State of Implementation of **Rejuvenators** in Asphalt Pavements

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Cargill® Helping the world thrive

Asphalt Chemistries

Helping the world thrive

155,000 employees

155 years of experience

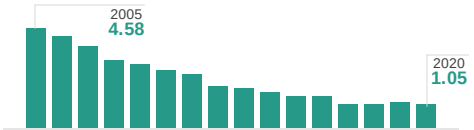
Working in **70** countries

$114,6 billion in annual revenue

Our commitments

Safe

We relentlessly work to improve the safety of our people. Reduction in injuries per 200,000 hours worked over 15 years.



Responsible

We strive to strengthen the communities where we live and work.

$115 million
Total charitable contributions last year across 56 countries

Attendance at our farmer trainings for sustainable agricultural practices totaled 860,000 last year

Sustainable

- Agriculture is how we will protect the planet and our shared future.
- Climate change: Reducing supply chain emissions per ton of product 30% by 2030, and absolute operational emissions 10% by 2025
- Water resources: Achieving sustainable water management in all priority watersheds by 2030
- Land use: Eliminating deforestation in our supply chains by 2030

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Mix

State-of-the-art Asphalt Lab

Cus ses

Compositional and analytical evaluation

Advanced rheology and thermal analysis

Agenda

1. Background on use of Recycling Agents
2. Assessing of the Impact of Rejuvenation
3. State of RA Implementation through BMD

Background on **Recycling Agents**

Defi
R Engineered Solution

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

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estores cracking resistance, maintains rutting performance

Improves workability, compaction, and appearance

Improves aging susceptibility of the pavement

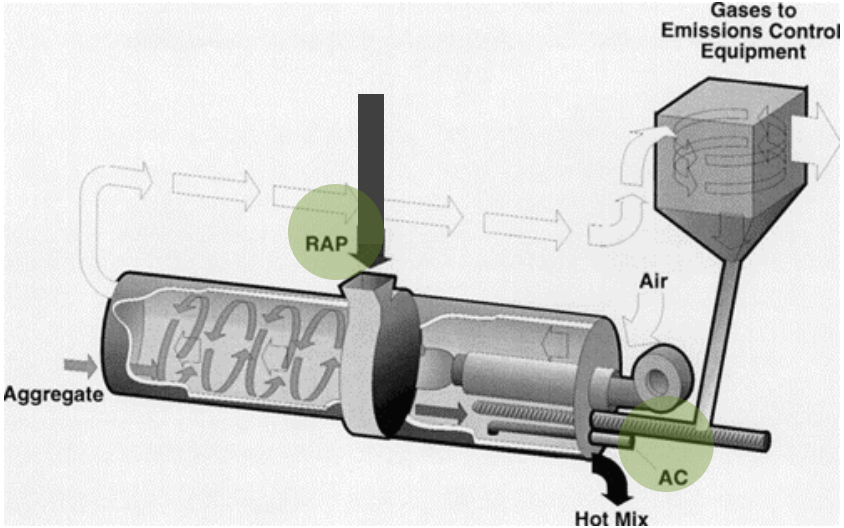
Provides predictable and reliable results

How are Rejuvenators Used?

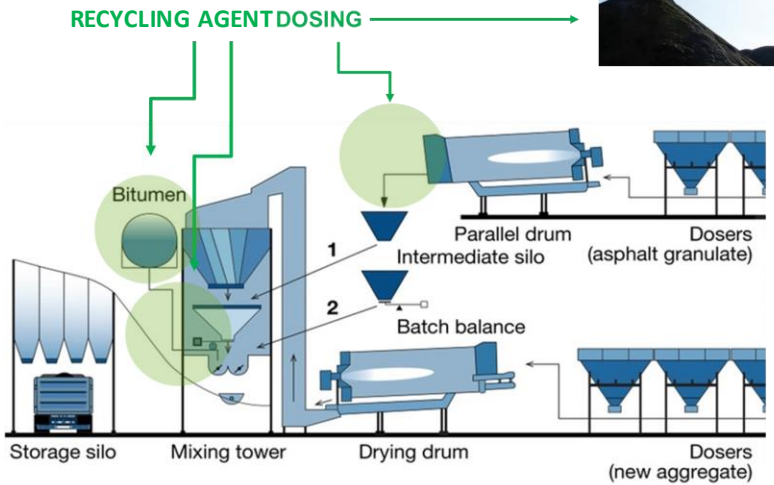
Typically, **1-3% wt. of the binder or 0.05-0.15% wt. of the mix**, added via:

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)

