Role of Bio Materials in Decarbonizing Road Construction

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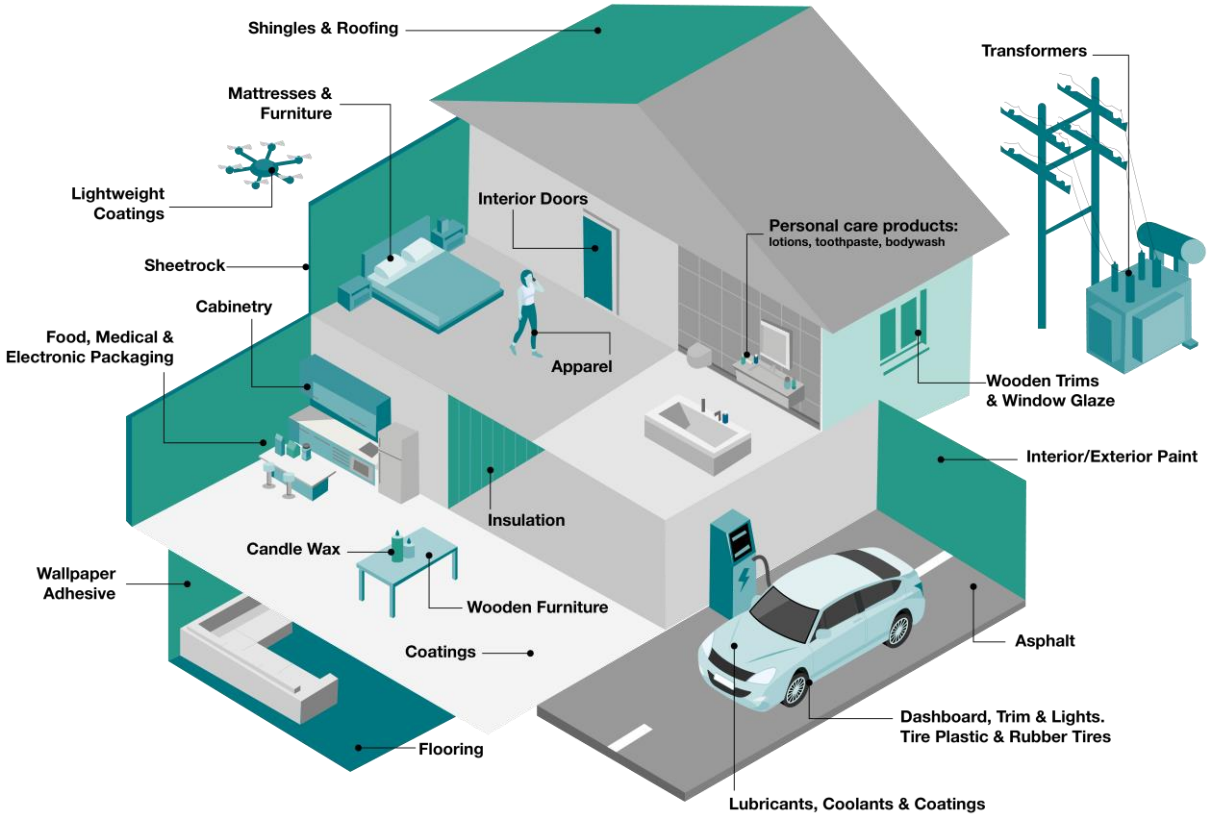
Cargill

Cargill Bioindustrial is made for this moment.

We're harnessing the power of nature-derived ingredients to help meet the world's needs for renewable materials.



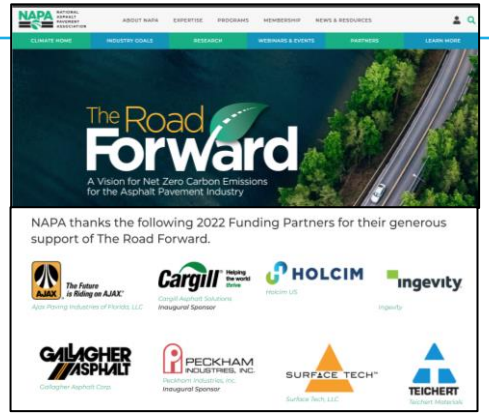
What is Bio Material?

What does “Bio-based” Mean?

- **Definition can be very broad.**
- Often refers to material derived from:
  - Vegetable or Tree-based fatty acids, triglycerides, and derivatives
  - Starches, sugars, proteins, and derivatives
  - By-products such as gums, fatty distillates, recovered oils, etc.
  - Pyrolysis products of lignin, husks, nutshells, animal sources…
- In the asphalt industry the label “bio-based” is often used to describe oils, or “**Bio-oils**”, however there is still large diversity of products under this umbrella.
- The “Bio-based” label does not imply any specific performance level. Bio-based material can be **chemically modified** or **“Engineered”** into specialty chemicals to have various properties and functionalities.
  - **Classifying bio-based additive solely based on raw material source can be misleading.**

Why is this important?

