Preservation Treatments Are Environmentally Sustainable

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Today's pavement preservation treatments are environmentally sustainable strategies for road maintenance and life extension.

Recent analyses of energy inputs and emissions outputs of pavement preservation treatments—compared to conventional rehabilitation and reconstruction practice—show that these treatments have significantly lower energy usage and greenhouse gas emissions than conventional rehab and reconstruction.

Energy Consumption (MJ/t) for Each Type of Product						
Product	Binders	Aggregates	Manufacture	Transport	Laying	Total (MJ/t)
Bituminous Concrete	279	38	275	79	9	**680**
Road Base Asphalt Concrete	196	36	275	75	9	**591**
High Modulus Asphalt Concrete	284	38	289	79	9	**699**
Warm Mix Asphalt Concrete	294	38	234	80	9	**654**
Emulsion Bound Aggregate	227	37	14	81	6	**365**
Cold Mix Asphalt	314	36	14	86	6	**457**
Cement-Bound Materials	200	32	14	67	6	**319**
Cement-Bound Materials & AJ	203	32	14	67	6	**323**
Aggregate w/Hydraulic Road Binder	50	29	14	61	6	**160**
Aggregate w/Hydraulic Road Binder & AJ	54	29	14	61	6	**164**
Cement Concrete Slabs without Dowels	598	40	14	84	2.2	**738**
Continuous Reinforced Concrete	1,100	29	14	81	2.2	**1,226**
Untreated Granular Material	0	40	-	68	6	**113**
Soil Treated In-situ w/Lime + Cement	63	0	-	7	12	**81**
Thermo-Recycling	98	4	-	12	456	**570**
Concrete Bituminous w/10% RAP	250	35	275	73	9	**642**
Road Base Asphalt Concrete w/20% RAP	157	33	275	64	9	**538**
Road Base Asphalt Concrete w/30% RAP	137	39	275	58	9	**510**
Road Base Asphalt Concrete w/50% RAP	98	25	275	47	9	**454**
Emulsion In-situ Recycling	105	4	-	15	15	**139**

Table 1: Total Energy Use for Pavement Construction Materials (Chappat and Bilal, 2003)

In the analysis, the basics of energy use (inputs) and greenhouse gas (GHG) emissions for various pavement materials, construction processes, and pavement preservation techniques were considered. We also compared energy use and GHG emissions on an annualized life-extension basis. Any way it is looked at, pavement preservation techniques offer reduced energy inputs and lower GHG emissions compared to classic hot-mix asphalt, and even warm-mix asphalt reconstruction techniques.

Any pavement strategy will require a series of procedures that use energy and emit greenhouse gases. Pavement rehabilitation and reconstruction require large amounts of energy to obtain and process raw materials, transport, mix and apply the final product, while pavement preservation processes require much less energy to apply the final product to the road surface. The big benefit is during the technique's service life. We present data on energy usage per unit area of pavement life extensions via pavement preservation treatments and compare it to typical design lives of reconstruction and rehabilitation techniques.

Pavement preservation treatments typically include spray-applied surface seals, thin overlays, crack treatments, chip seals, slurry seal/micro surfacing, surface recycling, and others.

Each preservation treatment reduces damaging effects of aging and deterioration of the pavement surface layer and helps protect the integrity of the underlying pavement structure. If proactive preservation treatments are not used, pavements will deteriorate more rapidly, and will require major rehabilitation with structural overlays or reconstruction much earlier.

Alternatively, conventional construction, rehabilitation and maintenance of pavements require obtaining, processing, transporting, manufacturing and placement of large amounts of construction materials, including base materials, aggregates, and asphalt cement or Portland cement binder. These conventional processes use substantial amounts of energy, and generate greenhouse gases.

Vastly different amounts of energy are consumed between the different construction, rehabilitation and preservation techniques. These various techniques also provide differing amounts of pavement design lives and life extensions.

The life extension of each preservation treatment can be compared to the required energy and GHG emissions to determine an annualized energy use and GHG emission level. To minimize energy inputs and GHG emissions over the life of the pavement, treatments having the lowest annualized energy use and GHG emissions should be considered.

