Balancing Asphalt Mixtures Engineering Performance with Environmental Impacts

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Acknowledgement

- Ibrahim Elnaml
- Jun Liu
- Heather Dylla
- FHWA Sustainability Program

Key Topics

- Background
  - Louisiana BMD Framework
  - FHWA Climate Challenge
- Increased RAP Levels
  - Illustrative Case
- Early Results
- Key Takeaways

Stages of Asphalt Mixture in Flexible Pavement

- **Design**
  - » Selection of Materials
  - » Mixture Design
  - » Small Scale ~ 200 lbs
- » **Produce**
  - » Validation
  - » Large scale
    - » 200 – 400 tons/hr
- » **Construction**
- » **Accept**
  - » Parameters/Properties
  - » Density, Smoothness
  - » Mechanical Properties
- Use
- End of Life

Cradle to Gate

4

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- **End of Life**

Cradle to Grave

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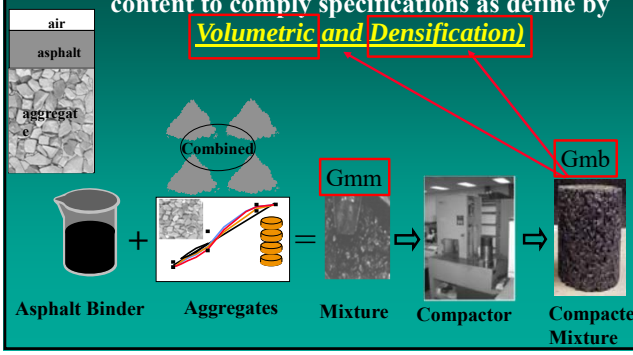
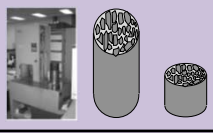
Design of Asphalt Mixture

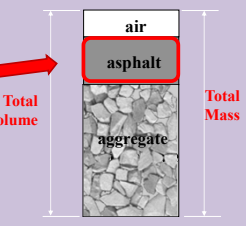
selection of an optimum amount of asphalt cement content to comply specifications as define by *Volumetric and Densification)*



Design of Asphalt Mixture

- Volumetrics
  - Voids in the Total Mix, *VTM*
  - Voids in the Mineral Aggregate, *VMA*
  - Voids Filled with Asphalt, *VFA*
- Densification
  - Stages during lab compaction process
- Optimum asphalt binder content
  - Volume → Quantity
  - NOT QUALITY
  - Aged Binders
    Replace virgin binder
    RAP and/or RAS





Balanced Mix Design (BMD)

- "asphalt mix design using performance tests on appropriately conditioned specimens that address multiple modes of distress taking into consideration mix aging, traffic, climate, and location within the pavement structure."

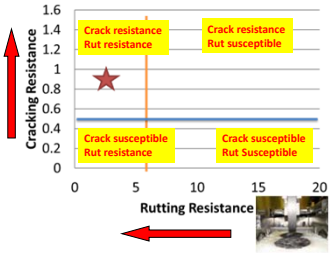
Asphalt Mixtures Stress Tests

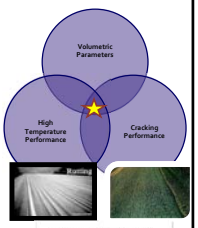
Tech Brief, Office of Preconstruction, Office of Preconstruction, Construction, and Pavements, FHWA-HIF-22-048, FHWA, US Department of Transportation, April 2022.

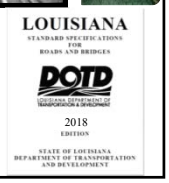
Louisiana's Approach -- Durable Flexible Pavement

Balanced Asphalt Mixture Design

- *Volumetric and Performance Mixture Testing*
  - *Rutting (AASHTO T 324): LWT test (50°C, Wet)*
  - *Cracking (ASTM 8044): SCB test (25°C)*







