name a few manufactures.

Case Study – Anti-Idling

To illustrate the cost-effectiveness of anti-idling equipment in a highway situation, three scenarios were examined:

1. Don't purchase an anti-idling device—just use the truck's engine for idling.
2. Purchase a diesel fired heater (DFH) to provide winter warmth.
3. Purchase an auxiliary power unit (APU) to provide winter warmth, summer air conditioning, and electric power for the cab.

The following table provides some typical cost and fuel consumption information for these devices. For the purpose of this exercise, a 7 year investment period was used, and an interest rate of 5 percent. According to manufacturers' claims, anti-idling devices have service lives of up to 12 years.

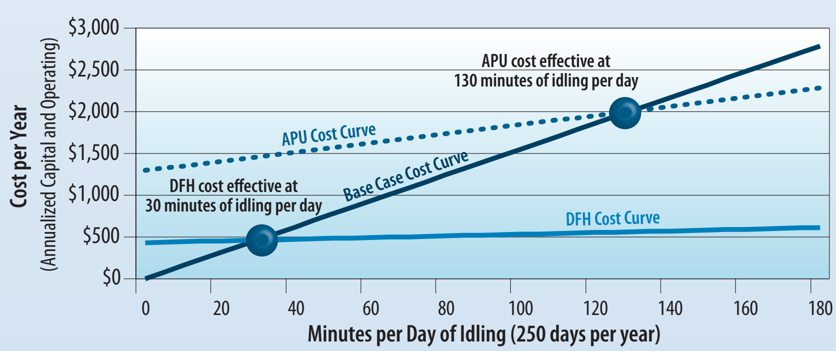
Scenario	Capital Cost	Investment Period	Annualized Capital Cost	Fuel per hour of idling
1. Use engine	$0	7 years	$0	3.1L/h
2. DFHs	$2,500	7 years	$432	0.2 L/h
3. APU	$7,500	7 years	$1,296	1.1 L/h

Using this information, the "cost per minute of idling" can be calculated for the three scenarios. This is illustrated in the graphic below. From this graph, a couple of conclusions can be drawn:

A DFH can be a cost effective way to reduce idle-related fuel consumption, but would only be used during the winter months

An APU becomes cost effective for long-haul trucks idling two hours per night, and can be used year-round as it provides both heating and cooling.

As all anti-idling devices have different costs, power outputs, and fuel consumption ratings, the device distributors will be able to provide more specific information on the potential payback periods for their devices.



2.6 DRIVER BEHAVIOUR

Among the many factors that can affect operational efficiency, improvements in the driving techniques of truck and equipment operators have been shown to be the most significant measure for reducing operating costs, fuel use and emissions. It is estimated that drivers trained in fuel-saving behaviour can increase fuel economy by 15 percent.

There are a number of opportunities for contractors and their workers to improve vehicle and equipment operation. Contractors can consider implementing training programs to refresh driver or equipment operator skills and help them understand the effects of operating strategies on fuel efficiency. Potential areas of improvement include:

Speed management (on-road) – Truck speed has the single largest operator impact on fuel economy. As speed increases over 80 km/h, more and more horsepower goes to overcoming aerodynamic drag. For a highway truck, each 2 km/h increase in speed above 90 km/h decreases fuel economy by about 2 percent.[10]

At higher speeds, the efficiency losses are typically greater for haul trucks than highway trucks because of the lack of aerodynamic add-ons and irregular loads. In addition, drivers can also

- Maximize the use of cruise control on flat terrain (but not on hills), and choose a lane that avoids having to turn it off and on.
- Avoid rapid acceleration and shift gears progressively on a manual transmission.
- Cut down on sudden braking and coast in gear as far as possible to slow down.

Many contractors and trucking companies have set policies for their drivers to reduce cruising speeds, or use electronic speed limiters (engine governors) to mechanically manage speeds.

Other operating techniques (on and off road) – There are numerous strategies for drivers and equipment operators to further improve fuel economy, for example:

- Operate in the highest gear unless otherwise required for off-road applications (i.e., keep the engine below 1,500 rpm and downshift around 1,100 rpm).
- Avoid idling and minimize engine warm-up (e.g., 5 minutes) and cool-down times[11]

10 See "Secrets of Better Fuel Economy."

11 See Section 4.4 for information on anti-idling equipment.

- Minimize accessory loads on the engine (air conditioning, fan on-time, etc.)
- Using electronic devices such as fuel economy displays and boost gauges to provide feedback on fuel use and allow drivers to make adjustments.

Engineers for one excavator manufacturer report that operators have a tendency to keep bumping hydraulic levers in an effort to lift beyond the equipment's capacity.[12] They estimate that one less hour out of ten of this activity would save about 225 gallons of fuel annually. As in the case of trucks, new excavator designs are incorporating features such as manual or automatic "Economy"/"Power" modes and advanced hydraulic controls to enable more fuel-efficient operator behaviour.

Vehicle and equipment mobilization – Contractors can plan their operations to more efficiently mobilize trucks and equipment for fuel economy. For example, wherever feasible they can shift more fuel-efficient vehicles and machinery into higher duty cycles, while less efficient ones can be reserved for lower duty tasks. The number of required trucks on hand can be kept to a minimum (typically 10 percent extra) and backhauls can be used as much as possible. Better communications between the jobsite, asphalt plant and haul units is also vital. Weights can also be minimized by removing any unnecessary equipment or loads, and by removing items like roof racks when not in use.

Route optimization – Truck route management is another key factor in fuel efficiency. A Global Positioning System (GPS) navigation system can be used to optimize haul routes between the plant and jobsite. Haul roads can be improved and traffic congestion managed to enable faster travelling times. You can also plan ahead by using services like DriveBC or other weather forecasts to learn about weather or construction delays.

Fuel use tracking – In addition, contractors can develop a tracking system to record fuel consumption by vehicle and equipment item, to help identify fuel leaks and inefficient trucks and machinery. Then, as operating and equipment improvements are made, the impact on fuel consumption and emissions can be assessed and used to inform future decisions.

12 Komatsu, cited in "Manufacturers Begin to Tour Fuel Efficiency."

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2.7 SOLAR AND GRID-BASED POWER

Solar Power

Solar power is being increasingly used in the road construction industry to power changeable message signs. This new technology is replacing the older portable changeable message signs (PCMS), which are powered with diesel or gasoline-fuelled generators. This new generation of solar-powered message signs function with lower operating costs, while eliminating GHG and other emissions from the gasoline or diesel generators they replace.

The new generation of solar-powered PCMS do not require fuel, or any labour required for fuel filling or fuel storage. They are powered by photovoltaic (PV) cells, which produce DC electricity when light shines on their surface. Most units can last between 20 to 30 days without sunlight.

The PV cells power light-emitting diodes (LED), made of a special semiconductor material that produces light when a small electric current is applied. While LEDs are more expensive to produce than incandescent lights, they are very efficient and produce light at very low voltages. LEDs can be designed to emit specific colors (e.g. red, green amber), without filtering broader spectrum light which was the previous approach to producing coloured light for traffic control.

Overcast weather and low light conditions does not necessarily have a major effect on power output from PV cells. This is because solar energy contains infrared and ultraviolet radiation, as well as visible light. About half of the solar energy the PV cells receive is visible light and rest is invisible infrared and ultraviolet radiation.

Solar PCMS are designed to fully power the LED lights and have the capacity to provide a charge to the batteries in the lowest light conditions. This optimizes life expectancy of the batteries and minimizes the need for external battery charging. Most systems are equipped with on-board 120 volt charging system that will recharge the battery bank in 24 hours or less. A solar PCMS is usually fitted with eight batteries, but up to 12 batteries can be installed depending upon the requirement for self-sufficiency. The batteries are heavy duty deep cycle 6-volt DC (225 amp-hour) batteries wired in series to provide a 12 volt power supply.

The boxes on the next page illustrate the operational savings associated with solar power. As these figures only compare operating costs, contractors that have diesel or gasoline powered message signs may decide to wait until their fossil-fuel units wear out. However there are conversion kits available from manufacturers which maybe a more cost-effective investment than immediately replacing a fossil-fuelled PCMS, which may have significant remaining life in the unit.

Comparing the operating costs of CMS – 1,500 hours per year, over 15 years

Conventional CMS	Solar powered CMS
• 600 litres of fuel per year • engine replacement every 5 years • routine engine servicing, such as oil changes, oil, fuel and air filter changes • Trailer maintenance	• Replace 8 batteries every 5 years • Trailer maintenance
$8,400 per year per CMS	**$2,100 per year per CMS**

As solar powered CMS do not emit any GHGs, the emission savings include all of the gasoline fuel that otherwise would be burned in operating the sign. For a sign operating 1,500 hours per year, this is estimated at 1.6 tonnes per year.

Electrified Gravel Pits

Gravel pits throughout the province are used to maintain the provincial highway system. Most of these pits are used intermittently, but some are used more intensively. Although these pits are generally accessible from the highway, in most cases there is no power infrastructure on site.

When aggregate is needed, contractors must haul in diesel-electric generators to power their crushers, screening and paving plant equipment. A typical diesel generator achieves an energy conversion in the order of 30 to 33 percent. This is the percent of energy in the diesel fuel the gen-sets can convert to useful energy in the form electricity. The majority of the energy in the fuel is wasted through frictional and thermal losses in the diesel engine and some small losses in the generator.

If it were possible to supply grid-based electricity to some of these larger pits, the fuel costs, GHG emissions, and air pollutants could be reduced by eliminating the need for on-site diesel electric generation.

The business case for electrifying a gravel pit would have to take several factors into account, including:

- The cost of installing electrical power infrastructure
- The comparative costs of electricity and diesel fuel
- The rate of annual gravel extraction
- The amount gravel contained in the pit
- The greenhouse gas and air pollutant savings from using electricity.

The following case study illustrates the costs and benefits of supplying electrical power to a large gravel pit. To provide a more realistic case study, the costs and quantities for the Teko Pit south of Fort St. John were used. However, this simplified case study is for illustrative purposes only, and does not take into account any location specific issues, such as the proximity of an electrical supply or the costs of providing it to this particular site.

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Solar Portable Changeable Message Sign Manufacturers' Websites – ADDCO Corporation, American Signal Corporation, K & K Systems, U.S. Traffic Corporation

CASE STUDY – GRAVEL PIT ELECTRIFICATION

Based on the 1999-2008 history at Teko Pit near Fort St. John, a profile was established for a typical high-use gravel pit in B.C.:

- Average annual aggregate extraction (1999-2008): 350,000 tonnes
- Highest annual aggregate extraction (2000): 740,000 tonnes
- Maximum daily extraction rate: 8,500 tonnes per 12 hour shift
- Current mobile diesel power use per day: 24,000 kilowatt hours

To justify the installation of grid-based electricity at a gravel pit, the case would need to be made that the cost and emission savings from the use of the electricity outweigh the capital cost of installing the electrical supply.

As a first step, the operational costs of diesel and grid-based electrical power were compared:

Comparison of Operating Costs

	Mobile Diesel Power	Grid-based Electricity
Costs of power generation	53¢ per tonne of rock	14¢ per tonne of rock
Costs per day for power	$4,500 per day	$1,200 per day
Costs per average year for power	$185,000 per avg. year	$49,000 per avg.year

Comparison of Emissions

	Mobile Diesel Power	Grid-based Electricity
Diesel Fuel consumed/day	3,500 litres/day	0 litres/day
GHGs /day from diesel	25.6 tonnes GHG/day	0 tonnes GHG/day
GHGs/day from hydropower	0 tonnes GHG/day	0.4 tonnes GHG/day
Total GHGs per year	1,050 tonnes GHG/yr	15 tonnes GHG/yr

The analysis shows that, once in place, grid-based electricity is more cost effective and results in lower emissions, and would save approximately $136,000 per year in power costs. Over 1,000 tonnes of GHG emissions would also be saved.

The following table illustrates the upfront capital that could be invested at a pit where electrification would save $136,000 per year, and still break even over the life of the gravel pit.

The analysis shows that, for a large volume pit, capital investments could be considered. Contractors and Ministry staff could consider more detailed investigations of potential pits to determine if there is a positive return on investment.