- State of the Environment
- Administrations Change, emphasis on making progress
- Public Companies Reporting and Disclosures
  - Investors driving
  - Younger Workforce Interest
- NAPA Industry Road Forward.
  - Net Zero by 2050
  - Pathway starting today
  - Immediate options
- Inflation Reduction Act
- Buy Clean Legislation



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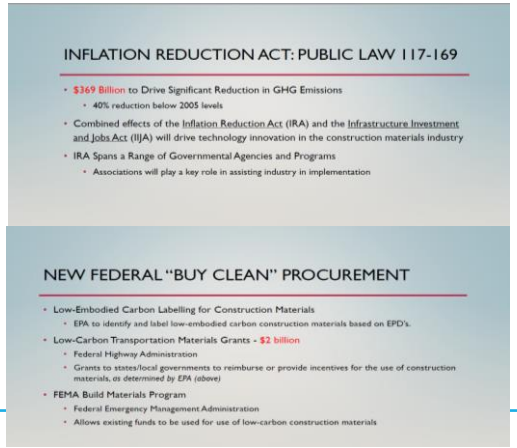
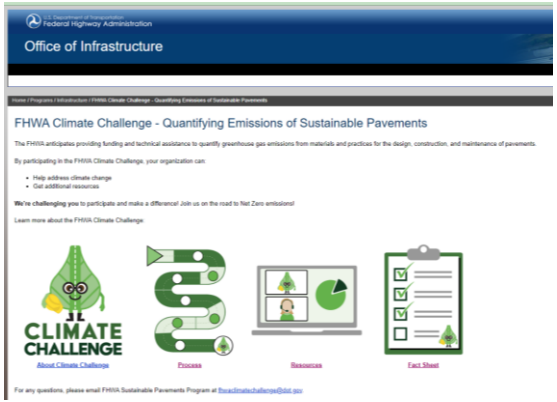
The Securities and Exchange Commission proposed rule amendments that would require a domestic or foreign registrant to include certain climate-related information in its registration statements and periodic reports, such as on Form 10-K, including:

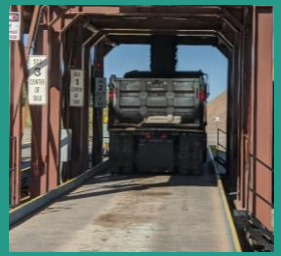
- Climate-related risks and their actual or likely material impacts on the registrant's business, strategy, and outlook;
- The registrant's governance of climate-related risks and relevant risk management processes;
- The registrant's greenhouse gas ("GHG") emissions, which, for accelerated and large accelerated filers and with respect to certain emissions, would be subject to assurance;
- Certain climate-related financial statement metrics and related disclosures in a note to its audited financial statements; and
- Information about climate-related targets and goals, and transition plan, if any.

The proposed disclosures are similar to those that many companies already provide based on broadly accepted disclosure frameworks, such as the Task Force on Climate-Related Financial Disclosures and the Greenhouse Gas Protocol.





Rheology Modifier (Binder Additive)



Adhesion Promoter & Warm Mix Additive

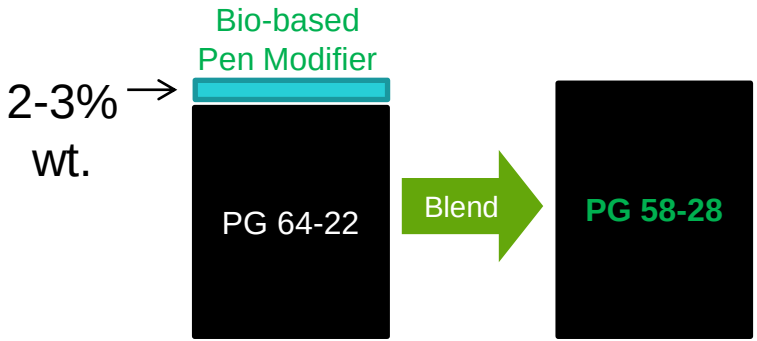
Recycling Agent (Mix Additive)

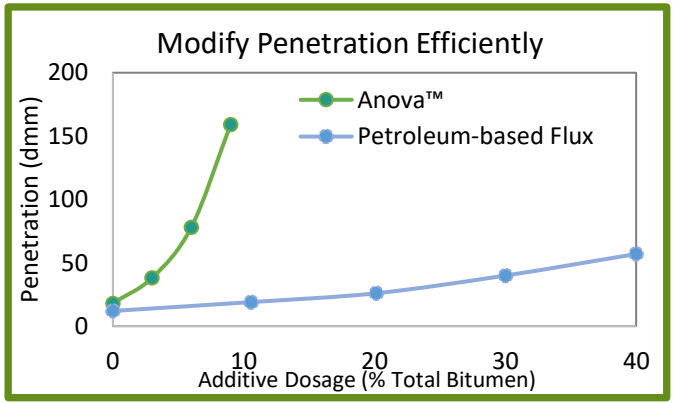
Bio-Binder

Applications of Bio Materials

1- Bio-based Rheology Modifiers

- Vegetable-oil based modifiers widely used as binder PG modifiers (mostly softeners).
- Various grades and qualities exist
- **<u>Alternatives to conventional aromatic and paraffinic oils</u>** due to:
  - Versatility
  - Low dosage
  - Easy pumpability
  - EHS advantages
  - High flashpoints
- Some grades are suitable for use in asphalt emulsions; while other “bio-solvents” have become popular in cutback applications.





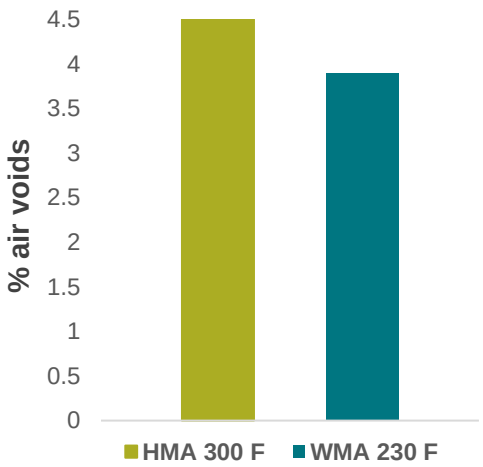
2- Warm Mix: Organic Additives vs. Biobased Additives

- Fischer-Tropsch and Fatty Amid waxes. “Organic” in this sense typically does not mean biobased.
- Melting points lower than typical hot mix compaction temperatures
- Act as **bitumen plasticizers** (viscosity reducers) when above their melting temperatures.

