Asphalt Pavement Sustainability

Society

Economy

Sustainable Transportation

Environment

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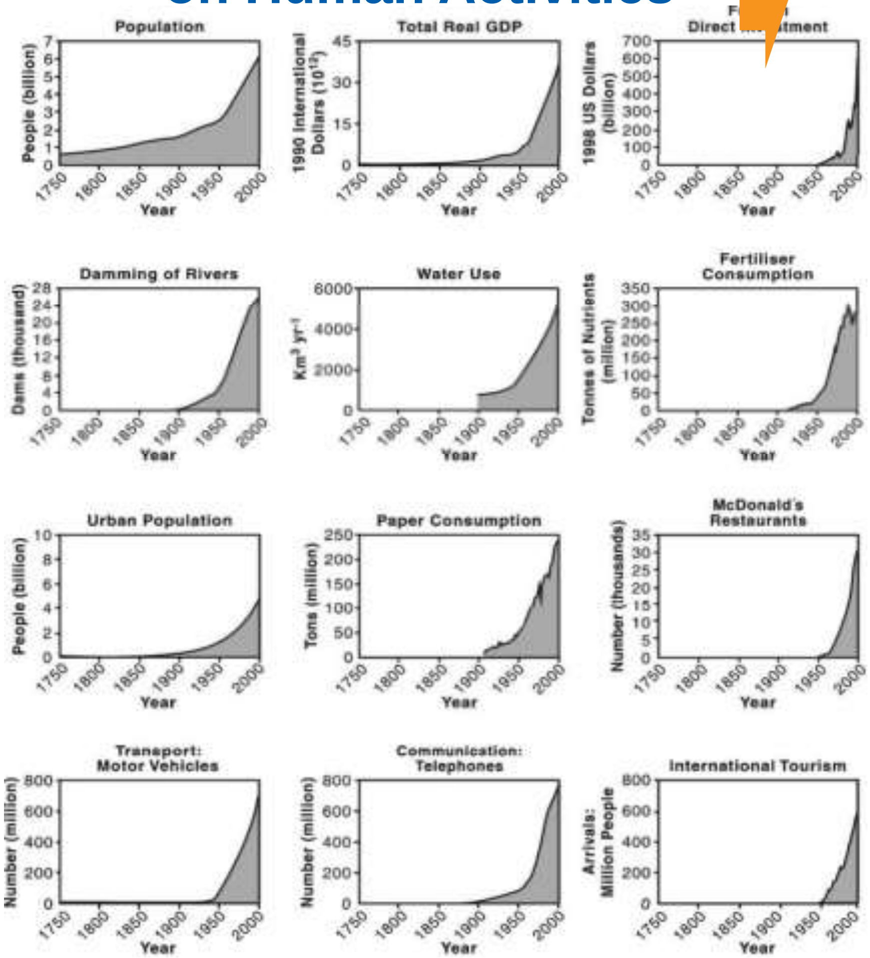
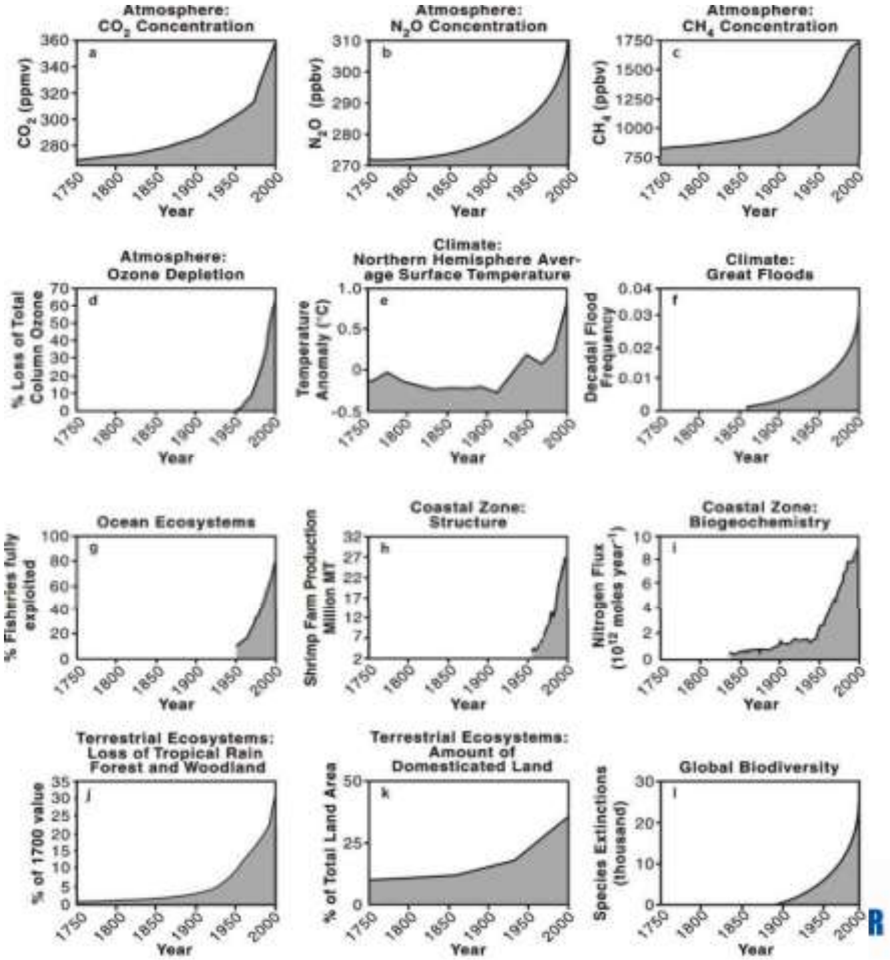
Human Activities vs. Environment!

Great Acceleration on Human Activities

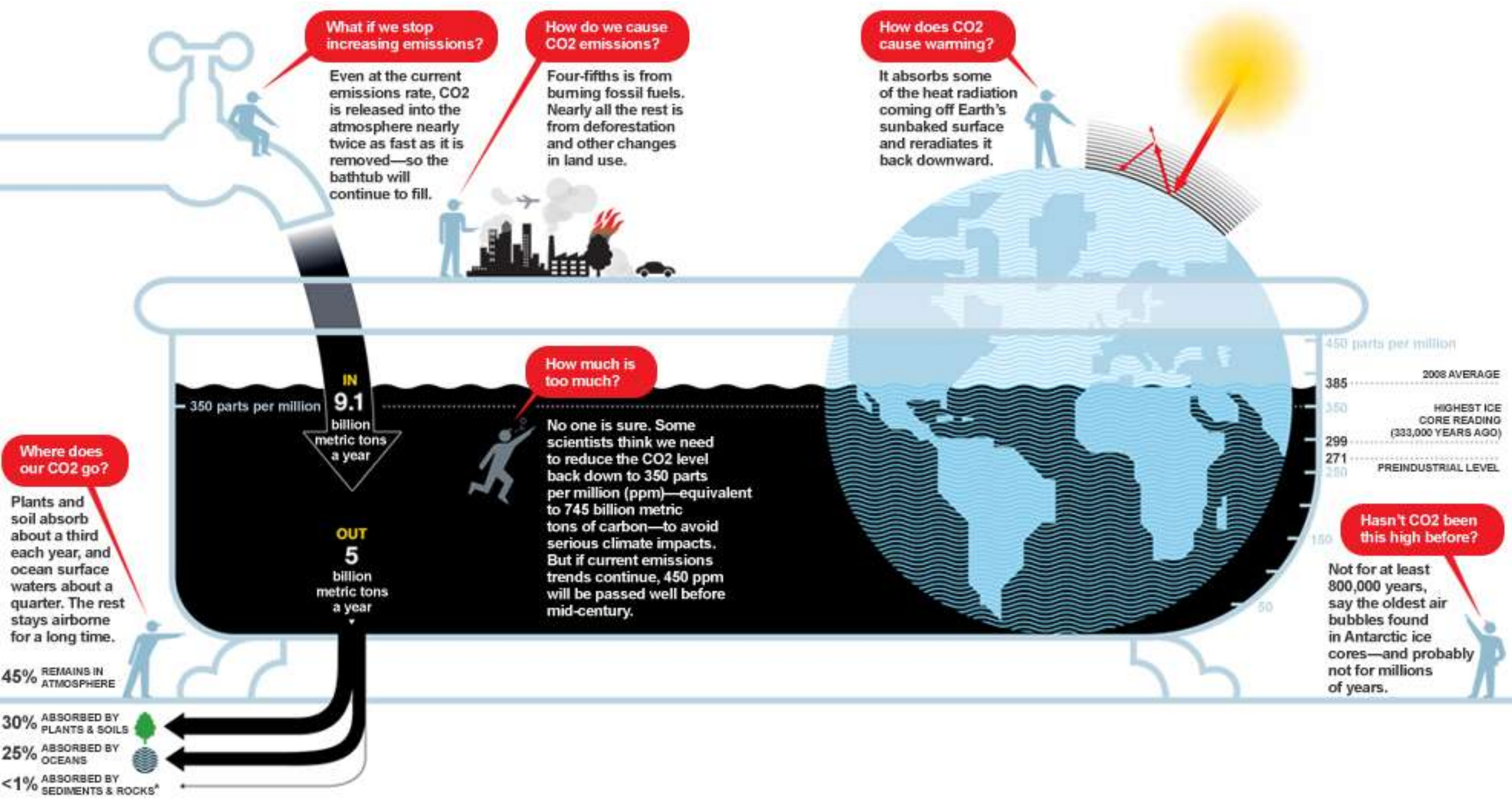


Environmental & Ecological Consequences Could be 9 Times WORSE!



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

CO_2 Status



What if we stop increasing emissions?

Even at the current emissions rate, CO2 is released into the atmosphere nearly twice as fast as it is removed—so the bathtub will continue to fill.

How do we cause CO2 emissions?

Four-fifths is from burning fossil fuels. Nearly all the rest is from deforestation and other changes in land use.

How does CO2 cause warming?

It absorbs some of the heat radiation coming off Earth's sunbaked surface and reradiates it back downward.

How much is too much?

No one is sure. Some scientists think we need to reduce the CO2 level back down to 350 parts per million (ppm)—equivalent to 745 billion metric tons of carbon—to avoid serious climate impacts. But if current emissions trends continue, 450 ppm will be passed well before mid-century.

Where does our CO2 go?

Plants and soil absorb about a third each year, and ocean surface waters about a quarter. The rest stays airborne for a long time.

Hasn't CO2 been this high before?

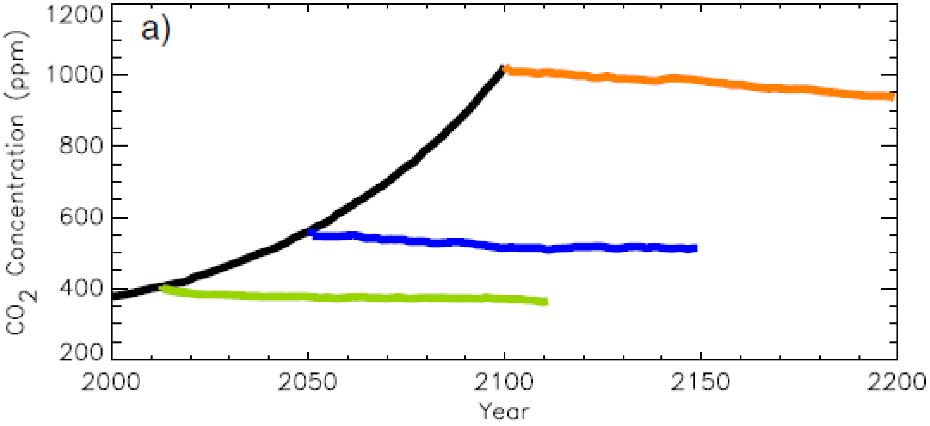
Not for at least 800,000 years, say the oldest air bubbles found in Antarctic ice cores—and probably not for millions of years.

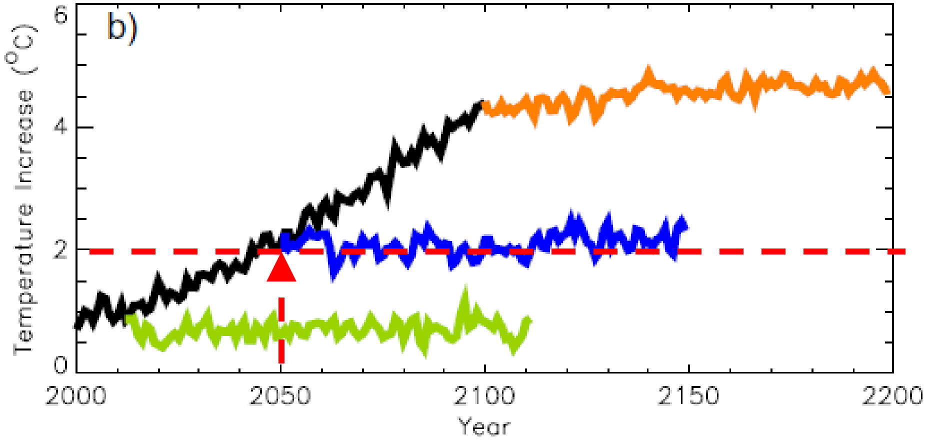
* PERCENTAGES DO NOT ADD UP TO 100 BECAUSE OF ROUNDING.