Gravel Pit Life	Break-Even Capital Investment
10 years	$1.1 Million
20 years	$1.7 Million
30 years	$2.1 Million

2.7 ROAD WEATHER INFORMATION SYSTEMS

Weather conditions and pavement surface conditions are key pieces of information for staff that are maintaining and rehabilitating the road network. Collaboration between contractors and the Ministry of Transportation and Infrastructure has resulted in a comprehensive weather information system that provides all partners with frequent and reliable weather and pavement information.

B.C.'s Road Weather Information System (RWIS)

Weather Station in Kicking Horse Canyon on Highway 1

British Columbia's Road Weather Information System (RWIS) is a web-based portal that provides access to hourly data from three distinct networks of stations—Road Weather Stations, Remote Avalanche Weather Stations, and Frost Probe Stations. The RWIS web site is at https://apps.th.gov.bc.ca/saw-rwis. Access to the site is controlled through the B.C. Electronic Identification (BCeID) system—contractors need to obtain a BCeID to access the data.

The Road Weather Network (61 stations as of early 2011) is specifically designed to provide data and forecasts to aid in decision making related to winter highway maintenance. Each station has a standardized set of instruments that measure a complete set of atmospheric parameters as well as a set of pavement sensors. Pavement sensing consists of measuring the surface temperature of the asphalt, the surface condition (dry, wet, snow, ice), and the freezing point of any moisture that may be present on the sensor's surface, as well as a sub-surface temperature sensor at a depth of 25 cm.

In addition to the hourly data, the Ministry provides a forecast service for each Road Weather Station through a contract with Northwest WeatherNet Inc. Site specific forecasts are issued twice daily for each station, at 5 AM and 3 PM. Each issue contains hour by hour pavement temperature forecasts and pavement condition forecasts (dry, wet, wet and precipitating, dew, frost, snow, or ice) for the next 24 hours, and a text description of the weather over the next three days.

Benefits of Weather Information

The combination of accurate hourly data from the station and its pavement sensors, and the forecasts of future pavement temperatures, conditions, and weather enable maintenance personnel to effectively plan their winter maintenance activities for maximum efficiency. Some potential benefits include:

- Optimized and targeted maintenance strategies based on forecasted conditions can lead to a reduction in distances travelled and materials used, while maintaining highways to established standards.
- Selecting condition-specific surface treatment materials (sand, salt, salt solutions, or combinations of these) and careful timing of applications can lead to improved de-icing.

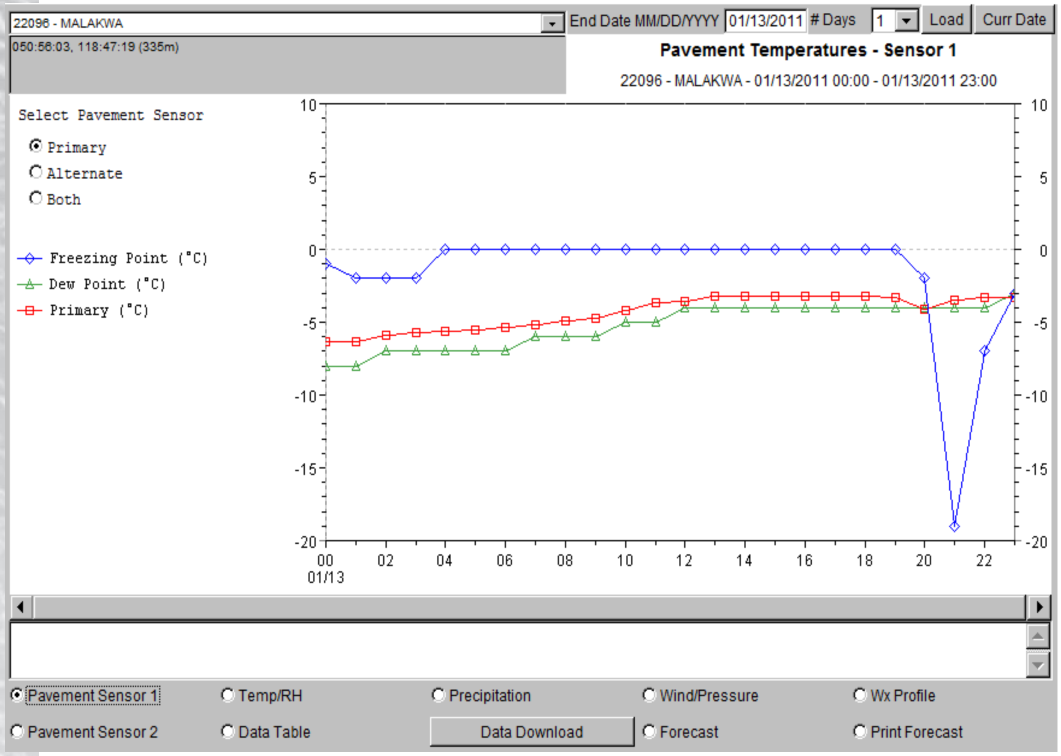
The most effective strategies involve preventing the formation of a strong bond between accumulating compact snow and the pavement surface by applying some form of salt to the pavement surface before the snow starts to accumulate. This enables removal of the compact snow after the storm has ended with much less work than if the snow is strongly bonded. In turn this translates to less equipment usage, less GHG emissions, and overall cost savings while accelerating the return to safe winter driving conditions after a storm.

In addition to the winter applications listed above, paving contractors can also take advantage of weather data in the summer time. The data can provide weather forecasts that allow contractors to plan their jobs, and pavement temperature data that allows them to calibrate their mixes and machinery.

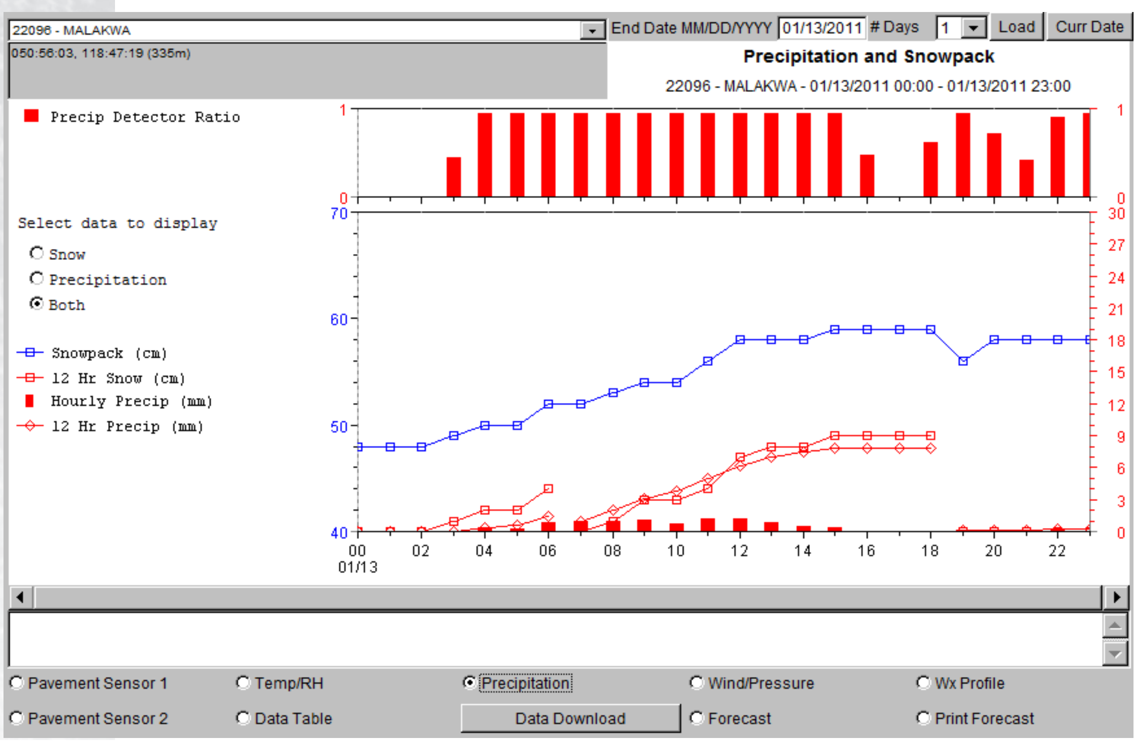
Examples of Data from B.C.'s RWIS

The next two pages provide some examples of the output from B.C.'s RWIS system.

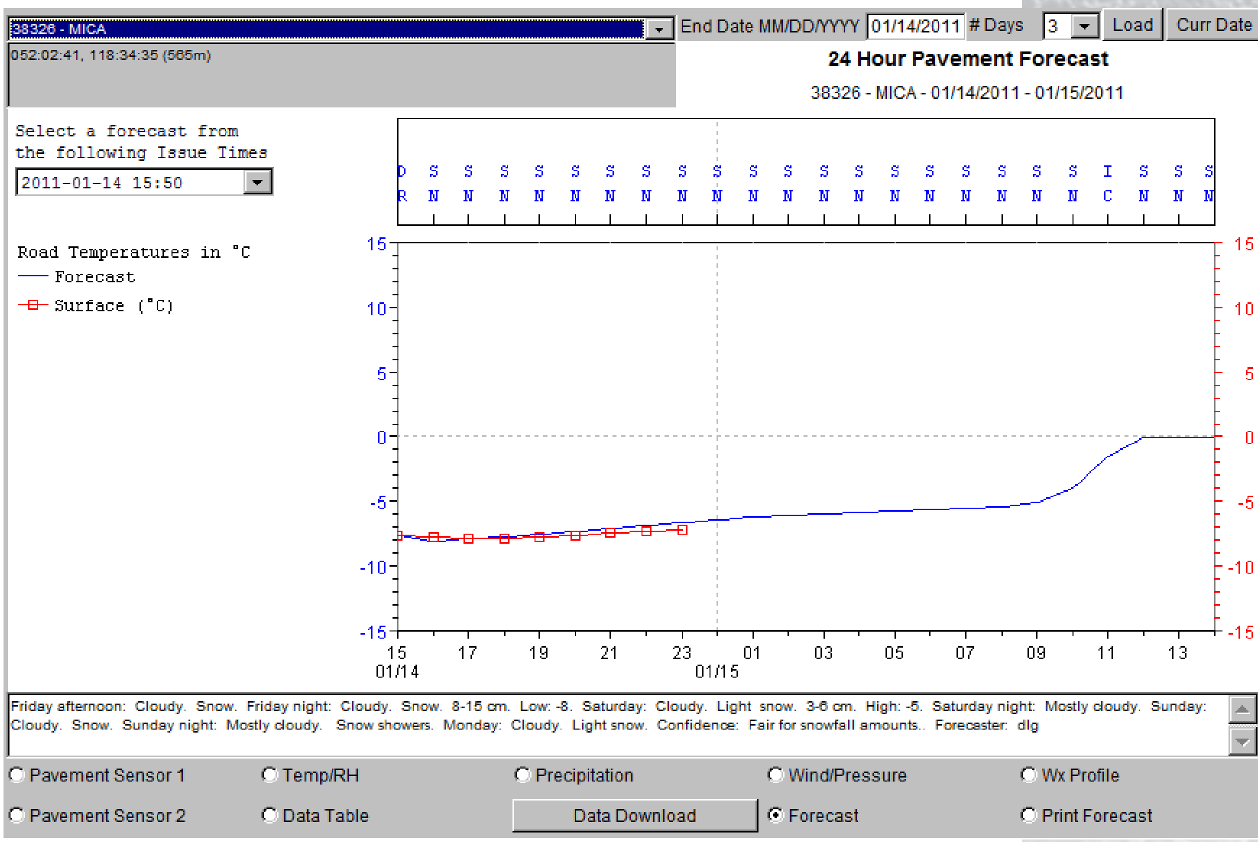
Graph of pavement surface temperature, dew point, and freezing point temperature.



Graph of snow and precipitation data. Upper 'Precip Detector' graph represents the portion of each hour during which precipitation was detected.