Drum Plant Example

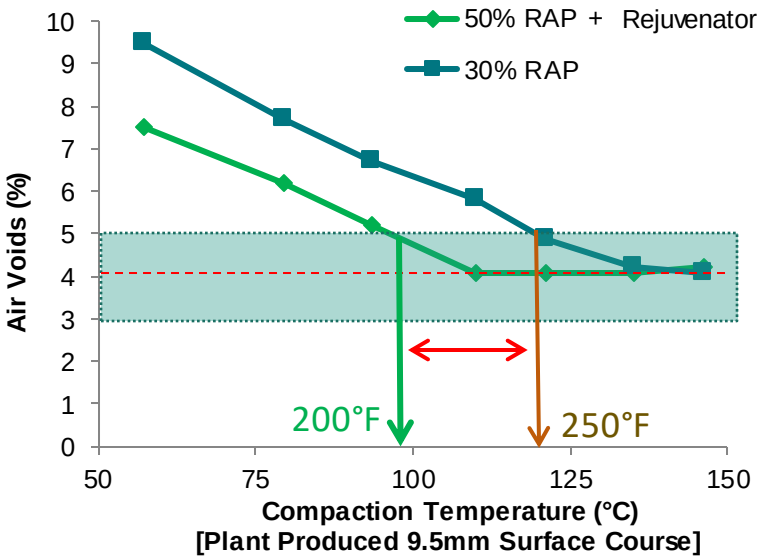


Batch Plant Example

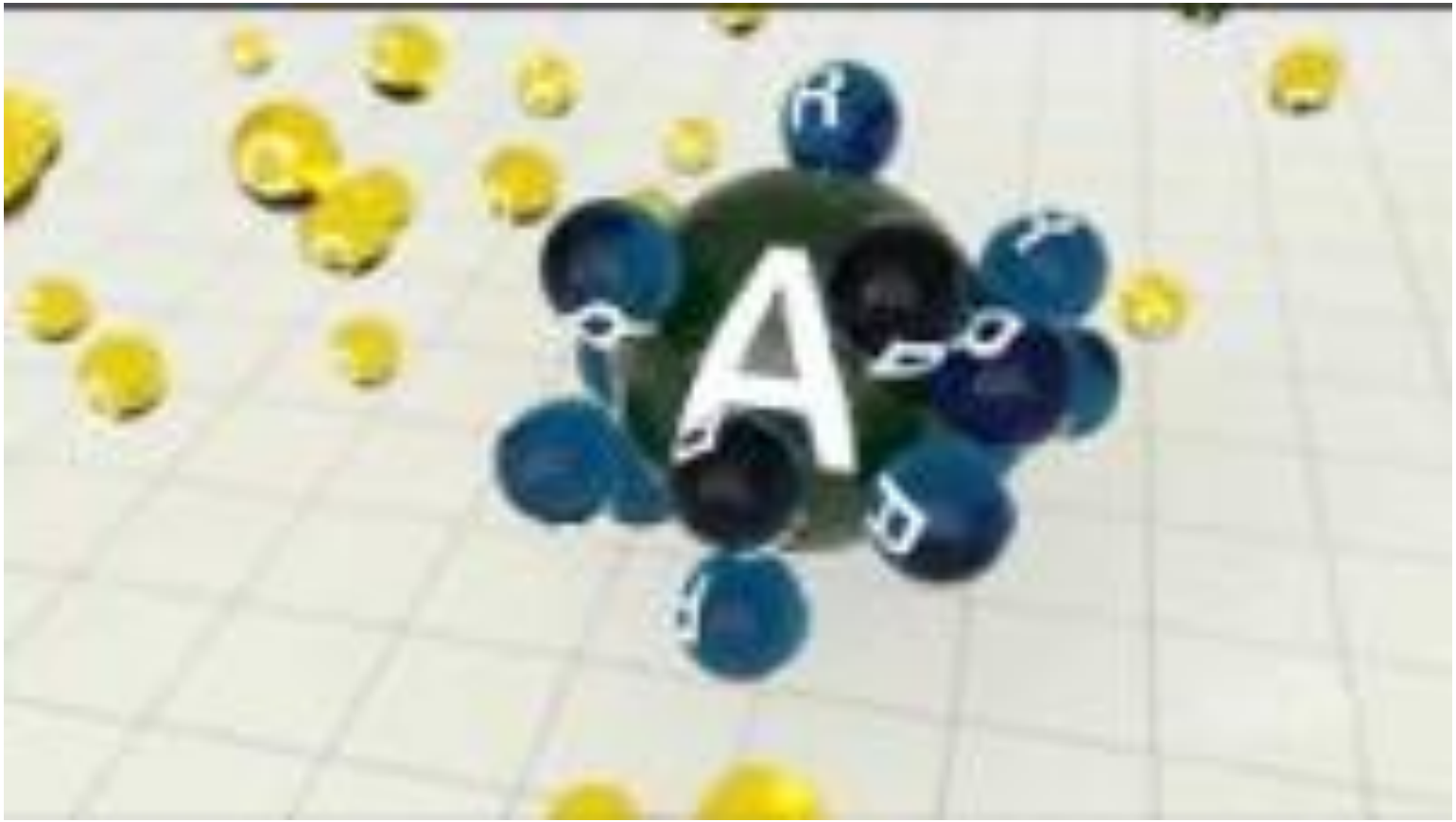


First Impressions: Improved workability

- Rejuvenation significantly improved the Compactability, even after a 20% increase in RAP content.
  - A large improvement in compaction temperatures achieved
  - No over-compaction at hot mix temperatures.



Defining Rejuvenation vs. Softening



– Link to video: https://youtu.be/uwfYjy4PHDU

Assessment of **Impact of Rejuvenation**

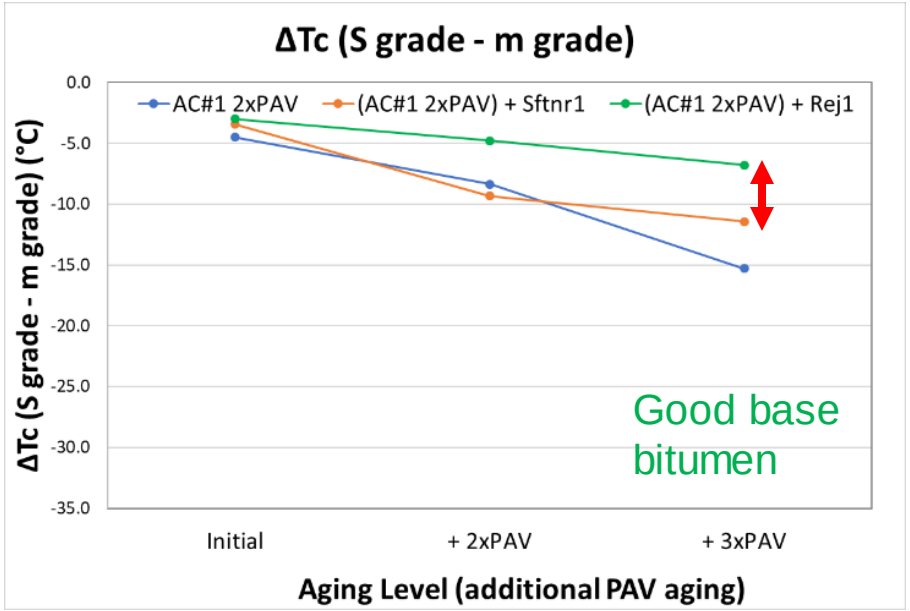
How to Assess Effectiveness of Rejuvenation Impact?