National Geographic http://ngm.nationalgeographic.com/big-idea/05/carbon-bath (May 18, 2011)

Future Predictions

- In 2009 Copenhagen Accord (UNFCCC[1]), many nations agreed to hold the temperature increase below 2°C by reducing emissions
- According to the recent predictions[2], 2°C can be exceeded by 2050 with business as usual





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[1] UNFCCC: United Nations Framework Convention on Climate Change

[2] Huntingford et al. Environ. Res. Lett. (2012)

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**, foster **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*

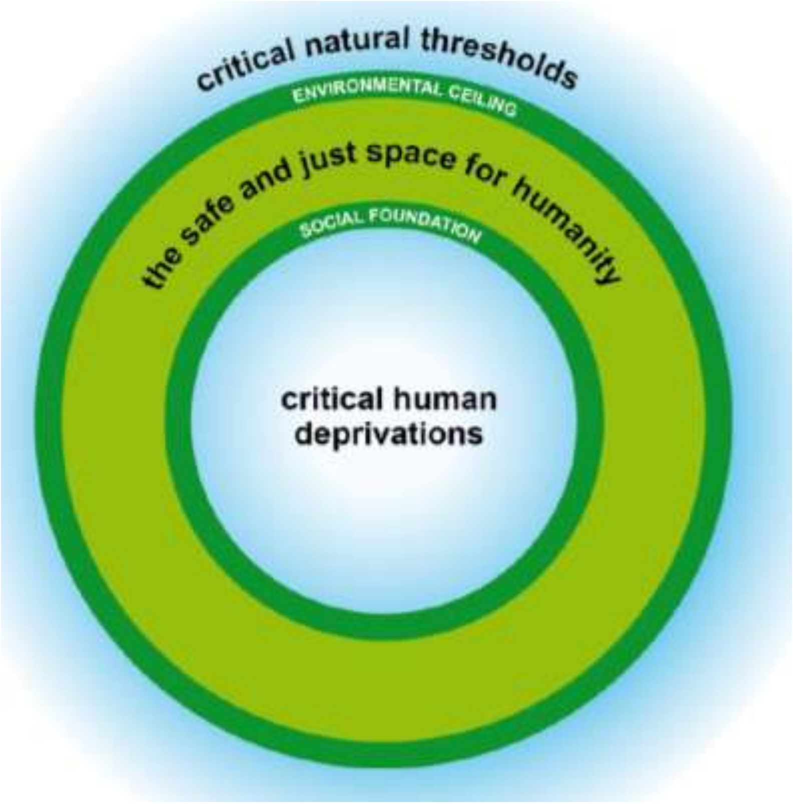
[2] *Transportation and Sustainability Best Practices Background*

‘Doughnut Model’ for Sustainable Development

- Building a sustainable and desirable economy in society and in nature

- **<u>Social foundation</u> forms an inner boundary**
- **<u>Environmental ceiling</u> is in the outer boundary beyond which environmental degradation occurs**
- **Between the two boundaries is a safe and just space for humanity to thrive in**

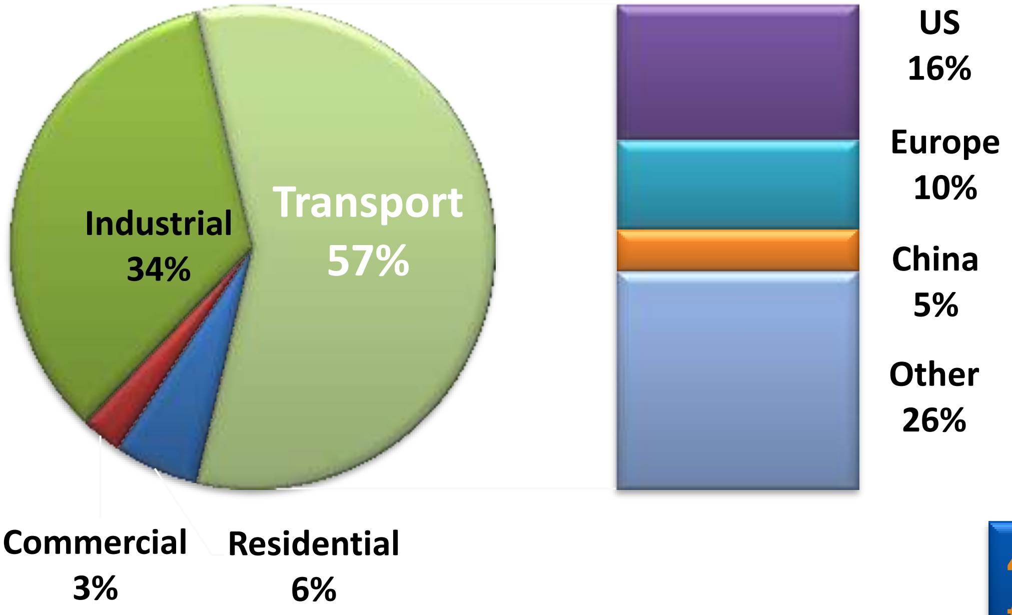
Classical triple bottom line definition



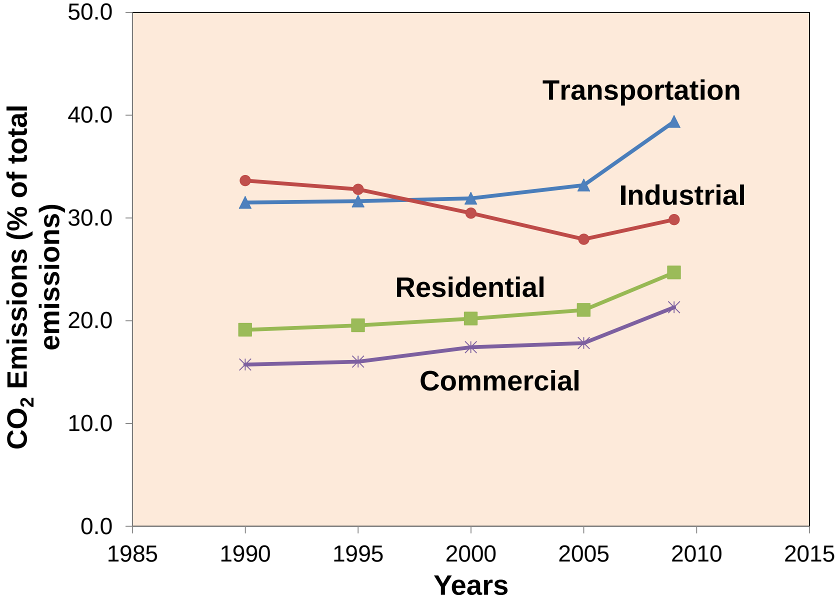
Sustainable and desirable doughnut model (Rowarth, 2012)

Transportation Has a Major Impact on Energy Use and Resulted Emission!

World Petroleum Consumption by End-Use Sector



CO_2 Emissions by Sectors



40 % of total emissions is from transportation sector

U.S. DOT National Transportation Statistics, 2011

International Energy Outlook (2013)
World Energy Council Global Transport Scenarios 2050 (2011)

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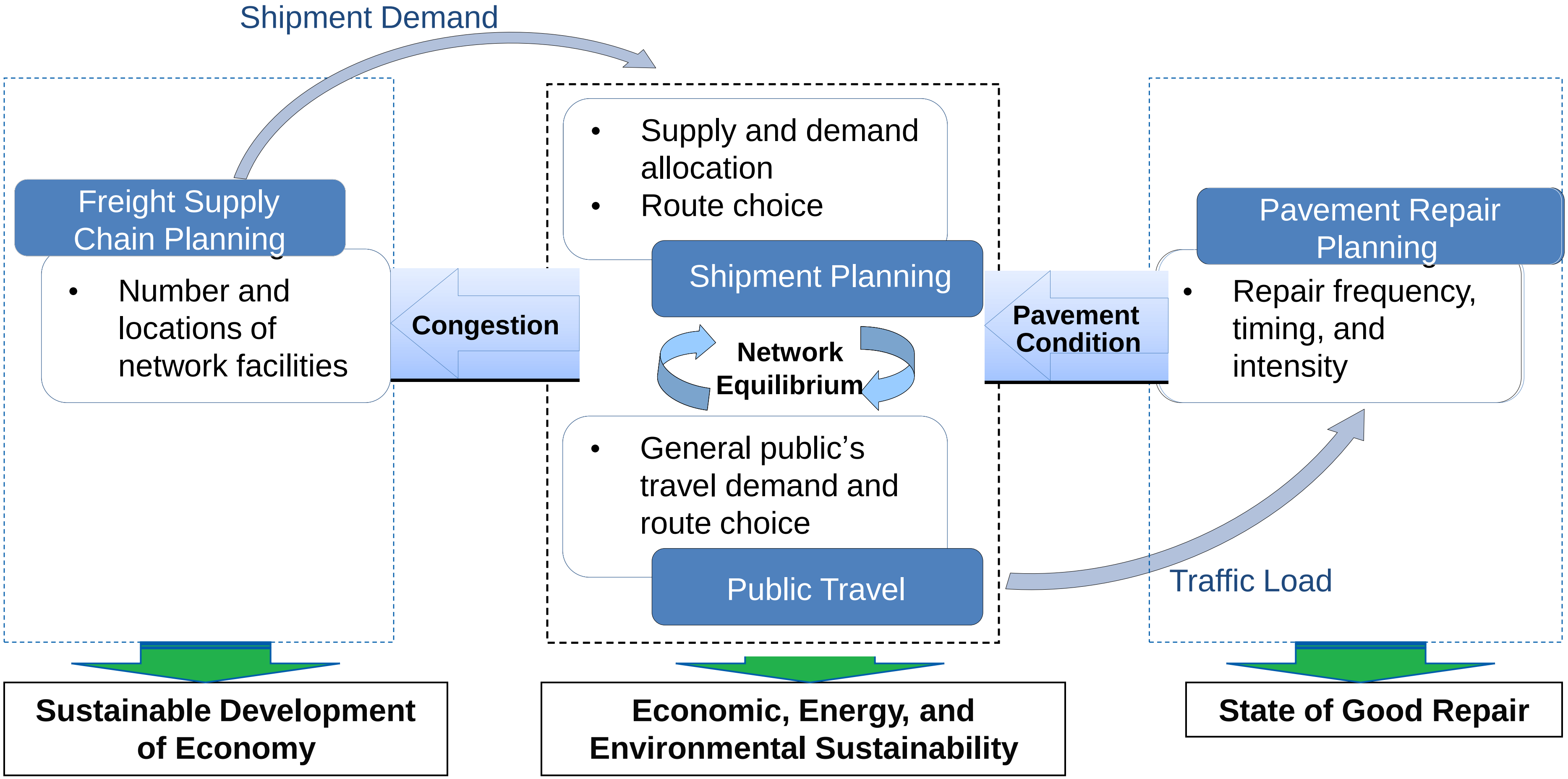
Transportation System Impacts the National Economy

- The cornerstone of the economy and directly affects competition in the foreign market
  - Transportation system supports the Gross National Product (GNP)
  - It affects the daily life of people
  - Approximately 20% of the household expenditures is on transportation

Integrated Modeling for Sustainable Development of Freight Transportation, Highway Operations, and Network Infrastructure Management

- When transportation demand continues to grow, congestion increases dramatically
  - Delay
  - Pollution
  - Energy consumption
  - Pavement deterioration



Shipment Demand

Freight Supply Chain Planning

- Number and locations of network facilities

Congestion

- Supply and demand allocation
- Route choice

Shipment Planning

Network Equilibrium

- General public's travel demand and route choice

Public Travel

Pavement Condition

Pavement Repair Planning

- Repair frequency, timing, and intensity

Traffic Load

Sustainable Development of Economy

Economic, Energy, and Environmental Sustainability

State of Good Repair

Sustainable Pavement!



Maximize Recycled Products

(Economical and Environment Friendly)

Reclaimed Asphalt Pavement (RAP)

Tire Rubber

Recycled Asphalt Shingles (RAS)



Innovative Paving Technologies

(Economy, Environment, Livable Communities)

Warm-Mix Asphalt

Innovative Surfaces

Sprinkle Mix

Performance of High RAP Mixes

Good mix performance characteristics can be achieved with > 50% RAP

Permanent Deform.

Fatigue Life

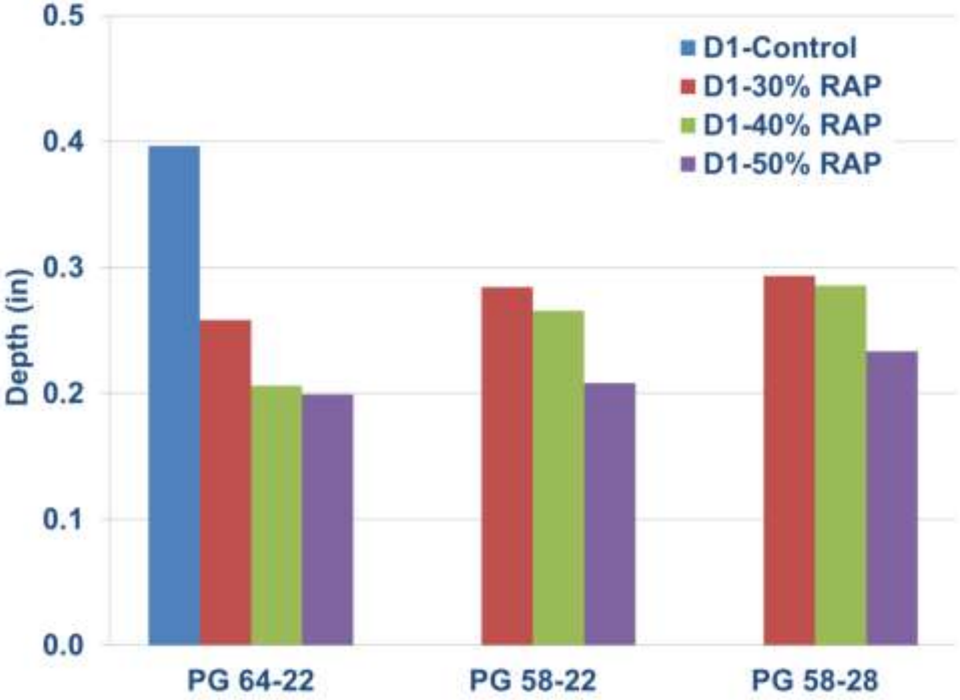
Cracking

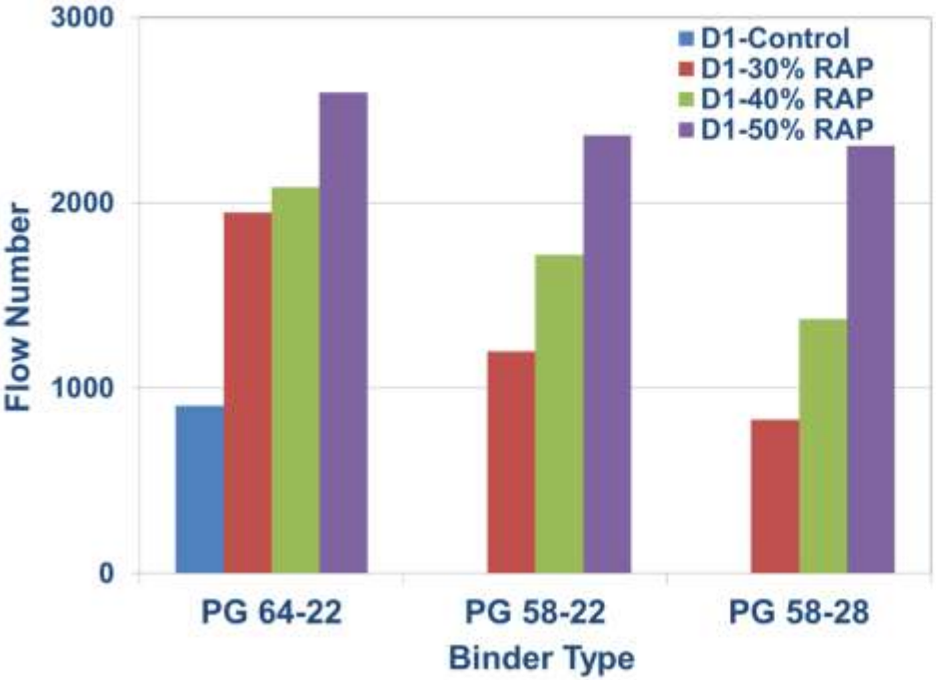
Mixture Volumetrics with High RAP

RAP (%)	Total AC (%)	Binder Replaced (%)	Air Void (%)	VMA (%)	VFA (%)
0	4.9	0	4.0	13.7	70.8
30	4.9	27.6	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

