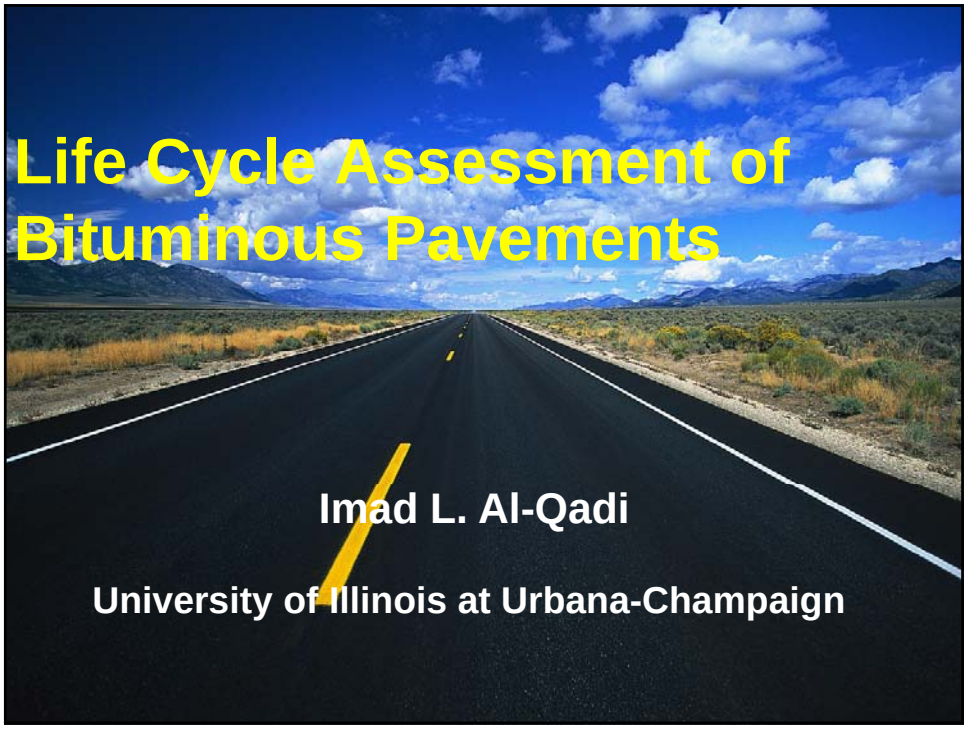


What Is "SUSTAINABILITY"?

"Meeting the needs of the present without compromising the needs of future generations to meet their own needs"

"An overarching conceptual framework that describes a desirable, healthy, and dynamic balance between human and natural systems"

"A system of policies, beliefs, and best practices protecting the diversity of the planet's ecosystems, fosters economic vitality and opportunity, and create a high quality life"

"A vision describing a future that anyone would want to inhabit"

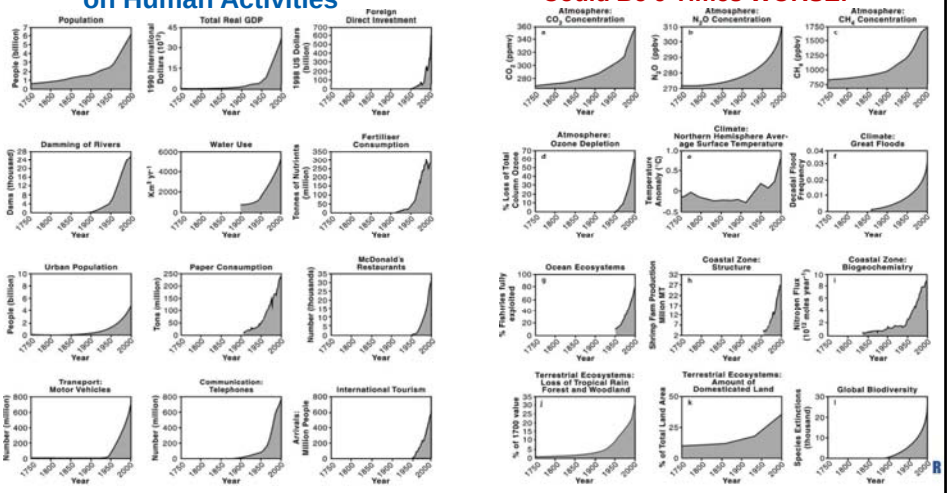
[1]UN World Commission on Environment and Development
[2]Transportation and Sustainability Best Practices Background

TRANSPORTATION

Human Activities vs. Env-Eco Impact

Great Acceleration on Human Activities

Environmental & Ecological Consequences Could Be 9 Times WORSE!

