Establishing EPD Benchmarks for Asphalt Mixtures within Oklahoma BMD Framework

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Acknowledgment

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- Oklahoma DOT: Dr. David Vivanco, Matt Romero
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- Haskell Lemon Construction Co: Jay Lemon

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3 3

Adeoluwa Gbolade

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Presentation Outline

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- Background: Climate Change, Sustainability and Life Cycle Assessment
- Problem Statement, Need for Research, Research Objectives
- Methods to Benchmark Asphalt Mix GWP
- Strategies to Reduce GWP of Asphalt Mixes
- Summary and Conclusion
- Other Activities from Climate Challenge Project: WMA Field Study

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Climate Change, Sustainability and Life Cycle Assessment

Climate Change

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There is increasing trend in the occurrences of adverse weather conditions

- **Rising Global Temperatures**
- **More Droughts and Wildfires**
- **Glaciers Melting**
- **Rising Sea Level**
- **Increased Flooding**

- **Human activities are the main drivers of Climate Change (Herring, 2022).**
- **There is need to reduce our contributions to Climate Change – urgent need to move towards sustainability.**

Sustainability

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Sustainability in relation to pavements refers to a pavement's ability to:

- ❑ **Achieve its engineering goals.**
- ❑ **Preserve and restore its surrounding ecosystem.**
- ❑ **Use financial and environmental resources economically.**
- ❑ **Meet human needs such as health, safety, and comfort.**

https://careers.atkinsrealis.com/blogs/2024-9/three-pillars-of-sustainability-and-the-built-environment

Harvey, J., J. Meijer, H. Ozer, I. L. Al-Qadi, A. Saboori, and A. Kendall (2016). "Pavement life cycle assessment framework". No: FHWA-HIF-16-014. Federal Highway Administration. United States.

How To Move Towards Sustainability in Asphalt Pavements

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By making decisions that minimizes economic, social, and environmental costs/impacts

- ❑ Using an alternative pavement design approach – perpetual pavements
- ❑ Optimizing plant production activities to consume less fuel
- ❑ Producing mixes at lower temperatures
- ❑ Using recycled materials like RAP and RAS

Source: FHWA

How do we reduce emissions from pavement systems?

State DOTs can start using **life-cycle assessment (LCA)** to assess embodied environmental impacts of highway transportation systems. LCA can provide a comprehensive estimate of life-cycle impacts to decision-makers and can help indicate areas of improvement.

Life Cycle Assessment and Environmental Product Declaration

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Life Cycle Assessment (LCA)

- ❑ LCA entails the tracking and evaluation of inflow and outflow of materials, energy, waste and emissions for a particular product/service to quantify environmental impacts.
- ❑ LCA can be used to compare alternative products based on their environmental impacts.

Environmental Product Declaration (EPD)

- ❑ An EPD presents how much impacts a particular product has on the environment at a specified stage of its life.
- ❑ *An EPD declares the result of an LCA study carried out on a product.*

ACRONYM	INDICATOR	UNIT	QUANTITY PER METRIC TONNE ASPHALT MIXTURE (PER SHORT TON ASPHALT MIXTURE)			
			MATERIALS (A1)	TRANSPORT (A2)	PRODUCTION (A3)	TOTAL (A1-A3)
GWP-100	Global warming potential, incl. biogenic CO2	kg CO2 Equiv.	30.11 (27.32)	6.65 (6.04)	38.55 (34.98)	75.32 (68.33)
ODP	Ozone depletion potential	kg CFC-11 Equiv.	1.60e-08 (1.45e-08)	4.02e-08 (3.64e-08)	1.32e-07 (1.20e-07)	1.88e-07 (1.71e-07)
EP	Eutrophication potential	kg N Equiv.	8.05e-03 (7.30e-03)	1.98e-03 (1.80e-03)	3.39e-03 (3.08e-03)	1.34e-02 (1.22e-02)
AP	Acidification potential	kg SO2 Equiv.	8.68e-02 (7.88e-02)	3.39e-02 (3.08e-02)	1.30e-01 (1.18e-01)	2.51e-01 (2.28e-01)
POCP	Photochemical ozone creation potential	kg O3 Equiv.	1.80 (1.64)	1.09 (0.99)	1.78 (1.61)	4.67 (4.24)

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Problem Statement/Need for Research

A Peek Into the Future: In a World of Sustainable Pavements

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Decisions are guided by life cycle thinking, not just tradition or routine.
Decisions are guided by sustainability consideration, not just cost and function.