Site specific Road Weather Forecast



3. PAVING AND CONSTRUCTION SECTOR

3.1 OVERVIEW

Hot-mix asphalt (HMA) is produced from a mixture of aggregate (crushed stone, gravel and sand) and asphalt binder (asphalt cement). Typically, aggregates make up 94 to 96 percent of the mix and the remainder is the black asphalt cement (AC). An urban arterial road would generally use about 1,000 tonnes of asphalt per lane-kilometre: 950 tonnes of asphalt aggregate and 50 tonnes of AC.

Typical portable asphalt plant

There are two basic types of asphalt manufacturing facilities: batch plants and drum plants. In a batch plant, the aggregate is screened, stored (in hot bins), weighed and mixed with the asphalt cement. In a drum plant, the mix happens continuously and requires storage in insulated silos before transportation to the paving site. Both plant types can be stationary or portable. The following description explains the general process and equipment for a portable drum-mix plant, as typically used in a Ministry rehabilitation paving project.

Aggregate Preparation

In advance of asphalt production, the aggregate is extracted from the gravel pit bank and crushed and screened to meet the Ministry specification for the asphalt mix. The processed aggregates are stored in separate stockpiles in different size aggregations for subsequent blending to meet the design mix.

Plant Mobilization and Set-up

A typical production process plant may require more than ten large trucks to relocate a portable plant to a new site. Once on site, the plant is assembled with components that include the cold feed bins, conveyor to the drum dryer, baghouse, AC cement tanks, fuel tank for the diesel-generator, control house, asphalt mix conveyor and hopper assembly (i.e., storage silo) to load the trucks for shuttling the hot mix to the paving site.

Cold Feed Bins and Loaders

Once asphalt production begins, the loader(s) transport the sorted aggregate to the cold feed bins. These bins are used to accurately proportion the aggregate by size gradations required by the mix design. The amount of each aggregate gradation is controlled by a combination of the gate opening at the bottom of the bin and conveyor belt speeds. Because drum plants produce mix continuously, a weigh scale is used to weigh the aggregate before it enters the dryer, so that the amount of asphalt cement can be accurately added—about 4 to 7 percent by weight of dry aggregate.

Power Generation

Since most paving plants are located in aggregate pits without grid power, they must self-generate their electricity on site. This is done by large trailer-mounted diesel-electric generators (called "gen-sets") that supply all the power to run electric motors, pumps, electric heaters, lighting and control equipment. The gen-set is fed from a large trailer-mounted diesel fuel tank. In some cases, the fuel tank trailer also supports the control booth, which allows the operator to oversee the dryer and truck loading operation.

Emissions Control

As hot air passes through the aggregate in the dryer it picks up fine sand and dust particles. Most of these particles are removed by the emissions control system, or baghouse, before the air goes into the atmosphere. The fine sand and some dust are collected and can be returned to the mix.

Designed to handle heavy particulate loads, a baghouse usually consists of a blower, particulate removal system and filter-cleaning system. The particulate-laden hot exhaust gases from the dryer travel through a large overhead duct and into the baghouse and pass through fabric bags that act as filters. These bags can be of woven or felted cotton, synthetic or glass-fibre material, in either a tube or envelope shape. The baghouse filters can achieve a collection efficiency of more than 99 percent for particulates.

Asphalt Cement Tanks

The asphalt cement (AC) is delivered in insulated tanker trucks and must be offloaded before it cools and begins to thicken at about 120°C (248°F). Upon arrival, the tanker trailers are offloaded and the AC is transferred into heated tanks to maintain the desired viscosity. The tanks are heated with diesel-fired heaters to maintain a high uniform temperature of about 150°C (300°F), so that the cement is viscous enough for pumping into the aggregate dryer mixer.

Waste Oil Fuel Tanks

Portable plants using waste oil have the fuel delivered in tanker trailers to the site and positioned at the burner end of the aggregate dryer. Typically, two tanks are interconnected with a valve and hoses to large filters and the fuel is pressurized and electrically heated to attain the burner manufacturer's recommended viscosity.

Aggregate Dryer

The pre-measured aggregate is conveyed into the aggregate dryer. Aggregates are first dried of their ambient moisture—usually 3 to 6 percent—and heated as they tumble through a hot air stream. The rotating drum dryer contains "flights" that lift and spread the aggregate in a veil to enable heating and drying of the aggregate before mixing with the liquid asphalt at the lower end of the drum. The aggregate is typically heated to temperatures ranging from 135°C to 163°C (275°F to 325°F) and then coated with asphalt cement. The hot air is created by a burner and is pulled through the drum by a fan.

Aggregate Mixing

In a counter-flow dryer, the aggregate flows in the drum opposite or counter to the direction of the burner flame. The liquid AC mixing zone is located behind the burner flame zone, which acts to remove the coated aggregate from direct contact with hot exhaust gases. Because the aggregate and liquid AC are mixed in a zone behind the hot exhaust gas stream, counter-flow drum mix plants will likely have lower volatile organic compound (VOC) emissions than parallel-flow drum plants.

Hopper Storage

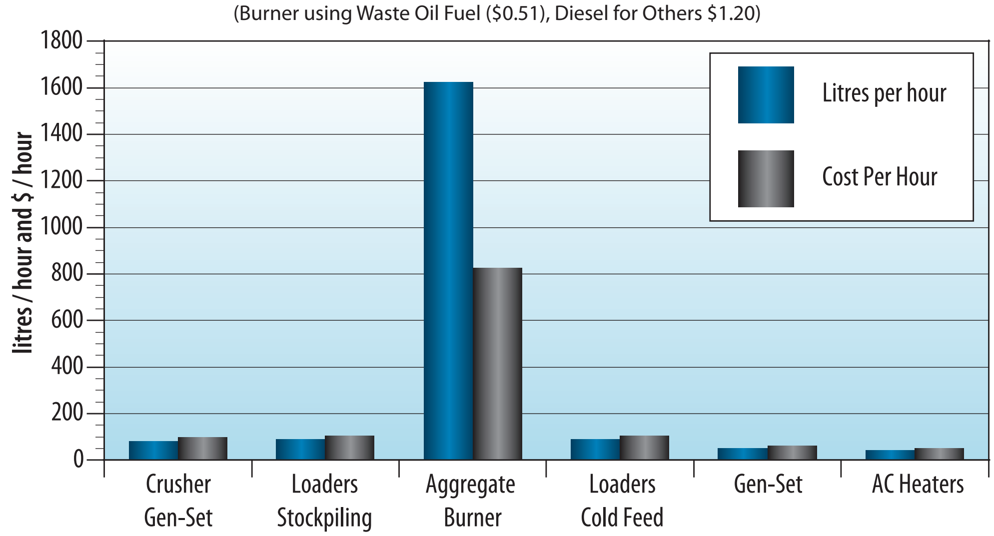
After mixing, the asphalt is removed from the lower end of the drum and conveyed to a storage hopper, where it is gravity loaded into trucks.

Energy Use

In their various components, asphalt plants use waste oils, heavy fuel oil, diesel fuel, propane, natural gas and electricity. Energy use is governed by many variables, from ambient operating temperatures and moisture content of aggregates to the efficiency of the manufacturing process itself.

Typical Mobile Asphalt Plant Energy Use and Cost/hr

(Burner using Waste Oil Fuel ($0.51), Diesel for Others $1.20)



A typical portable asphalt plant uses waste oil for the dryer burner, off-road diesel for the loaders, gen-sets and AC heaters and on-road diesel for the haul trucks. The aggregate burner is by far the largest energy consumer and, hence, the largest source of GHG emissions (see figure on previous page).

Transport

Once loaded, the haul trucks proceed to the paving site, where the mix is dumped in long narrow windrows in front of the paving and pick-up machine.

The number of trucks depends on average length of the haul between the asphalt plant and laydown area and average cycle times. Ideally, the plant would be about equidistant from both the start and end of the paving project, which would generally reduce total travel distance. However, the cycle time can depend on many variables, including the amount of adverse grade, traffic congestion, number of curves, average speed limit and the ability of trucks to get through traffic line-ups near the laydown site.

Since the plant operates continuously, an adequate truck capacity must be ensured. Otherwise, the asphalt production process risks being backed up waiting for trucks or the paving crew to catch up. This, in turn, reduces plant efficiency.

Lay Down

The pick-up machine, attached to the front of the paver, picks up the windrow mix on the road and feeds it into the paving machine hopper. The paving machine uniformly flattens the mix, using electric preheaters to heat the screed. Like the haul trucks, the pick-up and paving machines and rollers burn diesel fuel.

Emission Reduction Measures

Key opportunities for reducing GHG emissions in the paving process include:

- Reduce aggregate stockpile moisture
- Improve dryer burner combustion efficiency
- Upgrade paving plant insulation
- Modernize dryers and restore worn flights
- More efficient hot-oil heater design
- Lower carbon fuels for dryer burners
- Use of the hot-in-place asphalt recycling method
- Use of reclaimed asphalt pavement (RAP) in hot-mix asphalt
- Use warm-mix asphalt

3.2 REDUCE AGGREGATE STOCKPILE MOISTURE

Managing stockpiled aggregate to minimize its moisture content can significantly reduce fuel used for drying, which is the single largest source of GHG emissions in asphalt production. Aggregate management practices are relatively low-cost, low-tech ways to cut emissions and secure other environmental benefits.

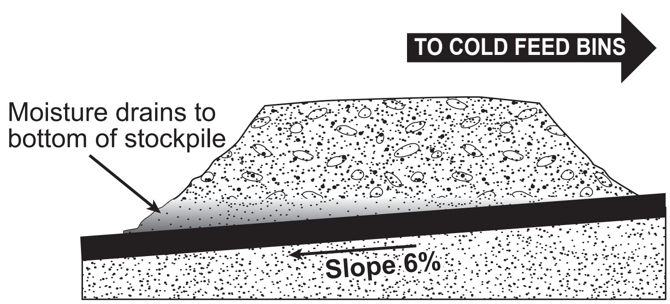
Description

Typically, aggregate is mined, processed, and stored in uncovered stockpiles where it is exposed to the elements. This exposure can increase the aggregate's natural moisture content from 2 or 3 percent to as much as 4 to 5.5 percent on average across British Columbia. Since the aggregate must be heated and dried before mixing with the asphalt binder, additional moisture means greater energy use and attendant GHG emissions.

The extra moisture in aggregate stockpiles can be reduced by several means:

- Slope the grade under each stockpile to promote drainage away from the south-facing operating side
- Cover stockpiles with heavy tarps immediately after the aggregate has been extracted

In some limited cases, pave under the stockpile to accelerate drainage and keep moisture from being drawn into the pile.[13]



Covering and sloping allows the stockpile to drain naturally and prevents the accumulation of excess moisture during inclement weather. Keeping the aggregate as dry as possible reduces burner fuel consumption, air emissions, and production cost.[14]

13 Sloping the grade under the stockpiles would likely be the most-cost-effective measure. Since some pits are only used every 15 to 20 years, paving would not likely be cost-effective.
14 Stockpiles should also be located as close as possible to the cold feed bins to minimize loader fuel use.

The table below shows the significant energy savings that are available from the implementation of these best practices. For example, industrial fuel oil use can be reduced by 21 percent by avoiding an increase in the aggregate moisture content from an ambient level of 3 percent to 5 percent when exposed to heavier precipitation.

Energy Savings from Reduced Aggregate Moisture Content

Initial Moisture	Moisture After Best Practice *(Cold Feed Moisture)*		
(percent)	(percent)		
	2.0	2.5	3.0
5.5	34%	29%	24%
5.0	31%	26%	21%
4.5	27%	22%	16%
4.0	23%	17%	11%
3.5	18%	12%	6%
3.0	13%	6%	0%
2.0	0%	N/A	N/A

a Applies to hot-mix asphalt production.

Source: NAPA, Energy Conservation in Hot-Mix Asphalt Production, Table 3, p. 9.