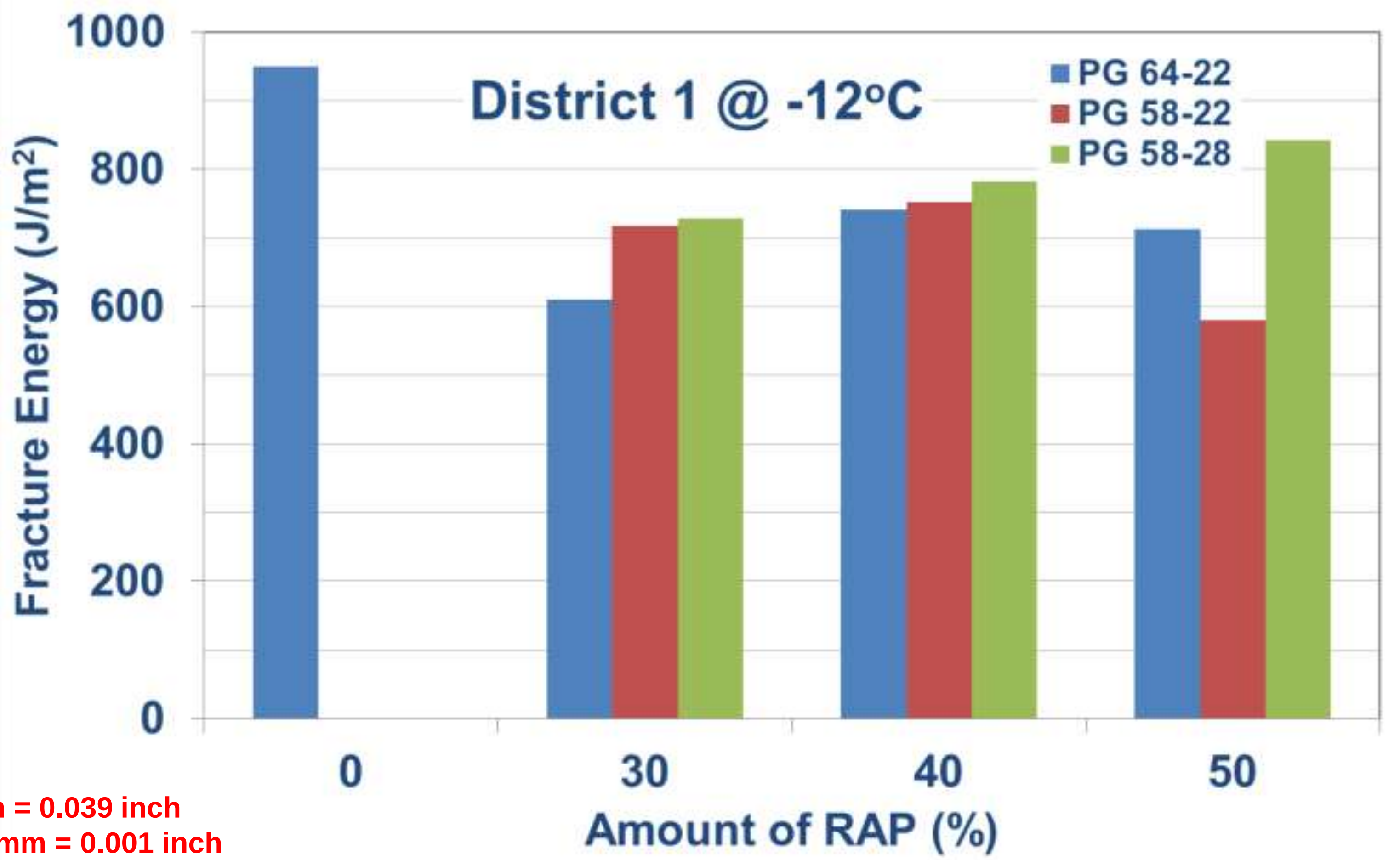
Achieving field and lab volumetrics is no longer an issue when RAP is fractionated and properly handled.

Rutting Potential



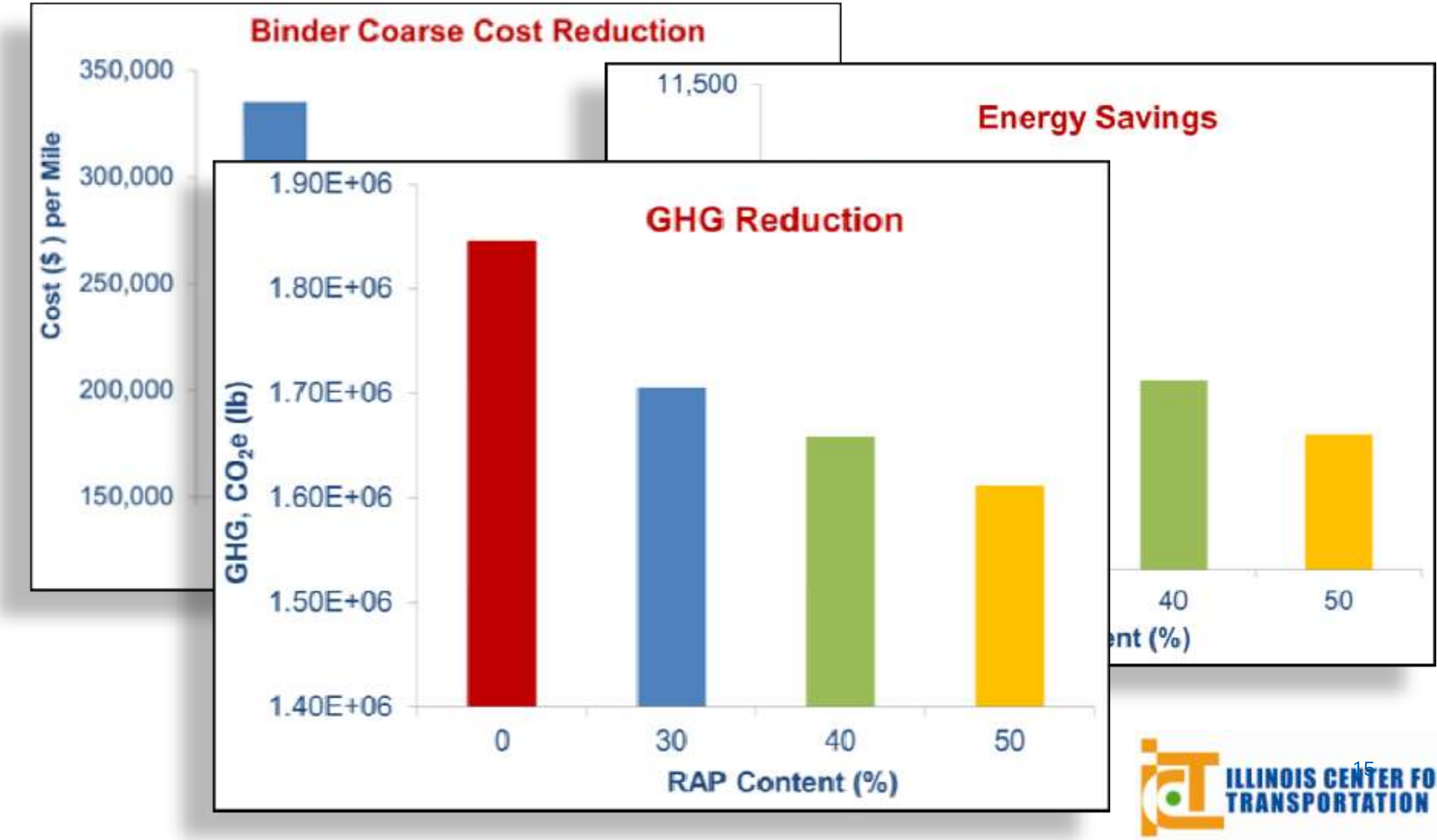


Semi-Circular Bending (SCB) Test



1 mm = 0.039 inch
0.03 mm = 0.001 inch
1J/m^2 = 1N-m/m^2 = 0.00571 lb-in/in^2

RAP Benefits



TOTAL RECYCLE ASPHALT

Total Recycle Mixes


Steel Slag: 15%


Recycled Concrete: 27%

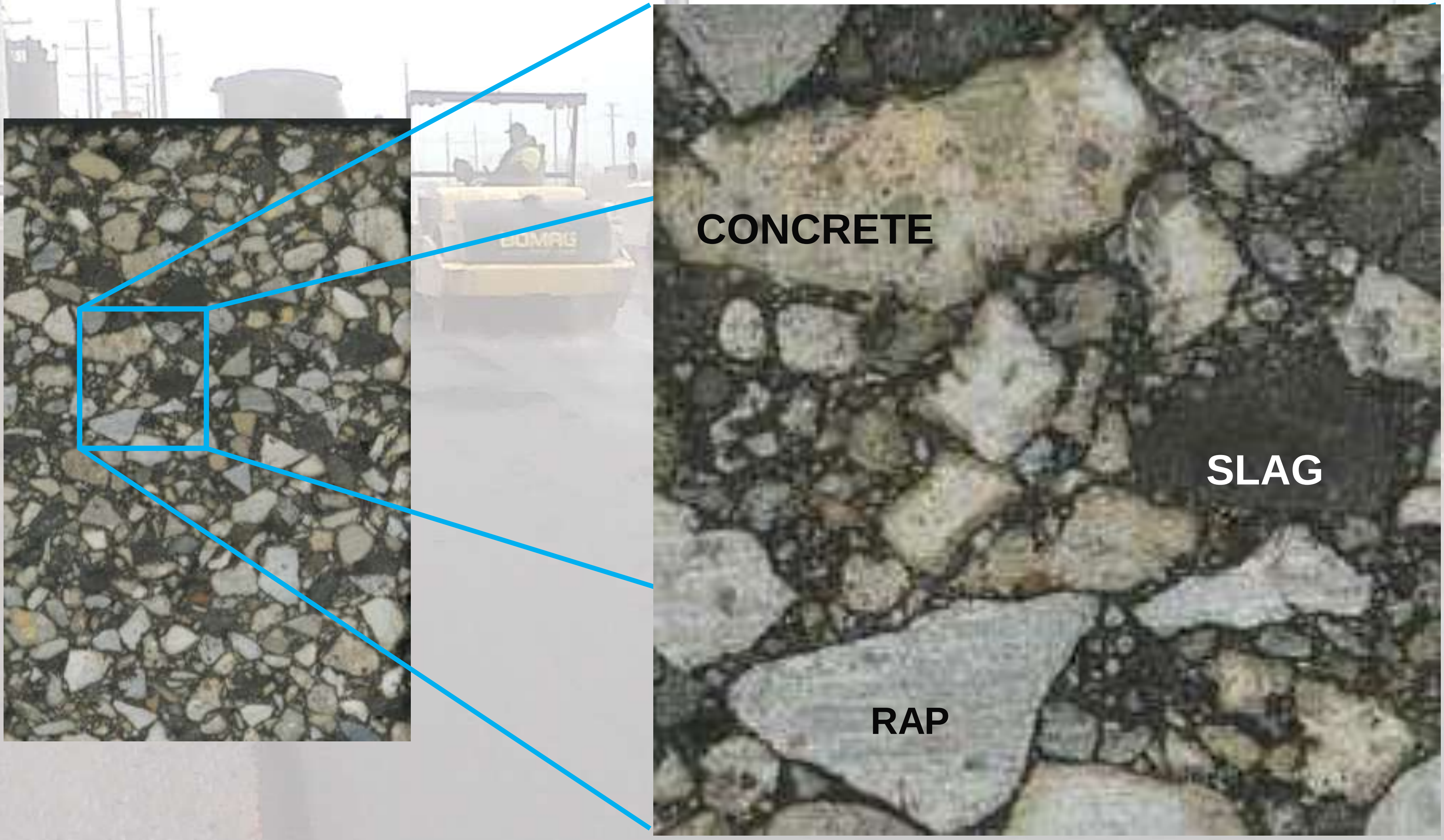

RAP: 53%


Recycled Shingles: 5%


Virgin Binder (~3%)