'GREEN' HIGHWAYS CONSIDERED

Many of us are familiar with the *Leadership in Energy and Environmental Design* (LEED) system for structures. By incorporating approved, environmentally sustainable design elements, materials or construction practices, a structure may attain LEED certification by the U.S. Green Building Council, or even achieve coveted Silver, Gold or Platinum certification levels.

A new LEED-ND (for *Neighborhood Development*) category focuses on complete residential, commercial and mixed-use projects developed by a single entity, and includes pavement attributes for project certification.

A similar system now exists to assess environmental sustainability of roadways. *Greenroads* provides a sustainability performance metric for roadway design and construction. The system defines environmentally sustainable attributes of roadways, provides a system for evaluation of roadway sustainability, and includes a collection of sustainable design and construction practices.

The system includes 11 project requirements, including items ranging from the existence of pavement preservation and environmental maintenance plans, to construction quality control, and life-cycle cost analysis. Credit can be given for use of several pavement technologies, including warm mix asphalt, cool pavements, and quiet pavements, to name a few. Additional voluntary credits are available that can be added to produce a final Greenroads score. The score can be used for tracking and evaluating roadway project and system sustainability.

And as the environmental sustainability of individual roadways gets a closer look via Greenroads, the actual energy inputs and emissions of pavements has garnered closer scrutiny. For example, BASF Corp. recently developed an eco-efficiency analysis (see *Micro Surfacing Scores High Points in Ecological Sustainability, Efficiency*, PPJ, Winter 2010, pp 8-13).

The *Road Rehabilitation Energy Reduction Guide for Canadian Road Builders* by the Canadian Construction Association (2005) was developed to provide information on methods to reduce energy usage during road construction and maintenance operations.

Treatment	Details	Pavement Life Extension (years)	Energy Use per Year		GHG Emissions per Year	
			BTU/yd²	MJ/m²	lb/yd²	kg/m²
Hot Mix Asphalt	Thickness .5" (3.8 cm)	5 – 10	4,660 – 9,320	5.9 - 11.8	0.9 - 1.8	0.5 - 1.0
	Thickness 2.0" (5.0 cm)	5 – 10	6,080 - 12,160	7.7 - 15.4	1.2 - 2.4	0.7 - 1.3
Hot In-place Recycling	Thickness 1.5" (3.8 cm) 50/50 Recycle/New	5 – 10	3,870 – 7,740	4.9 - 9.8	0.7 - 1.4	0.4 - 0.8
	Thickness 2.0" (5.0 cm) 50/50 Recycle/New	5 – 10	5,130 - 10,260	6.5 - 13.0	0.9 - 1.5	0.5 - 1.0
Chip Seal	Emulsion 0.44 g/yd² (2.0 L/m²) Aggregate 38 lb/yd² (21 kg/m²)	3 – 6	1,170 - 2,340	1.5 - 3.0	0.15 - 0.3	0.08 - 0.10
	Emulsion 0.35 g/yd² (1.6 L/m²) Aggregate 28 lb/yd² (15 kg/m²)	2 – 5	1,026 - 2,565	1.3 - 3.3	0.14 - 0.35	0.08 - 0.2
Slurry Seal / Micro-surfacing	Type III, 12% Emulsion, 24 lb/yd² (13 kg/m²)	3 – 5	1,026 - 1,710	1.3 - 2.2	0.12 - 0.2	0.06 - 0.10
	Type II, 14% Emulsion, 16 lb/yd² (8.7 kg/m²)	2 – 4	968 - 1,935	1.2 - 2.4	0.10 - 0.20	0.05 - 0.10
Crack Seal	1 lin.ft./ yd² (0.37m/m²), 0.25 lb/ft (0.37 kg/m)	1 – 3	290 - 870	0.4 - 1.1	0.05 - 0.14	0.03 - 0.08
Crack Fill	2 lin.ft./ yd² (0.74 m/m²), 0.50 lb/ft (0.74 kg/m)	1 – 2	930 - 1,860	1.0 - 2.0	0.13 - 0.25	0.07 - 0.14

Table 2, Part 1: Annualized total energy use and GHG emissions for pavement preservation treatments (after Chappat and Bilal)

But a landmark study by M. Chappat and J. Bilal – *The Environmental Road of the Future: Life Cycle Analysis, Energy Consumption and Greenhouse Gas Emissions* – was released by the Colas Group in 2003 and is an in-depth analysis of energy consumption and GHG emissions of over 20 different paving product types by ton of material placed (see Table 1). Chappat and Bilal show that portland cement concrete (PCC) paving materials and processes demand the most energy, followed by hot mix asphalt (HMA) paving. The report also showed that cold-in-place (CIP) recycling is the least energy-intensive process.