Asphalt Mixtures Stress Tests

2018 Louisiana DOTD Specifications for Roads and Bridges

Table 502-7[1]
Asphalt Concrete General Criteria

Nominal Max., Size Agg.	0.5 inch (12.5 mm)		0.75 inch (19 mm)		1.0 inch (25 mm)			1.5 inch (37.5 mm)	SMA
Type of Mix	Incidental Paving[2]	Wearing Course	Wearing Course	Binder Course	Binder Course	Base Course	ATB[3]	Base Course	Wearing
LWT, max. rut-design, mm @ # passes, @ 50° C	10 @ 10,000	10 @ 20,000 / 6 @ 20,000	6 @ 20,000	10 @ 20,000 / 6 @ 20,000	10 @ 20,000 / 6 @ 20,000	12 @ 20,000	10 @10,000	12 @ 20,000	6 @ 20,000
Dust/Effective Asphalt Ratio, %	0.6 – 1.6								
SCB (Semi Circular Bent Test), Jc, KJ/m² 25°C, aged	All Level 1 mix designs must meet a minimum Jc value of 0.5. All Level 2 mix designs must meet a minimum Jc value of 0.6								

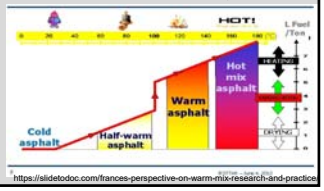
AASHTO R 30, 5 days, 85°C

Research projects to create new specification parameters
LTRC Report 536: http://www.ltrc.lsu.edu/pdf/2016/FR_538.pdf
LTRC Report 558: http://www.ltrc.lsu.edu/pdf/2016/FR_558.pdf

Sustainable Asphalt Pavement Technologies

- Materials
  - Recycled materials
    - RAP, RAS
  - Industrial waste extender
    - Sulfur
  - Plant-based
    - Bio-binder
    - Bio-rejuvenator
  - Recycled Plastics
    - LDPE/HDPE, PP, PS, PET
- Pavement construction practice
  - Warm Mix Asphalt (WMA)
    - Chemical WMA additives
      - Evotherm, Rediset, etc.
    - Organic WMA additives
      - Sassobit, Sasoflex, Asphaltan
    - Water-based WMA additves
      - Advera, Aspha-min zeolite, etc.
    - Water-Foaming WMA Equipment
      - Astec Double Barrel Green, AquaBlack

JP Forte, 2020



Background

- Practice of including RAP and/or Recycled Asphalt Shingles (RAS) in new asphalt mixtures has increased in recent years
  - economic and environmental benefits
- RAP has been widely used
  - Wearing Course: 15%
  - Binder Course: 20%
  - Base Course: 30%
- RAP is valuable components in asphalt mixtures
  - With increased demand and limited supply of aggregate and binder
- Concerns
  - Hardened and oxidized asphalt binders
  - Causing premature cracking in pavements

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- RAP is valuable components in asphalt mixtures
  - With increased demand and limited supply of aggregate and binder
- Common Solution
  - Recycling agents – Rejuvenators
  - Restore aged binders' properties

Use of RAP and/or RAS in Asphalt Mixtures

- **12.5 mm Asphalt Mixture**

Mix ID	Mix Code	RAP	RAS	Recycling Agent
Mix 1	70CO	0	0	None
Mix 2	70PG5P	0	5	None
Mix 3	52PG5P-RA 1	0	5	PG 52-28
Mix 4	70PG5P-RA 2	0	5	5% V. D. O.
Mix 5	70PG5P-RA 3	0	5	12% N.O.
Mix 6	70PG5P-RA 4	0	5	20% Softening Agent
Mix 7	70PG5P15RAP-RA 2	15	5	(0.75% + 5%) V. D. O.

Mohammad, L. N., Cooper, Jr., S., and Kim, M., "Sustainable Materials for Pavement Infrastructure: Design and Performance of Asphalt Mixtures Containing Recycled Asphalt Shingles." Louisiana Transportation Research Center, Report No. FHWA/LA.17/594, Baton Rouge, Louisiana, July 2019

Binder Availability from Recycled Materials

- Volumetric property-based procedure
  - » Mohammad et al. (2019)
- Ignition oven method
  - » NCHRP 9-58
- Dynamic modulus prediction and back-calculation based method
  - » Bonaquist and Christensen 2005
- Binder PG properties-based method
  - » Shirodkar et al. 2011; Yu et al. 2017
- Gel permeation chromatographic-based method
  - » Bowers et al. (2012, 2014)
- FTIR based method
  - » Ding et al. 2016; Sreeram et al. 2018; Hettiarachchi et al. 2020)
- Fluorescence microscopy-based method
  - Ding et al. (2018)