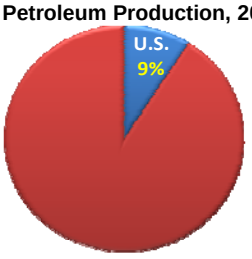


Steffen, et al. *Global Change and the Earth Systems: A Planet Under Pressure*; Springer-Verlag: Heidelberg, Germany, 2005

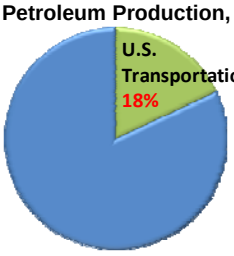
Sustainable Transportation System Is a Network of High-quality and Long-lasting Modes

- **28% of the total US energy is used in transportation**

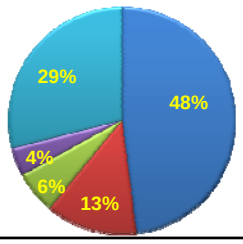
U.S. Share of World Petroleum Production, 2009



U.S. Transportation' Share of World Petroleum Production, 2009



Transportation mode of Total U.S. Petroleum Consumption, 2009



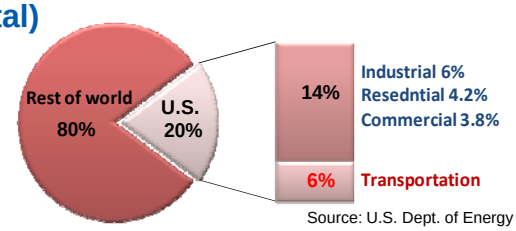
- Cars and Light Trucks
- Trucks
- Aviation
- Other modes
- Non-transport

Source: U.S. Dept. of Energy

Transportation Drives Oil Imports

- Transportation System is **second** to electrical power generation for **greenhouse gas emissions** in the U.S. (Approx. **33%** of the total)

Annual CO_2 Emissions, 2008

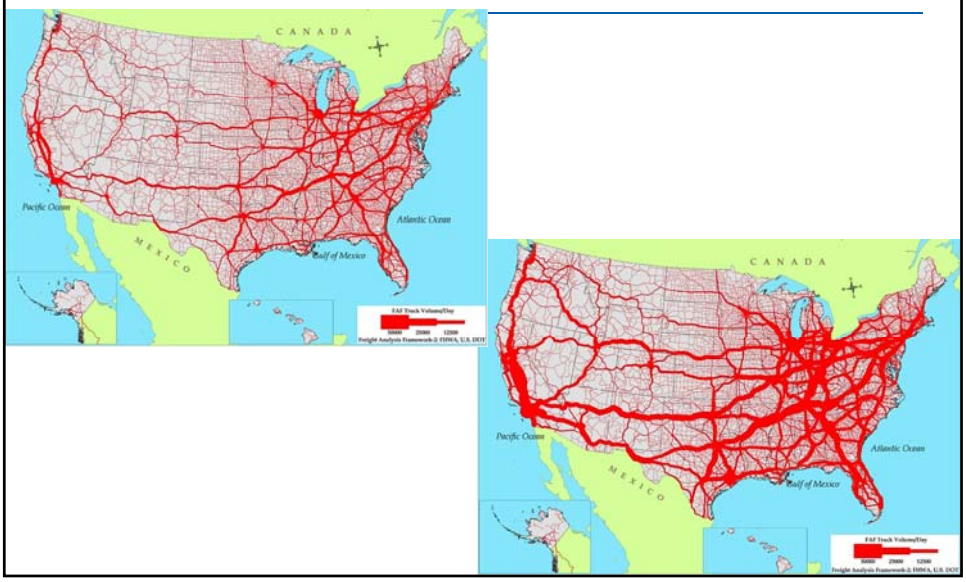


Source: U.S. Dept. of Energy

- Transportation plays a major role on the sustainable development efforts
  More fuel-efficient transport/ Less dependency on oil/ Renewable energy (carbon-neutral fuel)/ Reduce emission

Energy conservation and sustainability are at the core of the successful renewal and expansion of the national transportation infrastructure

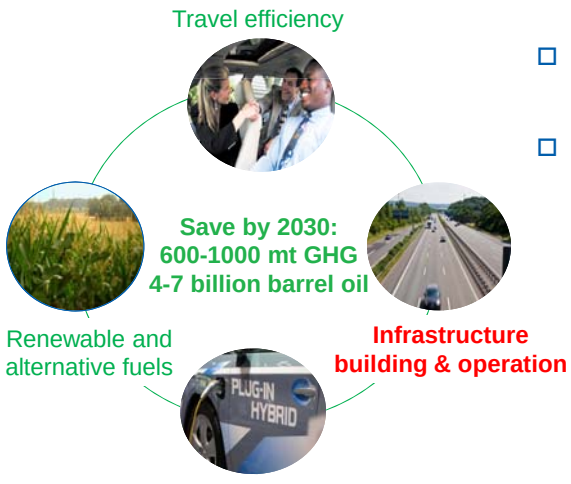
Truck Volume: 2002 - 2035



Sustainability Efforts in the US

- Nationwide and regional efforts to achieve sustainable growth in the transportation sector
  - FHWA's sustainable transportation and pavement programs (INVEST rating, sustainable pavements)
  - Statewide efforts to develop strategies and metrics for self-assessment (I-LAST, GreenLites, etc.)
- Environmental Protection Agency (EPA) acknowledge the weight of transportation sector
  - Regulations & standards for fuels, vehicle technologies, travel efficiency
- The ultimate goal is to slow down emissions and fuel use with a socially balanced approach