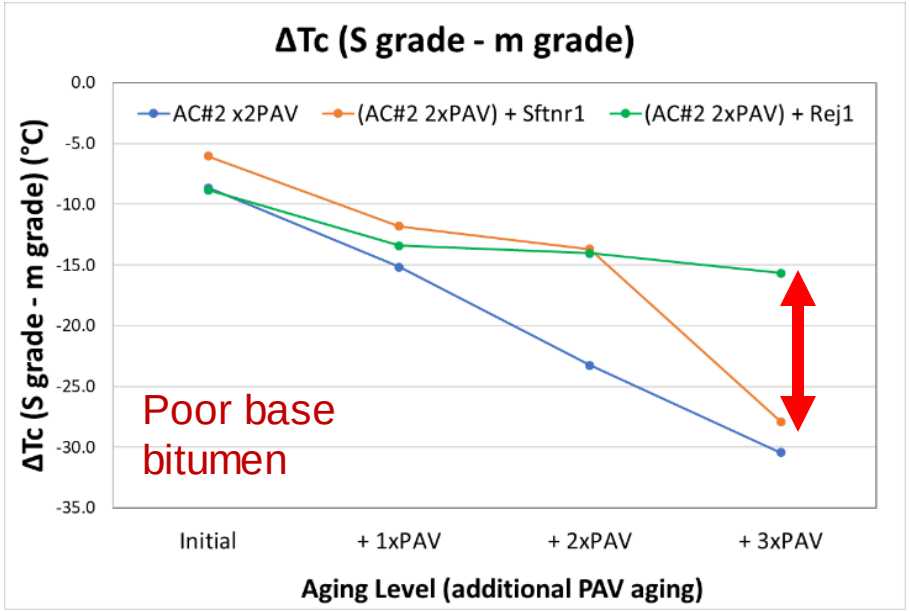
- The difference between “Rejuvenation” and “Softening” is in the ability to “compatibilize” asphaltene-association structures in asphalt.

- Directly measuring asphalt compatibility is not easy. However:
  - We know that **long term-aging** decreases the compatibility of asphalt
  - We can **measure the change** in properties as a result of aging.

- Examples of property changes compared after long term aging:
  - Measuring the change in Analytical indices (e.g. “Colloidal Instability Index”, AFM structures)
  - Measuring change in Miscibility thermal analysis (i.e. Tg properties)
  - Measuring the change in BBR m-grade or ΔTc