- Common due to **ease of implementation** and **lack of impact on standard bitumen grade**.
- Perform through modification of the bitumen **internal friction** and ability to **coat the aggregates**.
- Some additives include a partial bio component while others are fully derived from bio materials

WMA Evaluation - MN

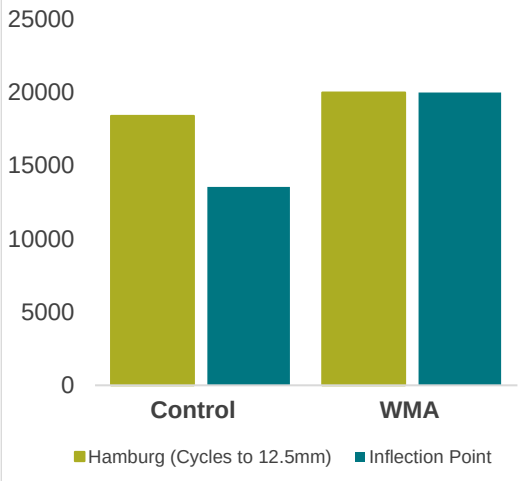
Mixture with WMA achieved lower air voids compared to control



Moisture resistance*

*AASHTO T283 IDT Tensile Strength Ratio test, after one freeze thaw cycle.

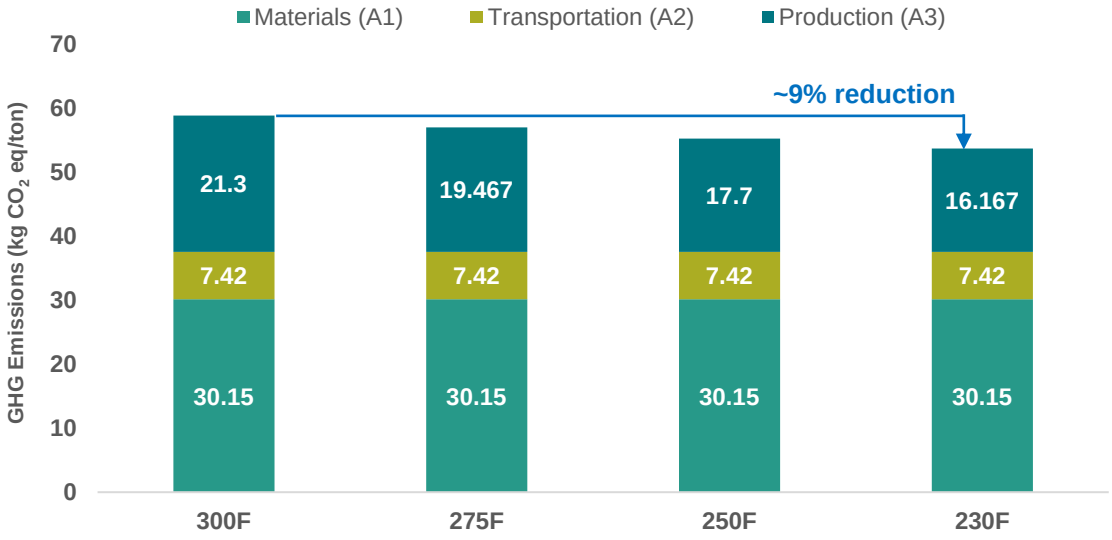
Rutting resistance**



**AASHTO T324-14 Hamburg wheel tracking.

Impact of WMA on Emissions

Use of Warm Mix Asphalt and Plant Operation GHG Emissions

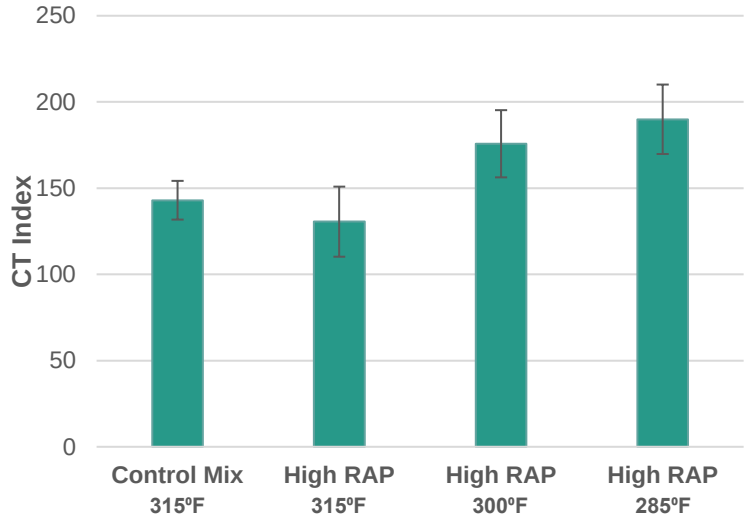


	300F	275F	250F	230F
Total (A1-A3)	58.87	57.04	55.27	53.74

Lowering asphalt plant production temperature lowers the plant operations environmental impact