Reduction in Energy and Emissions



- Current US strategy relies on 4 branches
- Life-cycle approach is used to simulate benefits of each strategy in the short- and long-term

Source: http://www.epa.gov/otaq/climate/solutions.htm

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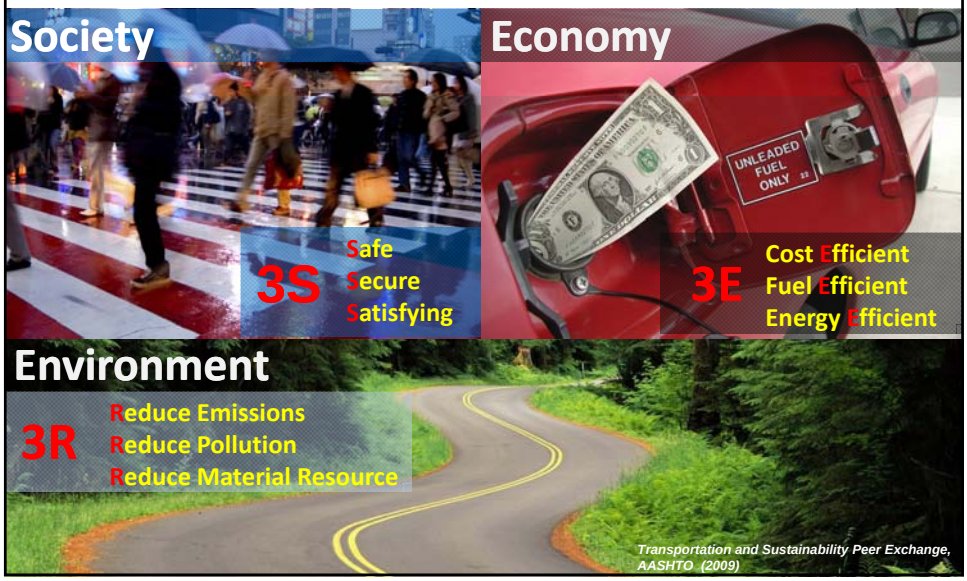
Three Goals to Achieve



Sustainability in Pavements

- Sustainability is not a new concept for pavement industry
  - According to EPA and FHWA, asphalt pavements are among America's most recycled product
    - Perpetual pavement, warm mix, RAP/RAS, …
  - Cooperation between trucking and tire industries to reduce fuel usage and emissions
- Next is to quantify the environmental impact in the context of a balanced approach considering economic, environmental, and social parameters

Recent ICT Studies on Sustainability of Asphalt Pavements

- Maximizing recycled materials in asphalt mixtures
  - High RAP performance characterization
  - Recycled roofing shingles (RAS) and high asphalt binder replacement
- Hot-in-place recycling
- Warm mix asphalt and curing time
- Durable, thin, high friction, and quiet overlays
- National Wide-Base Tires
- National Sustainable Pavement Guidelines
- Life Cycle Assessment

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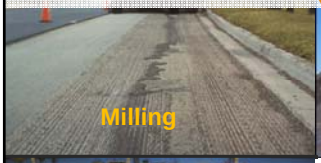
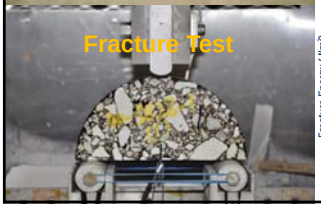
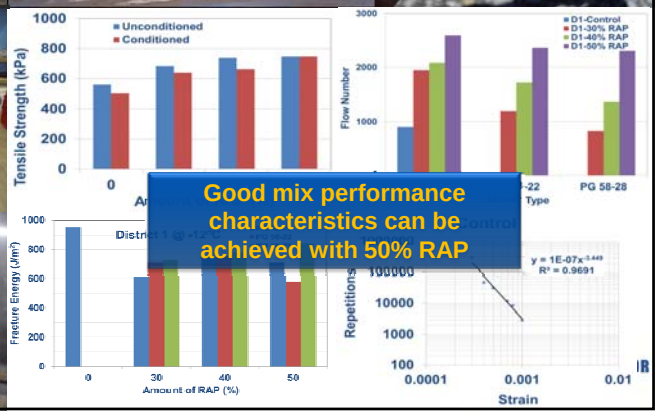
Performance of High RAP Mixes

(up to 50% RAP)