Sketch Credit: OpenAI

Where We Are Now

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- ❑ Owners often rely on cost and tradition, with limited environmental considerations.
- ❑ Contractors lack adoptable strategies to reduce pavement environmental impacts.
- ❑ Contractors face uncertainty around the impact and feasibility of alternative practices.
- ❑ Scientists lack data and tools to support real-world decision-making.

Toward Sustainability: What Is Needed?

- ❑ Owners need to be equipped with implementable frameworks for specifying environmental goals in procurement – benchmarking is vital.
- ❑ Scientists need harmonized models for consistent sustainability quantification.
- ❑ Contractors need strategies that can help reduce pavement impacts.

Problem Statement/ Need for Research

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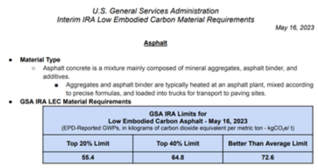
- ❑ For low carbon procurement, materials are required to have published EPD and meet reference GWP values.
- ❑ GSA adopted interim benchmarks developed by EPA.
- ❑ Region-specific factors influence the environmental impacts of materials – climate, raw material availability.

There is a great need for region-specific benchmarking.


U.S. General Services Administration
Interim IRA Low Embodied Carbon Material Requirements

May 16, 2023

Asphalt

- **Material Type**
  - Asphalt concrete is a mixture mainly composed of mineral aggregates, asphalt binder, and additives.
    - Aggregates and asphalt binder are typically heated at an asphalt plant, mixed according to precise formulas, and loaded into trucks for transport to paving sites.
- **GSA IRA LEC Material Requirements**

GSA IRA Limits for Low Embodied Carbon Asphalt - May 16, 2023 (EPD-Reported GWPs, in kilograms of carbon dioxide equivalent per metric ton - $kgCO_2e/t$)		
Top 20% Limit	Top 40% Limit	Better Than Average Limit
55.4	64.8	72.6

Problem Statement/ Need for Research Contd.

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- ❑ After benchmarking, it is important to identify what producers can do to reduce mix GWP.
- ❑ How can we reduce the environmental impacts of our materials?
- ❑ How do decisions made during mix design stage affect environmental impacts?
- ❑ Hypothesis
  - ❑ Environmental impacts can be reduced by;
    - ❑ Producing asphalt mixes at reduced production temperature – Warm Mix Asphalt.
    - ❑ Using more recycled materials without compromising on performance – Balanced Mix Design.

Research Method: Life Cycle Assessment

Research Objectives

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1. Present methods for determining region-specific GWP benchmarks of asphalt mixes.
2. Demonstrate the difference between the benchmarking methods using asphalt mixes used in the state of Oklahoma as a case study.
3. Evaluate the potency of WMA and BMD in reducing the GWP of asphalt mixes.

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Methods to Benchmark Asphalt Mix GWP; Oklahoma Case Study

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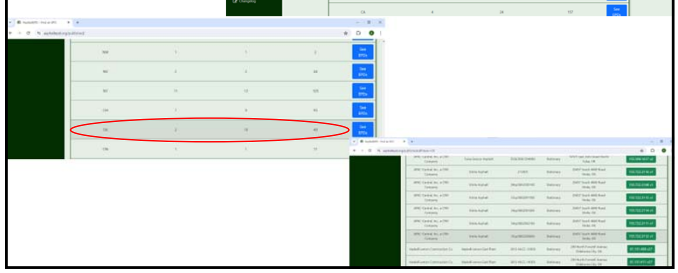
Approach 1: EPD-Based GWP Benchmarking