Measuring Change in Rheological Properties

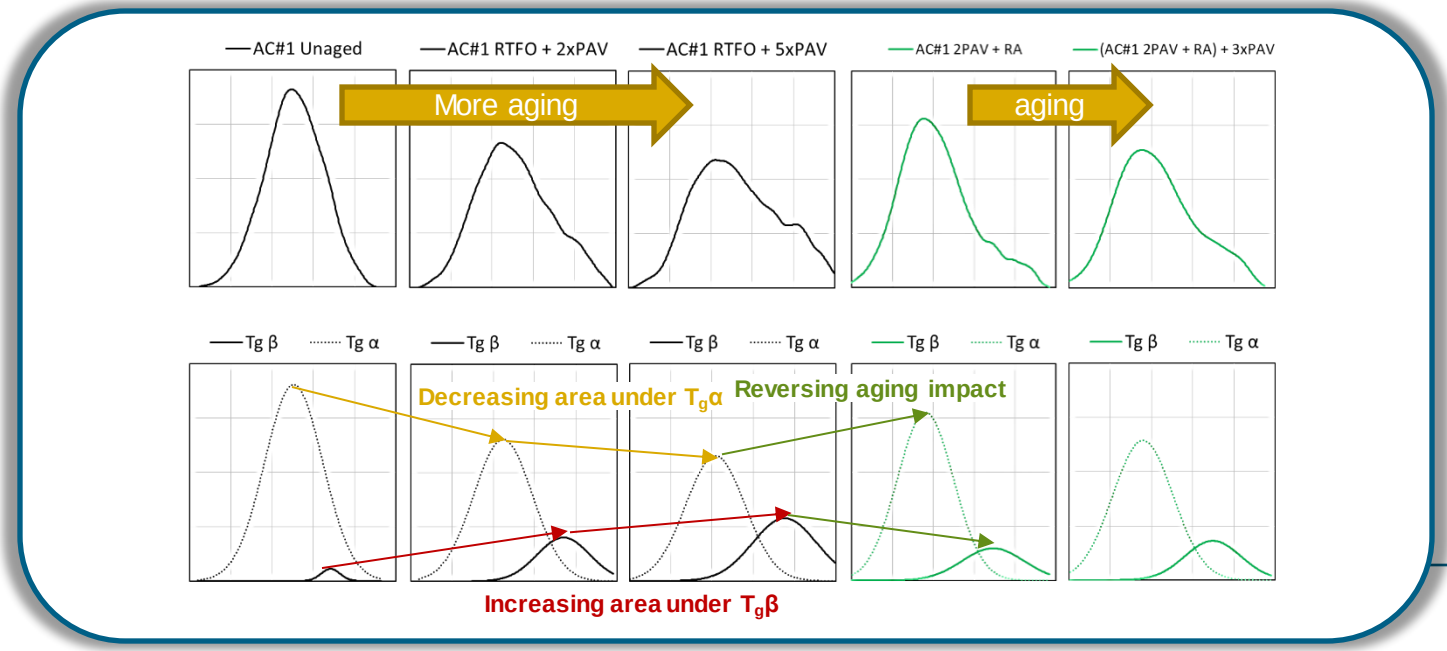


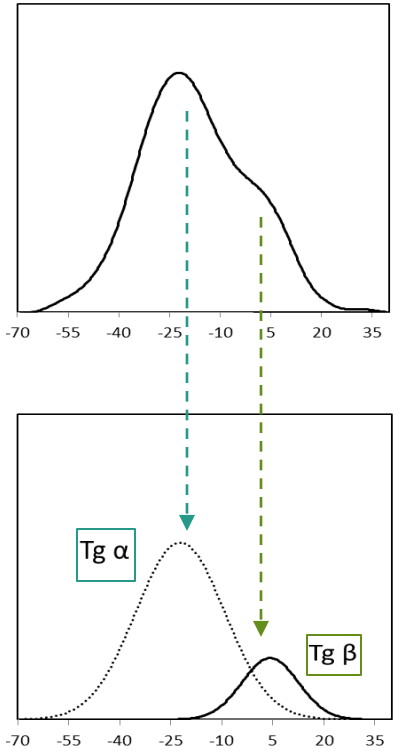


- Rejuvenating power of additives compared through ability to maintain ΔTc with aging.
- Relative value of ΔTc at a single aging level can be misleading (example: PMAs)
  - The change in ΔTc with aging is the differentiator, not the value at a given condition.

Measuring Change in T_g and Miscibility/Compatibility

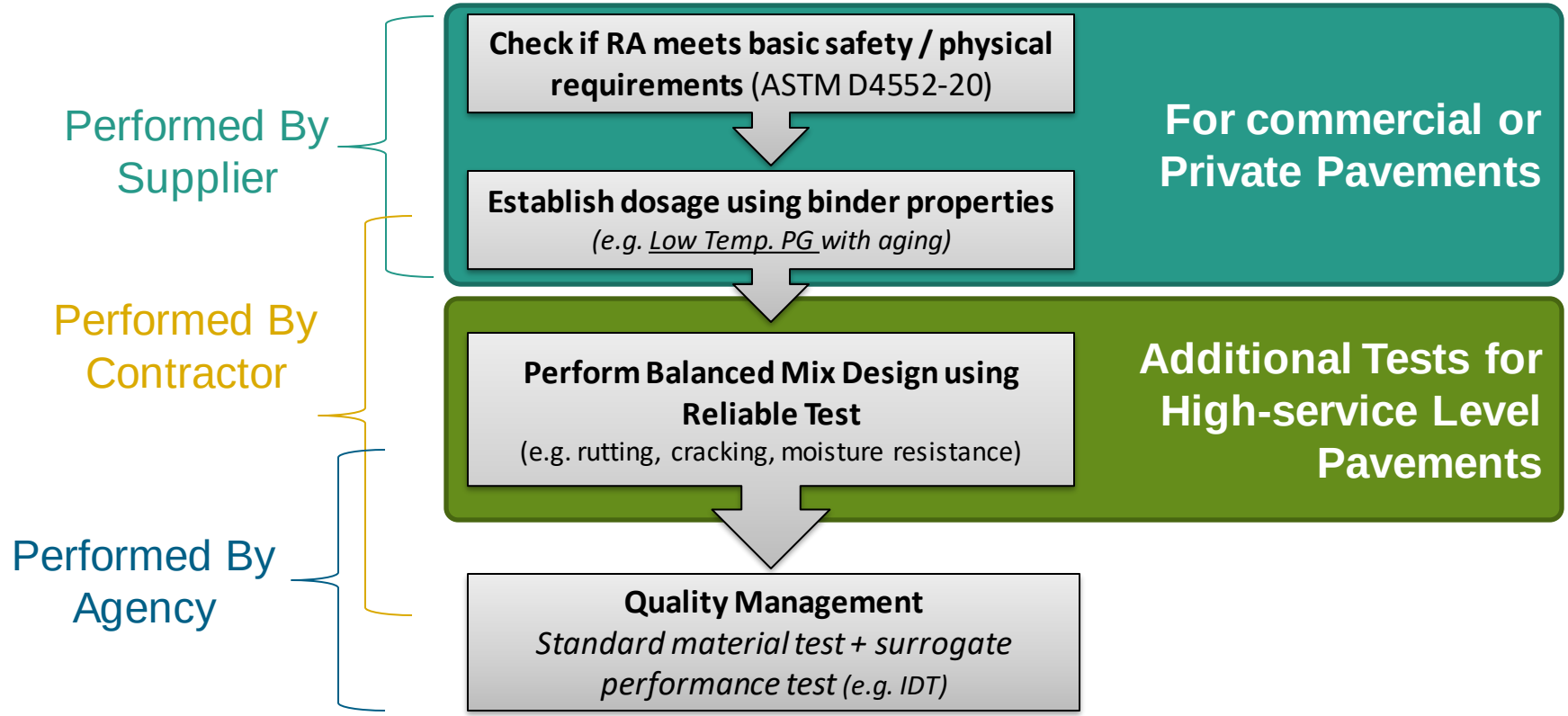
- **Miscible blends show a single combined T_g**. The more clearly defined T_gs, the less miscible.
- **Bitumen aging** increases intensity of secondary T_gs (e.g. $T_g\beta$)
  - Increased area fraction of $T_g\beta$ (and decreases % area of $T_g\alpha$)
  - Broadens overall transition width a multiple Tgs become more resolved
- **Proper rejuvenation reverses these trends.**





State of Implementation of **Recycling Agents using BMD**

Implementation: High RAP-Rejuvenated Design



Step 1: Recycling Agent Categorization - ASTM D4552-20

Assesses basic safety, thermal stability, storage stability, and compatibility property for use in asphalt plants.