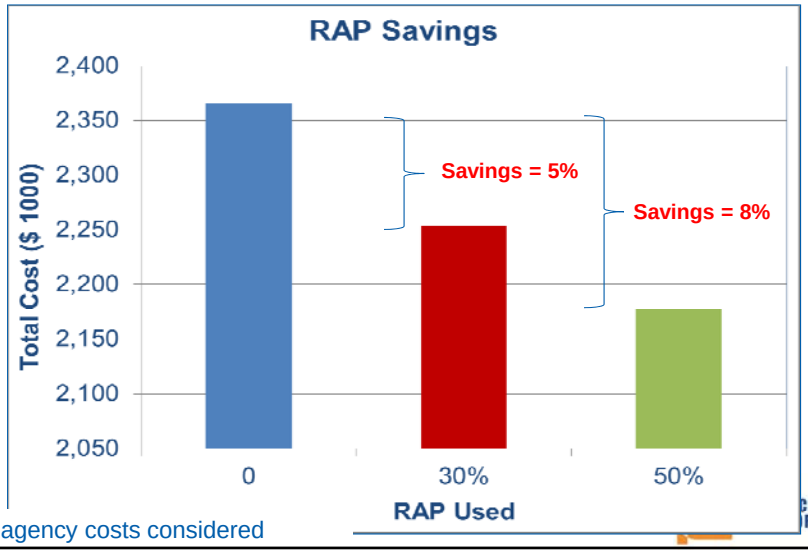
Good mix performance characteristics can be achieved with 50% RAP

Mixture Volumetrics with High RAP

RAP (%)	Total AC (%)	Binder Replaced (%)	Air Void (%)	VMA (%)	VFA (%)
0	4.9	0	4.0	13.7	70.8
30	5.0	34.6	4.0	13.6	70.6
40	5.1	34.6	4.0	13.7	70.8
50	5.0	43.7	4.0	13.7	70.8

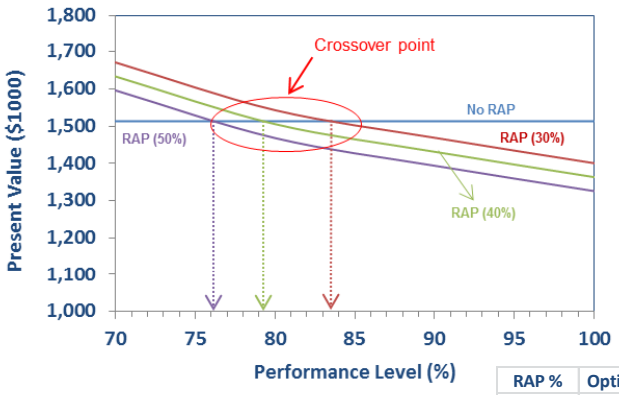
Achieving field and lab volumetrics is no longer an issue when RAP is fractionated and properly handled.

RAP and Economy*



*Only agency costs considered

RAP Optimum Performance Level



RAP %	Optimum Performance Level*, (%)
30	83.0
40	79.0
50	76.0

* based on Agency Cost Only

Performance of Mixes with RAS

(Binder replacement ~43-64%)

- The mixes are aiming at high binder replacement levels (up to 64%)
- Fracture, fatigue, modulus, and rutting tests were performed:
  - Good rutting performance, comparable fracture resistance, reduction in fatigue life

Stiffness

Cracking

Permanent Deformation

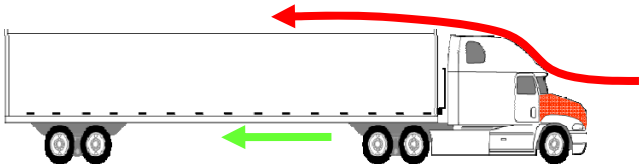
Fatigue Life

Where Does the Fuel Go?

aerodynamic drag — At 60 mph (100 km/h), aerodynamic drag consumes approximately 40% of the fuel

mechanical losses — Mechanical losses consume approximately 25% of the fuel.

rolling resistance — Rolling resistance accounts for approximately 35% of the fuel consumed.



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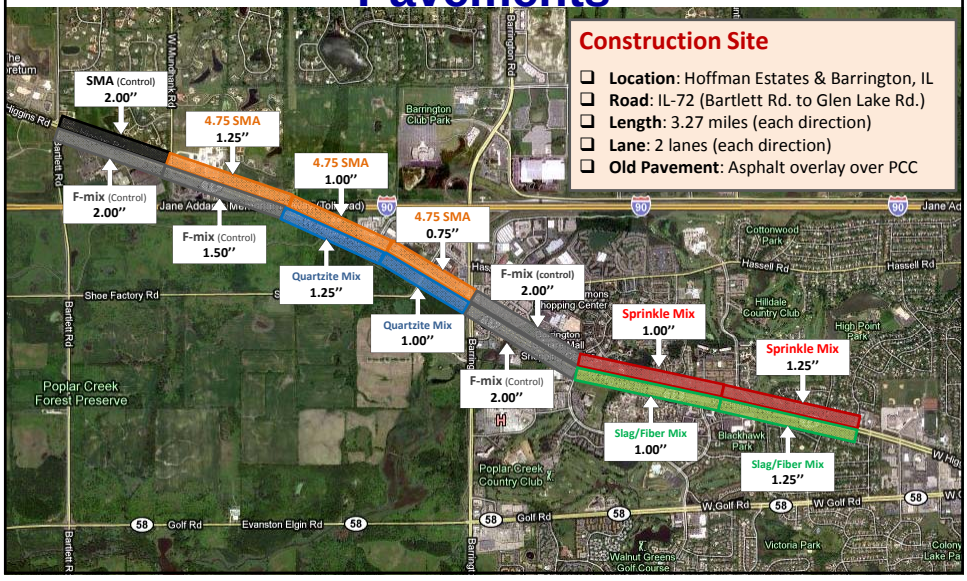
Durable, Thin, High Friction, Quiet Pavements