Approach 1 EPD Data



Approach 1 – OK EPD Data

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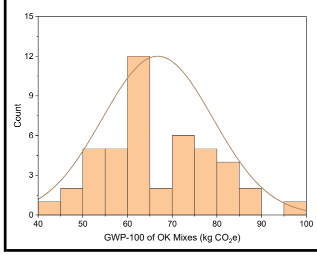
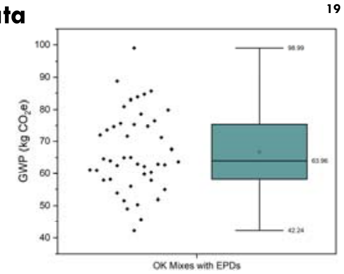
- ❑ Data collected from 49 EPDs in OK.
- ❑ Four were screened out because of data gaps.





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Approach 1 – OK EPD Data

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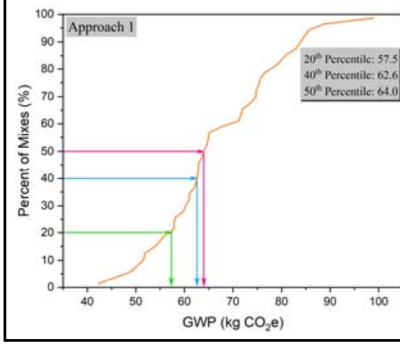

Average: 66.7 kg CO_2e

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- ❑ **Approach 1 (EPD Dataset)**
  - ❑ Problem?
    - ❑ Relatively low number of published EPDs.
    - ❑ Are the currently available EPDs truly representative of all the mixes in the state?

Solution: Use a method that allows the incorporation of mixes without published EPDs.

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Approach 2: Use of Intensity Factors for A1 GWP Quantification

Approach 2 - Modified from NAPA's SIP-108 Report (Miller et al. 2024)

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$$GWP_{total} = (x_1y_1 + x_2y_2 + \cdots + x_ny_n) + A2 + A3$$

$$\text{Such that} \quad \sum_{i=1}^{n} x_i = 1\ tonne$$

where;
- GWP_{total} = total A1-A3 GWP of the mix
- x_i = mass contribution of material i
- y_i = GWP intensity of material i
- A2 = average A2 GWP for the state
- A3 = average A3 GWP for the state

Material	GWP Intensity (y), kg CO_2e/tonne of Ingredient
Neat Binder	631.51
3.5% SBS Modified Binder	758.71
Lime	1389.00
RAP	0.781
Aggregate (USLCI, prescribed)	1.94

Note: We are not using a baseline/representative mix

Mixes Considered

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155 asphalt mix designs (Superpave) recently developed in Oklahoma were considered.

NMAS
- ❑ 19mm mixes - 60
- ❑ 12.5mm mixes - 76
- ❑ 9.5mm mixes - 17
- ❑ 4.75mm mixes – 2

Binder Type
- ❑ Unmodified binder – 95
- ❑ Modified binder – 60

Approach 2 - Results

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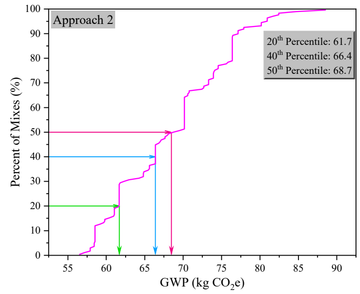

Average: 68.5 kg CO_2e

Problem?

There is still great reliance on average data

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Approach 3: Intensity Factors for A1 and A2 GWP Quantifications

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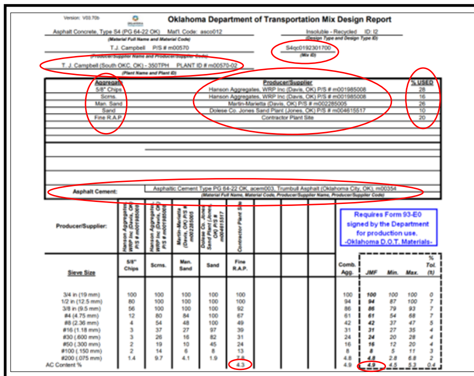

- Extracted data from all 155 mix design sheets.
- Established addresses of the sources from ODOT website and google maps.
- Wrote R code to compute distance from plant to all the different material sources.