The Ministry sponsored three pilot projects to test aggregate tarping at Duffy Lake (Hwy 99), Thornhill (Hwy16) and Kicking Horse Pass (Hwy 1). The results on moisture reduction due to aggregate tarping from these pilot projects varied due to local weather, ability to maintain tarps on stockpiles (high winds) as well as a consistent approach to identify moisture contents during aggregate production and asphalt production. In general terms, untarped manufactured fines and shoulder aggregate stockpiles at Duffy Lake saw an increase in moisture content of 3.0% and 3.1% respectively. At Thornhill, untarped coarse aggregate, manufactured fines and natural fines saw increases in moisture content of 0.5%, 0.8% and 0.3% respectively. Results for Kickinghorse Pass are inconclusive at this time.

It is very clear from these pilot projects that additional training and orientation for Ministry and contractor staff is required. It has been clearly documented from other jurisdictions that tarping aggregate stockpiles can produce significant savings. However, experience with the selection of tarping materials, securing of tarps and understanding the relevance for all parties to buy into the benefits of aggregate tarping are required.

In the interim, the use of tarping in Ministry contracts will be determined on an individual contract basis. Criteria will include but not be limited to the time of year crushing and paving occurs, geographic location and annual precipitation for that location.

Technical Issues

Management practices to reduce stockpile moisture can be implemented throughout B.C. The choice of practice depends on the volume of aggregate mining and frequency of use (see under Financial Considerations), rather than any particular technical constraints.

Tarps need to be installed as quickly as possible during wet weather, as moisture can collect under the tarp and add to the stockpile moisture content. Ideally, they should be removed during longer periods of dry weather to allow air to circulate over the stockpiles. A permanent roofed structure with open sides is preferred in this respect, but may only be cost-effective for larger aggregate pits like those close to urban centres.

Financial Considerations

Many Ministry paving operations across the province are relatively remote and require fairly intermittent supply from nearby aggregate pits. Given the temporary use of these pits, tarping the aggregate and sloping the grade under the stockpiles may be the most cost-effective practices to control moisture. For high-volume pits that are accessed more regularly, the cost of a permanent structure over the stockpiles would likely be better justified.

Assuming a 50,000 tonne production run of hot-mix asphalt (HMA) and a drying cost of $4.45 per tonne, a reduction in aggregate moisture content from 5 to 3 percent would result in total fuel cost savings of about $46,700.[15] As fuel oil prices rise and other plant efficiencies are implemented, the cost savings can be higher.

To calculate a return on investment from these best practices, their capital and operating costs (e.g., to purchase and install the tarp or build the permanent cover) would have to be compared to the fuel cost savings over time. It is expected that the routine use of a practice such as tarping would lower application costs and improve the return on investment.

15 Based on a fuel oil price of $0.51 per litre, fuel concumption of 8.7 litres per tonne HMA, and a 21% fuel saving from Table 1.

Emission Impacts and Other Impacts

For the same 50,000 tonne HMA production run, a 21 percent saving in fuel oil consumption would translate into a reduction in GHG emissions of approximately 260 tonnes CO_2e.[16] Local air contaminants will also be reduced with the decline in fuel oil use.

These practices can also prevent or reduce dust and erosion and muddied stormwater runoff from aggregate piles.

References

B.C. Ministry of Energy, Mines and Petroleum Resources (2002), *Aggregate Operators Best Management Practices for British Columbia,* http://www.em.gov.bc.ca/Mining/MiningStats/55AOBMPHand_pdf.htm.

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St. Martin, Cooley, and Hainin (2003), *Production and Construction Issues for Moisture Sensitivity of Hot-Mix Asphalt Pavements,* http://onlinepubs.trb.org/Onlinepubs/conf/reports/moisture/06_TOP6.pdf.

16 Based on a 7 litres per tonne HMA and a savings of 2.2 litres of fuel oil per tonne.

3.3 IMPROVE DRYER BURNER COMBUSTION EFFICIENCY

The aggregate dryer uses the largest amount of fuel and produces the most emissions within the paving process. Optimizing the combustion efficiency of the dryer burner is an essential first step to begin minimizing fuel costs, GHGs and air pollutants. The use of waste oil fuel creates extra maintenance responsibilities toward these objectives.

Description

In B.C., asphalt plants do not have combustion monitoring equipment that could help operators continuously optimize burner efficiency. Typically, asphalt plants are stack-tested each spring and adjusted to meet the Ministry of Environment's Asphalt Burner Regulations (see Table below). Asphalt plant emission standards in the Lower Mainland are more stringent, requiring asphalt plants to use cleaner dryer burner fuel such as natural gas instead of waste oil.

B.C. Hot Mix Asphalt Plant Concentration Regulatory Limits

Parameter [17]	Lower Mainland	Rest of B.C.
	Lower Fraser Valley New Plants since June 27, 1997, and Modified Plants (+10%)	All other plants
Particulates	90 mg/m^3	120 mg/m^3
Organics	60 mg/m^3 (1 hr average)	120 mg/m^3 (1 hr average)
Opacity	20%	20%
Carbon Monoxide	200 mg/m^3	400 mg/m^3

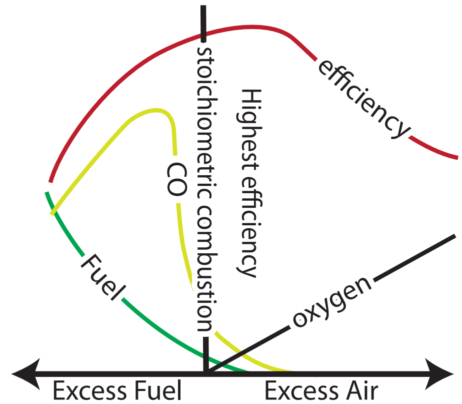
Portable plants plants are required to operate at different elevations and locations, using waste oil fuel that varies from batch to batch and processing aggregate that varies in quality and moisture content. These factors work to degrade the dryer's combustion efficiency, which can lead to excessive fuel use and emissions. In addition to creating excess emissions, unburnt fuels released into the drum risk contaminating the asphalt mix and fouling the baghouse.

Combustion Efficiency

In efficient combustion, the carbon in the fuel is converted to CO_2 (with incomplete conversion resulting in carbon monoxide, or CO), the hydrogen is converted to water vapour and the sulphur and nitrogen converted to their

17 Concentrations in mg/m^3 dry, corrected to 16 percent O_2 at 20°C and 101.325 kPa.

oxides (SOx and NOx). To achieve efficient combustion, a minimum amount of oxygen is necessary, referred to as "stoichiometric air."



Stoichiometric air would result in 0 percent oxygen (O_2)in the stack gases, since all oxygen has been consumed. However, since burning conditions are never ideal, efficient combustion generally needs more air than the theoretical requirement, known as "excess air." As depicted in the figure to the right, the high combustion efficiency is characterized by a certain amount of excess air, low CO and O_2. For example, power plant boilers burning fuel oil (No. 2 to No. 6) require about 10 to 20 percent excess air. If operated on natural gas, the requirement is about 5 to 10 percent. The less excess air required, the better for a given fuel type, since too much leads to an efficiency drop (see figure).

If insufficient air is supplied to the burner, unburned fuel, excess CO and smoke can result. If a dryer has been relocated at a higher elevation, its fuel/air ratio will change (less available air increases the fuel/air ratio). Insufficient air in a combustion process is indicated by high CO and low CO_2 emissions. In the case of insufficient air, increasing excess air will improve combustion efficiency to a point. However, efficiency will eventually fall off as the heat loss up the stack is greater than the additional heat generated.

When manually calibrated, an oil burner might be set at 15 percent excess air, which is about 3 percent excess oxygen. However, changing ambient conditions—including elevation, temperature, humidity, wind and air pressure—all affect the manual excess air setting. Some of these factors can change hourly. Too high an excess air setting during the spring setup to compensate for future conditions will degrade combustion efficiency, as stack heat losses are higher than necessary.

The ideal situation would be for the fuel/air ratio on the dryer burner to be automatically controlled by equipment that detects changes in key stack emissions. Oil-fired boilers use these automated systems, which are called O_2 trim packages.

Emission Indicators

Under most conditions, a typical aggregate dryer with efficient combustion characteristics should have emissions as follows:[18]

- Oxygen levels between 8.5 and 10.5 percent
- CO levels between 100 and 500 ppm (0.01 to 0.05 percent)
- CO_2 levels about 13 percent
- NOx at 130 ppm (oil fuels)
- NOx at 60 to 80 ppm (natural gas)

If these levels cannot be obtained by changing the fuel/air ratio, the dryer and burner could have other problems. These could include an incorrect nozzle size, partially plugged fuel nozzle, incorrect fuel temperature/viscosity, unaccounted for air leakage, poor dryer flighting, soot formation, poor flame characteristics, incorrect drum rotation speed, drum angle, incorrect fuel pressure, fuel control valve settings, etc.

The attainment of these emission levels is a necessary first step in minimizing fuel use and emissions for a given plant and governing ambient conditions. If, however, the equipment has other problems, additional, more involved adjustments may be necessary to obtain maximum asphalt mix production for the given conditions.

Waste Oil Fuel

Most portable plants in B.C. outside of the Lower Mainland use waste oil fuel, which involves extra maintenance effort to achieve consistent combustion efficiency and thereby minimize emissions and help prolong baghouse life.

- **Consistency –** Waste oil fuel is an unknown mixture of many types of used oils. It has a viscosity generally thicker than No. 2 fuel oil, which can vary load by load. Variations in fuel viscosity require that fuel heating temperature may need to be different between batches to achieve a consistent fuel viscosity at the burner. Burner manufacturers recommend heating waste oil fuel to attain a minimum viscosity of 90 Sayboldt Universal Seconds (SUS), but waste oil burns more completely at 70 SUS.[19] Operationally, some asphalt plants simply fix fuel heating temperature without checking fuel viscosity.
- **Pre-heating Temperatures –** Waste oil requires precise and consistent preheating to attain the correct viscosity so that it can be completely atomized at the burner nozzle. Fuel that is several degrees lower than optimum will not fully atomize. Proper fuel viscosity at the burner can save

18 See "Combustion Know-How"

19 Saybolt Universal Seconds (SUS) is a measure of vicosity, which is the time that 60 cm^3 of oil takes to flow through a calibrated tube at a set temperature.

on fuel consumption by 1 or 2 percent, as well as extending baghouse life and improving stack emissions.[20]

- **Heat losses –** For portable plants, heat losses can occur through the fuel line between the pre-heater and the burner. It is recommended that the viscosity of the heated fuel be checked at the end of the fuel line at the burner. An uninsulated fuel hose lying in the mud can greatly degrade burner combustion efficiency.
- **Contaminants –** Waste oil fuel is supposed to be filtered and dewatered by the supplier. Operators report water in the bottom of the fuel oil tanks and cellulose and other fibres (from engine oil filters) in their delivered fuel. Improperly filtered waste oil fuel can lead to a partially clogged nozzle, which hinders fuel atomization, wastes fuel and leads to accelerated wear in the fuel pump.
- **Sulphur content –** According to one major waste oil supplier in B.C., sulphur content varies in their products from 4,000 to 8,000 ppm depending on the grade. This compares to off-road diesel at a maximum of 500 ppm, which will be reduced to the on-road diesel sulphur limit of 15 ppm by 2010. The use of high sulphur fuels can lead to compounds such as sulphur and sulphuric acid being drawn through the dryer and baghouse, which are very corrosive. It is good practice to keep track of waste oil loads and check for sulphuric content.
- **Start-up –** Waste oil fuel must be at the recommended viscosity and required temperature when the dryer is fired, especially in the morning. This helps to attain efficient combustion and increases baghouse temperature as quickly as possible, minimizing the possibility of any condensation during warm-up. Preheated fuel will ignite faster and efficient combustion will be achieved quicker, reducing instances of unburnt fuel contaminating the baghouse.
- **Preheated baghouse –** Although it is routine to preheat the baghouse prior to aggregate drying, the goal is not simply to preheat the gases flowing through, but also the metal structure itself. If some internal parts of the baghouse are below temperature, condensation will occur on the metal plates even with hot exhaust gases flowing.
- **Combustion zone flights –** Intense burning of waste oil can damage combustion zone flights where the burner flame is directly contacting dryer flights. If this type of damage is suspected, most operators can eliminate the problem by reducing the rotation speed.
- **Post-shutdown purge –** With the high sulphur content in the waste oil fuels, it is recommended to run the baghouse through a post shut-down operation with fresh air to purge any sulphur-related emissions. If the corrosive gases have not been completely expelled before condensation takes place, corrosion will likely occur.