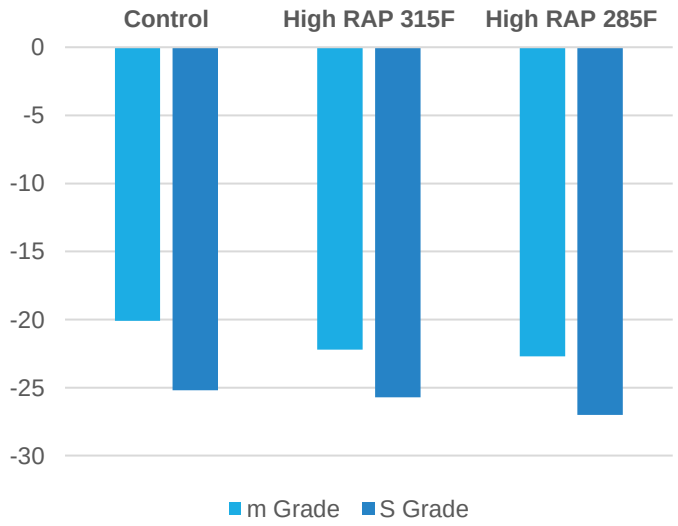
Lowers overall GHG emissions!

INDOT Climate Challenge



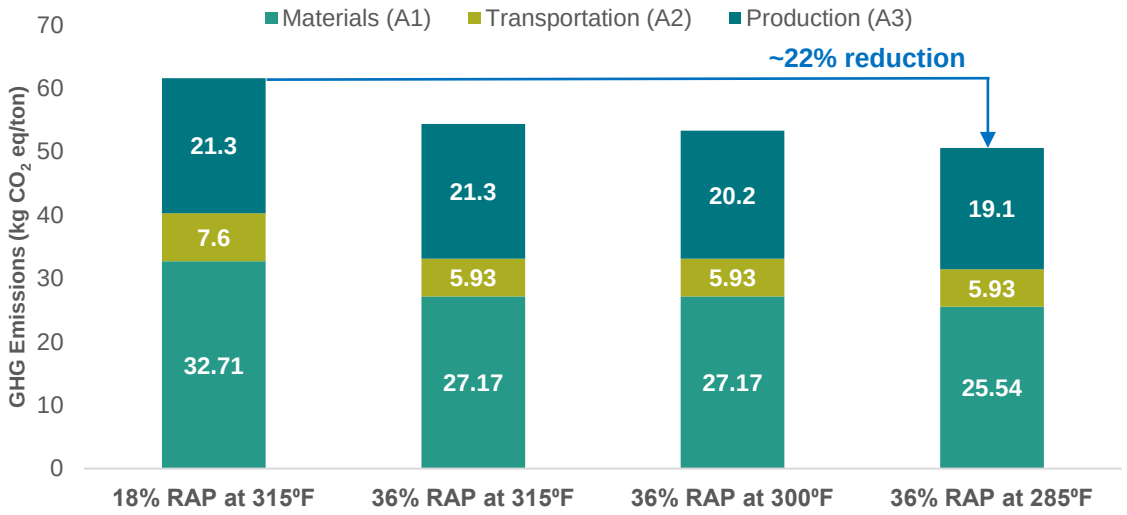
RAP %	18%	36%	36%	36%
AC Content	6.4	6.4	6.4	6.2
Air Void	7.3%	7.1%	6.6%	7.2%
Density	94.9%	98.4%	96.4%	96.7%

High Grade	71.3	71.6	70
Int. Grade	22.8	21.6	20.5
ΔTc	-5.1	-3.5	-4.3



Impact of WMA and RAP

Use of High RAP with Warm Mix Asphalt and Plant Operation GHG Emissions



Total (A1-A3)	**61.61**	**54.40**	**53.30**	**50.57**

Increasing RAP and lowering asphalt plant production temperature lowers the plant operations environmental impact

Lowers overall GHG emissions!

3- Bio-based Recycling Agents

The use of Petroleum-based recycling agents dates to the 1970's and 1980's, often using products such as **lube oil** processing by-product.

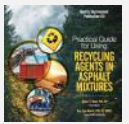
In the late 2000's, asphalt binder cost increased significantly. During this time, a wide range of **recycled oil** and **bio-based recycling agents** were developed.

The ASTM D4552-20 (commonly referenced in specifications) added the RA-0 category to specifically address and include the use of bio-based recycling agents for asphalt recycling.

Most Bio-oils Most Petro. oils

Test	ASTM Test Method	RA 0		RA 1		RA 5		RA 25		RA 75		RA 250		RA 500	
		Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Viscosity • 60 °C [140 °F], mm^2/s	D2170	10	49	50	175	176	900	901	4500	4501	12500	12501	37500	37501	60000
Flash Point, COC, °C [°F]	D92	219 [425]	...	219 [425]	...	219 [425]	...	219 [425]	...	219 [425]	...	219 [425]	...	219 [425]	...
Saturates, wt. %[A]	D2007	...	30	...	30	...	30	...	30	...	30	...	30	...	30
Tests on Residue from RTFO 163 °C [325 °F]	D2872														
Viscosity Ratio[6]	"	...	3	...	3	...	3	...	3	...	3	...	3	...	3
Wt Change, ±, %	"	...	4	...	4	...	4	...	3	...	3	...	3	...	3
Specific Gravity at 25 °C [77 °F]	D70 or D1298	0.900	1.100	0.900	1.100	0.900	1.100	0.900	1.100	0.900	1.100	0.900	1.100	0.900	1.100

NAPA QIP 131:
Practical Guide for Using Recycling Agents in Asphalt Mixtures



Rejuvenators: An Engineered Solution

“Rejuvenation” is an inaccurate, but popular term.