Approach 3 – Mix Design Data – Added Granularity

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- Compute A1 and A2 GWP for each mix, then add an average A3 GWP.

$$GWP_{total} = (x_1y_1 + x_2y_2 + \cdots + x_ny_n) + 1.35t(x_1z_1 + x_2z_2 + \cdots + x_nz_n) + A3$$

where;
GWP_{total} = total A1-A3 GWP of the mix
x_i = mass contribution of material i, such that $\sum_{i=1}^{n} x_i = 1$ tonne
y_i = GWP intensity of material i
z_i = transport distance of material i
t = GWP intensity of transport mode
$A3$ = average A3 GWP for the state

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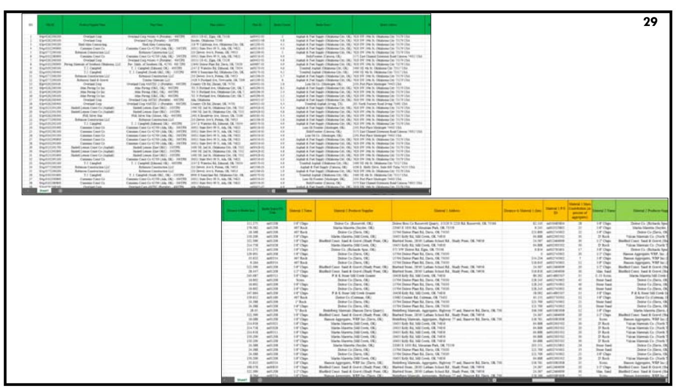

Preliminary Benchmarks

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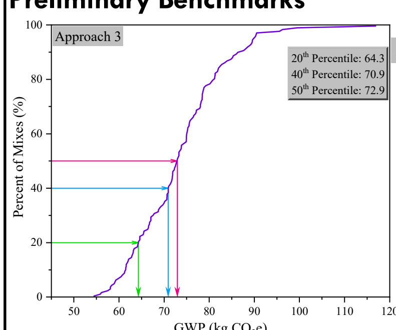

Average: 73.4 kg CO_2e

Used the same 155 asphalt mixes considered in Approach 2

Lessons Learned from Approaches 1, 2 and 3

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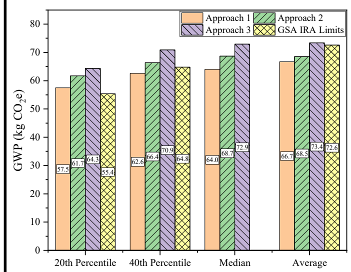

- ❑ Upward trend in the established benchmarks, going from Approach 1 to 3.
- ❑ From 1 to 2; increased number of mixes, better spread of GWP data.
- ❑ From 2 to 3; more granular data with A2 GWP computation.
- ❑ Difference between benchmarks and GSA Limits emphasizes need for region-specific benchmarking.

❑ **But what are we missing here?**
❑ **Mixes differ greatly from one another.**

Need for Mix Classification During Benchmarking

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- ❑ Adequately classifying mixes based on distinguishing factors in accordance with generic asphalt mix design knowledge is important – based on NMAS, binder type, etc.
- ❑ For state-specific benchmarking, DOT classification of asphalt mixes can be adopted for mix classification.
- ❑ May include classification based on mix functionality
  - ❑ mixes for high-traffic pavement vs. low-traffic pavements, or
  - ❑ mixes used in the surface vs. non-surface layers of pavement structures.

In Oklahoma's case study, NMAS and functionality were considered.