Construction Site

- **Location**: Hoffman Estates & Barrington, IL
- **Road**: IL-72 (Bartlett Rd. to Glen Lake Rd.)
- **Length**: 3.27 miles (each direction)
- **Lane**: 2 lanes (each direction)
- **Old Pavement**: Asphalt overlay over PCC

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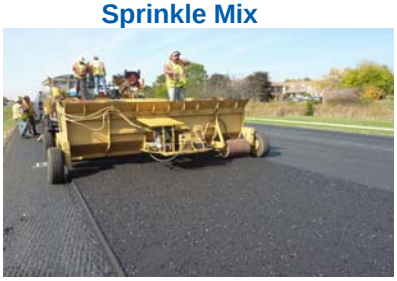
Durable, Thin, High Friction, Quiet Pavements

Sprinkle Mix

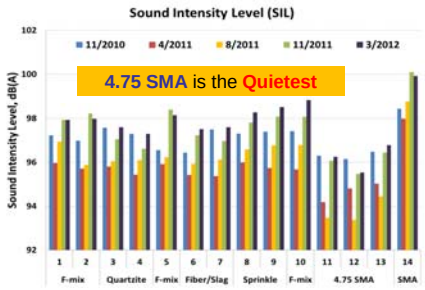


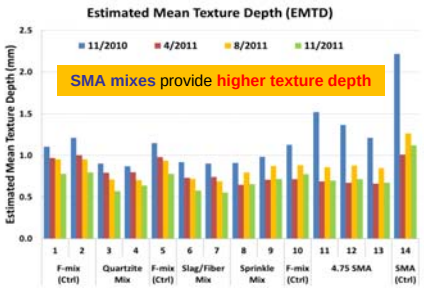
Fiber/ Slag Mix

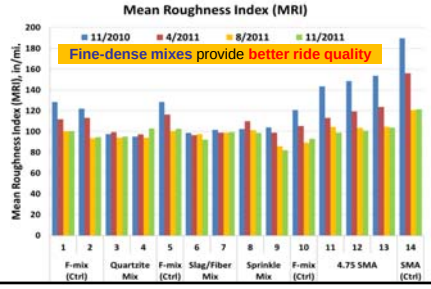
Quartzite Mix

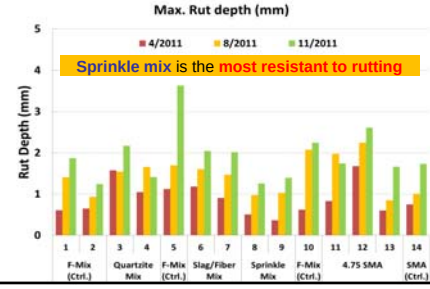
SMA 4.75mm

Field Performance Results









Engineering Benefit Analysis

$$Overall\ \ Performanæ\ \ Score = \frac{1}{\alpha+\beta}\left(\alpha\frac{\sum_{i=1}^{n} a_i^L \cdot R_i^L}{\sum_{i=1}^{n} a_i^L} + \beta\frac{\sum_{j=1}^{m} a_j^F \cdot R_j^F}{\sum_{j=1}^{m} a_j^F}\right)$$

where,
a_i^L, a_j^F: Weight factor of test i and j for lab performance and field performance, respectively;
R_i^L, R_j^F: Performance rating of test i and j for lab performance and field performance, respectively;
α, β: Weight factor for lab performance and field performance, respectively; and
n, m: Number of tests performed at the lab and the field, respectively

