A Modern Look at **RAP Binder Availability** and Proven Improvement Methods

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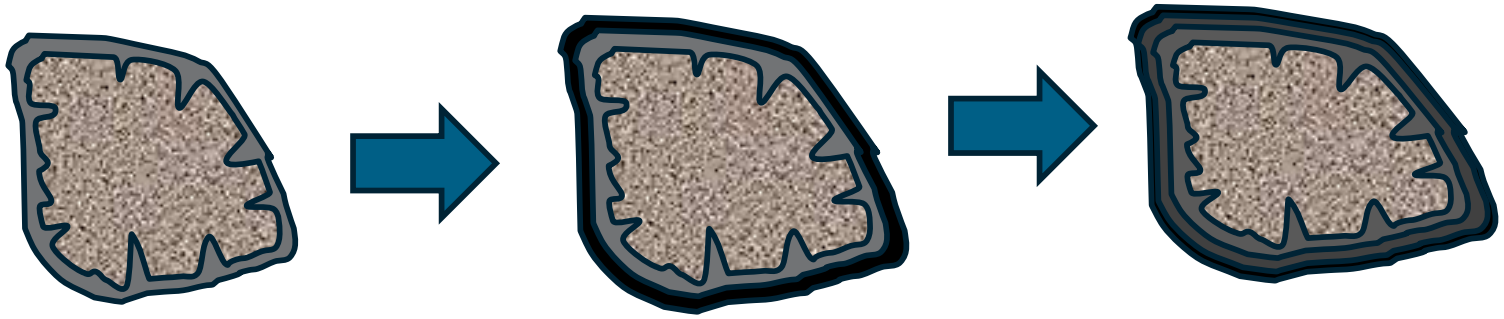
Agenda

- Introduction to RAP Binder Availability
- State of the Art and Research on Binder Availability Factors
- Important Consideration Dealing with Binder Availability
- Conclusions and Recommendations

Introduction

RAP Binder Quality and Blending

- RAP binder can be highly aged with varying quality.
- Quality of RAP binder is affected by type of virgin binder originally used, age, climate, and pavement type.
  - RAP quality in a given region can vary significantly by location and over time.



RAP Particle with Oxidized binder

RAP Particle with Oxidized binder coated with virgin binder

RAP and Virgin Binder intermingle to some degree, based on various factors

Image modified and adapted from: JP Fort, "Optimizing The Use Of RAP: Challenges And Effective Strategies", WoA/NAPA Presentation

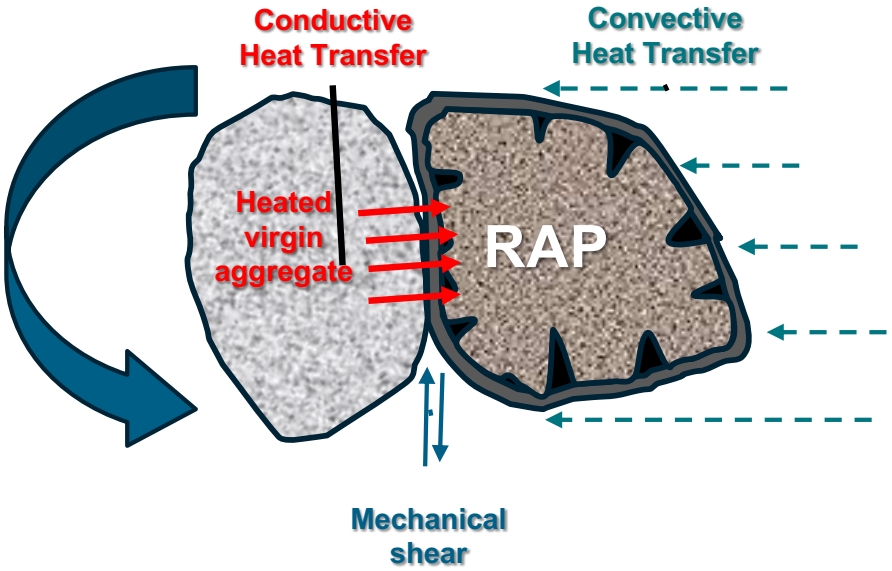
RAP Binder Availability - HEAT TRANSFER

JP Fort (NAPA), 2024

Adapted from: JP Fort, "Optimizing The Use Of RAP: Challenges And Effective Strategies", WoA/NAPA Presentation

PRODUCTION FACTORS:

- **Temperature:**
  - Virgin Aggregates T° (conduction)
  - Hot Air flow T° & Draft (convection)
- **Residence Time**
- **Plant configuration:**
  - Length of the mixing zone
  - RAP introduction location
- **Production rate**
  - Mix Storage time
  - Silo time
  - Hauling time