ENERGY, EMISSIONS FOR ROADWORK

A comprehensive and realistic measure of energy use and GHG emissions of a specific type of roadwork begins at the extraction of raw materials from the earth, and including all intermediate steps, such as transport, refining, manufacturing, mixing and placement. These energy input and emissions data then can be extended via an annualized life extension basis.

Energy consumption for **aggregate production** includes quarrying, hauling, crushing and screening. Chappat and Bilal demonstrate that energy consumption for aggregate production ranges from 25,850 to 34,470 Btu/t, and GHG emissions range from 5 to 20 lb CO_2/t.

Energy consumption for **asphalt binder production** includes crude oil extraction, transport and refining. Energy consumption for asphalt binders has been determined to be 4.2 mm Btu/t, and GHG emissions are 570 lb CO_2/t.

For asphalt emulsions, energy consumption is 3.0 mm Btu/t and GHG emissions are 442 lb CO_2/t.

Manufacturing includes all steps involved with handling, storing, drying, mixing, and preparation of materials. Typical manufacturing products for highway use include **hot mix asphalt (HMA), cold mix, crack sealant,** and **drying surface dressing aggregate.** Production of HMA consumes 237,000 Btu/t and produces 44 lb CO_2/t.

Warm mix asphalt production, as reported by Chappat and Bilal, consumes 201,000 Btu/t, approximately 15 percent less than HMA, although this varies widely due to the variety of different processes. Cold mix asphalt production only requires 12,000 Btu/t, as there isn't a need to heat aggregate to elevated mixing temperatures.

The produced construction **materials must be transported** to the work site. Energy consumed on transport varies with the distance and the quantity of material moved. Transport energy has been reported as 1,250 Btu/t-mile with 0.2 lb CO_2/t-mile.

Placement and construction consists of all activities required to install the materials or products, including traffic control, site and product preparation, compacting, finishing, clean up and waste disposal.

The highest energy-consuming process for placement is **hot in-place (HIP) recycling** at 393,000 Btu/t with 68 lb CO_2/t of GHG. This is due to the need to heat the road surface to soften and reclaim the existing pavement.

Placement of asphalt concrete and cold mixes require between 5,170 and 7,750 Btu/t with 0.8 to 2.2 lb CO_2/t of GHG. Placement energy for PCC is the lowest at 1,900 Btu/t with 0.4 lb CO_2/t of GHG.

Chappat and Bilal's data show that **portland cement concrete** pavements use the highest energy consumption at approximately 860,000 Btu/t, with the highest energy demand being required for pyroprocessing of raw materials to make cement.

Asphalt concrete utilizes less energy than PCC at 586,000 Btu/t, with the majority of energy being required for manufacture of the asphalt cement and heating of aggregate during the hot mix production process. Processes that use unheated aggregate and cold applied binders utilize the least amount of energy per ton.

A caveat: Different types of pavement construction, rehabilitation and preservation operations consume different amounts of energy. Energy use and GHG emissions per ton of product provide only a relative comparison of products.

The specific pavement structure or work-type—together with the actual quantities of materials—must be evaluated to more accurately compare energy use and GHG emissions for construction, rehabilitation and preservation. One estimate showed that for different pavement section designs yielding the same structural performance, energy use and GHG emissions can vary as much as 80 percent.

ENERGY, EMISSIONS FOR PRESERVATION

Energy use and GHG emissions are available for some pavement preservation treatments, including thin HMA overlays and HIP.

There have been some specific comparisons performed for various types of chip seals and for micro surfacing (no references could be found for fog sealing and crack treatments). To provide uniform comparisons, the information developed by Chappat and Bilal was used to calculate energy use and GHG emissions for typical preservation treatments.