Performance Rating	F-mix		12.5 SMA	Quartzite Mix		Sprinkle Mix		Slag/Fiber Mix		4.75 SMA		
	2	1.5	2	1.25	1	1.25	1	1.25	1	1.25	1	0.75
RUTTING	9.6	9.6	9.6	8.6	8.8	8.8	9.0	9.4	9.4	9.6	9.0	9.4
DURABILITY	10.0	10.0	8.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
FRACTURE	7.3	7.3	10.0	8.0	8.0	7.5	7.5	7.7	7.7	8.0	8.0	8.0
IDT	4.0	4.0	5.0	7.0	7.0	10.0	10.0	8.0	8.0	7.0	7.0	7.0
TSR	2.0	2.0	3.0	7.0	7.0	10.0	10.0	9.0	9.0	5.0	5.0	5.0
NOISE	6.5	7.8	5.0	7.3	7.8	6.5	6.3	7.0	8.5	9.3	10.0	10.0
FRICTION	7.0	6.8	8.1	8.3	6.8	7.4	9.1	6.5	7.1	7.0	8.9	9.0
Overall Performance Score	**6.6**	**6.8**	**7.0**	**8.0**	**7.9**	**8.6**	**8.8**	**8.2**	**8.5**	**8.0**	**8.3**	**8.3**
Cost ($1,000/lane-mile)	**68.8**	**66.0**	**97.6**	**58.1**	**58.0**	**59.9**	**59.5**	**60.6**	**60.0**	**69.0**	**66.8**	**64.5**
Unit Cost ($1,000/lane-mile, performance)	**10.4**	**9.7**	**13.9**	**7.3**	**7.3**	**7.0**	**6.8**	**7.4**	**7.1**	**8.6**	**8.0**	**7.8**

Warm Mix Asphalt (WMA)

- Numerous benefits of WMA:
  - Lower energy and emission
  - More environment friendly to nature and humans
  - Can work better with RAP and RAS

www.adverawma.com

Warm SMA Lab Performance

Tests	Effect of Curing Time			
	|E*| at 10Hz (MPa)	Rut depth (mm)	IDT Strength (MPa)	Work of Fracture (kN-mm)
Control SMA	3838* *19%***	3.4 *12%*	0.52 *14%*	4.1 *16%*
Evotherm SMA	3761 *16%*	3.6 *7%*	0.48 *13%*	2.3 *8%*
Foamed SMA	4380 *13%*	2.9 *8%*	0.61 *16%*	3.3 *17%*
Sasobit SMA	5838 *15%*	2.2 *13%*	0.76 *9%*	2.6 *7%*

** average and ** coefficient of variation*

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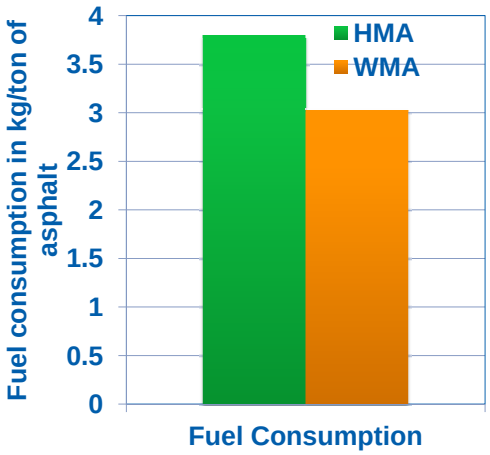
Cost Analysis – HMA vs. WMA



Material and labor cost ($/ton)

Conventional HMA	WMA
$85 ($108 quoted)	$85 ($108 quoted)

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Re-HEAT 100% In-Place Recycling

20-60% reduction in GHG emissions can be realized as compared to traditional asphalt concrete paving

Laboratory Evaluation of Re-HEAT

- **A pilot test section near Peoria, IL was selected**
- **Field samples prior to and during construction were collected**
- **A two phase experimental program to evaluate the effects of heating/recycling/rejuvenation on the mixture and binder level**

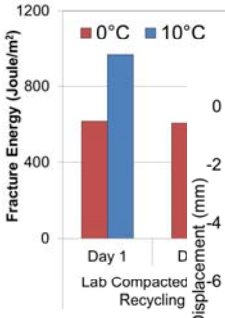

Prior to Recycling


After Recycling

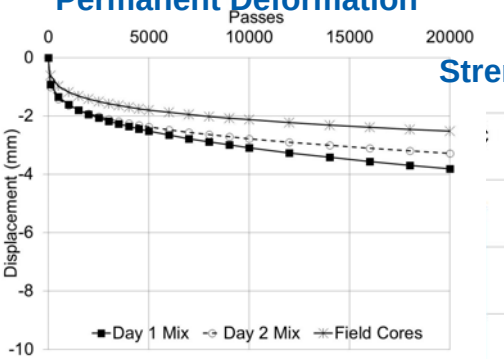

After Recycling

RE-HEAT CAN RECOVER ORIGINAL PAVEMENT PROPERTIES PRIOR TO RECYCLING

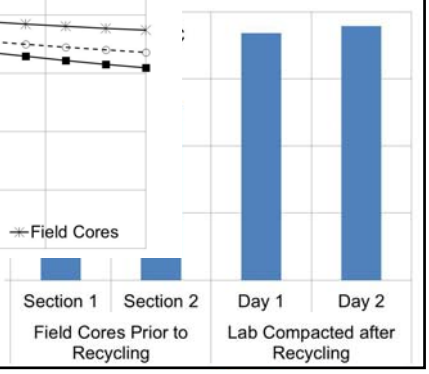
Low Temperature Cracking



Permanent Deformation

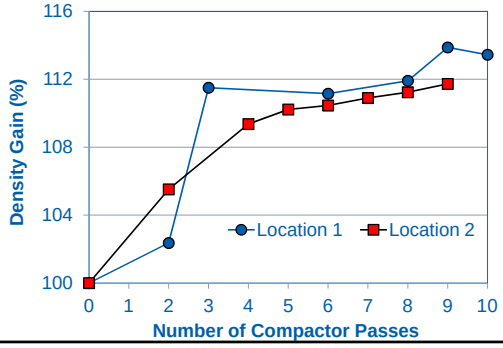


Strength



Re-HEAT In-Place GPR Density Measurements

- In-situ and real-time density measurements were taken by GPR
- GPR provides an autonomous platform to monitor construction quality