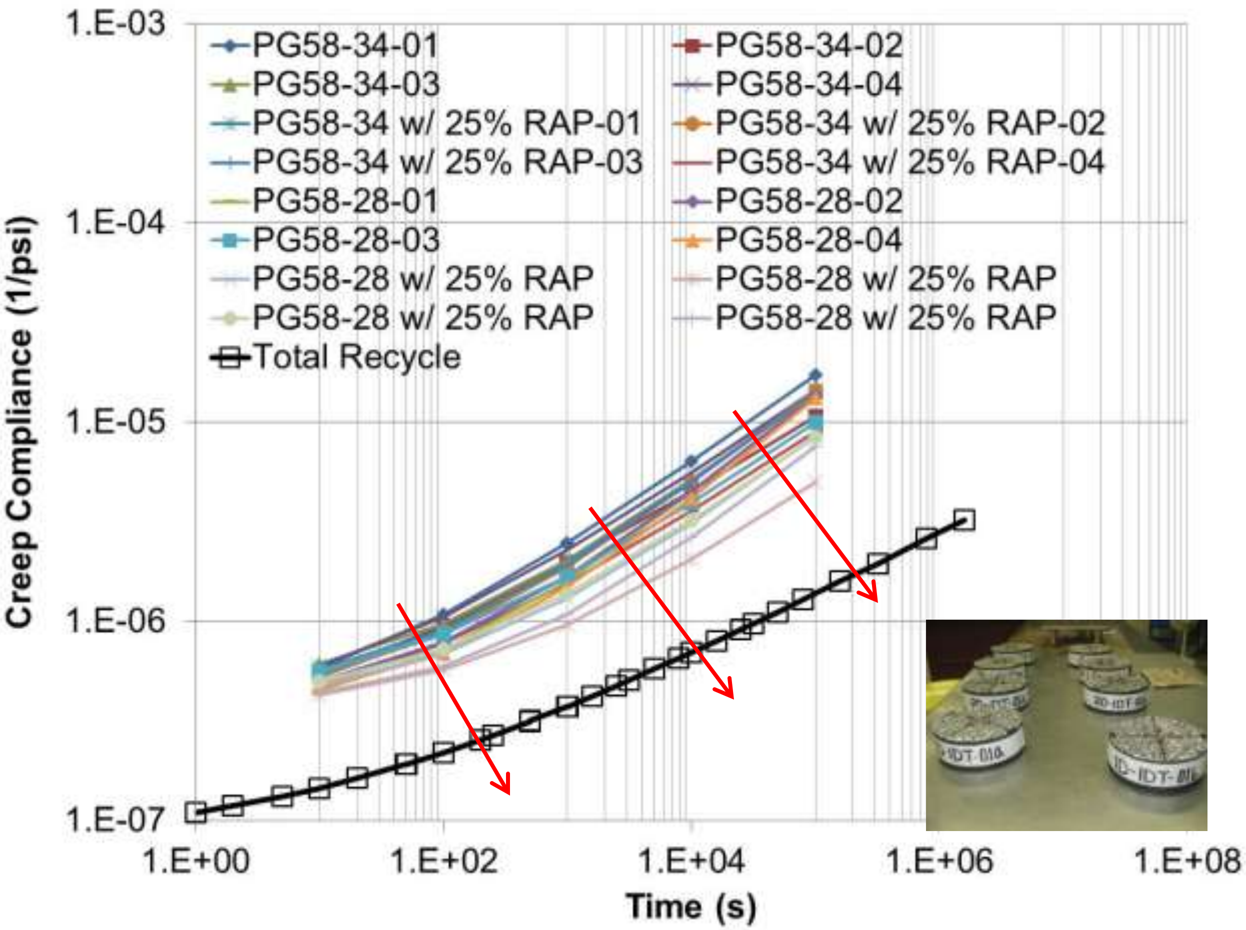

N50 surface mix

Total Recycle Asphalt



Mechanical Properties - Stiffness

- Compared to conventional mixes at various RAP levels[1]
- Significant decrease in compliance due to slag, crushed concrete, and shingles



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[1] Bonaquist , R. “*Characterization of Wisconsin Mixture Low Temperature Properties for the AASHTO Mechanistic-Empirical Pavement Design Guide.* WisDOT SPR# 0092-10-07, 2011.

Why RAS?

- The composition of RAS (good stuff in RAS)
- Sufficient RAS supply in the market

Material	% by Weight
Coated filler (limestone or fly ash)	32-42
Granules (painted rocks and slag)	28-42
Asphalt binder	16-25
Back dust (limestone and sand)	3-6
Fibers (paper, cotton rag, fiberglass)	2-15

Concerns with RAS

- Highly oxidized asphalt binder
  - High PG Grades 100-150
  - Poor relaxation potential (usually characterized by m-value)
- Thermal cracking potential due to brittleness of hardened binder
- Fatigue performance at intermediate temperatures when used at large quantities

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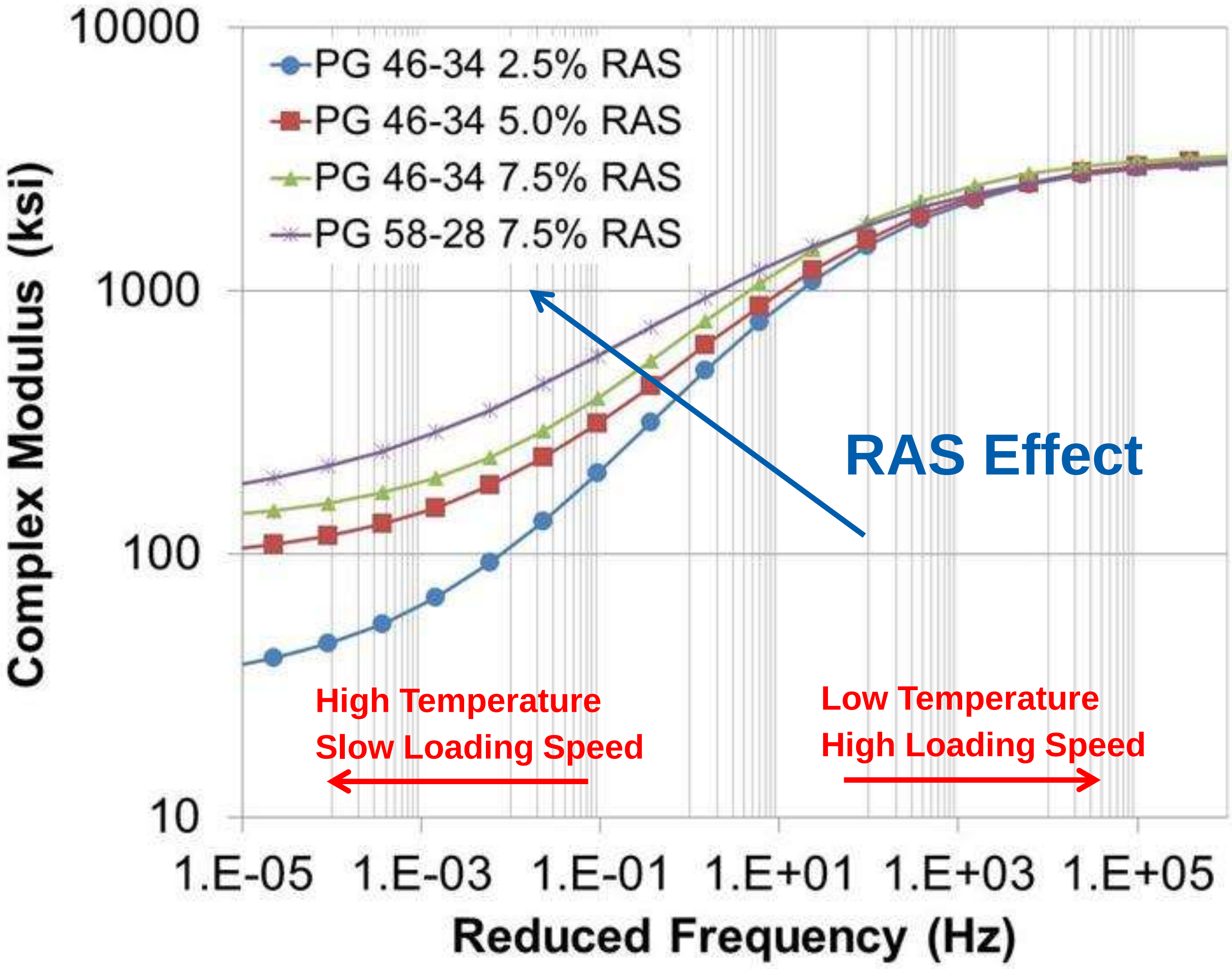
Complex Modulus Testing (AASHTO TP62-03)



RAS Effect

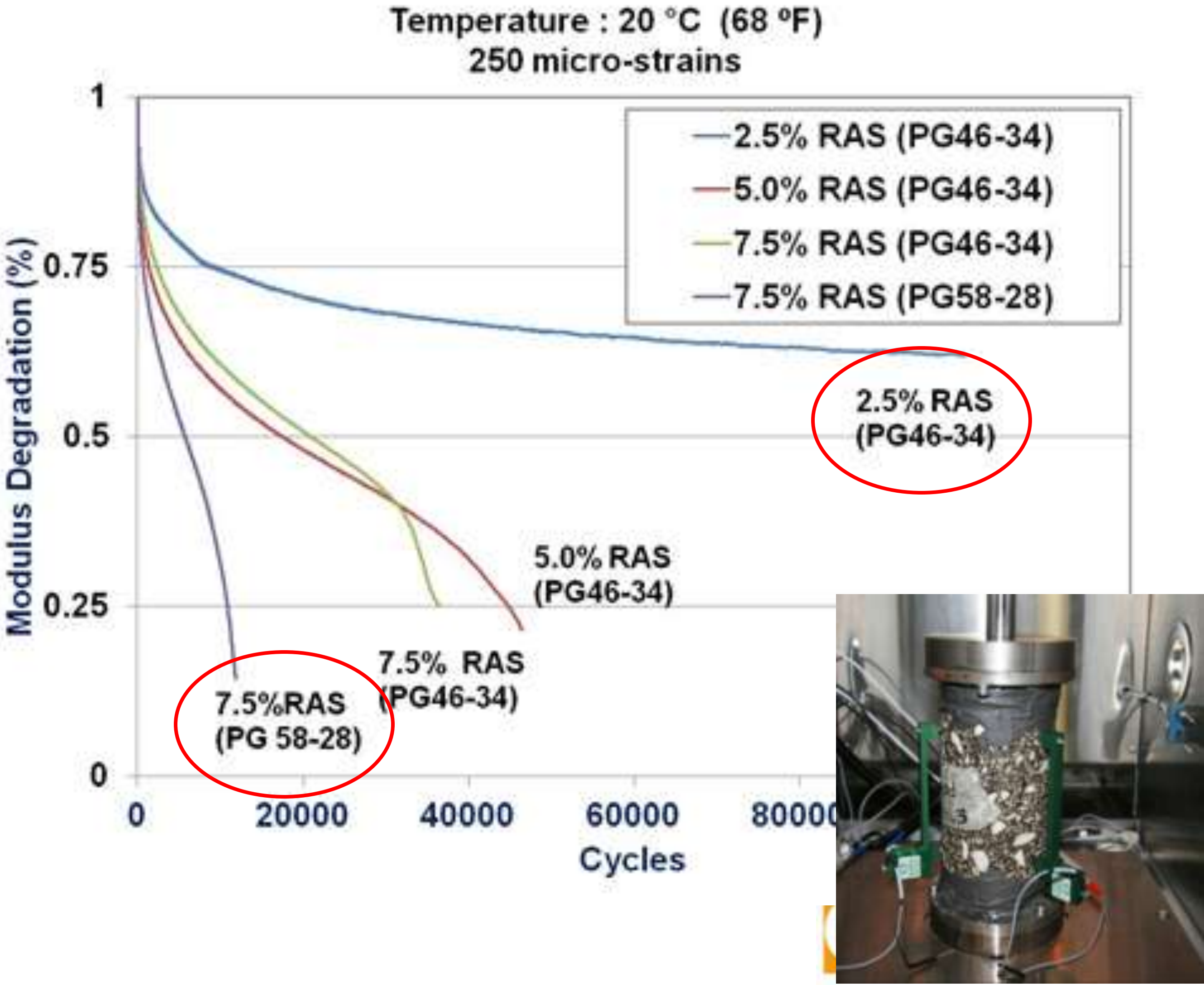
High Temperature
Slow Loading Speed

Low Temperature
High Loading Speed

Test Results

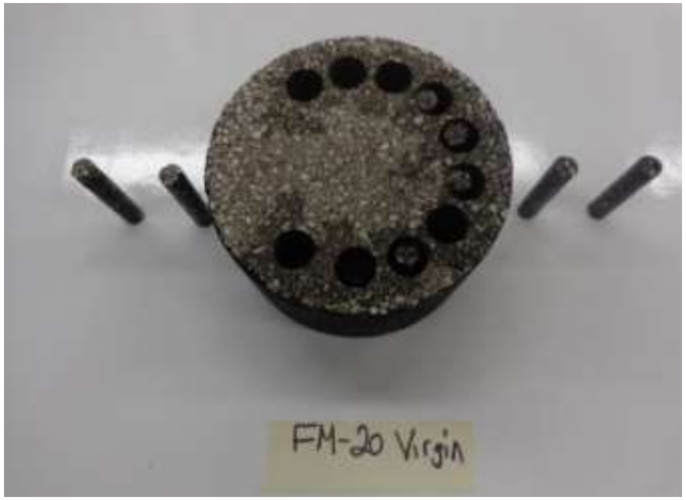
20°C (68°F) & 250 microstrains

- Calculate the decrease (damage) in modulus at every cycle
- 2.5% RAS survived more than 100,000 cycles
- 7.5% RAS and PG58-28 are not working very well (insufficient bumping?)