Benchmarking Based on NMAS

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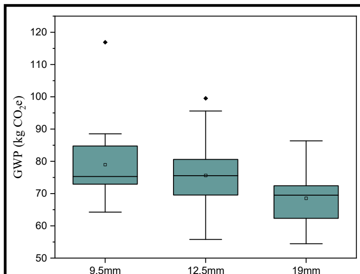

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Top 20% Limit	Top 40% Limit	Better Than Average Limit
55.4	64.8	72.6

OK Mix Class - NMAS	20th Percentile	40th Percentile	Median	Average	n
S5 - 9.5 mm Mixes	71.9	74.9	75.3	78.9	17
S4 - 12.5mm Mixes	66.3	73.8	75.5	75.6	76
S3 – 19mm Mixes	61.5	67.1	69.5	68.5	60

Benchmarking Based on Function

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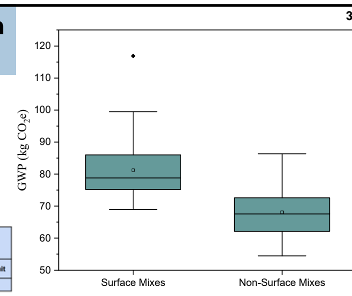
ODOT Spec. for Superpave Mixes

- ❑ Surface Mixes - All 0% RAP mixes with NMAS ≤ 12.5 mm.
- ❑ Non-Surface Mixes - 12.5 mm mixes with RAP > 0% + All 19 mm mixes.



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Top 20% Limit	Top 40% Limit	Better Than Average Limit
55.4	64.8	72.6

Functional Class	20th Percentile	40th Percentile	Median	Average	n
Surface Mixes	74.9	78.4	78.8	81.2	62
Non-Surface Mixes	61.6	65.9	67.6	68.1	87

Checkpoint

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Typical questions from mix producers

- ❑ What if I cannot meet the benchmark values?
- ❑ Is not meeting the benchmark values a death sentence for my asphalt plant?
- ❑ How can I improve my values with respect to these benchmarks?

How can we answer these questions?

- ❑ By conducting Life Cycle Assessment to identify alternative mixes with lower GWP

What has been hypothesized to help reduce GWP?

- ❑ Warm Mix Asphalt (WMA) and Balanced Mix Design (BMD)

Let's verify if its true.

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Exploring Strategies to Reduce GWP of Mixes with Life Cycle Assessment

Goal and Scope

- This study focused on exploring the ability of WMA and BMD in reducing environmental impacts of asphalt mixes.
  - WMA mixes are mixes produced at reduced production temperature.
  - BMD mixes focus on meeting threshold performance criteria.
- Considered same LCA phases as asphalt mix EPD (cradle-to-gate) – raw materials acquisition (A1), transportation (A2), and the production (A3).
- Functional Unit: *one tonne of mix suitable for paving the surface course of a pavement with traffic up to 3 million equivalent single axle loads (ESALs).*

Alternatives Considered

- DOT Specifications
  - ODOT (2019) – RAP not allowed in surface mixes.
  - ODOT Special Provisions (2023) – RAP allowed up to 15% in surface mixes designed with BMD.
- Hence, in this study, a BMD mix containing up to 15% RAP was considered to be functionally comparable to a Superpave (SP) mix without RAP.
- Alternatives considered in this LCA study include:
  - *SP HMA without RAP;*
  - *SP WMA without RAP;*
  - *BMD HMA with 14.3% RAP; and*
  - *BMD WMA with 14.3% RAP.*

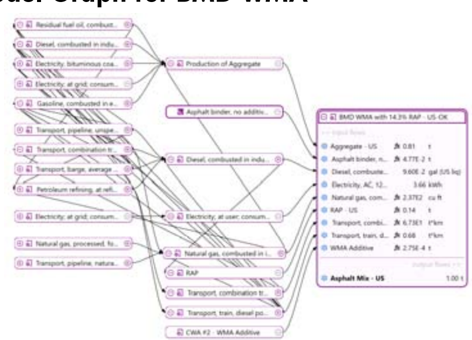
LCA: Constituents of Mix Alternatives

Material	SP HMA without RAP	SP WMA without RAP	BMD HMA with RAP	BMD WMA with RAP
Virgin Aggregate (%)	95.0	95.0	80.92	80.92
Total Binder (%)	5.0	5.0	5.5	5.5
Virgin Binder (%)	5.0	4.975[a]	4.8	4.7725[a]
RAP (%)	-	-	14.28	14.28
WMA Additive (%)	-	0.025	-	0.0275

a. Virgin binder content was slightly reduced to allow for WMA Additive.