Mohammad, L. N., Cooper, Jr., S., and Kim, M., "Sustainable Materials for Pavement Infrastructure: Design and Performance of Asphalt Mixtures Containing Recycled Asphalt Shingles." Louisiana Transportation Research Center, Report No. FHWA/LA.17/594, Baton Rouge, Louisiana, July 2019

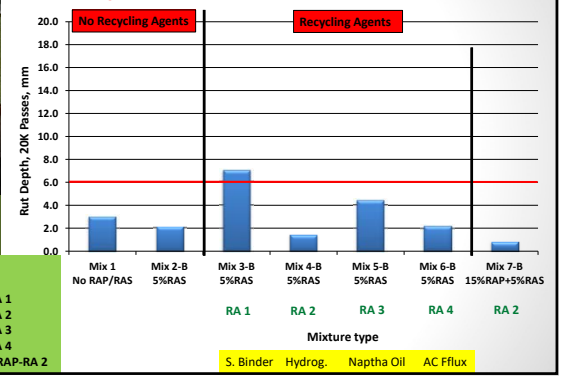
Binder Availability from Recycled Materials

- ***Volumetric property-based procedure***
  - » ***Mohammad et al. (2019)***
- Design a mixture with virgin materials
  - Compute reference Voids Filled with Asphalt, VFA_V
- Design a mixture with similar gradation containing recycled materials
  - Compute volumetric properties, specifically, VFA_r
- Determine recycled materials binder availability
  - Comparison of VFA_V to VFA_r
  - $VFA_r < VFA_V$,
    - » partial binder availability -- full mobilization is not achieved
    - » mobilization rate is determined from shortage in % asphalt binder
  - Increase virgin binder in mixtures containing recycled materials to have similar VFAs will ensure its durability.

Mohammad, L. N., Cooper, Jr., S., and Kim, M., "Sustainable Materials for Pavement Infrastructure: Design and Performance of Asphalt Mixtures Containing Recycled Asphalt Shingles." Louisiana Transportation Research Center, Report No. FHWA/LA.17/594, Baton Rouge, Louisiana, July 2019

Loaded Wheel Tracking Test Results, 50°C

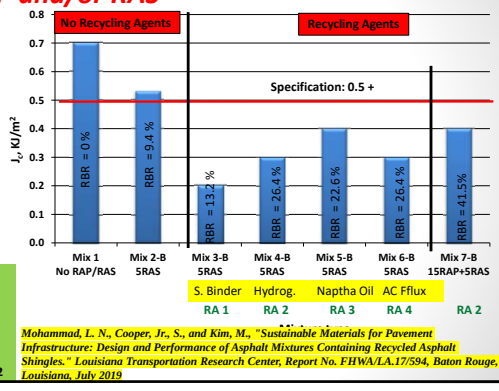
RAP and/or RAS



Mix 1 = 70CO
Mix 2 = 70PG5P
Mix 3 = 52PG5P-RA 1
Mix 4 = 70PG5P-RA 2
Mix 5 = 70PG5P-RA 3
Mix 6 = 70PG5P-RA 4
Mix 7 = 70PG5P15RAP-RA 2

Semi-Circular Bend Test Results, Jc, 25°C

RAP and/or RAS



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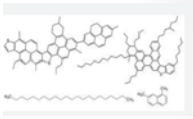
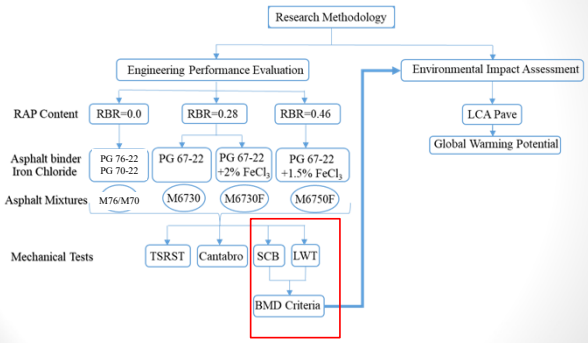
Effective Recycling Agents in asphalt pavement to improve durability and sustainability

- Increased RAP contents
  - Up to 50%
- Reagent catalyst
  - Lewis acid
  - Chemically modify aged RAP binder
  - disrupt associated molecules formed during aging
  - been already positively impacting with clean energy and green chemistry
- LA BMD Framework
  - Promote sustainability



Effective Recycling Agents in asphalt pavement to improve durability and sustainability



Effective Recycling Agents in asphalt pavement to improve durability and sustainability

RAP materials – Drying at 50°C Overnight/until weight is stable.