Mastic Testing

Gyratory compacted

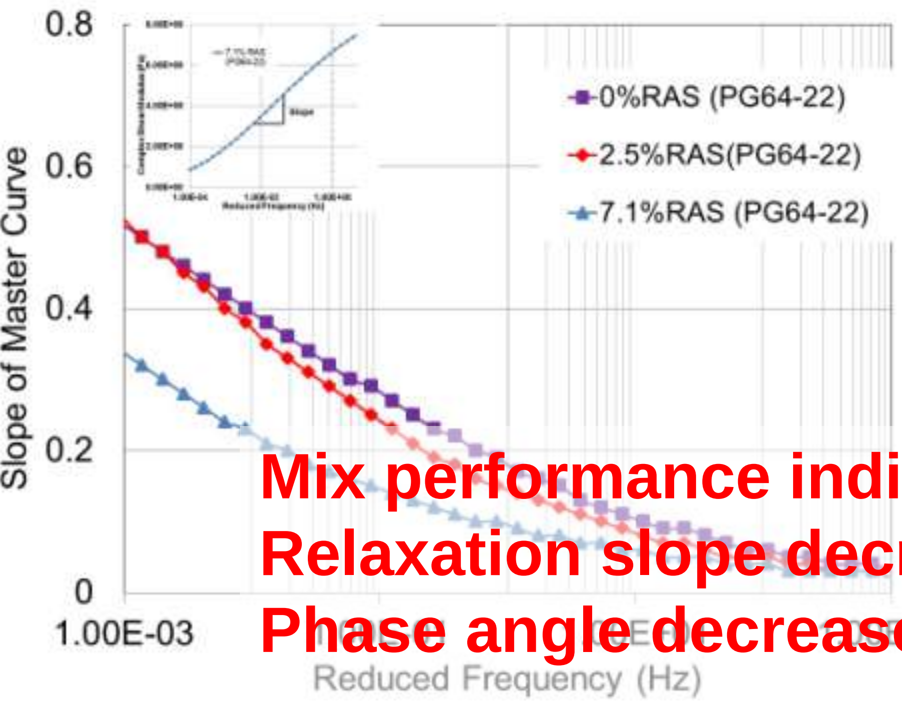


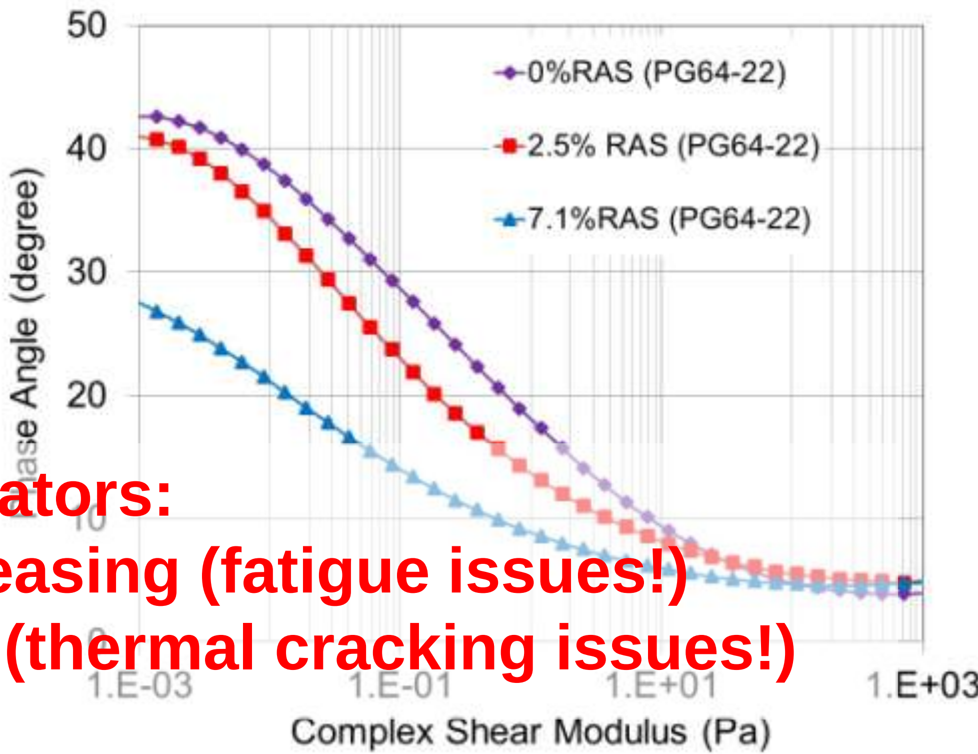
Manual compaction


DSR Testing

Preliminary Results of Viscoelastic Properties

- Relaxation slope with RAS:
- **Phase angle with RAS:**





Mix performance indicators:
Relaxation slope decreasing (fatigue issues!)
Phase angle decrease (thermal cracking issues!)

High ABR* Mixes

Mix Type	%ABR	%RAP	%RAS	Slag	RCA
IL-19 mm N50	50	42	4	-	-
IL-19 mm N50	60	42	6	-	-
IL-9.5 mm N70	25	29	-	-	-
IL-9.5 mm N70	38	30	6	-	-
IL-9.5 mm N70	50	30	5	-	-
IL-12.5 mm N80 (SMA)	25	8	5	-	-
IL-12.5 mm N80 (SMA)	50	10	8	-	-
IL-9.5 mm TR Joliet	38	30	-	70	-
IL-9.5 mm TR-K5	60	53	5	15	27
IL-9.5 mm TR-Sandeno	57	52	3.5	15	30

*ABR: Asphalt binder replacement

Testing Program for High ABR Mixes

+

Low Temperature + Fatigue Cracking

Low Temperature Cracking

Fatigue Cracking/ Service Temperature

Permanent Deformation

-40°C

-20°C

20°C

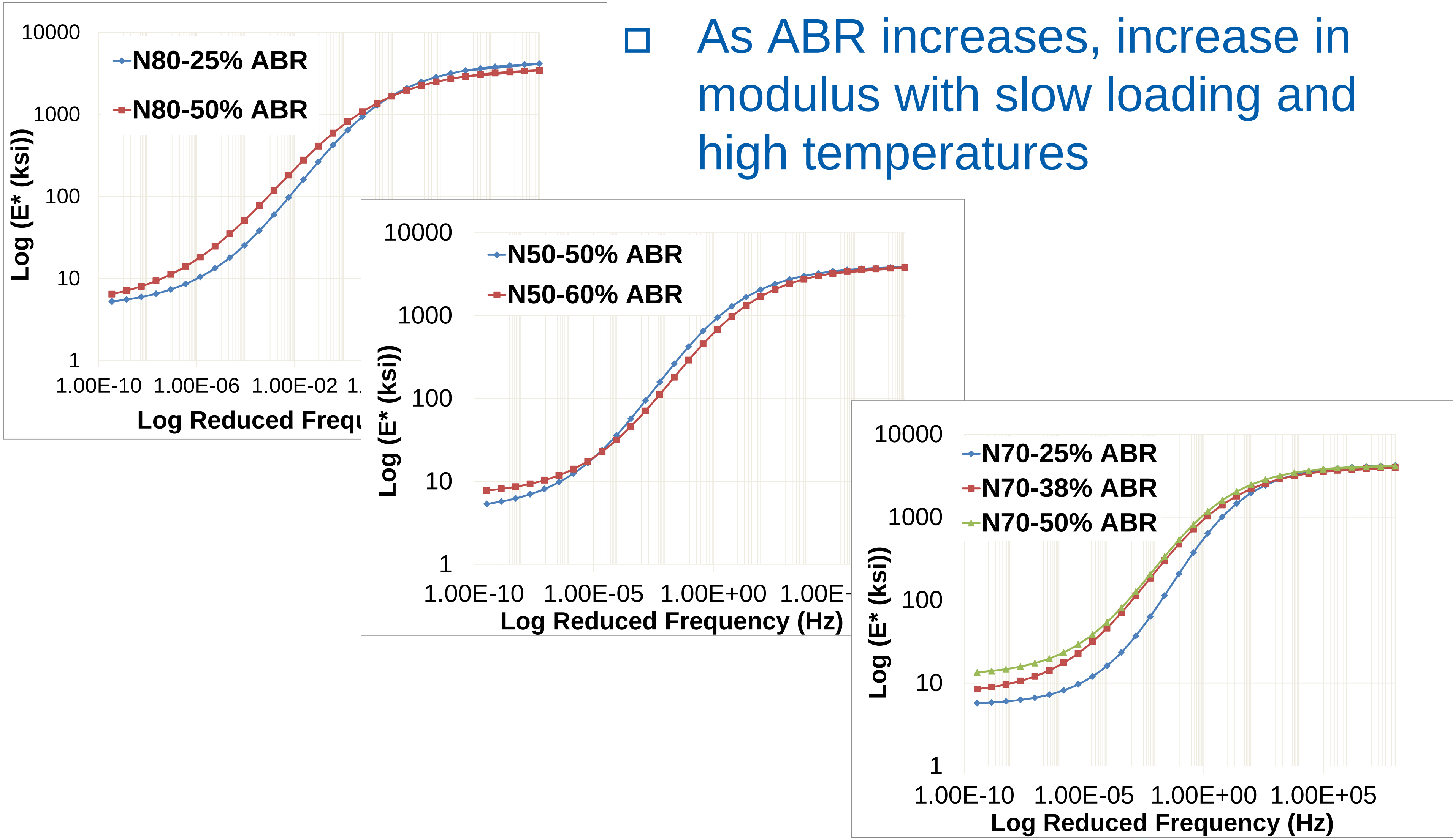
40°C

Low in-service temperatures

Intermediate in-service temperatures

High Temperatures

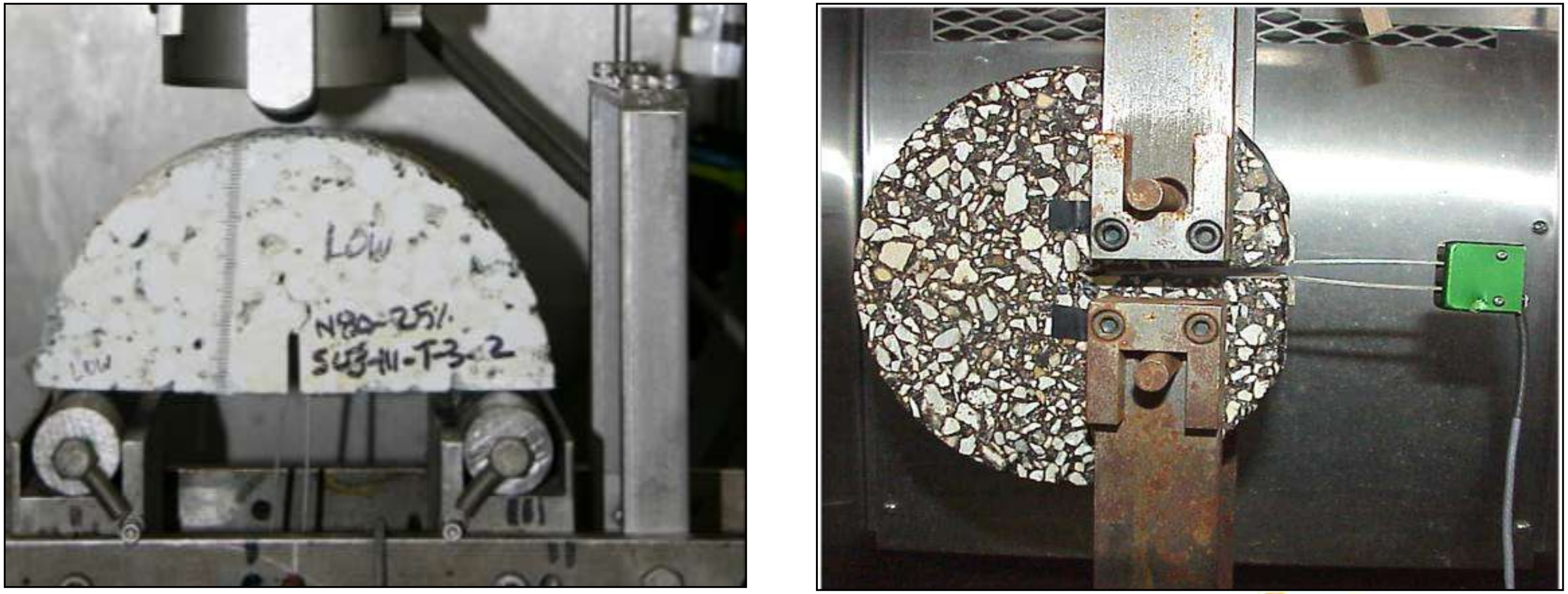
Modulus of High ABR Mixes



- ☐ As ABR increases, increase in modulus with slow loading and high temperatures

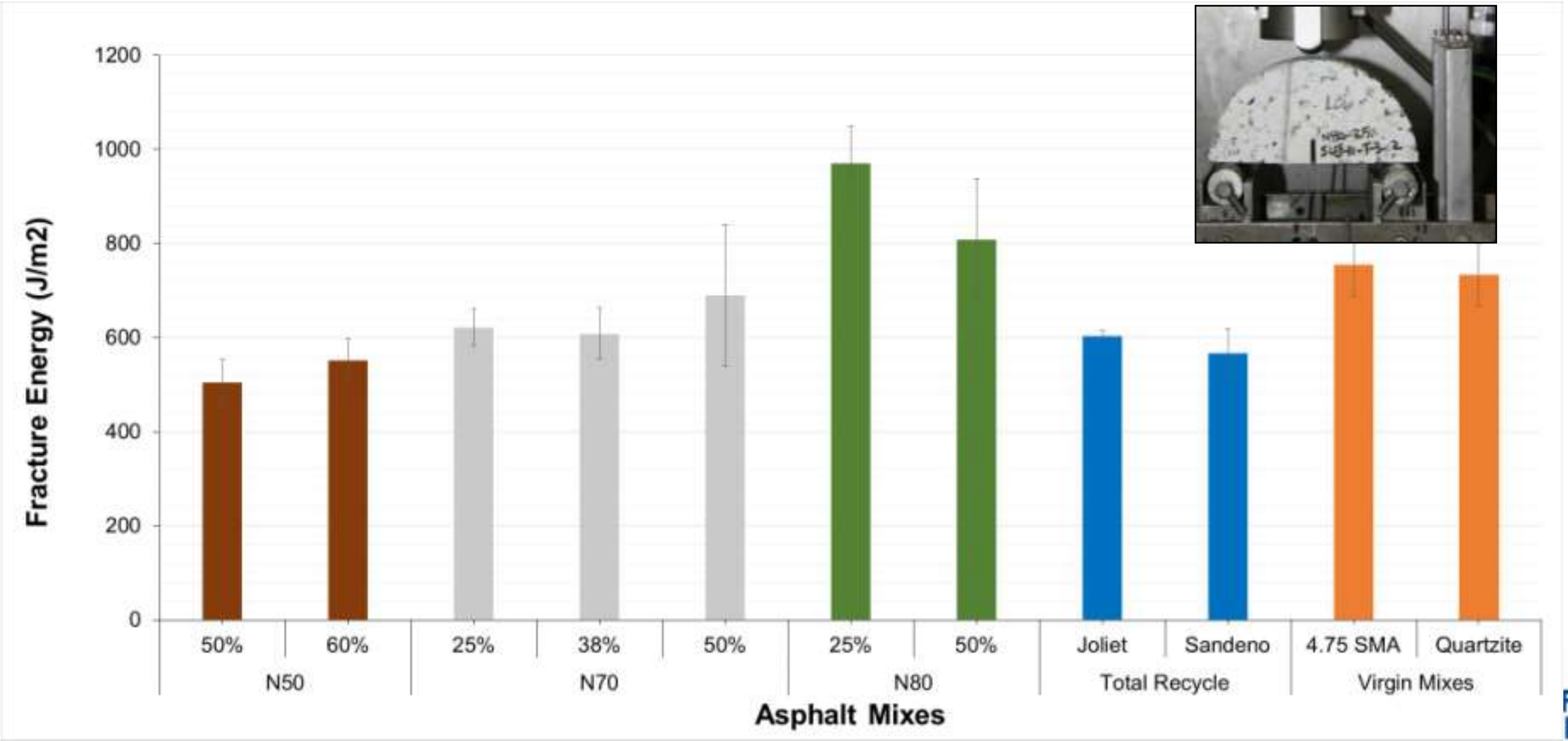
Fracture Tests for High ABR Mixes

- Semi-circular bending (SCB) and disc compact tension (DCT) tests are conducted at low and intermediate temperatures