Rejuvenators do not undo oxidative aging!

A good rejuvenator reverses the impact of aging on asphalt, reactivating the asphalt, to restore performance, and durability.

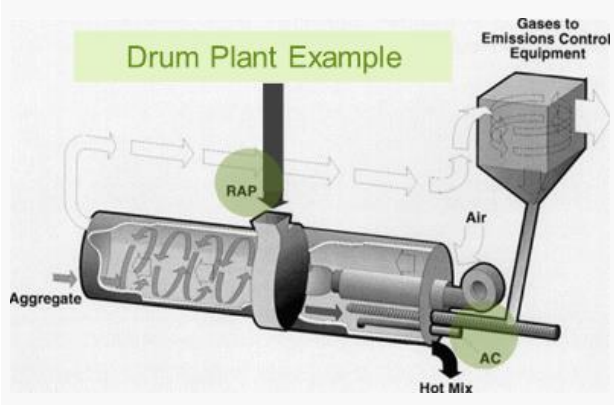
What does it mean to reverse the impact of aging and “Rejuvenate”?

- Restores cracking resistance, maintains rutting performance
- Improves workability, compaction, and appearance
- Improves aging susceptibility of the pavement
- Provides predictable and reliable results

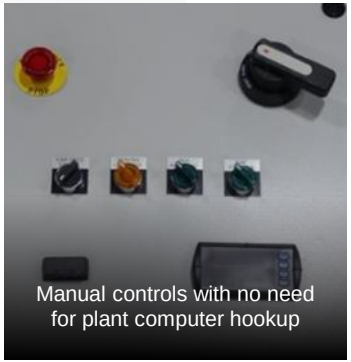
Plant Implementation

Typically, 1-3% wt. of the binder or 0.05-0.15% wt. of the mix, added via:

1. **In-line into virgin binder using additive pump**
2. Treatment of RAP (at collar or during processing)
3. Injection into pugmill or mixing drum
4. Pre-blended into virgin binder (least common)




Portable easy-to-install trial pump skids available from OEMs


Manual controls with no need for plant computer hookup


Pump can be simply hooked up to tote and piped into AC line

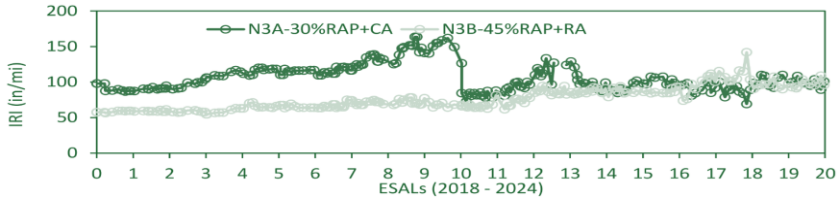
High RAP Evaluation

NCAT Field Performance

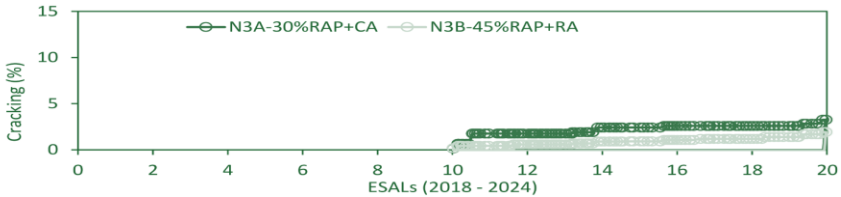
To demonstrate performance Cargill built a test section on the NCAT track using the typical 30% RAP mix with Bio-based WMA, and 45% RAP with Bio-based rejuvenator.

After 20 million loadings, <4% cracks appeared in the test section.

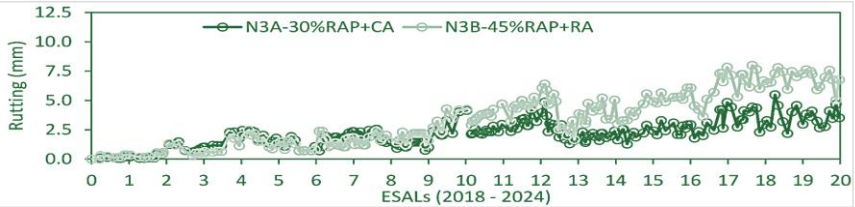
Maintaining Smooth Ride



Cracking



Rutting



* Data provided and measured by NCAT using plant produced mix.

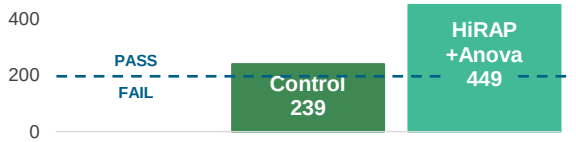
MnROAD High RAP Mix Lab Performance

To demonstrate performance against the typical 25% RAP mix, Cargill built a test section on MnRoad, using 45% RAP and Anova® rejuvenator.

The test section maintained great cracking performance through 4.8 MM ESALs and 6 winters.