Most Bio-oils Most Petro. oils

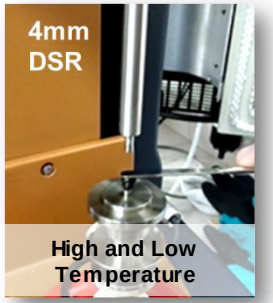
Test	ASTM Test Method	RA 1		RA 5		RA 25		RA 75		RA 250		RA 500	
		Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Viscosity • 60 °C [140 °F], mm²/s	D2170	50	175	176	900	901	4500	4501	12500	12501	37500	37501	60000
Flash Point, COC, °C [°F]	D92	219 [425]	...	219 [425]	...	219 [425]	...	219 [425]	...	219 [425]	...	219 [425]	...
Saturates, wt %	D2007	...	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
Wt Change, ±, %	"	...	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

$$ViscosityRatio = \frac{Viscosity\ of\ Residue\ from\ RTFO\ Test\ at\ 60°C\ [140°F]}{Original\ Viscosity\ at\ 60°C\ [140°F]}$$

Step 2: Initial RA Dosage Determination (By Supplier)

- RAP samples are extracted, graded and rheologically fingerprinted for initial dosage determination.

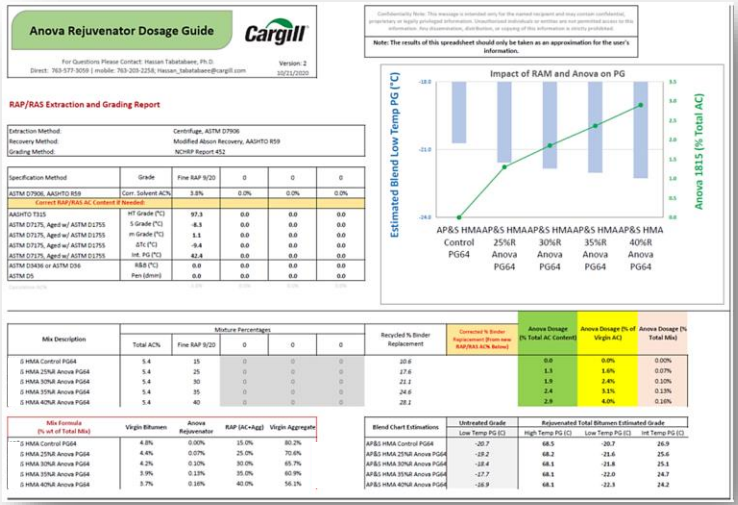
Extraction & Recovery



Low Temperature
Cracking Resistance

Grading and Analysis

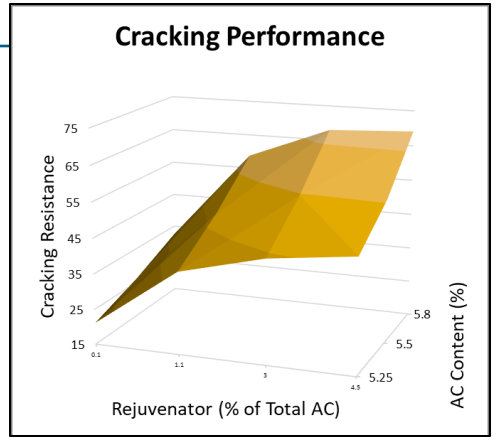
Dosage Determination Report for Target Mix Designs

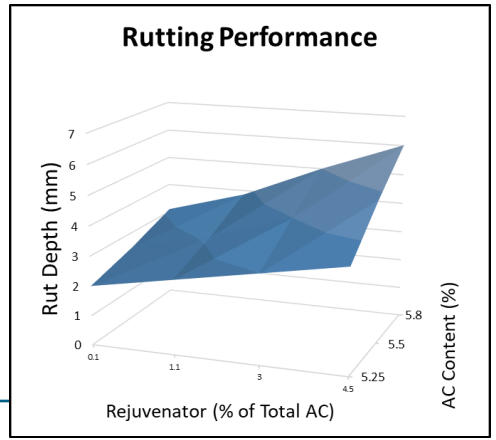


Mix Design (By Producer)

- Recycling agents have been used to modify performance attributes in a mix.

Mix Parameter	Expected RA Impact
Cracking Resistance	Improve
High Temperature Stiffness	Decrease
Moisture Resistance	Typically, None





Examples of Current or Considered BMD Systems

Agency:	New Jersey DOT	Chicago DOT	Illinois Tollway	Illinois DOT	City of Janesville	Virginia DOT	City of Columbus	ODOT (Trial)	City of Phoenix (Trial)
Cracking Test	Overlay Tester	DCT	DCT + IFIT	IFIT	DCT + IFIT	IDEAL-CT	IDEAL-CT	IDEAL-CT	IFIT
Rutting Test	APA	Hamburg	Hamburg	Hamburg	Hamburg	APA	HWT	HWT	HWT to approve RA
Binder Specification	None	Extracted pass PG XX-22, ΔTc > 5	None	None	Extracted pass PG XX-16	None	Extracted pass climate PG + 6	Extracted pass climate PG + 6	Meet virgin grade of 70-28
QC Process	Trial Strip + performanc e test	Extracted PG	Trial Strip + Performanc e test	TBD	Performanc e test	Surrogate tests, TBD	IDEAL-CT	IDEAL-CT	Basic VMD QC
State of Implementation	Active as of 2018	Active as of 2018	Active as of 2018	Active as of 2019	Active as of 2017	Trial spec as of 2019	Implement ation in 2022	Trial in 2021	Trials in 2021