20 See "Now you can successfully use waste oil in any hot-mix asphalt plant," p.32.

Financial Implications

The combination of these recommended operating practices will save significant fuel costs, reduce risk of downtime and prolong the life of the baghouse. For example, ensuring correct fuel viscosity at the burner can reduce fuel consumption by an estimated 2 percent, which equates to a cost saving of $4,000 for a 50,000 tonne hot-mix asphalt project. If the use of lower sulphur waste oil fuel results in a one-year addition to the baghouse life, this represents an annual saving of $2,100. Avoidance of dryer downtime related to waste oil fuel use and burner malfunctions could be worth at least $5,000 per hour, with other equipment and labour sitting idle.

Emission and Other Impacts

Although the combination of all these best practices benefits would be larger, a 2 percent reduction in waste oil fuel consumption would reduce GHG emissions by 24.1 tonnes for a 50,000 tonne paving project. Other waste oil fuel emissions, such as NOx, SOx, volatile organic compounds (VOC) and particulate matter (PM) would also be reduced.

References

"Combustion Efficiency and Excess Air," The Engineering Toolbox Website, http://www.engineeringtoolbox.com/boiler-combustion-efficiency-d_271.html

"Combustion Know-How," *Hot-Mix Magazine, Vol. 7(2).*

"Now you can successfully use waste oil in any hot-mix asphalt plant," *Hot-Mix Magazine, Vol. 10(2), B.C. Asphalt Plant Regulation* (Under the Environmental Management Act).

3.4 UPGRADE PAVING PLANT INSULATION

One of the easiest, most cost-effective ways to achieve higher operating efficiencies in asphalt production is to better insulate plant equipment. Paving plant insulation opportunities are often missed because of the comparatively low price of industrial fuel oil and the fact that fuel cost savings may be considered small relative to the total cost of a road paving project.

Description

The insulation of asphalt plant components avoids excessive heat loss, especially from piping and storage tanks operating at temperatures of 325°F. Insulation reduces the amount of energy required to replace heat losses, thereby cutting energy costs and emissions. Fibreglass and mineral wool blankets are commonly used products in these applications.

According to an equipment manufacturer, most heat loss in asphalt plants is caused by too little insulation on some components and no insulation on others.[21] Key targets for additional insulation include:

- **Dryer casings –** Heat loss occurs from the casing or shell of the asphalt dryer drum. Most new dryers and drum mixers are insulated to reduce casing losses. In the U.S., individual asphalt producers have reported fuel savings of around 5 to 10 percent from the insulation of dryer casing.[22]
- **Asphalt oil piping –** Many plants still have no insulation on pipe elbows, valves, hot-oil jumper lines, and small sections of asphalt pipe. The theoretical energy losses per linear foot from a 3” un-insulated asphalt pipe at 300oF are nearly 19 times higher (1,598 Btu per hour) than those from a pipe with 1.5 insulation (86 Btu per hour)[23].
- **Storage tanks and silos –** Most asphalt storage tanks are now built with 6 in. (15 cm) of insulation. Older models can have half that insulation thickness, resulting in significant heat loss to the atmosphere.

Technical Issues

Insulation products for asphalt oil piping and storage tanks are readily available and easy to install. Pre-formed insulation and insulation covers can be purchased for pipe and elbows. In the case of tanks and silos, any thermal insulation handbook will have the recommended type and thickness for the temperature ranges expected.

In the U.S., there are after-market suppliers who will insulate dryer casings and guarantee the fuel savings payback following an initial energy audit of the plant. If similar arrangements can be made in B.C., any technical and financial risks to the plant owner will be reduced considerably.

21 Heatec (1999), Heating and Storing Asphalt at HMA Plants, p.22.
22 NAPA (2007), Energy Conservation in Hot-Mix Asphalt Production, p. 12.
23 Ibid., p. 25

Financial Considerations

Given the useful life of an asphalt plant (e.g., 20 to 30 years for dryers and storage tanks), operating costs can add up to a lot of money over time and may greatly exceed the initial equipment cost. While insulation is always best installed in new equipment, even retrofits to an existing plant can be highly cost-effective because of the lifetime energy savings relative to the cost of installation.

For example, liquid asphalt producer Bitumar Inc. conducted an energy audit of its Montréal plant in 2003.[24] Funding assistance for the audit was provided by the national Office of Energy Efficiency and Gaz Métro. From the energy-saving measures identified in the audit, Bitumar Inc. selected insulation upgrades to its asphalt storage tanks and thermal oil piping, with estimated paybacks of 18 months and one month, respectively. The retrofits were done gradually, one tank at a time, so as not to affect production or storage levels. Implementation of the measures reduced the plant's annual natural gas bill by 36 percent and cut GHG emissions by more than 2,000 tonnes CO_2e per year.

Emission and Other Impacts

The fuel savings and emission reduction benefits will depend on a number of site-specific factors, such as the existing amount of insulation, type of fuel used, ambient temperatures, and asphalt production levels. If a combination of the three insulation measures identified here were to result in a 20 percent saving in industrial fuel oil, then the GHG reduction could be almost 250 tonnes CO_2e for a 50,000 tonne paving operation.

Insulation upgrades will also reduce other air emissions and can ensure better, more cost-effective storage of asphalt. In the example above, Bitumar Inc. reported that, prior to the upgrade, it had been necessary to pump the asphalt from the storage tanks to a heat exchanger for reheating because the inadequately insulated tanks could not keep the asphalt at the required storage temperature. This extra step also risked contaminating the product. As a result, the insulation retrofits improved the quality of asphalt storage, while at the same time reducing storage costs.

24 NRCan (2005), Case Study: Bitumar Inc. Energy-Efficient Asphalt Production

References

Heatec (2003), *Heatec Tec-Note: Don't be fooled about insulation,* Publication No. 803-108, http://heatec.com/literature/Tec-Notes/8-03-108/8-03-108p1.htm.

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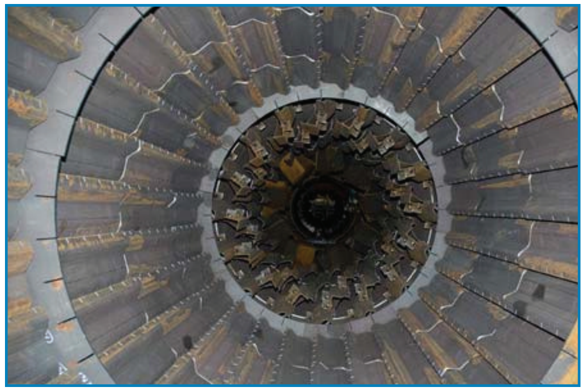
Natural Resources Canada (2005), *Case Study: Bitumar Inc. Energy-Efficient Asphalt Production, Office of Energy Efficiency,* http://www.oee.nrcan.gc.ca/publications/industrial/cipec/bitumar-casestudy.cfm?attr=24.

3.5 MODERNIZE DRYERS AND RESTORE WORN FLIGHTS



Newer dryer design technology, such as counterflow dryers can reduce emissions. Wear and tear on the dryer flights in drum mix facilities causes inefficient drying of the aggregate and wasted energy. Restoring worn flights or changing the flight pattern within the drum will improve fuel efficiency and plant productivity.

Description

There are two basic designs of drum dryers: parallel flow and counter flow. In a parallel-flow dryer, the sized aggregate is introduced into the drum at the upper burner end. As the drum rotates, the aggregates as well as the hot gases from the burner move toward its lower end in parallel. Liquid asphalt cement is introduced in the mixing zone midway down the drum where temperatures are lower, to coat the aggregate.

In a counter-flow design, the aggregate enters at the drum's upper end and travels down to the lower burner end. The material flow is counter to the direction of the exhaust gases travelling up the drum. In this case, the asphalt cement mixing zone is located behind the burner flame, to avoid direct contact with the hot gases and flame. As a result, counter-flow dryers tend to have lower VOC emissions than parallel-flow designs.

Both designs include steps or "flights" on the dryer drums that lift the aggregate and drop a veil of material through the hot gas stream for drying and heating. These dryer flights work like the fins inside clothes dryers, which lift and aerate the clothes in the heated air. Due to the heavy abrasive nature of the tumbling aggregate, flights wear over time and can fold over or break, reducing the dryer's thermal efficiency and increasing fuel use.

When the aggregate is not evenly lifted and spread across the inside of the drum, larger volumes of hot gases will be drawn through areas with the least amount of aggregate, leading to elevated exhaust gas temperatures. These high temperatures are a signal that the burner heat is not being effectively transferred to the aggregate. The result of worn dryer flights is improper aggregate drying, which means the plant operator must slow down asphalt production and/or increase fuel consumption.[25]

25 Kenco Engineering Inc., Asphalt Drum Dryer Flights

According to manufacturer models, every 40°F reduction in exhaust gas temperature will result in approximately a 4 percent decline in fuel consumption.[26]

Technical Issues

Worn dryer flights can be restored, or the flight pattern changed, to reduce the exhaust gas temperatures and improve fuel efficiency.[27]

Parallel-flow dryers – As the flights wear, exit gas temperatures can rise to as high as 360°F to 380°F (182°C to 193°C). At the same time, shell temperatures and casing losses to the dryer can increase, further reducing thermal efficiency. A parallel-flow dryer is most efficient when the exhaust gases are about the same temperature as the aggregate in the drum. Restoring the flights or improving the flight pattern should reduce gas temperatures to 300°F (140°C) for a 300°F mix.

Counter-flow dryers – Worn flights can increase exit gas temperatures to 275°F to 300°F (140°C to 149°C). Counter-flow dryers can be flighted to reduce these temperatures as low as the dust control and air-moving equipment can tolerate. When fitted with new flights, the gas temperature can fall to 220°F (104°C).

After-market suppliers provide higher efficiency heat transfer flights for retrofit into older plants. Flights can also be reconfigured into a pattern that reduces fuel consumption.

Financial Considerations

Lowering the exhaust gas temperatures to the ranges identified above could cut dryer fuel use by around 8 percent.[28] For an asphalt production run of 50,000 tonne per year and a fuel oil cost of $0.51 per litre, this fuel reduction would translate into a present value operating cost saving of nearly $70,900 over five years.[29]

Emission and Other Impacts

The 8 percent fuel saving would reduce GHG emissions by about 500 tonnes CO_2 annually.

Higher efficiency dryer flights will also reduce air pollutants (e.g., NOx, SOx, VOC) and improve plant productivity.

26 NAPA (2007), Energy Conservation in Hot-Mix Asphalt Production, p. 12.
27 Ibid., p. 25
28 Ibid.
29 Based on 8% interest rate for discounting future savings.

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Canadian Ortech Environmental Inc. and John Emery Geotechnical Engineering Limited (2002), *Multi-pollutant Emission Reduction Analysis Foundation (MERAF) for the Hot-Mix Asphalt Sector*, Report Prepared for Environment Canada and the Canadian Council of Ministers of Environment (CCME), http://www.ccme.ca/assets/pdf/hot_mix_asphalt_final_meraf_e.pdf,

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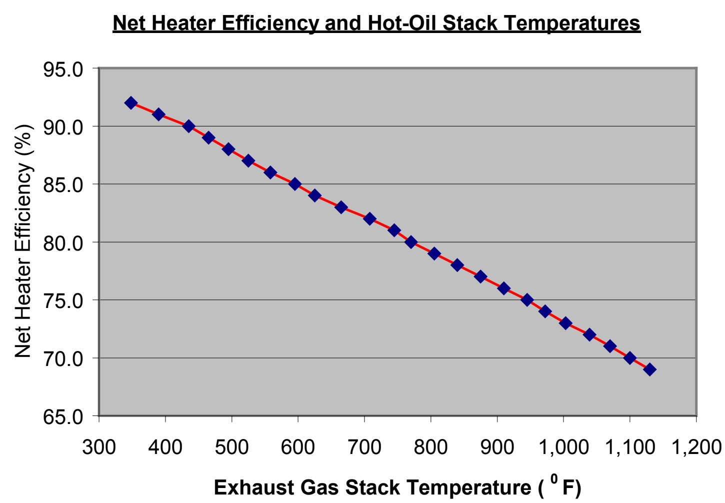
3.6 MORE EFFICIENT HOT-OIL HEATER DESIGN

Investment to improve the thermal efficiency[30] of hot-oil heaters can have a quick payback for asphalt plants. More efficient hot-oil heater design is a significant energy conservation opportunity, along with the appropriate maintenance and production practices to control fuel use.[31]

Description

HMA plants use heating oil to transfer heat to the liquid asphalt cement, asphalt transfer lines, pumps and valves, and storage tanks. The heat transfer oil can be heated electrically or, more commonly, with fuel oil-fired heaters.