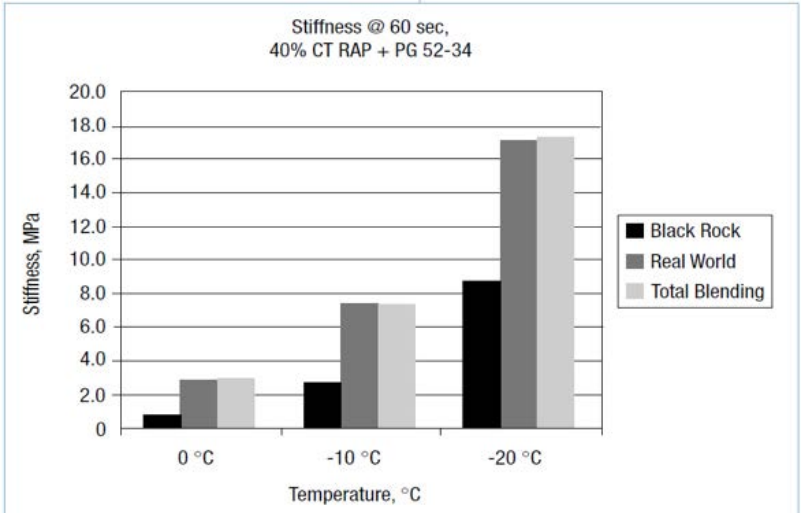


Review of RAP Binder Availability

NCHRP 9-12 - Becky McDaniel, Mike Anderson, et al. 2001

- Tested RAP from FL, CT, and AZ with highly varying stiffness
- Mixes tested at 10% and 40% RAP with a PG64-22 and PG52-34.

- Compared 3 scenarios:
  - **"Real World":** Normal mix of RAP, virgin binder, and virgin aggregate
  - **"100% Blending":** Extracted RAP binder and fully blended with virgin binder, and used in mix
  - **"Black Rock":** Extracted off RAP binder and excluded it from the blend of virgin binder, RAP aggregates and virgin aggregate.

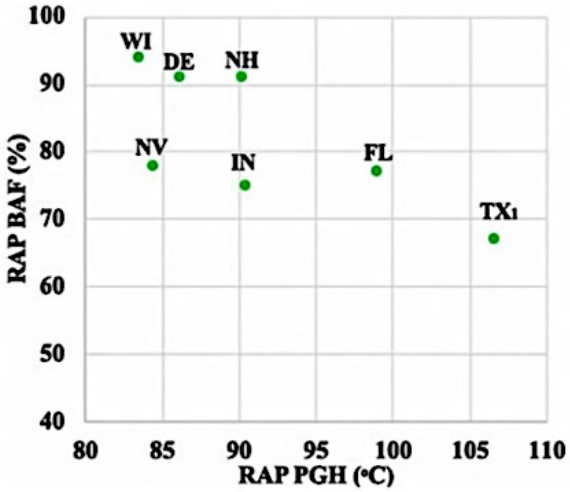


- **Outcome: "Real World" blending matched most closely with the "Total Blending" condition, i.e. RAP binder was nearly entirely available.**

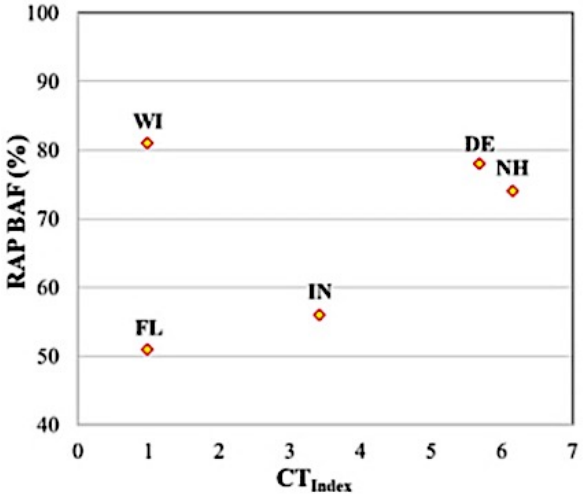
Review of RAP Binder Availability Factors (BAF)