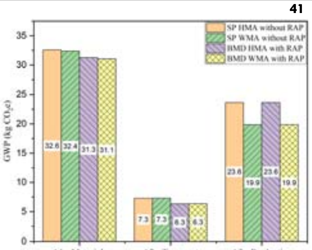
BMD mixes mostly require higher total binder contents

LCA Model Graph for BMD WMA



Results

Parameter	SP HMA without RAP	SP WMA without RAP	BMD HMA with RAP	BMD WMA with RAP
Total GWP (kg CO_2e)	63.5	59.5	61.2	57.3
Relative Total GWP (%)	100	93.7	96.4	90.2



- SP WMA < BMD HMA: *The incorporation of chemical warm-mix technology with production temperature reduction is more potent for reducing GWP than BMD implementation.*
- BMD WMA has least GWP: *The adoption of combined BMD and WMA concepts (BMD WMA with RAP) is the best alternative to SP HMA without RAP – 9.8% reduction in GWP.*

Summary and Conclusion

- As the emphasis on EPDs and low-carbon procurement increases, DOTs will be taking different approaches to establish benchmarks for their respective materials.
- Different benchmarking approaches can be adopted based on the granularity of data available.
- During the benchmarking process, it is advisable to establish different reference values based on mix classes.
- Both WMA and BMD can help reduce the GWP of asphalt mixes, but the greatest benefit is gotten when the two technologies are combined.

EPD-Based Analyses

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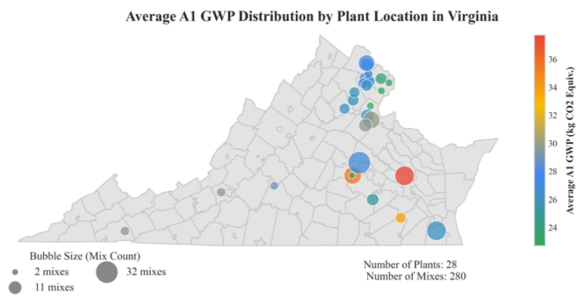

EPD-Based Analyses (2)

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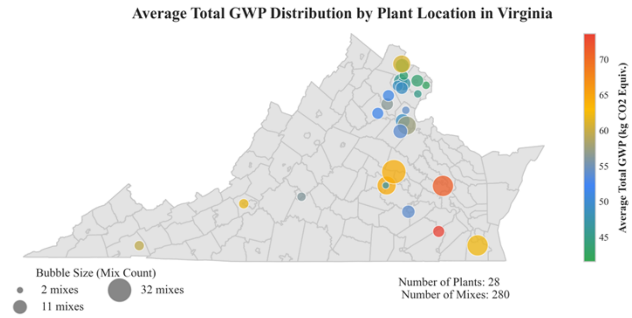

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Other Activities from Climate Challenge Project: WMA Field Study

Contributing Organizations

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Organization	Contribution
Oklahoma State University	Researchers
Oklahoma Department of Transportation and Oklahoma Turnpike Authority	Overseeing authority
Haskell Lemon Construction Company	Volunteer project contractor
Ingevity	Warm mix additive and injection system supplier
Highway Data System	Plant, truck, paver and roller instrumentation

Project Details

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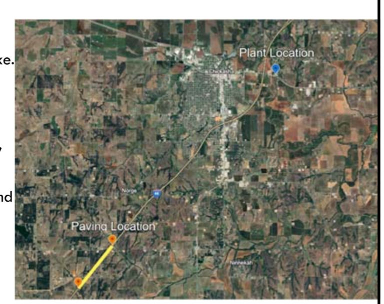
- 4 in. lift shoulder of H. E. Bailey Turnpike.
- HMA and WMA produced, paved and compacted.
- July 30, 2024 (HMA Day) and July 31, 2024 (WMA Day).
- 1593.3 tons produced on HMA Day, and 1297.7 tons produced on WMA Day.