Field Evaluation Projects

NCAT: Warm Climate

- 30% RAP (24% ABR); PG64-22 Binder + Anova® Warm Mix Additive
- 45% RAP (38% ABR); PG64-22 Binder + Anova® Rejuvenator
- Aggregates and RAP were shipped in from Virginia for the project

MNROAD: Cold Climate

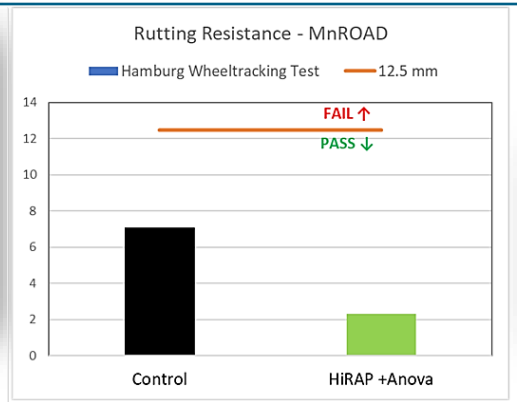
- 25% RAP (20% ABR); PG58-28 Binder
- 45% RAP (31% ABR); PG5828 Binder + Anova® Rejuvenator
- Aggregates and RAP were supplied locally in Minnesota for the project

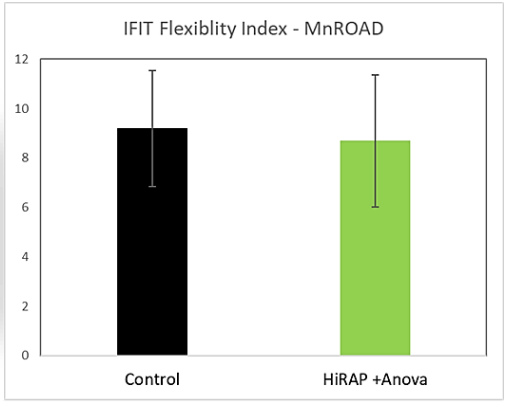
Type	Name	Description
Chemical Warm Mix	**Anova® 1501/1503**	A bio-based non-hazardous liquid warm mix additive, design for impact at low dosage without changing the bitumen grade
Recycling Agent	**Anova® 1815/1817**	An engineered bio-based oil, based chemical modification of vegetable oil for bitumen compatibility and oxidative stability

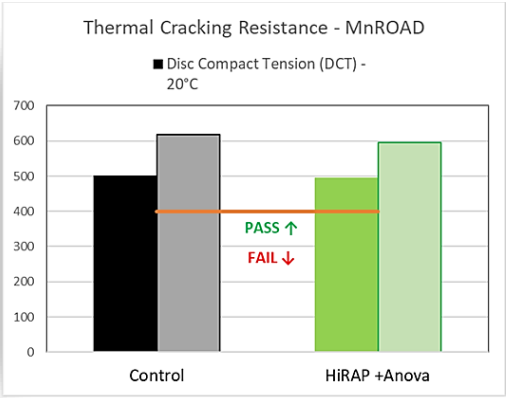
MNROAD High RAP Rejuvenated Project

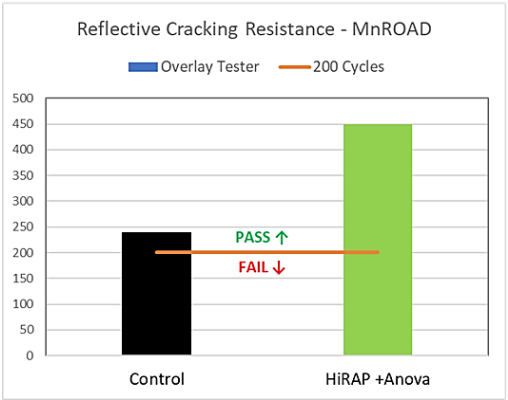
Designs were done using BMD system under consideration by MNDOT at the time (DCT vs. Hamburg)

Rejuvenation of the high RAP mix achieved comparable passing performance compared to the Low RAP control mix.









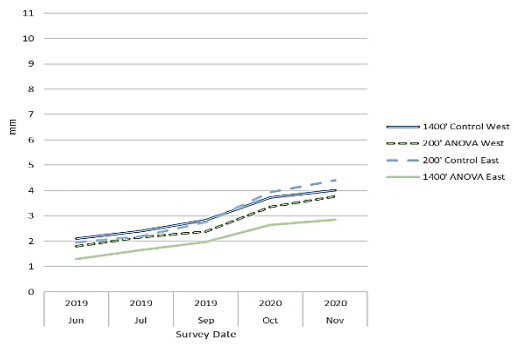
MNROAD Proven performance. With Anova® Rejuvenator.

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

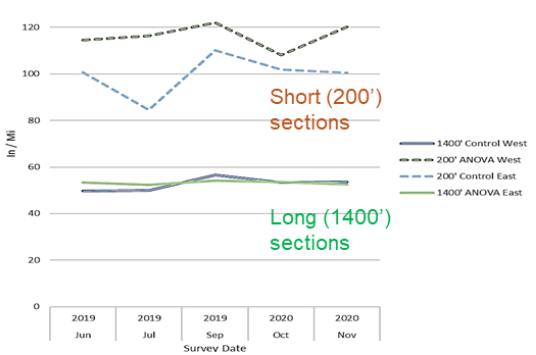
After 2.5 million loadings, fully meeting performance expectations

- About 800,000 ESALs of loading per year since 2018.
- No cracking beyond expected reflective cracking from base course observed, equivalent to control.
- Sections showing good rutting performance. Anova sections have slightly lower permanent deformation.
- Smoothness has remained consistent since construction. This especially clear on the sufficiently long sections.