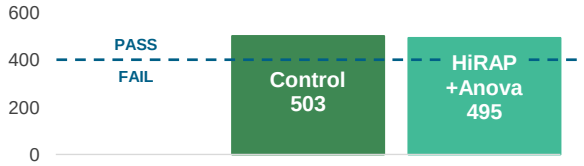
Increased reflective cracking resistance

Cycles to failure, overlay tester*



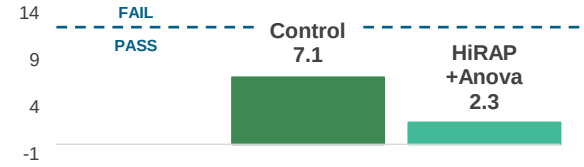
Improved thermal cracking resistance

Fracture energy (J/m2), DCT*



Maintaining rutting resistance

Rutting depth (mm), Hamburg wheel*

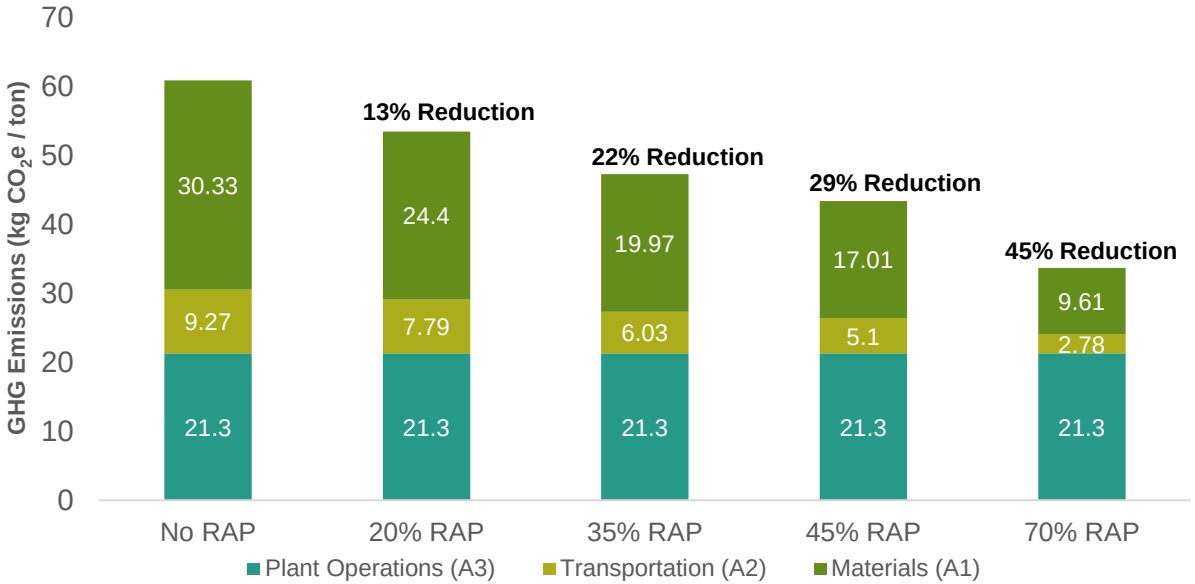


Target specification

* Data provided and measured by MnDOT using plant produced mix.

Use of Recycled Asphalt Pavement (RAP)

Use of RAP and Overall GHG Emissions



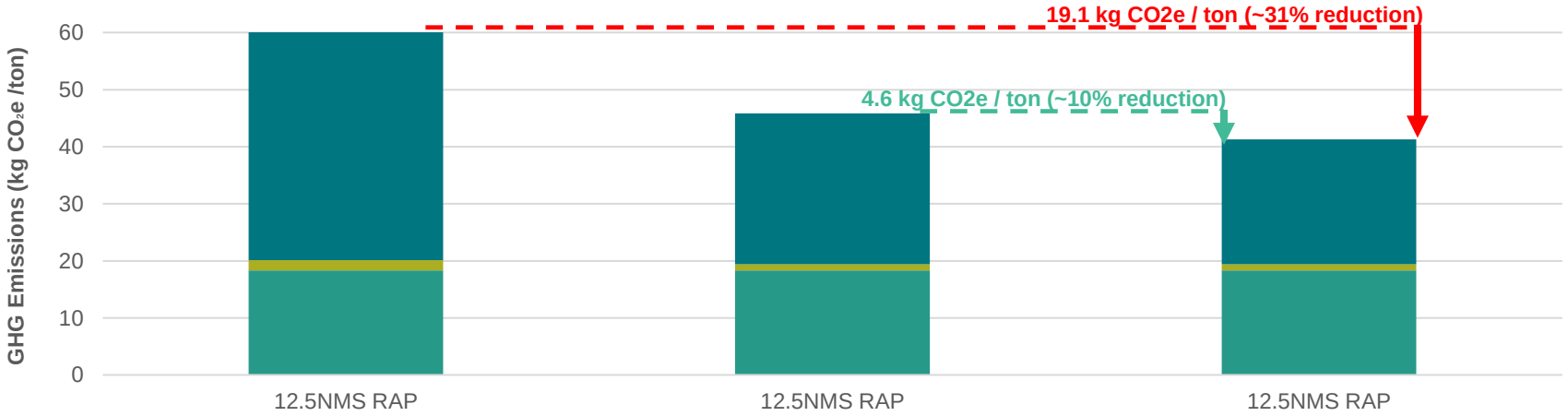
Total (A1-A3)	60.9	53.5	47.3	43.4	**33.7**

*Data From NAPA's Emerald Eco-Label Tool

Increasing RAP lowers total environmental impact of asphalt mix!

Getting Ahead of the curve on Decarbonization

- The combination of high RAP and bio-binder incorporation was estimated to provide a **31% reduction** in $kgCO_{2eq}$ emissions.