Hot oil heaters have a useful life of 20 to 30 years. Some of the older heater designs used in B.C. asphalt plants are not as efficient as those currently available. The more recent designs are typically up to 85 percent efficient, while the older heaters can be well below this standard. There is an opportunity for energy and emission savings through upgrades to hot-oil heater efficiency. Newer heater designs have a more efficient exposure of the hot oil to the heat source, using a two- or three-pass system to extract maximum heat from the combusted fuel. Another design is to capture as much of the waste heat as possible from the exhaust stack, in order to pre-heat the oil before it enters the coils in the main heat exchange area. Heat that exits the exhaust stack is wasted just like the heat losses from poor insulation of the heater shell.



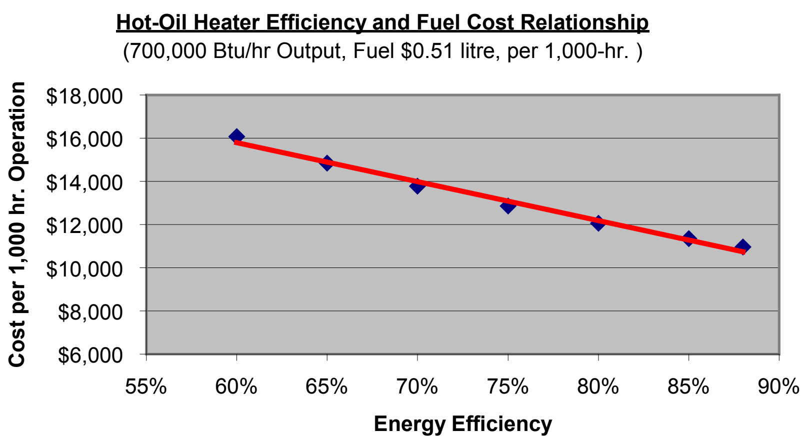
30 The thermal efficiency of a hot-oil heater measures the amount of heat (Btu) that the burner generates relative to the amount of heat actually transferred to the thermal fluid flowing through its coil.

31 Hot oil heater burners and lines should be regularly checked and cleaned to ensure that they are working according to specifications, and hot oil should be tested annually for oxidation. It is also important for fuel efficiency not to exceed the manufacturer's recommended temperatures for the pumping, delivery, and mixing of each performance-graded product.

Many asphalt plants do not separately meter fuel used for the aggregate dryer and the hot-oil heater. As a consequence, most operators are likely unaware of how much energy the heater alone consumes. And because the dryer burns fuel at a much higher rate than the heater, the latter is often ignored.

Technical Issues

To determine whether an upgrade is needed, the efficiency of the hot-oil heater must be assessed. Strictly speaking, this assessment requires calculating the overall heat balance of the system. However, in practical terms the efficiency can be "ball-parked" by measuring the exhaust gas temperature and assuming that the balance of the heat (except for insulation losses) is going to the hot oil. If the exhaust gas temperature is high, efficiency is low; if the exhaust temperature is low, efficiency is high. Some U.S. equipment manufacturers and suppliers will check the efficiencies of hot-oil heaters as a free service to HMA plant owners.



If the hot-oil heater is deemed to require an efficiency upgrade, then the options are to: (1) purchase and install a new heater; (2) rebuild the existing unit; or (3) retrofit the current heater with a heat exchanger near the stack for pre-heating the hot oil. The extent of the upgrade depends on its cost versus the potential energy savings over time.

Financial Considerations

Most often, efficiency upgrades involve an added heat exchanger or replacement of the entire unit. Based on a small 700,000 Btu/hr hot-oil heater and a low $0.51 per litre fuel cost, an efficiency upgrade of from 60 to 85 percent would generate about $3,500 in fuel savings for every 1,000 hours of use.[32] Typical paybacks for these measures are within one to two years or less.

32 NAPA (2007), Energy Conservation in Hot-Mix Asphalt Production, pp. 21-23.

Emission and Other Impacts

Using the above example, a 15 percentage point increase in heater efficiency would translate into approximately 6,800 litres in fuel savings and 26 tonnes CO_2e of GHG reductions per 1,000 hours of operating use.

Other fuel combustion pollutants, in particular nitrogen oxides and sulphur dioxide, will be reduced with the use of more efficient hot-oil burners.

References

Canadian Construction Association (2004), *Environmental Best Practices Guide for Hot Mix Asphalt Plants,* Standard Construction Document CCA 83, http://www.ccaacc.com/documents/ccalist_e.asp.

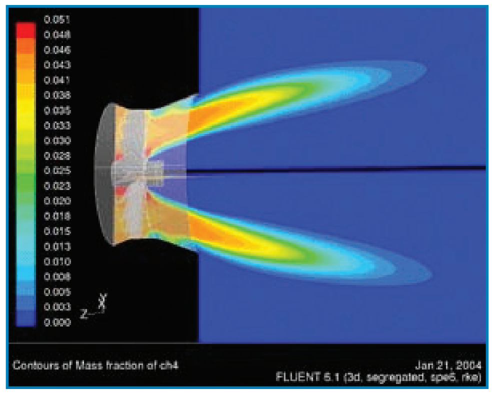
Heatec (1999), *Heating and Storing Asphalt at HMA Plants,* Technical Paper T-140, http://heatec.com/literature/Tech_Papers/T-140/T-140p1.htm.

National Asphalt Pavement Association (2007), *Energy Conservation in Hot-Mix Asphalt Production,*
http://www.hotmix.org/index.php?option=com_content&task=view&id=322&Itemid=696

3.7 LOWER CARBON FUELS FOR DRYER BURNERS

Switching from higher to lower carbon fuels in aggregate dryer burners can significantly reduce both GHG emissions and air pollutants, as well as reduce costs due to issues with using lower grade high carbon fuels which are described below. Fuel substitution opportunities are site-specific, depending on plant location and fuel availability and prices.

Description



The major fuels used in hot-mix asphalt production are fuel oil, natural gas, and propane. Many paving contractors use recycled lubrication oils purchased from industrial waste oil recyclers. This "industrial fuel oil" (waste oil) offers a high energy content at relatively low cost for use in direct-fired burner units, including asphalt paving plants. Industrial fuel oil is available at viscosities close to No. 2 diesel fuel, which does not have to be heated prior to burning. Heavier fuel oils, such as No. 4 or No. 5 fuel oil, typically must be heated to between 120°F and 160°F (49°C and 71°C) to achieve the proper viscosity for burning. This added heating step increases fuel use and emissions.

Most dryer burners can be equipped to burn both liquid and gaseous fuels. Many have manifolds that enable easy switching between fuel types. With this flexibility, asphalt producers can change fuels when relative fuel prices rise and fall.

Natural gas and propane are lower carbon fuels, with about 67 percent and 71 percent, respectively, of the GHG emissions from fuel oils. Natural gas is used extensively in asphalt plants in Greater Vancouver, while propane provides process heat for mobile HMA facilities throughout B.C.

Technical Issues

In many cases, paving contractors require portable fuels because they must operate from Ministry aggregate pits that are not close to a natural gas supply area. Where available, natural gas can often be cost-competitive with heavy fuel oils, but the operating savings may not be attractive enough for seasonal or small-scale operations. Propane is more expensive than both natural gas and heavy fuel oils for burner use.

Other items to consider when using waste oil fuel is the high variability in quality of the fuel. Variation in viscosity and the presence of contaminates can lead to clogged nozzles, premature fuel pump wear, higher fuel consumption and accelerated wear in the dryer and baghouse due to the higher sulphur content. These issues can also lead to greater downtime of the plant which may create other issues for the rest of the paving operations.

Financial Considerations

Conversion of a 50,000 tonne per year burner from fuel oil to natural gas could generate annual savings of $53,500 annualized over a 10-year period.[33] Although there is potential for cost savings and GHG reductions, distance to the natural gas tie-in and the amount of annual fuel use at each pit location would need to be examined on a case-by-case basis.

Other financial considerations are the accelerated wear of burner components such as pumps and nozzles due to the use of a lower quality fuel and the potential downtime costs due to malfunctions, which could be as high as $5,000 per hour due to other equipment and labour sitting idle while the plant is down.

Emission and Other Impacts

The above conversion would result in GHG reductions of about 385 tonnes CO_2e annually or 1,925 tonnes CO_2e over 5 years.

Using natural gas or propane will reduce air contaminants, including NOx, SOx VOC, and PM. Because they are cleaner burning, these fuels also allow for a longer bag house life—5 versus 3 years—compared to heavy fuel oils.

References

Environment Canada (2008), *National Inventory Report 1990-2006: Greenhouse Gas Sources and Sinks in Canada,* http://www.ec.gc.ca/pdb/ghg/inventory_report/2006_report/tdm-toc_eng.cfm.

National Asphalt Pavement Association (2007), *Energy Conservation in Hot-Mix Asphalt Production,* http://www.hotmix.org/index.php?option=com_content&task=view&id=322&Itemid=696.

Newalta Corporation (2007), *Industrial Fuel Oil (IFO) Fuel Spec Sheet*

33 Based on a 2007 analysis, including the costs of fuel equipment change-out.

3.8 HOT IN-PLACE ASPHALT RECYCLING

Hot in-place recycling (HIP) is an on-site rehabilitation method that can recycle 100 percent of the existing pavement to a certain depth. By saving on new materials, fuel and other resources, HIP can be very cost-effective in a number of highway uses, with substantially fewer GHG and other emissions.

Description

Hot in-place recycling is designed to address surface distresses that are not the result of underlying structural weaknesses. The HIP process involves heating, removing and mixing the existing surface asphalt with a recycling agent (asphalt cement rejuvenator) and admixture (heated aggregates and AC) as required, and repaving—all in a single continuous process.

HIP work can be performed in a single-stage or multi-stage operation. For example, in two-stage remixing, the pavement is heated and scarified in two successive passes, each about 25 to 37.5 mm deep. The goal is to get adequate heat penetration and minimize aggregate degradation.[34]

A typical two-stage milling process uses the following equipment in a continuous train:

- Direct fired and/or infrared preheaters to soften the asphalt and remove excess moisture;
- Two heater/milling machines to remove and windrow the pavement ;
- A conveyor that picks up the millings from the heater/millers and feeds them to a pugmill for mixing with the rejuvenator, new aggregates and/or new HMA[35]
- A standard paving machine for placing the asphalt
- Standard rollers for compacting the asphalt

In 2009, the Ministry of Transportation and Infrastructure contracted HIP work on 1.8 million square metres, or about 500 lane-kilometres, of B.C. highways. This represented around 25 per cent of the Ministry's total road area rehabilitated. Using HIP techniques, there is significant potential to extend the lives of our current highways and save energy, emissions and project costs at the same time.

34 See http://thinkgreenroads.com/index.php?option=com_content&view=article&id=8&Itemid=8,

35 In some cases, the rejuvenator is added before the pugmill, as part of the first unit, to allow more time for dispersion and mixing.

Globally, most of the recent innovation in HIP technology has come from British Columbia within the industry itself. Ideas such as adding 20% virgin asphalt admixture to improve the durability of the asphalt was developed in this province. Therefore, many of the improvements to practices for this technology are well known by this industry. However, a summary of those best practices is provided below as a reminder on how to obtain the most efficient use of this paving rehabilitation technique.