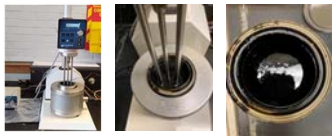
RAP materials – Splitting/Quartering To obtain representative samples

RAP materials – Adding 5% water to RAP materials and soak it overnight.

Effective Recycling Agents in asphalt pavement to improve durability and sustainability

2% FeCl3 of RAP Binder Content

Virgin Binder PG 67-22



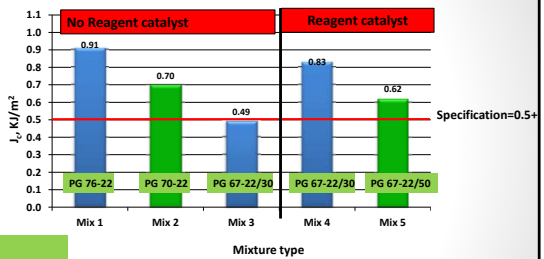
High shear mixer, 30 minutes, 165°C

Effective Recycling Agents in asphalt pavement to improve durability and sustainability

1. Super heat virgin aggregates
   1. 3 hours, 195°C
2. Adding RAP materials to mixing bucket
3. Adding heated virgin aggregates on RAP materials
4. Mixing RAP and virgin aggregates
5. Add Binder/Fecl3

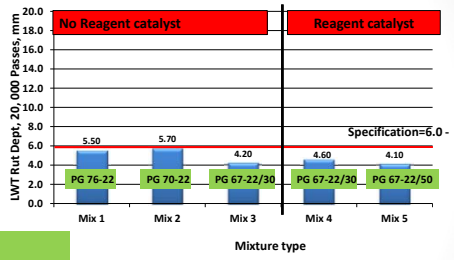
Volumetric/Mechanical Tests

Semi-Circular Bend Test Results, Jc, 25°C
Increased RAP Level Up to 50%



Mix 1 = M76
Mix 2 = M70
Mix 3 = M6730
Mix 4 = M6730+FeCl3
Mix 5 = M6750+FeCl3

Loaded Wheel Test Results, Rut Depth, 50°C
Increased RAP Level Up to 50%



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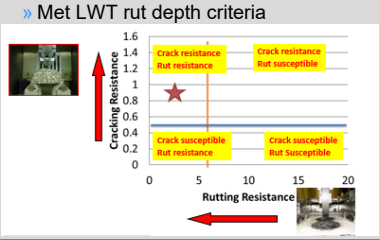
Effective Recycling Agents in asphalt pavement to improve durability and sustainability

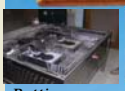
- Summary
- Use High RAP Level with Reagent Catalyst
  - Louisiana BMD Framework
    - » Met SCB J_c criteria for BMD
    - » Met LWT rut depth criteria



What is Next?

BMD vs Sustainability

Balancing Asphalt Mixtures Engineering Performance with Environmental Impacts



Rutting (AASHTO T 324):

Cracking (ASTM 8044):

Environmental Impact
PCR, EPD, TRACI, ACLCA
Life cycle assessment
Global warming potential

The Pursuit of Sustainable Pavements

Designing, constructing, and maintaining pavement systems which minimize environmental impacts while maximizing economic benefits and ensuring equitable social outcomes.

Source: FHWA SPWTG

Louisiana Department of Transportation and Development

DOTD
LOUISIANA DEPARTMENT OF TRANSPORTATION & DEVELOPMENT

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Sustainability through Development of Life Cycle Information Models for Pavements in Louisiana

Project Goals:

(1) Educate agencies on Environmental Product Declarations (EPD) and Life Cycle Assessment (LCA).
(2) Collect pavement production and construction data in an open-sourced format to inform development of standards for quantifying construction environmental impacts and enhancing the pavement repository in OpenLCA as well as LCAPave.
(3) Collaborate with the Asphalt Institute to explore and develop asphalt binder-specific publicly available background life cycle inventory data in aggregated formats.

Project Tasks:

- **Task 1:** Develop and Deliver Training. This include Project Kick off Training and Project Concluding Symposium.
- **Task 2:** Conduct LCA Case Studies on Selected Projects and Collect EPDs.
- **Task 3:** Assist in the Exploration and Development of Publicly available background life cycle inventories for asphalt binder.
- **Task 4:** Develop standards/frameworks to quantify environmental impacts of construction practices.