Plant Ops (A3)	18.31
Transportation (A2)	1.85
Materials (A1)	40.17
Total (A1-A3)	60.33

0% RAP

Plant Ops (A3)	18.31
Transportation (A2)	1.11
Materials (A1)	26.42
Total (A1-A3)	45.84

40% RAP

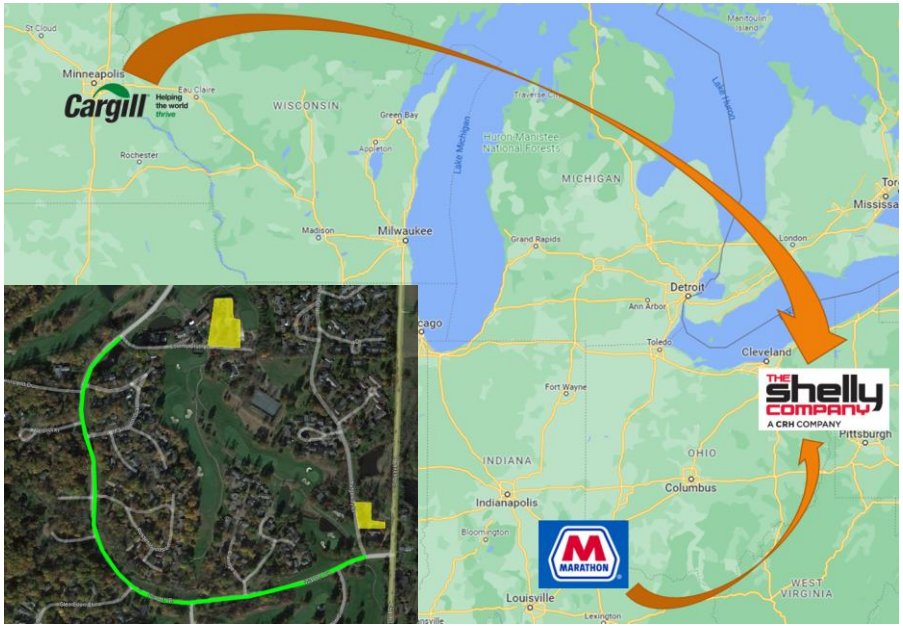
Plant Ops (A3)	18.31
Transportation (A2)	1.12
Materials (A1)	21.84
Total (A1-A3)	41.27

40% RAP Bio

Bio-Binder Evaluation

Cargill Bio Binder Evaluation Trial

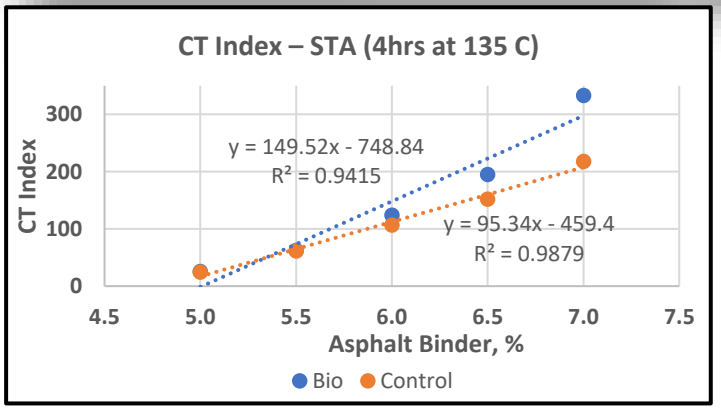
- **Company:** The Shelly Company
- **Location:** Shelly NE Plant (Cleveland), plant that has used rejuvenator in the past.
- **Mix:** T1 Surface Mix
- **Virgin Binder:** Hard pen (6-8) from Marathon North Bend (Ohio, near Cincinnati) selected.
- ~1,000 tons (US) were produced/placed in June 2023, ~0.7 miles (two lanes)
- Placed on Walden Drive
  Aurora, Ohio.
- Perrin Asphalt placed the mix. Shelly produced at the Bedford Heights, Ohio plant

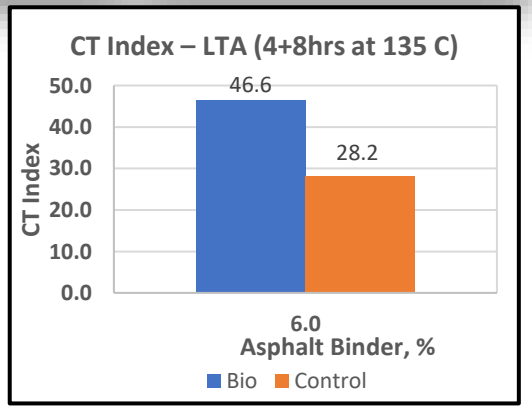


Design Selection

- Mix formulations using blend charts to estimate final extracted grade.
- The following blend was selected as good potential trial target: T1 mix using **40%RAP**
- The Bio-binder design met and exceeded the control across binder contents.
- Testing was performed at the volumetric optimum binder content (6%).
- The Bio-binder design actually exceeded the control mix in terms of long term aging durability.