Technical Issues

HIP is used to treat surface cracking, raveling, potholes, bleeding, low friction values, rutting, corrugations, shoving and slippage. It can also address problems such as bumps, swells and depressions that affect ride quality.

Pavements showing structural base failure or poor drainage are not appropriate candidates for HIP. Other features that can make a road unsuitable for this treatment are: an existing pavement thickness of less than 50 to 100 mm, stripping, wide cracking, heavy patching, extensive use of rubberized crack sealants, poor-quality aggregates and low oil content. Realignment of a road or a significant change in the slope of the road are also not good candidates for HIP.

When done properly, HIP can restore a road to its original condition or even improve it. A HIP project will require careful sampling and quality control procedures, including:

- Coring of the existing pavement and visual inspection for problems such as stripping, delaminations or water in the voids;
- Laboratory testing to determine the properties of the recycled aggregates and asphalt cement, air void content and the quantities of rejuvenator, new aggregates or new HMA needed; and
- Field work during HIP operations to monitor the depth of scarification, recycled mix properties, in-place density and uniform placement.[36]

Maintaining the quality of the existing asphalt that is being recycled is critical, since the recycled asphalt makes up 80 % of the final product. The HIP technique requires the existing asphalt to be heated to a minimum temperature prior to milling, but if the asphalt is overheated, oxidation of the binder oil can occur which reduces the life of the oil in the top 1mm to 3mm of the asphalt surface, which typically is already oxidized by wear and tear over time.

Single stage heating and milling without overheating the asphalt can still be achieved, however it will require more heat over more time, as compared to two-stage heating and millling. Therefore, a longer dwell or soak time

36 For more on these requirements, see Asphalt Institute (2007), The Asphalt Handbook, pp. 642-649, and U.S. DOT FHWA (2008), User Guidelines for Byproduct and Secondary Use Materials in Pavement Construction, "Reclaimed Asphalt Pavement."

is required in order to get adequate heat penetration to preserve the pre-enginered mix design by not pulverizing the existing aggregate in the road.

Like other paving projects, work is best carried out in warm, dry weather.[37] As a result, the summer months are most productive for HIP projects. Under certain conditions—a colder climate, higher-volume road or minimum existing pavement thickness—it may be necessary to add an overlay of new HMA to the recycled layer. This, in turn, will increase project cost (by up to 40 percent), fuel use and emissions. In many cases, however, no overlay is required.

Financial Considerations

As an on-site recycling process, HIP saves not only on material costs—for aggregate and asphalt cement—but also on the costs of transporting, processing and stockpiling new hot-mix asphalt and old (reclaimed asphalt) pavement. In addition, with HIP, only one lane of traffic is detoured and the pavement can be driven within an hour after compaction. As a result, the costs of traffic disruption are minimized.

Emission and Other Impacts

The HIP process minimizes GHG emissions by reducing the amount of new aggregate and asphalt oil required and minimizing transport of these materials to and from the job site. B.C.'s forward thinking has allowed for over 12,000km to be reclaimed and recycled. However, the heating of the existing asphalt before milling requires a considerable amount of energy which can result in emissions from the heating fuel along with emissions from the heated asphalt itself if it is heated to the point that gases from the asphalt are burned off.

Methods to reduce the amount of emissions from the HIP process include utilizing the two-stage heating/milling of the asphalt in thinner lifts to minimize any overheating of the asphalt and to consider emission control devices on the pre-heaters to capture and control any vapours that may be generated as a result of the heating process.

Another item to consider during hot weather is heat damage or even ignition of vegetation along the highway as the pre-heaters pass by. Spraying of the roadside vegetation with water is recommended to prevent this issue from occurring.

37 According to Green Roads Recycling Ltd., the minimum requirements for HIR work are a temperature of about 45o F (5o C) and no rainwater accumulation on the road.

References

Asphalt Institute (2007), *The Asphalt Handbook,* MS-$, 7th Edition, http://www.asphaltinstitute.org/handbook.

Green Roads Recycling Ltd. website, http://greenroadsrecycling.com.

Martec Recycling Corporation website, http://www.martec.ca.

Natural Resources Canada (2006), *An Analysis of Resource Recovery Opportunities in Canada and the Projection of Greenhouse Gas Emission Implications,* http://www.recycle.nrcan.gc.ca/summaries_e.htm.

Ecopave Systems website, http://www.ecopavesystems.com.

U.S. Department of Transportation, Federal Highway Administration (2008), *User Guidelines for Byproduct and Secondary Use Materials in Pavement Construction,* "Reclaimed Asphalt Pavement," FHWA-RD-97-148, http://www.fhwa.dot.gov/pavement/pub_details.cfm?id=384.

(1997), *Pavement Recycling Guidelines for State and Local Governments: Participant's Reference Book,* Publication No. FHWA-SA-98-042, http://www.fhwa.dot.gov/pavement/recycling/98042.

3.9 RECLAIMED ASPHALT PAVEMENTS

Recycling old asphalt pavement for use in new hot-mix asphalt can save significantly on material costs, energy use, and emissions. Best management practices can allow for greater use of reclaimed asphalt pavement (RAP) in B.C. highways without jeopardizing safety and performance.

Description

Before repaving a highway, a contractor either mills the top layer or, in some cases, removes the old asphalt pavement altogether.[38] The RAP is then transported to a central location where it can be processed and stockpiled for later use. Processing involves crushing and screening the material into different sizes prior to reuse.[39]

Milled or crushed RAP can serve as an aggregate substitute and asphalt cement supplement in new asphalt mixes (hot, warm or cold mix). It can also be used as a granular base or sub-base, stabilized base aggregate or embankment fill material in road construction. In hot-mix asphalt production, the RAP is combined with new or "virgin" aggregates, new asphalt cement and/or recycling agents in a drum mix or batch plant.

In the U.S., it is estimated that of the 90 million tons of asphalt pavement reclaimed annually, more than 80 percent is recycled and used.[40] All state highway agencies permit the use of RAP in the base course of asphalt pavement, typically up to a maximum of 15 to 30 percent of the HMA mix. Ten states do not allow RAP in the surface mix and, of those that do, some limit it only to low-volume roads.

In B.C., the Ministry of Transportation and Infrastructure allows 10% RAP in the top lift (up to 50 mm) on secondary highways and up to 30% RAP on low volume roads. On the bottom lift (lower 50 mm of pavement) the Ministry allows up to 30% RAP on primary and secondary highways and up to 100% RAP on low volume roads

Technical Issues

Processing of RAP tends to occur near major centres where stockpiles are large enough (e.g., 30,000 to 50,000 tonnes of material) to justify bringing in crushing equipment. On the other hand, smaller portable processors are now available that can cost-effectively crush stockpiles as small as 3,000 tonnes.

In B.C., the feasibility of substituting RAP for virgin aggregates in hot-mix asphalt plants depends on the distance between the stockpile and the plant.

38 This discussion excludes hot in-place and cold in-place recycling, which removes asphalt pavement, pulverizes and mixes it with additives on site, and places and compacts the resulting mix in a single pass.

39 NRCan (2006), *An Analysis of Resource Recovery Opportunities in Canada and the Projection of Greenhouse Gas Emission Implications,* p. 217.29

40 Asphalt Pavement Alliance (2006), "Asphalt: The Sustainable Pavement," http://www.pavegreen.com

Longer transport distances erode the cost savings of recycled over new materials. Stockpiles are more likely to be used where there are other demands for the RAP, such as fill for side roads.

When using RAP in new HMA pavement, contractors should observe recognized best practices, including:[41]

Stockpiling – RAP can show significant variability, depending on where the material comes from (e.g., different project sites, different pavement sections for a given site). This variability can affect the gradation, asphalt content, compaction, and volumetric properties of the hot-mix asphalt. With higher percentages of RAP, it is advisable to separate or "fractionate" the material by size into multiple stockpiles for a more uniform mix. To the extent possible, RAP from different sites should not be mixed together and should be prevented from contamination from excessive fines.

As it sits in stockpiles, RAP tends to gather moisture and solidify, forming a hard outer crust on the pile. Moisture retention is a major concern because RAP is typically introduced into the HMA process after the dryer, when the hot virgin aggregates mix with and heat up the RAP. The higher the moisture content, the lower the amount of RAP that can be used or the lower the rate of asphalt production. Therefore, measures such as tarping or storing the stockpiles under a permanent structure (see Reduce Aggregate Stockpile Moisture) are critical for higher RAP contents.

Sampling and testing – RAP contents higher than 25 percent will mean more sampling and testing of materials. When RAP is added to the HMA mix, its component aggregates become part of the new aggregate structure and its asphalt cement joins with the new binder. As a result, users need to know the physical properties of the RAP aggregate (e.g., gradation, specific gravity) and the amount of binder in the RAP. The aggregates can be sampled in the ground before pavement removal, from haul trucks, and in stockpiles. To sample the RAP asphalt cement, it must be extracted from t he aggregates through burning in an oven or the application of solvents.

Asphalt cement grade – Higher RAP percentages require the use of a softer new asphalt cement binder to compensate for the higher viscosity of the aged cement in the RAP. For RAP contents of up to 15 per cent, the standard binder grade is acceptable. Between 15 and 25 percent, one grade softer should be selected. If the RAP exceeds 25 percent, a grade blending chart should be used to ensure that the combined binder properties meet the HMA specifications.[42]

41 For these and other best practices, see for example Asphalt Institute (2007), *The Asphalt Handbook, and NAPA (2007), Designing HMAMixtures with High RAP Content: A Practical Guide.*

42 See Figure 13.11 in Asphalt Institute (2007), p. 644

Financial Considerations

Using more recycled content in the asphalt production mix saves energy and money by directly reducing the quantity of virgin aggregates and new asphalt binder needed. The results of two life-cycle assessment studies showed that RAP contents of 20, 30, and 50 percent could result in total energy savings of 20, 25, and 33 percent, respectively, relative to conventional hot-mix asphalt (over a 30-year lifecycle).[43] In the U.S., one source reported a 14 to 28 percent cost saving from incorporating RAP contents of 20 to 40 percent.[44]

Emission and Other Impacts

The use of more RAP avoids the generation of GHG emissions to extract and process virgin aggregate in the pit, produce new asphalt cement at a refinery, and transport both of these materials.

Recycling asphalt can also help to keep construction waste out of landfills and cut down on local air pollution.

References

Asphalt Institute (2007), *The Asphalt Handbook,* MS-$, 7th Edition, http://www.asphaltinstitute.org/handbook.

National Asphalt Pavement Association (2007), *Designing HMA Mixtures with High RAP Content: A Practical Guide,*.
http://store.hotmix.org/index.php?productID=497.

Natural Resources Canada (2006), *An Analysis of Resource Recovery Opportunities in Canada and the Projection of Greenhouse Gas Emission Implications,* http://www.recycle.nrcan.gc.ca/summaries_e.htm.

___________ (2005), *Road Rehabilitation Energy Reduction Guide for Canadian Roadbuilders,* http://oee.nrcan.gc.ca/industrial/technicalinfo/benchmarking/roadrehab/Roadhab_eng_web.pdf.

U.S. Department of Transportation, Federal Highway Administration (2008), *User Guidelines for Byproduct and Secondary Use Materials in Pavement Construction,* http://www.fhwa.dot.gov/pavement/pub_details.cfm?id=384.

43 Reported in NRCan (2005), *Road Rehabilitation Energy Reduction Guide for Canadian Roadbuilders,* p. 17.
44 “Can You Afford Not to Use RAP?: The Case for Using Reclaimed Asphalt,” Ohio Asphalt, Fall 2005.

3.10 WARM MIX ASPHALT PAVEMENTS

Warm mix asphalt (WMA) pavements were originally developed to reduce the carbon footprint of asphalt pavements in response to the Kyoto protocol in the 1990s. WMA is designed to provide similar coating performance at lower mixing temperatures compared to conventional Hot-Mix Asphalt (HMA).

Lower mixing temperatures reduce dryer fuel costs and combustion emissions of greenhouse gas emissions (GHGs) and other Criteria Air Contaminants (CACs). Warm mix asphalt is a promising technology and research is demonstrating that WMA systems can provide significant environmental benefits and some technologies have shown they can improve paving practices and field performance.