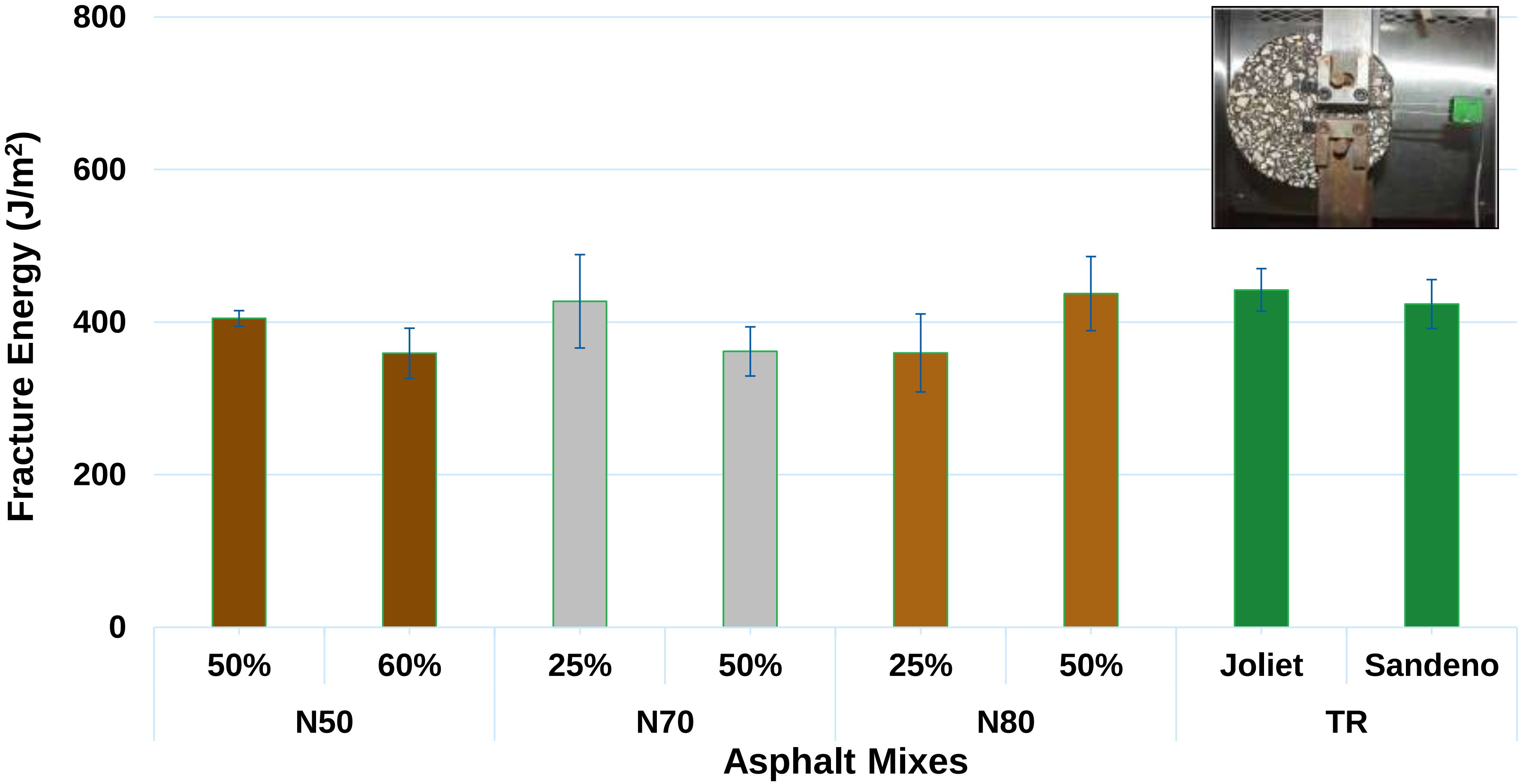
Low Temperature Fracture Results

- SCB tests conducted at -12°C for high ABR mixes in addition to some virgin mixes



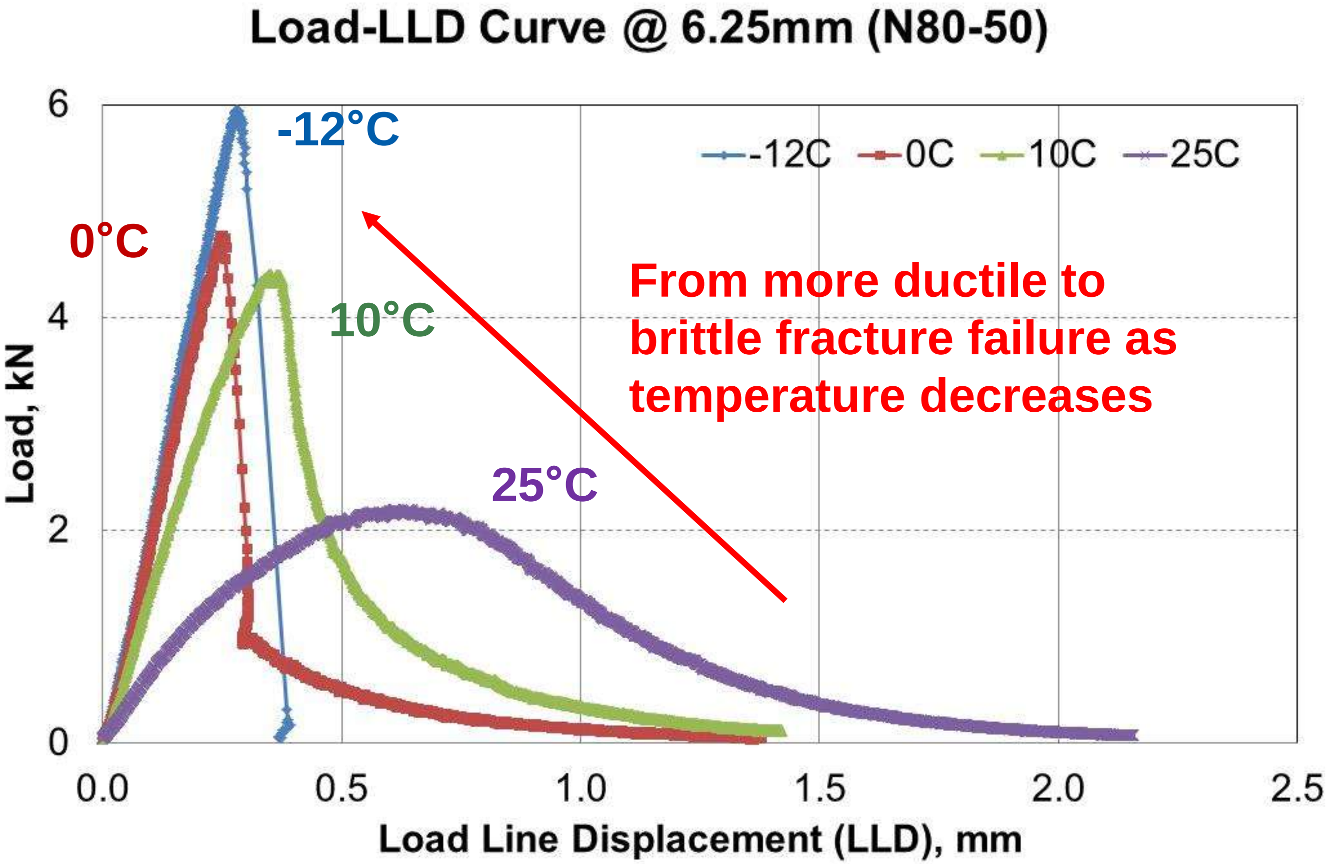
DCT Fracture Test Results

- DCT tests are also conducted at -12°C for some mixes



Temperature and Rate Dependency

- ☐ Fracture experiments were conducted at a sweep of temperatures and loading rates



From more ductile to brittle fracture failure as temperature decreases

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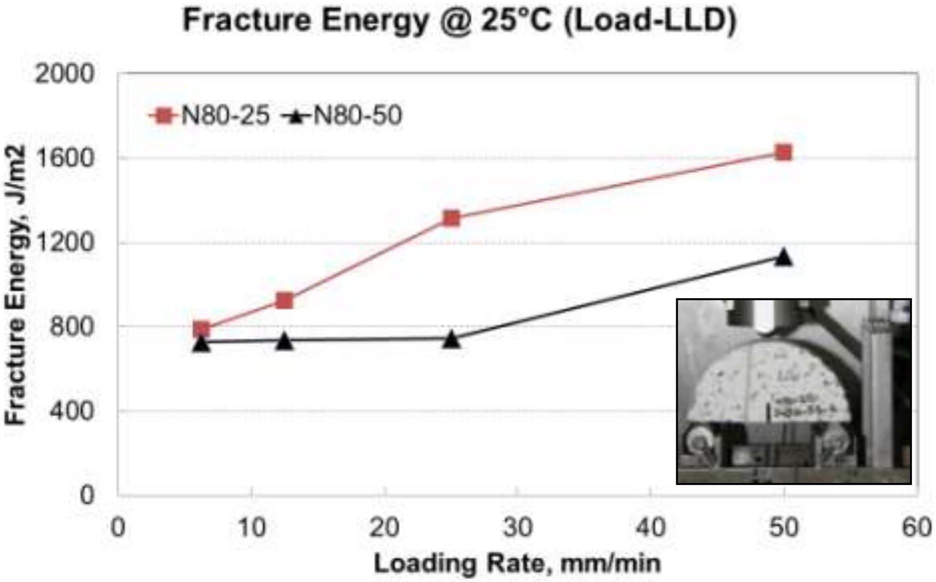
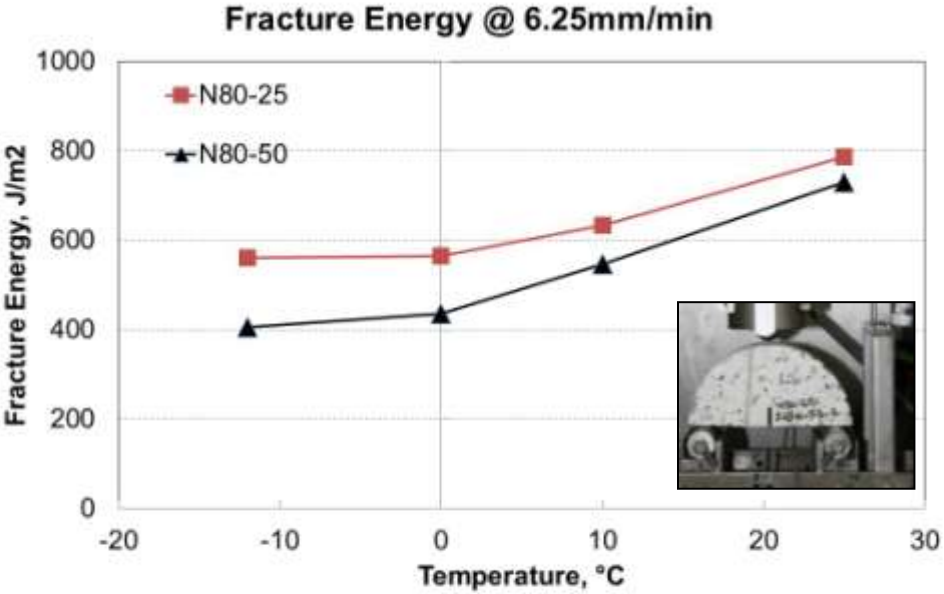
Temperature and Rate Dependency

- ☐ **Fracture energy change with loading rate is sensitive to ABR**





- ☐ **Fracture energy changes with temperature**

Measuring Sustainability

- **Performance assessment**
  - Metrics providing information about the health of pavement over its life-cycle
- **Life-cycle cost analysis (LCCA)**
  - Total user and agency costs over its life-cycle
- **Life-cycle assessment (LCA)**
  - Environmental burden of a pavement from cradle to grave
- **Rating systems**
  - A list of sustainability best practices with a common metric

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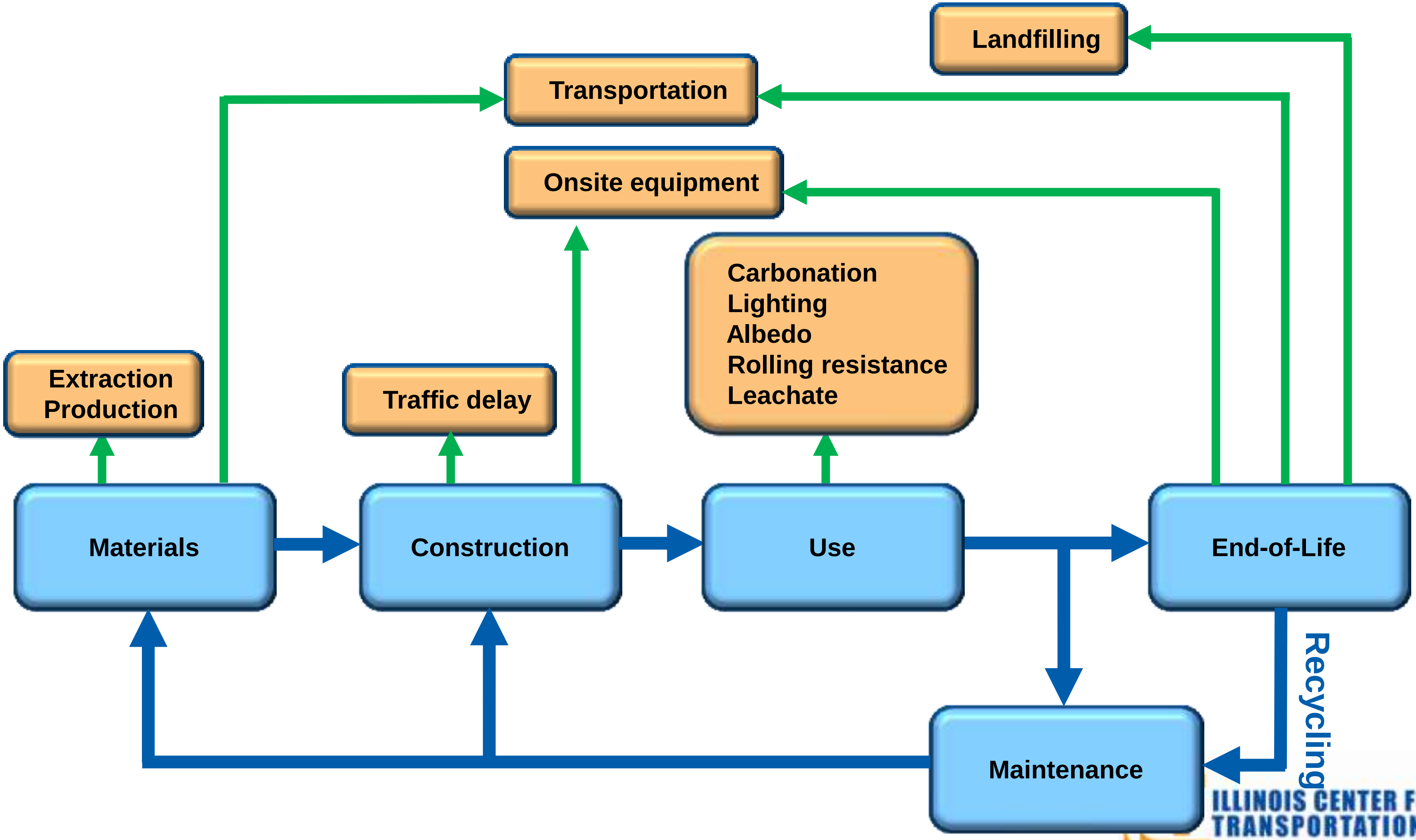
Phases of a Pavement LCA