No Rutting

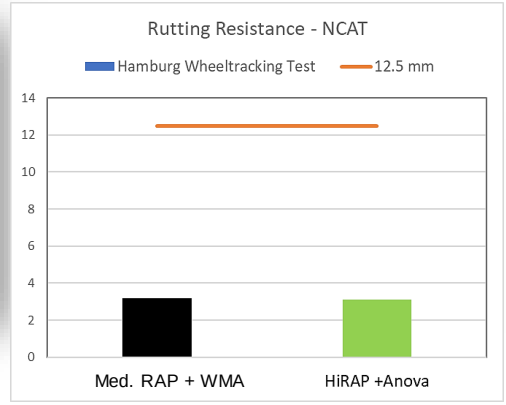


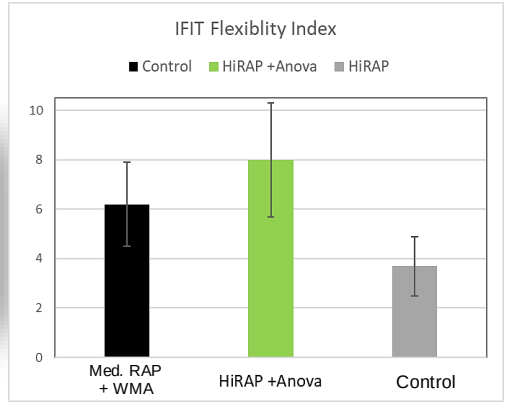
Maintaining Smooth Ride

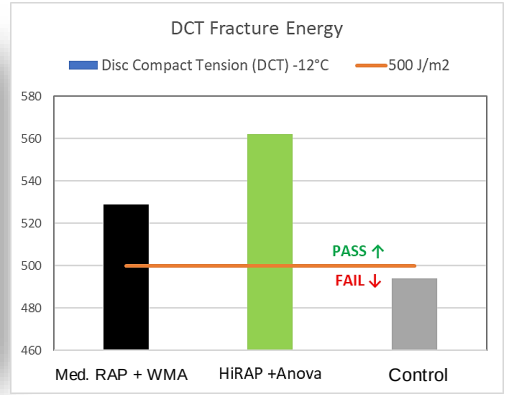


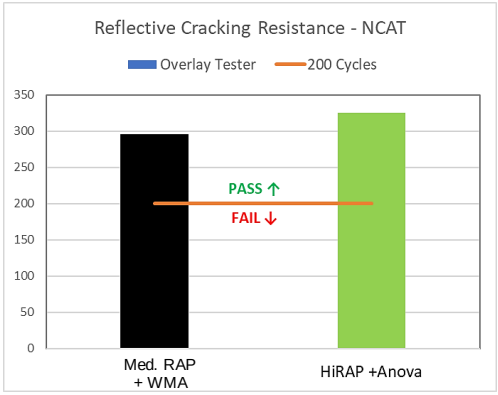
NCAT High RAP and WMA Project

- Designs were done using BMD system under consideration by VADOT at the time (IDEAL vs. APA)
- Rejuvenation of the high RAP mix achieved comparable passing performance compared to the WMA mix.
- Both the RA and WMA mix outperform the high-RAP control mix.







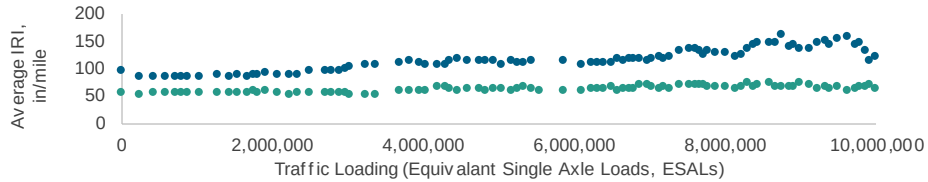


NCAT Proven performance. With Anova® Rejuvenator and WMA

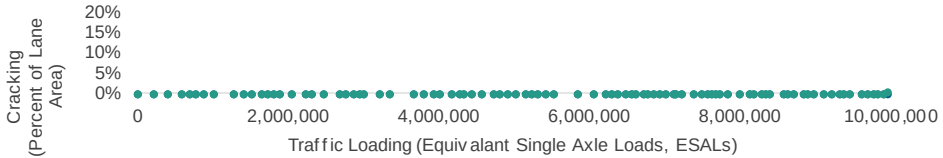
To demonstrate performance Cargill built a test section on the NCAT track using the typical 30% RAP mix with Anova® WMA, and 45% RAP with the Anova® Rejuvenator.