Energy use and GHG emissions were calculated per unit area of the pavement surface, using typical quantities of raw materials for each treatment. Preservation treatments considered include the HMA overlay, HIP, chip seal, micro surfacing/slurry seal, crack fill, crack seal and fog seal. For some treatments, several different application rates of the treatment were considered.

Table 2 shows calculated energy use and GHG emissions for these pavement preservation treatments. The analysis of energy use and GHG emissions includes the entire process for each treatment, including raw materials, transport, processing, mixing and installation.

Thin HMA overlays, placed approximately 1.5 to 2.0 inches thick, are commonly used as a pavement preservation treatment. GHG data are calculated based on using a 140 lb/ft^3 in-place density. The 1.5-in. thickness uses 0.079 t/yd2 and the 2-in. thickness uses 0.105 t/yd^2. The analysis used an energy use of 586,000 Btu/t for the entire process.

Hot In-Place (HIP) Recycling consists of heating, removing and remixing of one inch of the existing pavement surface, followed by installation of a new 1-in.-thick asphalt concrete overlay producing a 2-in.-thick treatment. Energy use basis is 491,000 Btu/t. Data are calculated using a 140 lb/ft^3 in-place density.

Two **chip seal treatment** designs were analyzed. First, a high quality design using 0.44 g/yd^2 of asphalt emulsion with 38 lb/yd^2 of aggregate. The second design, a lesser binder application rate of 0.35 g/yd^2 with a smaller aggregate gradation of 28 lb/yd^2. Energy use is calculated including emulsion and aggregate raw materials, transport and installation.

Two **slurry seal/micro surfacing** treatment designs were analyzed. First was a typical Type III aggregate, with 12 percent emulsion and a 24 lb/yd^2 application rate, and the second design was a typical Type II aggregate, with a 14 percent emulsion and a 16 lb/yd^2 application rate. Energy use is calculated including emulsion and aggregate raw materials, transport and installation.

Crack sealing was calculated for a typical pavement cracking density

Treatment	Details	Life Extension	Energy Use per Year		GHG Emissions per Year	
			BTU/yd²	MJ/m²	lb/yd²	kg/m²
Fog Seal	0.05 gal/yd² (0.23 L/m²) 50/50 Diluted Emulsion	1	250	0.4	0.04	0.02
	0.10 gal/yd² (0.46 L/ m²) 50/50 Diluted Emulsion	1	500	0.8	0.07	1.04
	0.15 gal/yd² (0.69 L/ m²) 50/50 Diluted Emulsion	1	750	1.2	0.12	0.07

Table 2, Part 2: Annualized total energy use and GHG emissions for pavement preservation treatments (after Chappat and Bilal)

on the basis of 1 ft. of crack sealing per square yard. This density is equivalent to one full length longitudinal crack per lane, and full width transverse cracks spaced at 36 ft. This crack pattern, for a typical lane mile, produces 7,040 linear feet of cracking for the area of 7,040 yd², which is one linear ft/yd². An installation rate of 5,000 lb per day is used. The application yields four linear feet per pound of sealant, producing an installation amount of sealant of 0.25 lb/yd². Energy use is calculated including raw materials, manufacturing, transport, field heating, reservoir cutting and installation.

Crack filling was calculated for a typical pavement cracking density of 2 ft. of crack filling per square yard. This density is equivalent to a crack pattern of two full length longitudinal cracks, and full width transverse cracks spaced at 18 ft. This crack pattern, for a typical lane mile, produces 14,080 linear feet of cracking for the area of 7,040 yd², which is 2 linear ft/ yd². An installation rate of 5,000 lb per day is used. The application yields 4 linear feet per pound of sealant, producing an installation amount of sealant 0.50 lb/yd². Energy is calculated including raw materials, manufacturing, transport, field heating and installation.

Fog sealing is calculated for three different application rates; 0.05, 0.10, and 0.15 g/yd² of a 50:50 water-diluted asphalt emulsion. Energy use is calculated including raw materials, manufacturing, transport and installation.

For comparison purposes, energy use and GHG emissions per square yard for HMA new construction, HMA rehab, and WMA rehab were determined.

HMA new construction. The structural section for this pavement is 4 in. of HMA placed on 6 in. of compacted aggregate base course. Energy is calculated including raw materials, heating, mixing, transport, placement and compaction.