Description

There are many WMA products available throughout the world. Some of the best known technologies have been classified below into two main groups, based upon their delivery system and nature of the product. These are plant foaming, product foaming (both water-based), organic and chemical additives.

Water-Based Systems

Water injection system on a drum mixing plant

Plant foaming and product foaming systems rely on the controlled introduction of small amounts of water into the asphalt mixing chamber. These water-based technologies rely on the fact that when the water is rapidly converted to steam vapour it expands about 1,700 times, which greatly increases the volume of the binder (i.e. asphalt cement) which lowers viscosity and improves coating of the aggregate.

Plant foaming technologies rely on the injection of water through high pressure nozzles into the mixing chamber. These systems require a water injection system, foaming nozzles, water supply and a water metering system. This technology is available in new WMA drum plants, such as Astec's Double Barrel Green system or Gencor's Ultrafoam technologies or available as a retrofit modification kit for existing plants.

Product foaming technologies rely on the addition of water contained in hydrophilic (water loving) additives, such as synthetic zeolite contained in

Advera and Aspha-Min. Some suppliers recommend the use of anti-stripping agents to address the risk of inadequate drying which can lead to stripping problems.

Organics and Chemicals

Organic or wax additives such as Sasobit and Asphaltan can be added to the mixing chamber, which has the similar effect of reducing viscosity allowing lower mixing temperatures. After hardening some wax products can increase the stiffness of the binder and improve rut resistance.

The last group are the chemical technologies (e.g. Evotherm, Rediset WMX), which use various emulsification agents, surfactants, polymers and additives designed to improve coating, workability, compaction and anti-stripping performance.

The advantage of additives is they can be injected into the mixing chamber or some products can be manually pre-mixed with the binder requiring minimal equipment modification investment. However, from a quality control standpoint all WMA technologies require proper delivery and metering of the water or additives to ensure consistent production quality and to reduce the risk of incorrect proportions by relying on manual mixing methods.

Technical Issues

WMA technologies allow the binder to be viscous enough to coat the aggregate at 120° C to 135°C, rather than temperatures of 140°C or above for HMA. Viscosity change in the binder is the main principle which makes it possible to produce asphalt pavement at lower temperatures with no loss of workability. WMA technologies are designed to obtain a level of strength and durability that is equivalent or potentially better than HMA.

In addition to reduced emissions there are other benefits and concerns related to the production and use of WMA products, which are summarized below:

- **Reduced Fuel Use –** lower mixing temperatures means less fuel used by the dryer and fuel cost savings to the contractor.
- **Easier Compaction –** some WMA technologies have shown to achieve densities easier than conventional HMA with the same or less compaction effort.
- **Earlier Site Openings –** the lower WMA temperatures and curing characteristics can result in earlier site openings, although for products that involve foaming actions adequate dissipation of moisture is important.
- **Extended Hauls and Paving Season –** since mix temperatures are closer to ambient temperature, WMA mixes do not lose heat as quickly as HMA. The reduced rate of heat loss can help paving in cooler temperature, and increase the distance of operation for mix plants.

- **Rut Resistance –** WMA technologies have shown to have similar or improved rut resistance (e.g. Sasobit) than conventional HMA.
- **Increased RAP Usage –** since WMA binders are less oxidized than conventional mixes and experience less hardening through the production process, WMA can allow the use of higher percentages of recycled asphalt materials (25% to 45%), which reduces the need for new binder and crushing new aggregate.[45]
- **Worker Comfort and Job-site Emissions –** reduced mat temperatures and fumes improve working conditions for paving workers, a significant benefit during extreme summer temperatures.
- **Potentially Longer-Lasting Pavement –** it is suspected (not field proven) that since WMA binders are less oxidized they may age slower and last longer than HMA pavements.

WMA Issues and Concerns

- **Production Challenges –** WMA is less tolerant of burner out-of-adjustments than HMA. Experience in the US and by the Ministry (Evotherm in 2007) has shown that operating at lower temperatures can exacerbate deficiencies in a plant that is not properly tuned.
- **Moisture Sensitivity –** for some WMA technologies that involve foaming, there are reported concerns that residual moisture could be left behind in the mix that may lead to premature rutting and stripping. Many foaming suppliers recommend the use of anti-stripping additives to address this concern.
- **Low Temperature Performance –** another concern that has been reported is certain organic additives may stiffen the binder at low temperatures raising the concern of thermal cracking.[46]

Financial Considerations

Depending upon the technology selected, WMA can involve the purchase of a new foam-injection drum plant or the purchase of new injection equipment, or simply the costs of the product if it is manually added. Evotherm, Sasobit and Aspha-min are considered to be among the lowest cost technologies because they can be used with minimal modification. The data in the following table is gathered from various sources and provides a general idea of the equipment and application rates for the different WMA methods.

Although the use of WMA reduces fuel used in the dryer it appears that the value in energy costs savings (using waste oil fuel) is not enough to cover the increased costs of using WMA additives. Therefore contractors are unlikely to adopt WMA technologies on cost-saving grounds alone. However some

45 RAP percentages are typically limited due to the concern that the recycled binder might lead to premature cracking.

46 Zaumanis (2010, pg. 55).

asphalt pavement suppliers have invested in new WMA drum plants in anticipation that it will provide them with a competitive marketing advantage by being able to offer a 'green' paving alternative to their customers. Also, the other technical advantages mentioned above (potential for extended haul ranges and paving in cooler temperatures) may be seen as an advantage to some suppliers over their competitors.

Approximate Warm Mix Asphalt Equipment and Application Rates[47]
(Costs will vary based on volume purchased and transportation)

Cost Component	Chemical Additives	Organic or Wax Additives	Product Foaming (water based) Additives
Equipment	Minimal. Metered injection equipment available	Minimal. Metered injection equipment available	Minimal. Metered injection equipment available
Application Rate	Typically 0.25 – 0.75% by binder weight	Avg. 1.5% by binder weight	Avg. 0.30% by weight of mix

Life Cycle Costs

Since WMA technologies have been used for less than 10 years in North America there is no data on the service life of these pavements or information about the life cycle costs of WMA compared to conventional HMA. It is hoped that the lower production temperatures will contribute to less binder aging and reduced susceptibility to fatigue and temperature cracking. If WMA is found to extend pavement surface life by one or two years, this could be sufficient to make WMA more cost effective than conventional HMA, if it assessed on a life-cycle basis.

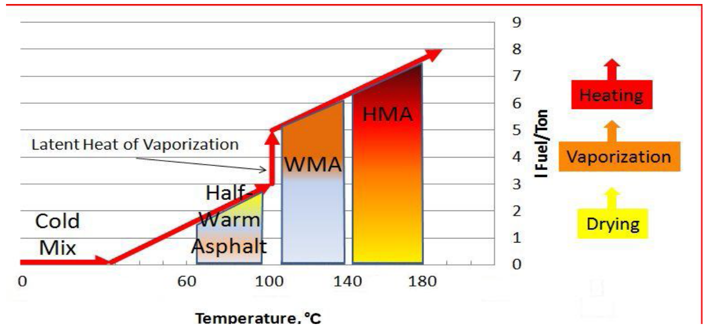
Emission and Other Impacts

Warm mix asphalts are produced at temperatures generally below 140° C, or between 15°C to 35°C (60°F to 90° F) lower than hot mix asphalt.[48] The reduction of GHGs and fuel combustion emissions is generally proportional to the reduced energy demand for a given fuel type. By keeping mix temperatures below 135°C the production of Volatile Organic Compounds (VOC) is reduced since this is the temperature the light distillate oils in the binder begin to vaporize.

The use of WMA can allow the production of asphalt at lower temperatures, but the full achievement of these advantages depend on the paving plant's operator familiarity with WMA and the operating efficiency of the plant.

47 Forfylow and Middleton (2008), Zaumanis (2010) and other information.
48 Prowell, Brian D. and Graham C. Hurley (2008).

A US report on warm mix best practices states that European and North American experience have resulted in the following emission reductions.[49] Although there are wide variations in reported emission reductions, reductions for most contaminants are significant.



Emission	Report Reduction vs. HMA
Carbon dioxide (CO_2)	15-45 %
Carbon monoxide (CO)	10-60 %
Particulate matter (PM)	20-25 %
Volatile organic compounds (VOCs).	20-50 %
Nitrogen oxide (NOx)	60-70 %
Sulphur dioxide (SO_2).	5-40 %

Lower temperatures and reduced emissions are also reported to improve worker comfort. The literature notes that worker exposure to HMA is typically within emission exposure safety limits, however the use of WMA has been reported to reduce emission exposure by 30 to 50 percent compared to HMA, which increases the comfort margin.[50]

Although US reports of GHG savings have been in the range of 15 to 45 percent, reductions in B.C. and Manitoba have been found in the 10 to 25 percent range using new materials. When greater percentages of RAP are used with WMA (e.g. from 15% to 45%), which have been successfully documented, this would further reduce the carbon footprint of WMA compared to conventional HMA.[51]

49 US National Asphalt Pavement Association (2007). *Warm-Mix Asphalt Best Practices,* QIS 125. Page 28.
50 US Federal Highway Administration (2008). *Warm Mix Asphalt: European Practice,* International Technology Scanning Program.

Ministry WMA Pilot Projects

The Ministry has conducted two WMA pilot projects, the first using a chemical additive in the Kootenays in 2007 and the second using an organic wax based additive near Lillooet in 2010. The table below summarizes the emission results with reference to the HMA for the two pilot projects.

Although the Ministry's second trial was more successful that the first trial, both projects resulted in reductions in several Criteria Air Contaminants, and a 11 percent reduction in GHG from the chemical additive and 16 percent from the wax additive. Both trials resulted in reductions in most contaminants, such as carbon monoxide, particulates, sulphur dioxides and nitrogen oxides. With the exception of VOC results, the most recent test results indicate that using WMA reduces emissions, in some cases substantially over conventional HMA.

With respect to paver emissions, the chemical additive was found to be significantly reduced as compared to HMA, whereas for the wax additive the sampled paver emissions were similar for both HMA and WMA. The potential explanation for the low emission levels sampled during the wax additive trial may be due to the characteristic of the asphalt cement itself.

Summary of Ministry's Wax Additive and Chemical Additive Emission Results[52]

(3 test average, measured values,no 16% 02 correction)

GHG and CAC Parameter	Wax WMA Hwy 99	Chemical WMA Crawford Bay	Other Reported Difference
Difference from HMA	(%)	(%)	(%)
Carbon Dioxide	-10.9	+10.3	-15 to -45
Particulates	-38.7	-13.4	-20 to- 25
Carbon Monoxide	-48.8	- 62.3	-10 to -60
Sulphur Dioxide	-13.2	- 5.3	-5 to - 40
Nitrogen Oxides	-1.0	-3.0	-60 to -70
VOCs	+53.7	- 21.2	-20 to -50
Total GHG Reduction	- 16.3%	-11.0%	-15 to -45
Average Mix Temp.	-10% (131°C)	-15% (128°C)	-20 to -25

51 Manitoba reports higher fuel and emission reductions using RAP as reported below.

52 McCall Environmental(2010) *Testing for Dawson Constructin Ltd. Highway 99 near Lillooet, B.C. Hot Mix Asphalt vs. Warm Mix Asphalt.* Permit Number RA-14518.

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4. SUMMARY

The B.C. Roadbuilders and Heavy Construction Association and the B.C. Ministry of Transportation and Infrastructure have partnered in this unique project to collect the best practices for reducing greenhouse gas emissions. These best practices highlight many of the opportunities currently available to assist the road building and highway maintenance industry reduce greenhouse emissions. We hope that every project we work on will be able to incorporate these practices, and make them the industry standard. It's hoped that the costs to implement them will decline, and new technologies will also become available.

Each project that we work on will also lead to new ideas for more efficient and lower emission practices. As these ideas take shape, we will be adding them to this document, ensuring that it always reflects the most current practice. Readers are encouraged to assist in ensuring these guidelines remain current by sharing their knowledge of associated practices and technologies. Please direct your comments to Tom.Greene@gov.bc.ca.