Maximizing Recycling in Pavements

- Significant cost reductions can be realized when utilizing recycled materials in pavements
- Laboratory performance of mixes with RAP/RAS, WMA appears to be comparable to control mixes
- However, there is more than cost savings ….
  - Reduction in petroleum based fuel usage
  - Reduction in emissions
- The question is how to measure such environmental benefits?

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LCA Definitions

- ISO 14040, 1997:
  - Compilation and evaluation of the inputs, outputs and potential environmental impacts of a product system throughout its life-cycle
- EPA, 2006:
  - A cradle-to-grave approach for assessing industrial systems that evaluates all stages of a product's life and provides a comprehensive view of the environmental aspects of the product or process

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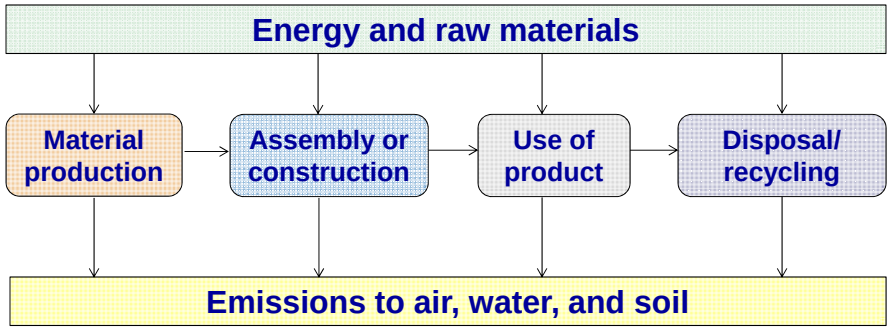
Life Cycle of Asphalt Concrete
'Materials Stage'

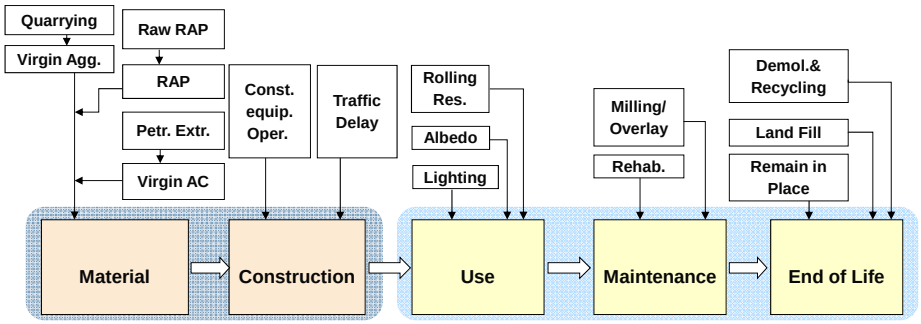
Life Cycle Assessment (LCA)

- Cradle to grave interactions of environment and product system



Source: www.bath.ac.uk

LCA for AC Pavements



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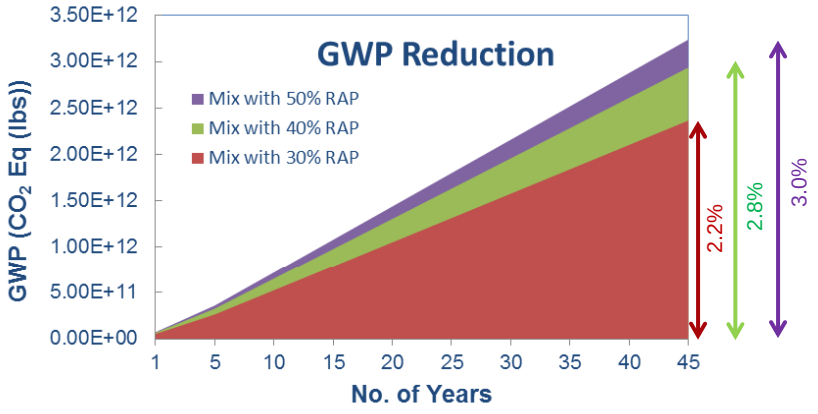
RAP - GWP Reduction