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Example: Life Cycle of Asphalt Concrete

“Materials Stage”

Raw Materials

GHG (CO_2, CH_4, N_20)

Air Pollutants

Crude Recovery

Crude Transportation

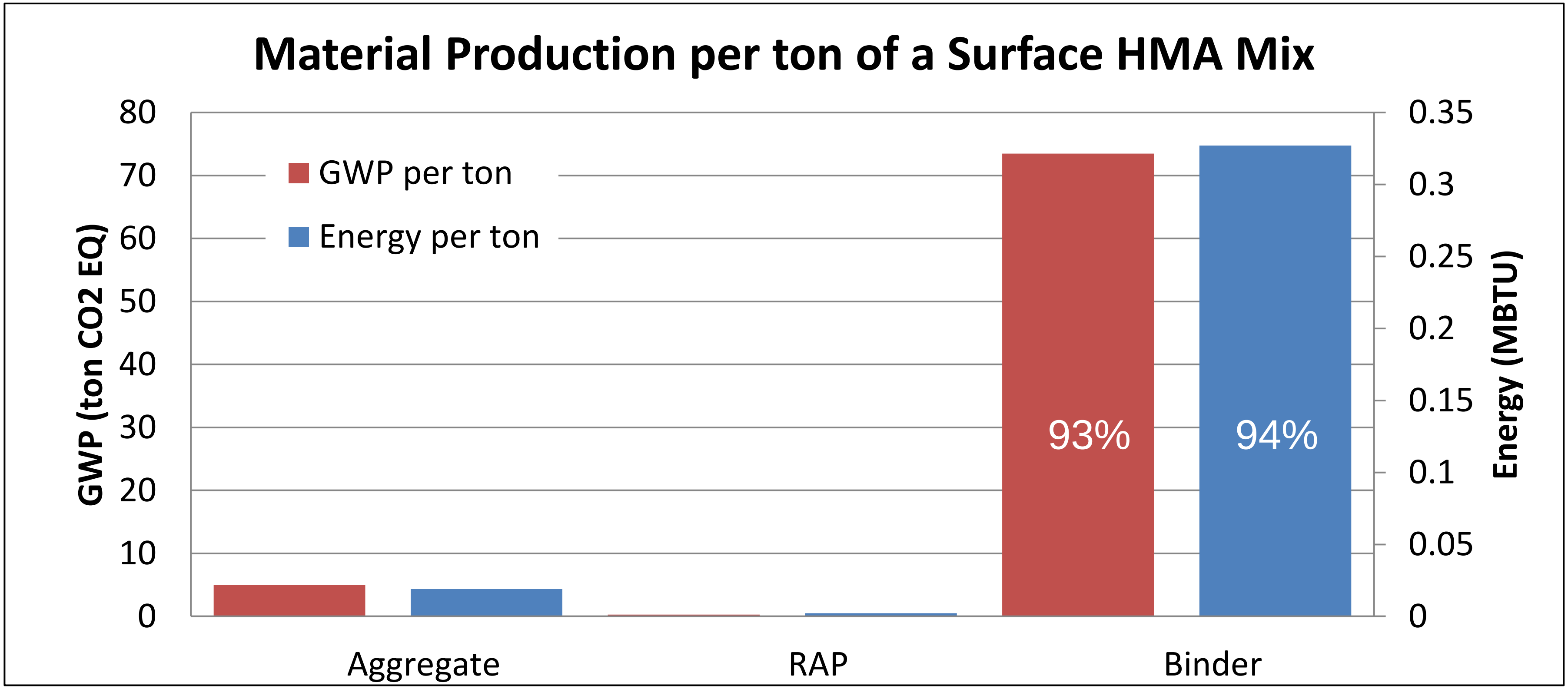
Crude Refining

Fuel & Asphalt Transportation

Electricity Transport

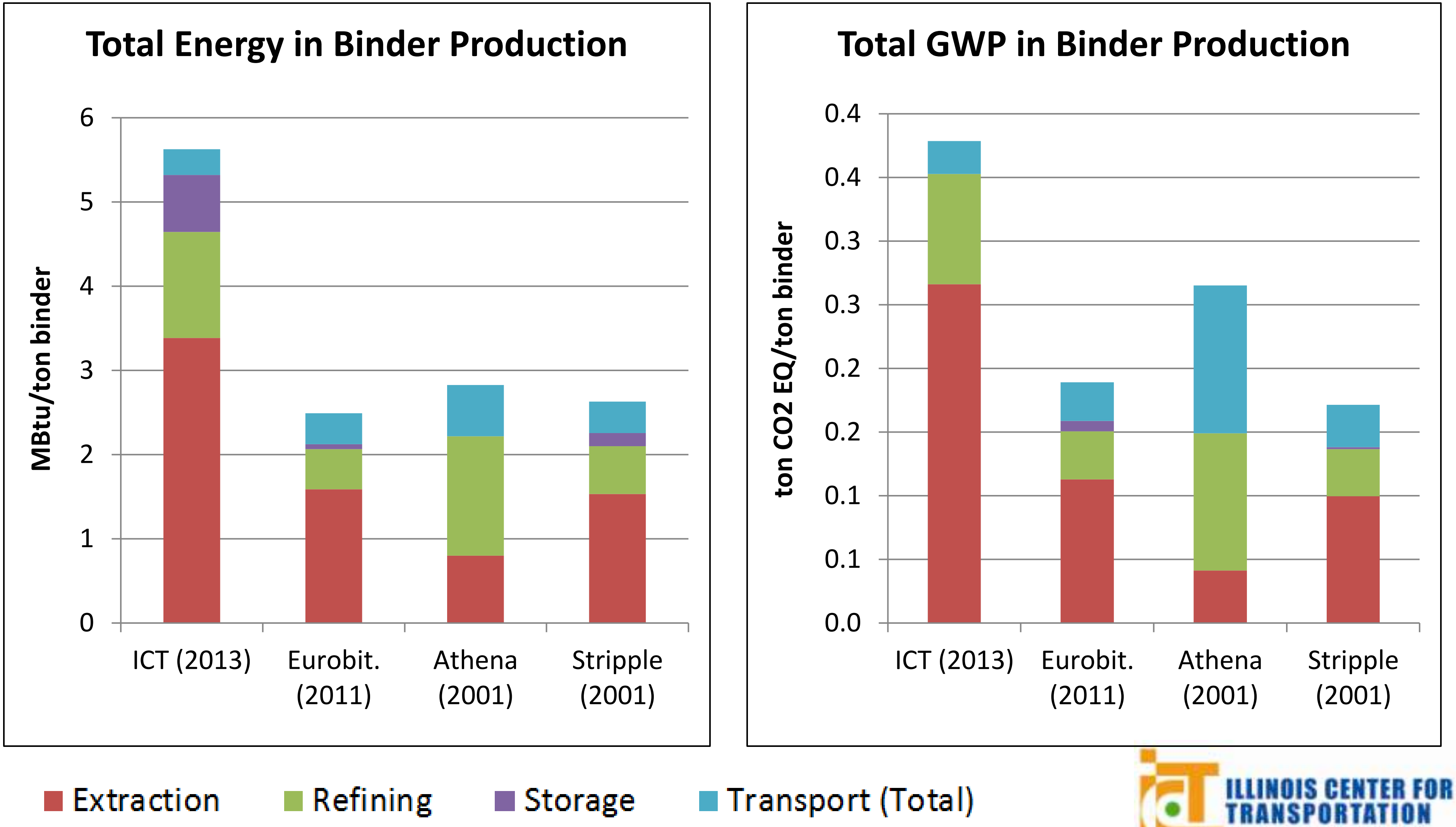
Electricity Generation

Importance of Binder

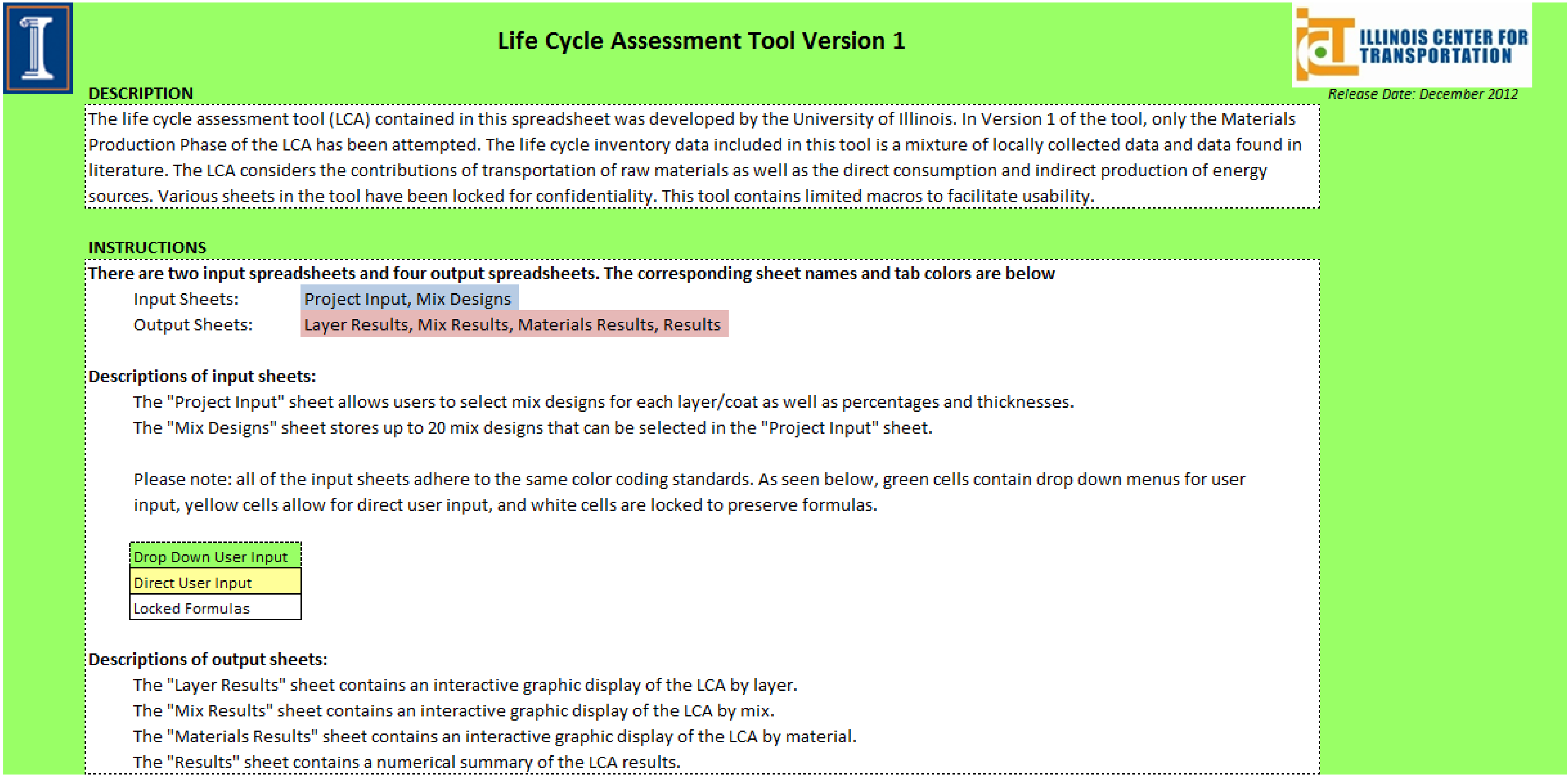


5.6% of mix design, >90% of energy and GWP

Preliminary Results



LCA Tool Version 1.0



Life Cycle Assessment Tool Version 1

Release Date: December 2012

DESCRIPTION

The life cycle assessment tool (LCA) contained in this spreadsheet was developed by the University of Illinois. In Version 1 of the tool, only the Materials Production Phase of the LCA has been attempted. The life cycle inventory data included in this tool is a mixture of locally collected data and data found in literature. The LCA considers the contributions of transportation of raw materials as well as the direct consumption and indirect production of energy sources. Various sheets in the tool have been locked for confidentiality. This tool contains limited macros to facilitate usability.

INSTRUCTIONS

There are two input spreadsheets and four output spreadsheets. The corresponding sheet names and tab colors are below

Input Sheets:	Project Input, Mix Designs
Output Sheets:	Layer Results, Mix Results, Materials Results, Results

Descriptions of input sheets:

The "Project Input" sheet allows users to select mix designs for each layer/coat as well as percentages and thicknesses.

The "Mix Designs" sheet stores up to 20 mix designs that can be selected in the "Project Input" sheet.

Please note: all of the input sheets adhere to the same color coding standards. As seen below, green cells contain drop down menus for user input, yellow cells allow for direct user input, and white cells are locked to preserve formulas.