TXDOT Review– Epps Martin, et al. 2021

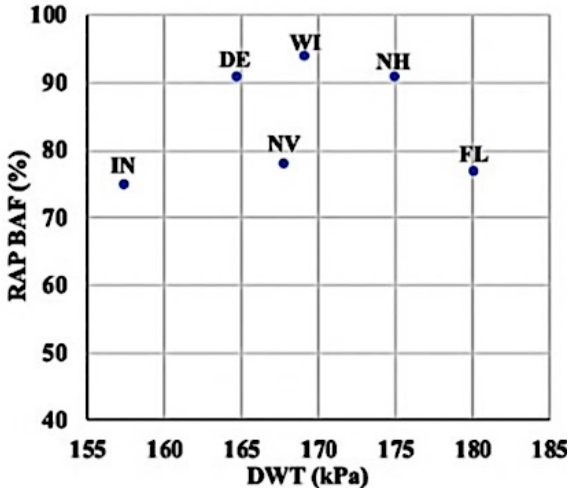
- Collected data from various studies and test methods using RAP from various sources.



NCHRP 9-58 Phase 1 by Coating



RILEM RAP TG5 – By IDT



FHWA DWT Method

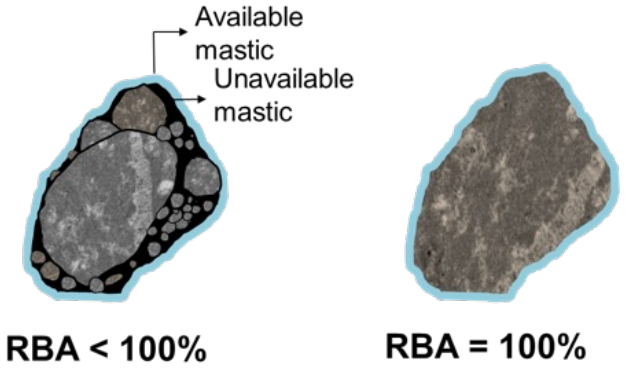
- Studies using performance, coating, and volumetrics have suggested that not all of the RAP binder functionally contributes to performance
- Measured Binder availability were generally between 75-95%, varying based on criteria

RAP Binder Availability Studies

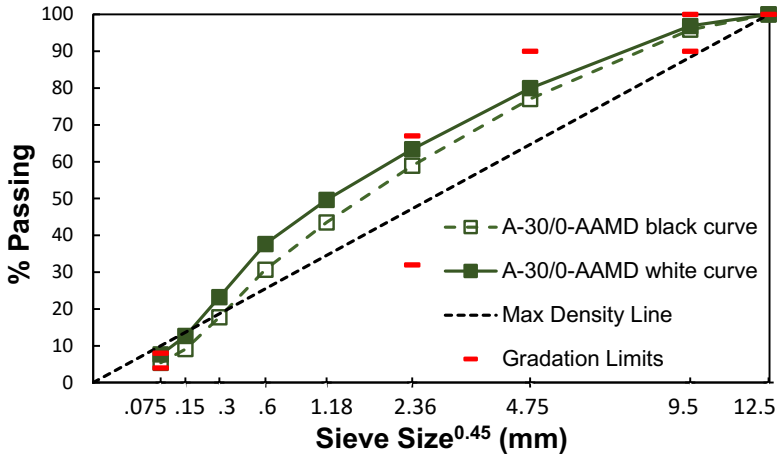
NCSU Studies – Cassie Castorena, et al. 2024

- The premise of these studies was that agglomerations of RAM particles prevent recycled and virgin binder from blending.
- Recommended modified design method:

Component	Change to Conventional Volumetric Mix Design
Design of the aggregate structure	Use the RAP and RAS black curves rather than white curves
Volumetric property inferences	Include unavailable recycled binder in the bulk aggregate volume



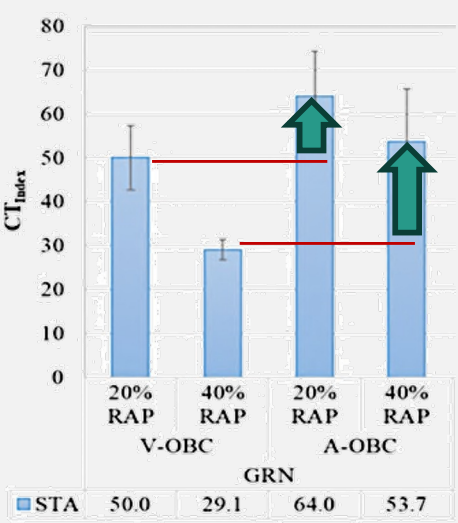
- In tested examples the method resulted in:
  - **0.7% higher AC** for 30% RAP, and
  - **1.6% higher AC** for a 25/5 RAP/RAS mix.
- BMD performance tests showed comparable ranking
- The increased AC content and modified gradation:
  - Improved the CT-Index (from ~20 to 40), without APA impact.
  - Lower performance compared than virgin control