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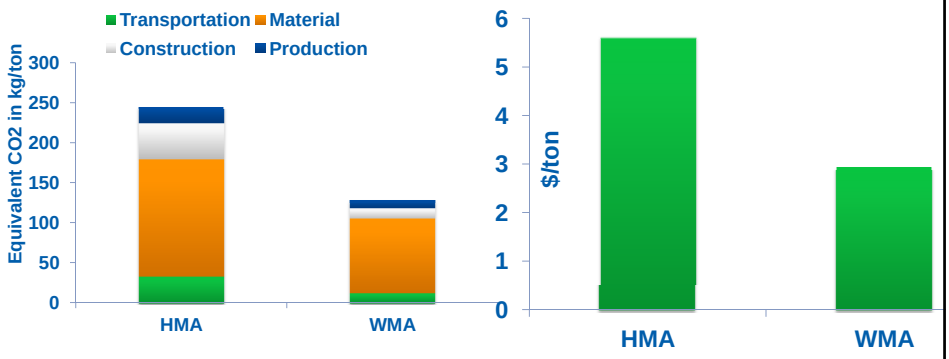
Warm Mix Green House Gas



GHG Emission

Emission price

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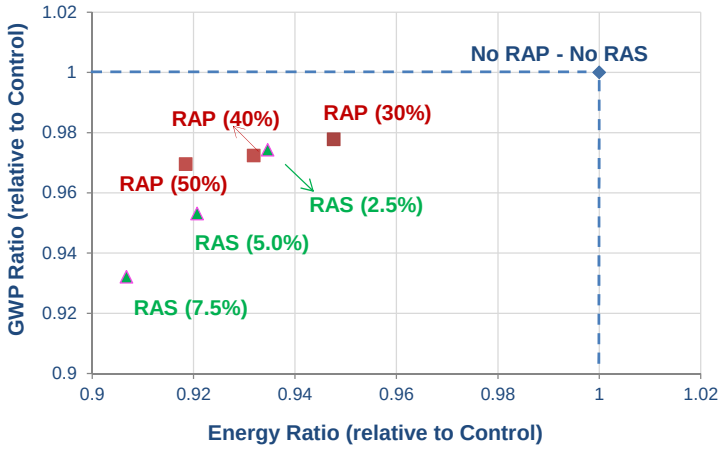
Energy and GHG Savings

- Energy savings from the production stage of asphalt pavements using RAP and RAS



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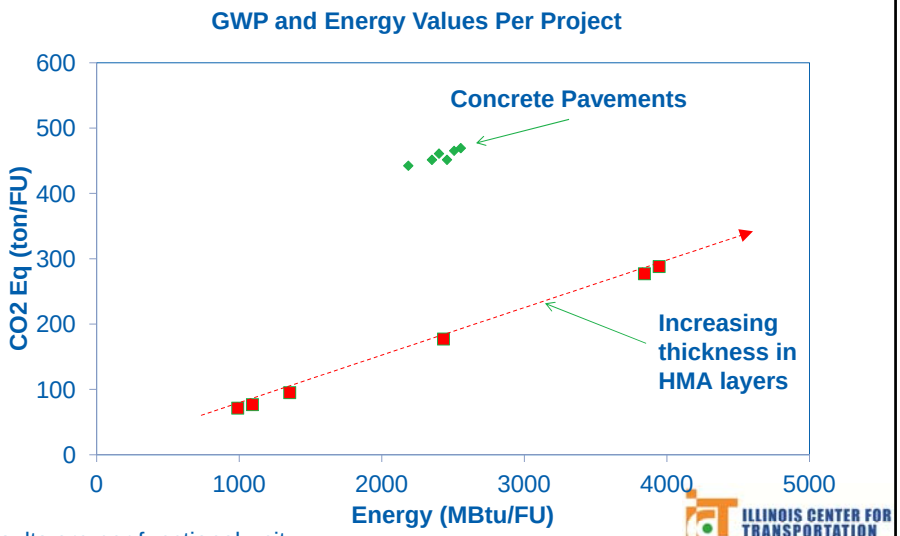
Energy and Emissions*



*Results are per functional unit

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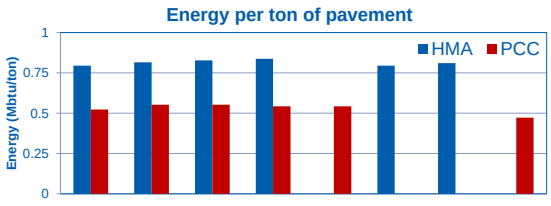
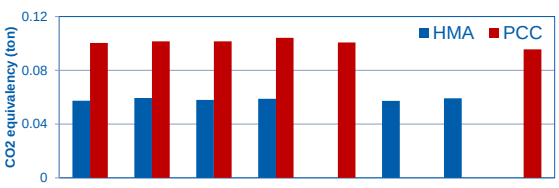
Energy and Emissions

- Per ton of pavement material
- Clear trends in HMA and PCC results
- Fairly consistent values





Summary and Remarks

- Good performance of sustainable asphalt mixtures can be achieved
- Economical benefits of recycling is invaluable
- Life-cycle assessment is a very useful metric to determine the benefit of each alternative over the life-cycle of pavements
- In order to meet sustainable development, a systematic approach is needed to optimize economic, performance, environmental, and social benefits

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