Drop Down User Input
Direct User Input
Locked Formulas

Descriptions of output sheets:

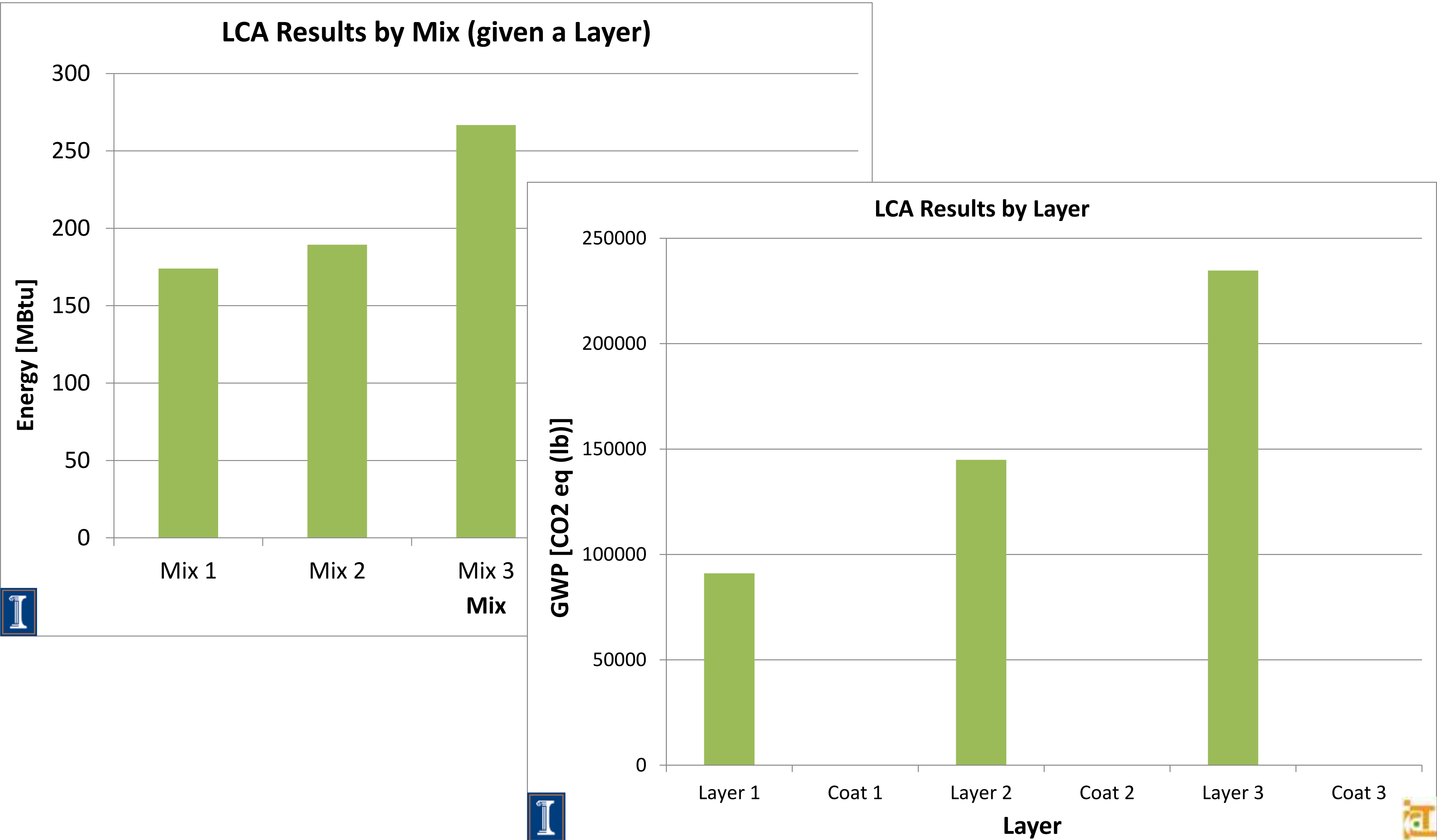
The "Layer Results" sheet contains an interactive graphic display of the LCA by layer.

The "Mix Results" sheet contains an interactive graphic display of the LCA by mix.

The "Materials Results" sheet contains an interactive graphic display of the LCA by material.

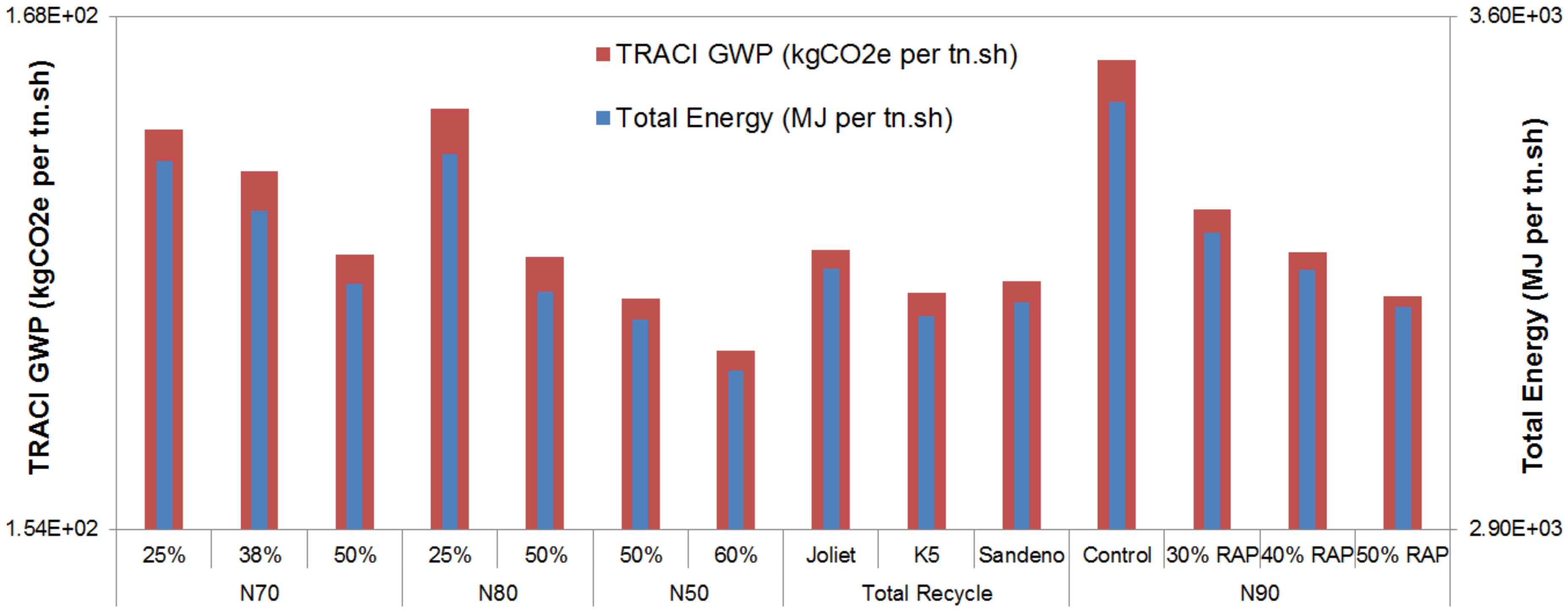
The "Results" sheet contains a numerical summary of the LCA results.

Sample Results: By Mix



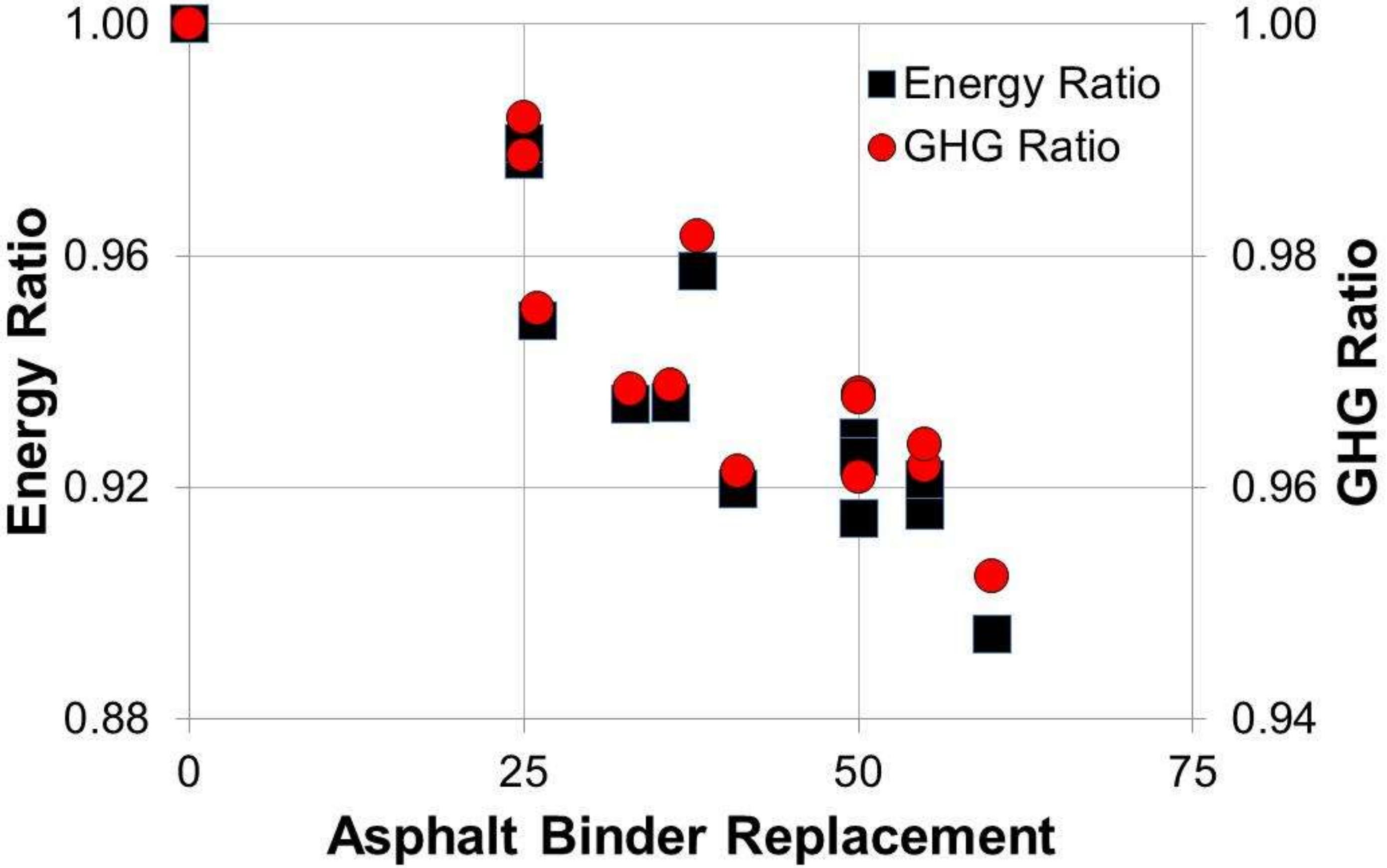
Sustainability Assessment of Asphalt Mixes

- Life-cycle assessment of high ABR mixes for material and production stage illustrates reduction in energy consumption and CO_2 emissions

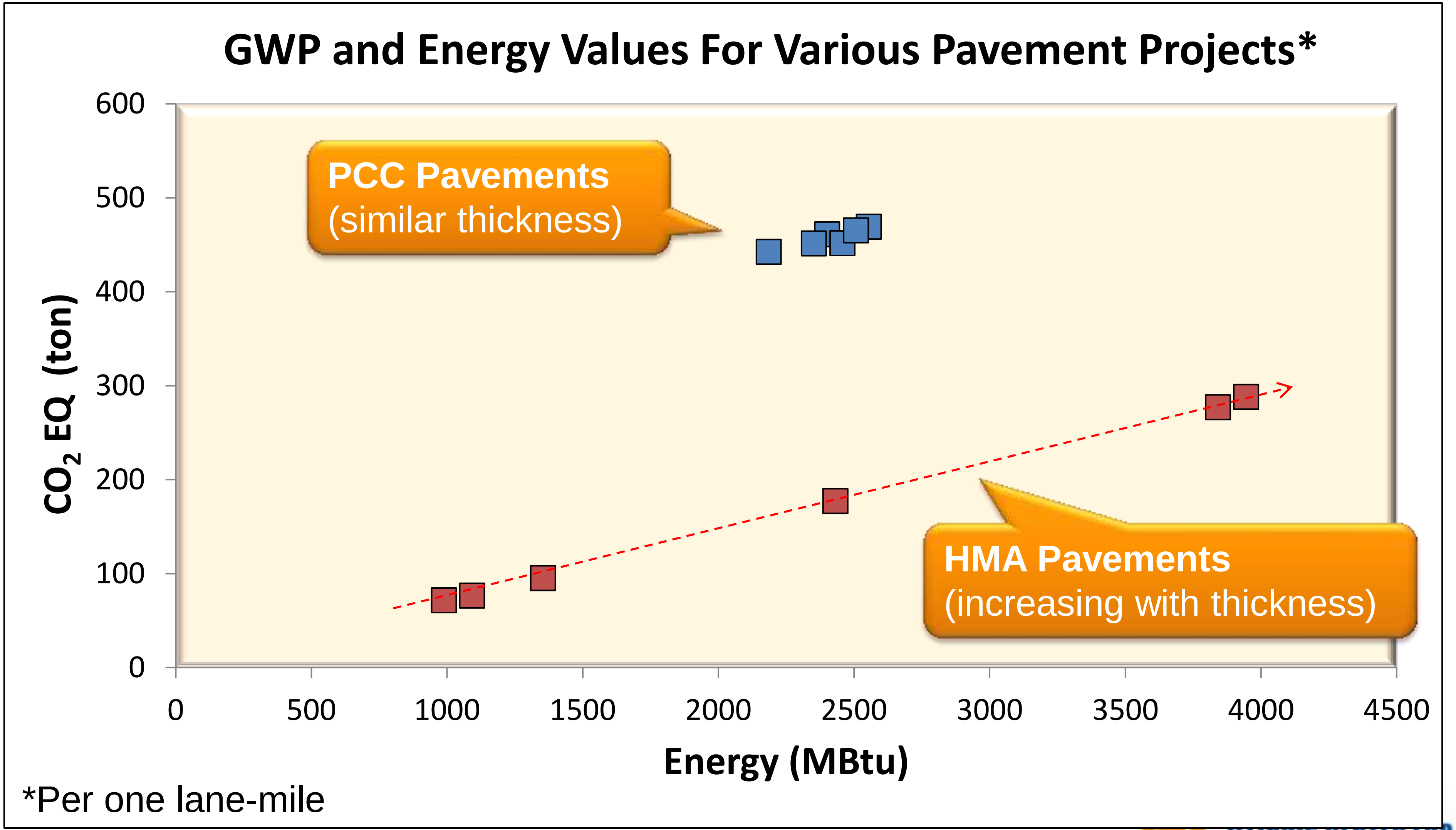


Impact of ABR

- A clear linear trend in the reduction of energy and GHG emissions with increasing ABR



LCA Results: Energy and Emissions



PCC Pavements
(similar thickness)

HMA Pavements
(increasing with thickness)

*Per one lane-mile

Summary

- A sustainable transportation system is invaluable
- Recycling is one of the most effective ways for achieving more sustainable pavements
- Short-term and long-term performances are needed to maintain economic competitiveness
- Fatigue and thermal cracking appear to be a concern when high ABR is used; mix design must be engineered
- Must use effective tools to quantify environmental, social, and economical impacts

Acknowledgements

- This presentation is based on the results of ICT projects
- IDOT engineers
- ICT staff and students
- STATE Lab

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THANK YOU

Main Quad – University of Illinois at Urbana-Champaign