HMA rehab. Both a 4-in.-thick HMA overlay and a 3-in.-thick overlay are investigated. Energy is calculated including raw materials, heating, mixing, transport placement and compaction.

WMA rehab. Both a 4-in-thick warm mix asphalt (WMA) overlay and a 3-in.-thick overlay are examined. Energy is calculated including raw materials, heating, mixing, transport placement and compaction.

ANNUALIZED ENERGY USE

Several studies have attempted to determine the amount of life extension provided by different pavement preservation treatments. The resulting life extensions have varied widely. Pavement life extensions provided by preservation treatments range from one year for fog sealing, up to 10 years for thin HMA overlays and HIP.

The energy and GHG data must be normalized for the expected pavement life extension to appropriately compare energy use and GHG emissions of preservation treatments. The normalization is accomplished by dividing unit area energy and GHG data by the life extensions to produce annualized results. The annualized results for pavement preservation treatments are shown in Table 3. In Table 3 the ranges for energy use and GHG emissions are due to the ranges of life extension times.

The annualized energy and GHG data for pavement preservation treatments ranges from 250 Btu/yd²-yr for a 0.05 g/yd² fog seal application upwards to 12,160 Btu/yd²-yr for 2-in. of HMA overlay. Annualized results for the new construction and rehabilitation work types range from 6,780 to 7,840 Btu/yd²-yr.

The results group into three categories. The first category includes the **thin HMA overlay, HIP, new construction** and **rehabilitation**, and has the highest annualized results, ranging from 3,870 to 12,160 Btu/yd²-yr energy and 0.9 to 2.4 lb/yd²-yr of GHG.

Treatment	Details	Design Life (years)	Energy Use per Year		GHC Emissions per Year	
			BTU/yd²	MJ/m²	lb/yd²	kg/m²
New Consruction	4" (100 mm) HMA over 6" (150 mm) Aggregate Base	20	7840	9.9	1.2	0.7
Major Rehab Hotmix Asphalt	4" (100 mm) Overlay	15	7500	9.4	1.3	0.8
	3" (75 mm) Overlay	12	7050	8.9	1.3	0.7
Major Rehab Warm Mix Asphalt	4" (100 mm) Overlay	15	7210	9.2	1.3	0.8
	3" (75 mm) Overlay	17	6780	8.5	1.3	0.7

Table 3: Annualized Energy Use and GHG Emissions for Asphalt Concrete Pavement Construction and Rehabilitation

The second category includes **chip seal, micro surfacing,** and **crack fill** at 930 to 2,565 Btu/yd^2-yr energy and 0.13 to 0.35 lb/yd^2-yr of GHG. The third and final category includes **fog sealing** and **crack sealing** with 250 to 870 Btu/yd^2-yr energy and 0.04 to 0.14 lb/yd^2-yr of GHG.

Results show that on an annualized basis, different process types require differing amounts of energy per year of pavement life. **New construction, major rehabilitation, thin HMA overlay,** and **HIP** have the highest energy use and range from 5,000 to 10,000 Btu/yd^2-yr. **Chip seals, slurry seals, micro surfacing,** and **crack filling** utilize lower amounts of energy per year of extended pavement life and range from 1,000 to 2,500 Btu/yd^2-yr. **Crack seals** and **fog seals** use the least amount of energy per year of extended pavement life, at less than 1,000 Btu/yd^2-yr.

In conclusion, pavement preservation techniques use significantly less energy, and have reduced GHG emissions per year of pavement life, than HMA and WMA rehabilitation overlays, and new construction.

Preservation processes require less energy and generate less GHG emissions due to due to their targeted applications of specific materials, in greatly reduced quantities, than with new construction or rehabilitation.

To minimize energy use and GHG emissions of pavement systems, appropriate pavement preservation processes should be utilized as much as possible, considering pavement conditions.

Chehovits is vice president, operations, Crafco, Inc., an Ergon Company, and Galehouse is director, National Center for Pavement Preservation, Okemos, Mich. This article is adapted from a technical paper, the full version of which is available from http://www.pavementpreservation.org/icpp/paper/65_2010.pdf