Mix Description	Mixture Percentages		Bio Bitumen	Total Bitumen Estimated Grade	
	Total AC%	7/21 RAP		High Temp PG (C)	Low Temp PG (C)
T2 30%RAP Control	5	30	3.4%	**72.3**	**-21.1**
T2 30%RAP X1%Bio	5	30	3.4%	**76.6**	**-21.2**
T2 50%RAP X2%Bio	5	50	2.4%	**76.6**	**-22.6**
T2 50%RAP X3%Bio	5	50	2.4%	**70.0**	**-28.0**
T1 30%RAP Control	6	30	4.4%	**71.1**	**-21.4**
T1 30%RAP X1%Bio	6	30	4.4%	**75.8**	**-21.5**
T1 40%RAP X2%Bio	6	40	3.9%	**72.7**	**-24.7**
T1 40%RAP X3%Bio	6	40	3.9%	**63.8**	**-32.0**

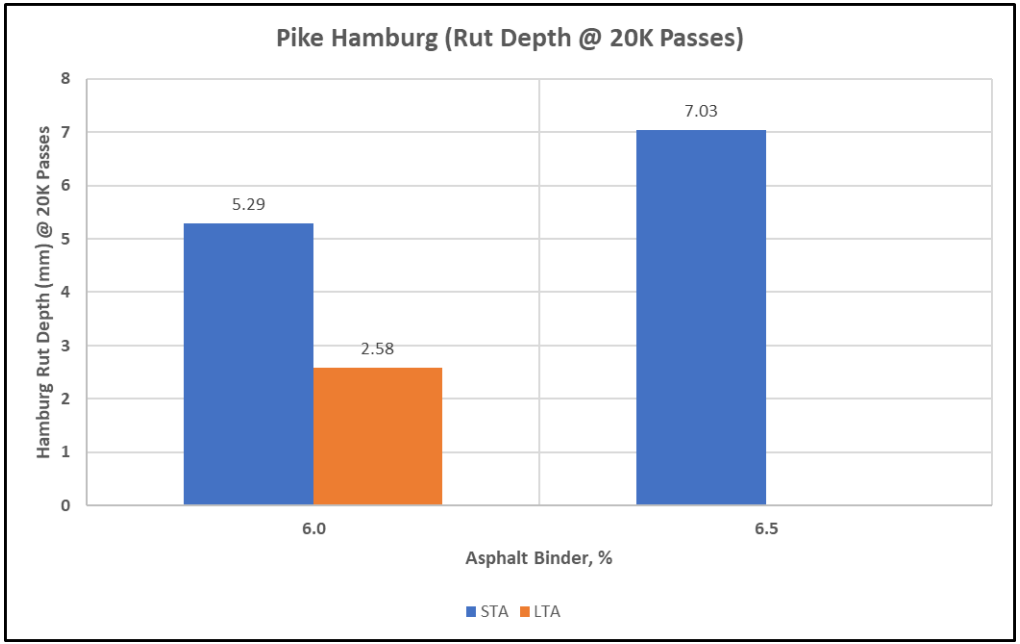




Hamburg Wheel Tracking (HWT)

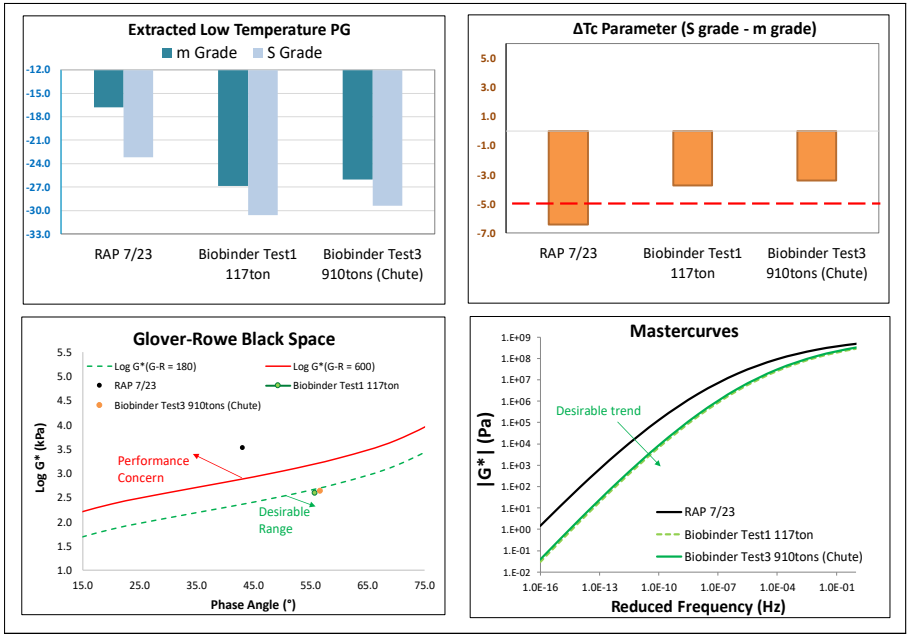
- Rutting susceptibility was tested at both STOA and LTOA levels up to 20K cycles.
- Results showed no rutting susceptibility issues.

HAMBURG WHEEL-TRACKING TEST



Post Trial Evaluation: **Binder Performance**

- The extracted binder grade from the mixes consistent met a **~PG 67-26** grade.
- Rheological binder parameters such as **ΔTc** and the **Glover-Rowe** parameter were in the commonly considered “desirable ranges”.
- Based on extracted binder results desirable performance is expected on mixture testing, to the extent of binder component contribution to mix performance.



Key Findings

- Low-carbon asphalt mix designs can be produced using a combination of tools available:
  - Increasing the RAP content
  - Replacing fossil-based bitumen with bio-based material
  - Reducing production temperatures

- Dropping temperature by **70ºF** can reduce **GHG_{eq} by ~9%** and increasing recycling by **25%** can reduce **GHG_{eq} by ~15%** while improving compaction and cracking resistance.

- The bio-binder + high RAP in this study was calculated to have a **31% lower GHG_{eq}** impact as a combination of both RAP and bio-material inclusion compared to a virgin mix.

- The bio-binder + high RAP mix exceeded the control mix in terms of IDEAL-CT cracking performance, both at **short-term** and **long-term aging**, showing high CT-Index values.

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