Implementation

- **Develop and integrate** decision-making tool
  - ✓Evaluating sustainability of pavement designs and products into LADOTD specifications
- Harmonizing **engineering** performance with **environmental** and **economic** performances.
  - ✓Assist designers and decision makers to select most sustainable pavement design/materials
    - that meets and balances the criteria necessary for engineering, economic, and environmental performances

$$Performance = \frac{\%\,Eng_1 + \ldots + \%\,Env_1 \ldots}{\frac{\%\,Eng_1}{Eng_1\ Parameter} + \ldots + \frac{\%\,Env_1}{Env_1} + \ldots}$$

Pavement Life Cycle

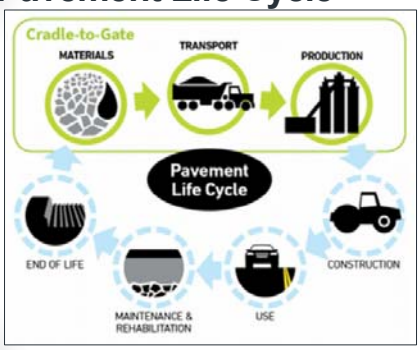
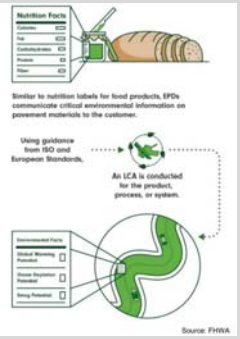


IMAGE CREDIT: NAPA

How Do You Measure Environmental Performance of Pavements?

- Environmental Product Declarations (EPDs)
- Life Cycle Assessment

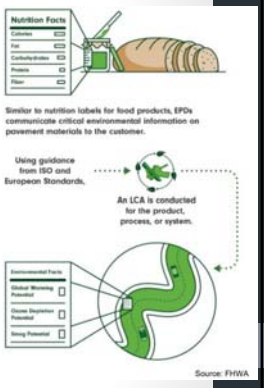
FIGURE CREDIT: FHWA



Source: FHWA

Environmental Product Declarations (EPDs)

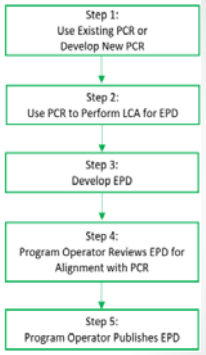
- Labels used to communicate environmental performance of products.
  - Multiple impacts reflective of supply chain
- Procurement aid in highway construction specifications
  - CODOT, Caltrans



Source: FHWA

Development of EPDs

- **Product Category Rule (PCR) :**
  - PCR is a set of industry-consensus standards and guidelines used to develop EPDs
- **Using standards defined in the PCR document**
- **Updated periodically: ~ every 3 to 5 years**
- **Report 7 mandatory impact indicators:**
  - Global warming potential (*GWP*)
  - Depletion potential of the stratospheric ozone layer (*ODP*)
  - Acidification potential of soil and water sources (*AP*)
  - Eutrophication potential (*EP*)
  - Photochemical smog creation potential (*POCP*)
  - Abiotic depletion potential for fossil resources (*ADPf*)
  - Fossil fuel depletion (*FFD*)
- **An example EPD:** Print EPD.pdf



Steps in the development of EPDs

Life-Cycle Assessment (LCA)

- **Methodology to quantify potential environmental impacts of a product or process from raw material extraction to the end of life**
- **Provides a comprehensive approach to evaluate total environmental burden of a product or process**
  - **examining all inputs and outputs over the life cycle, from raw material production to end of life**

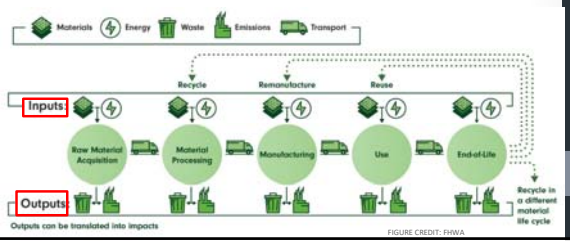
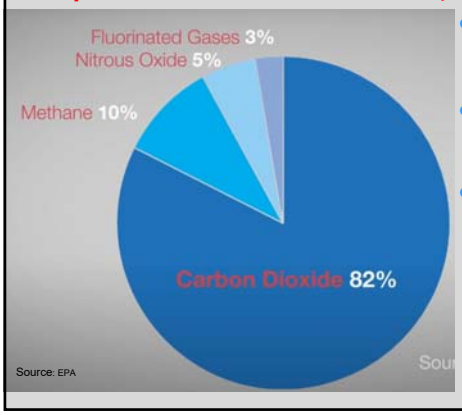