Production Plant Layout

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Temperature Measurements

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EPLANT ESILO ELOAD eTec VisIR Optrix

Some Glimpses

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Paving Temperature

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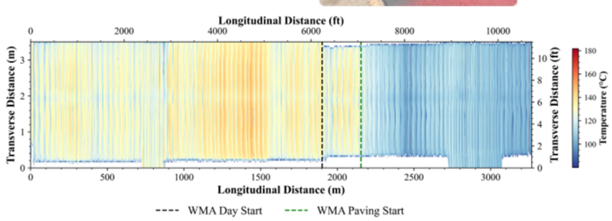

Heat Loss Comparison

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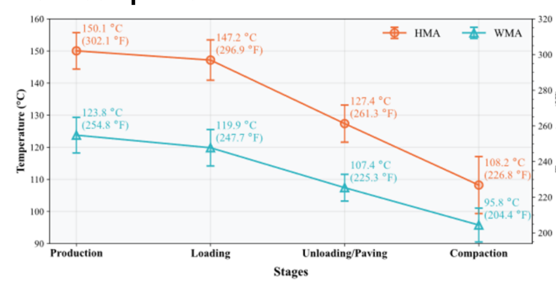

Fuel Savings During Production

- R_H = 194.54 ft³/ton, R_W = 161.80 ft³/ton
- Fuel Savings due to WMA Production = **16.83%**

Density Determination

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Both pavement sections attained similar in-place density

Relative Concentrations of Particulate Matter

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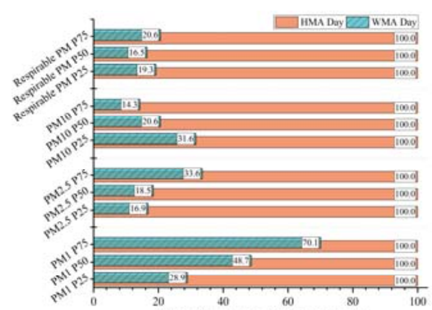

Construction Equipment Data

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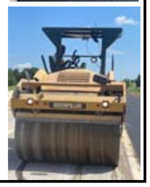
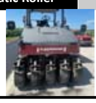
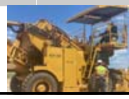
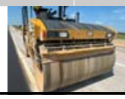
Function	Equipment	Engine	Mass (kg)	Power rating (hp)
MTV	Weiler E1250C	Cat C7.1	24222	250
Paver	CAT AP1055F with SE60 V screed	Cat C7.1 with ACERT Technology	20452	225
Vibratory Roller	CAT CB54 XW	Cat C4.4 with ACERT Technology	11898	137
Pneumatic Roller	Dynapac CP1200	Cummins QSF2.8	12100	74
Static Roller	CAT CB15	Cat C4.4	14185	142

Life Cycle Phases Comparison

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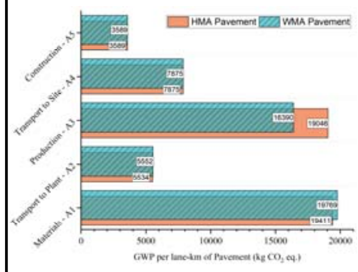

Just for 1 lane-km of pavement

- 2280 kg of CO_2 saved
- Equivalent to GWP of 44 tonnes (48.5 tons) of WMA **(~2 full truckloads of asphalt)**

Hypothetical Nationwide Adoption of WMA

- 174.09 million tonnes of mix per year – more than 200,000 lane-km of 4 in. thick pavement.
- 456,000 tonnes of CO_2 eq. saved yearly.
- **Equivalent to offsetting emissions from 1.87 billion km driven by average gasoline-powered passenger vehicle.**

https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator

Special Thanks To

57 57

Jay Lemon
Haskell Lemon Construction

Dr. David Vivanco
ODOT

Richard Steger
Ingevity

Matt Wheatley
Highway Data System

OKLAHOMA Transportation

ingevity

HDS

Thank you!!

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COLLEGE OF ENGINEERING
THE CHARLES E. VIA, JR. DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING
VIRGINIA TECH

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