After 10 million loadings, zero cracks appeared in the test section

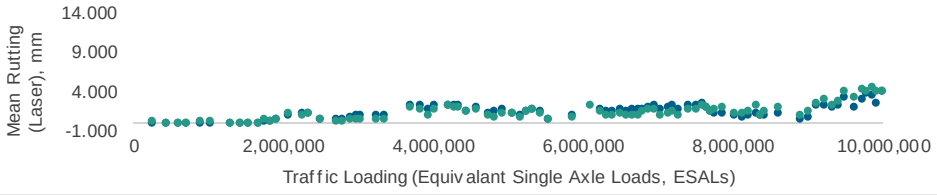
Maintaining Smooth Ride

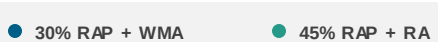


0 Cracking



No Rutting





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

Conclusions and Summary

- Implementation of high RAP + Rejuvenator by BMD is highly practical today, with millions of tons produced every year.
  - MNROAD and NCAT monitored sections are great examples of practical utility of such products.
- We can assess rejuvenation through its impact on the compatibility of asphalt as it ages.
  - For example: Measuring the change in BBR m-grade or ΔTc
- Process requires a framework that provides **transparency and reliability for all stakeholders**:
  - Step 1: Recycling Agent Property Certification (e.g. through ASTM D4552-20) - by supplier
  - Step 2: Initial dosage determination based on rheology, led by supplier
  - Step 3: Balanced Mix Design (BMD) process, led by producers
  - Step 4: Robust quality management practices by all parties
- More clarity on this topic expected from the results of in-progress NRRA project:

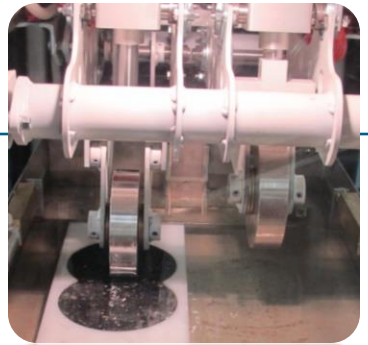
National Road Research Alliance

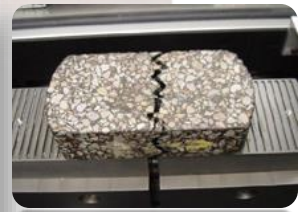
Project in Progress: AN INNOVATIVE PRACTICAL APPROACH TO ASSESSING BITUMEN COMPATIBILITY AS A MEANS OF MATERIAL SPECIFICATION

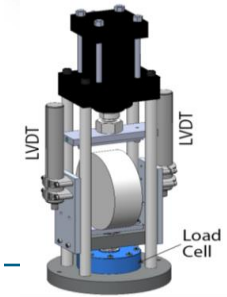
- *PI: University of New Hampshire, Co-PI: Cargill*

Examples of High RAP Design Specifications

Characteristic	Test
Rutting Stability and Moisture Damage Resistance	Hamburg Wheel Tracking Test Passes to failure
	Stripping Inflection Point (SIP)







RAP/RAS QC Report - All Wisconsin- '18-'20

well-established process for Commercial Mixes

- Support producer with periodic material sampling and verification throughout season.

Producer:

- Maintain appropriate frequency of RAP analysis (binder content and gradation control.)
- Maintain RAM processing protocols and consistency
- Mix performance verification as needed.

Owner/Agency (in development across country):

- Per agency specification
- Frequent Quality verification of mix composition/volumetrics
- Full mix design performance verification on first plant production of a specific design
- Periodic simple/surrogate mix performance verification

Recovery Method:	Modified Abson Recovery, ASTM D1856	Low Temp PG	ASTM D7175, Aged w/ ASTM D6521
Grading Method:	NCHRP Report 452, ASTM D7643	Inter. Temp PG	ASTM D7175, Aged w/ ASTM D6521

Results expressed in this report are provided for the customer's information only. The results are not certified.

RAP

			High Temp PG	Low Temp PG				
Sample Date	Plant	Binder Content*		S Grade	m Grade	ΔTc	Int. PG	
Nov-19	RAP 1	4.81%	82.3	-23.8	-18.3	-5.5	27.9	-18.3
Nov-19	RAP 2	4.54%	79.8	-23.8	-16.9	-7.0	28.6	-16.9
Nov-19	RAP 3	3.91%	83.0	-22.3	-23.1	0.9	26.4	-22.3
Nov-19	RAP 4	4.55%	82.3	-21.9	-17.6	-4.3	27.4	-17.6
Feb-20	RAP 5	4.16%	81.8	-25.9	-17.9	-8.0	25.9	-17.9
Jul-18	RAP 6	4.86%	81.7	-22.7	-17.2	-5.5	26.6	-17.2

** Binder content from solvent extraction. No correction factor applied.*

	Average	4.47%	81.8	-23.4	-18.5	-4.9	27.1	-18.3
	Max	4.86%	83.0	-21.9	-16.9	0.9	28.6	-16.9
	Min	3.91%	79.8	-25.9	-23.1	-8.0	25.9	-22.3
3/11/2020	Design RAP	From QC Report	81.8	-23.4	-16.9	-6.5	27.1	-16.9

RAS

			High Temp PG	Low Temp PG				
Sample Date	Plant	Binder Content*		S Grade	m Grade	ΔTc	Int. PG	
Nov-19	RAS 1	21.24%	144.5	-30.0	12.9	-42.9	35.4	12.9
Nov-19	RAS 2	25.79%	150.2	-23.3	10.1	-33.4	35.5	10.1
Nov-19	RAS 3	24.73%	148.1	-29.4	17.2	-46.6	36.6	17.2
Nov-19	RAS 4	22.42%	144.1	-29.7	13.2	-42.9	38.8	13.2
Feb-20	RAS 5	26.41%	131.4	-31.3	12.7	-44.0	32.2	12.7
Jul-18	RAS 6	26.93%	133.5	-27.1	14.5	-41.7	35.3	14.5

** Binder content from solvent extraction. No correction factor applied.*

	Average	24.59%	142.0	-28.5	13.4	-41.9	35.6	13.4
	Max	26.93%	150.2	-23.3	17.2	-33.4	38.8	17.2
	Min	21.24%	131.4	-31.3	10.1	-46.6	32.2	10.1
3/11/2020	Design RAS	24.88%	146.7	-23.3	17.2	-40.5	36.6	17.2