FIGURE CREDIT: FHWA

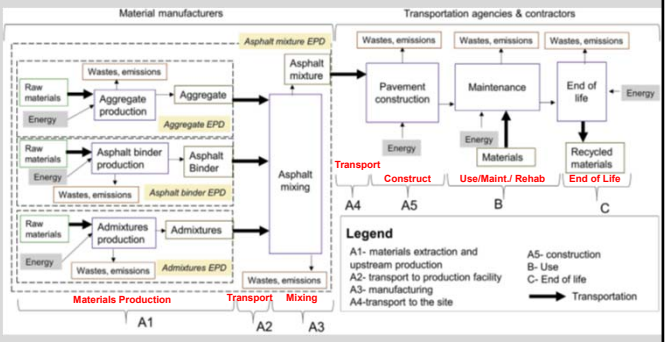
Composition of GreenHouse Gases (GHG) --- GWP



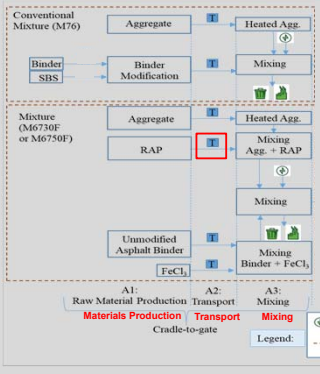
Source: EPA

- Concentration
  - relative contribution of a gas toward global warming
- Life time:
  - How long does it take to remove a gas from the atmosphere
- IR radiation
  - How much IR radiation that molecule absorb

Asphalt Pavement Product System for LCA
Cradle-to-Gate vs Cradle-to-Grave

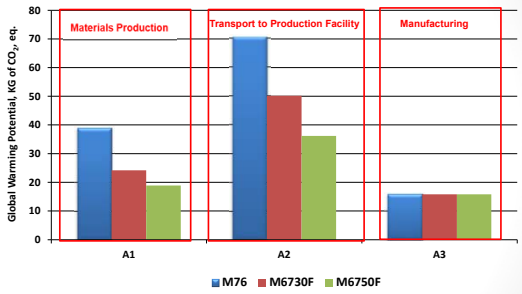


Asphalt Pavement Product System for LCA
Cradle-to-Gate -- similar performance

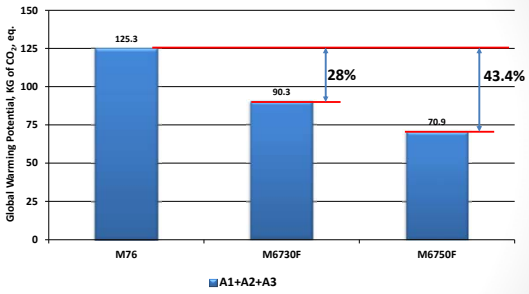


- Cradle-to-Gate
  - A1 = raw materials extraction / manufacturing
  - A2 = Transportation
  - A3 = asphalt mix production
- Potential Environmental Impacts
  - Public background datasets
    - » ACLCA Open Standard
    - » FHWA LCA Pave
- Public background datasets
  - supports green public procurement
    - » more transparent and verifiable
    - » facilitates broader LCA harmonization and reuse of results

Impact of Global Warming Potential
Cradle-to-Gate



Impact of Global Warming Potential
Cradle-to-Gate (A1+A2+A3)



Takeaways

- Integrate Environmental Impact (LCA) with Engineering Performance (BMD Framework) in harmony with key principles of green public procurement
- Illustrative Example --- Use High RAP Level with Reagent Catalyst
  - Positive *intermediate temperature cracking resistance* for mixtures containing up to 50% RAP
    - » Met SCB J_c criteria for BMD
  - No negative impact on *permanent deformation resistance*
    - » LWT test
  - Improved mixtures' *durability*

- Environmental impact analysis
  - Compared to conventional mixture M76
    - » 30% RAP reduced GWP by 28%
    - » 50% RAP reduced GWP by 43%

THANK YOU