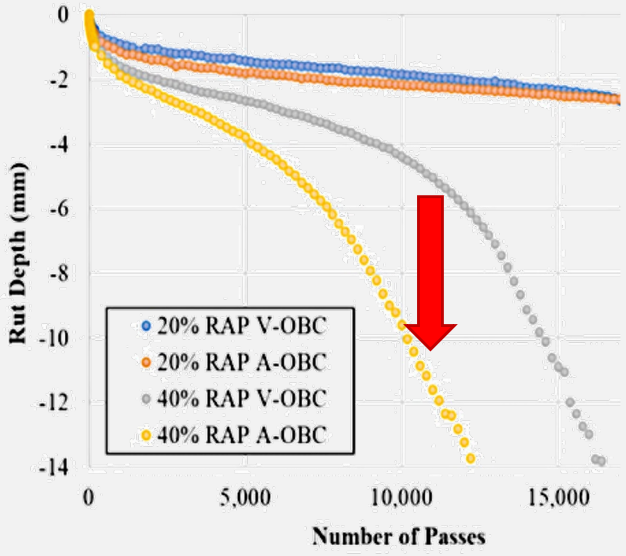


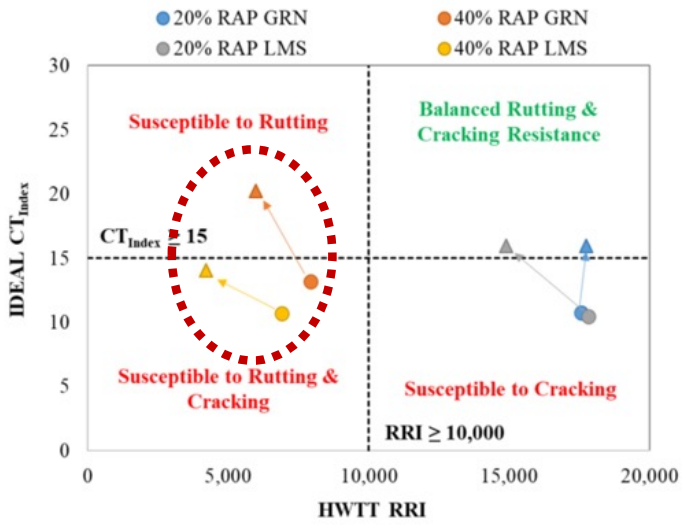
Review of RAP Binder Availability Factors (BAF)

FDOT Study (NCAT), Yin, et. al. 2024

- A few states have experimented with adjusting virgin binder based on an assumed BAF, for example 80% BAF for FL, and a 60% BAF for GA.
- NCAT studied the impact of the FL 80% BAF, resulting in **~0.5% higher binder content** at 40% RAP





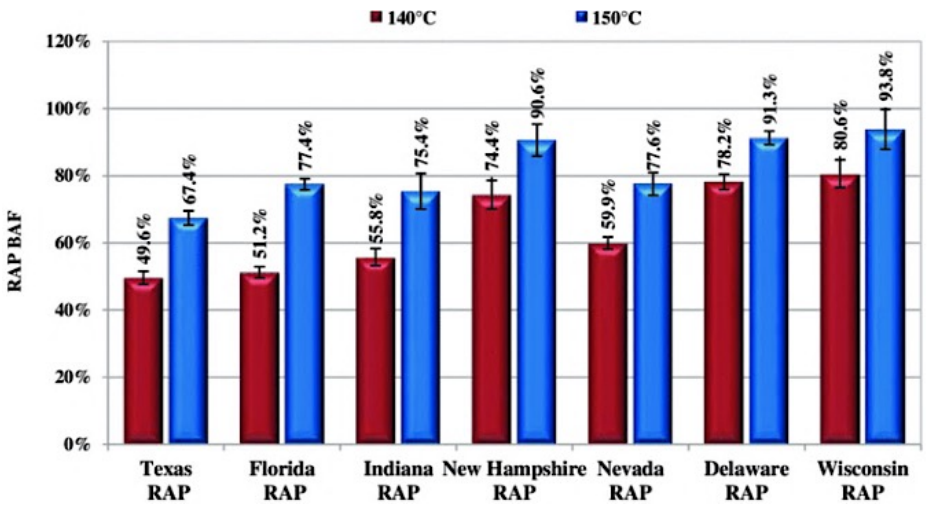


- Increased virgin AC using BAF lead to an improvement in IDEAL-CT
- When combining BAF (increasing AC) with soft binder, need to keep an eye on potential rutting imbalance

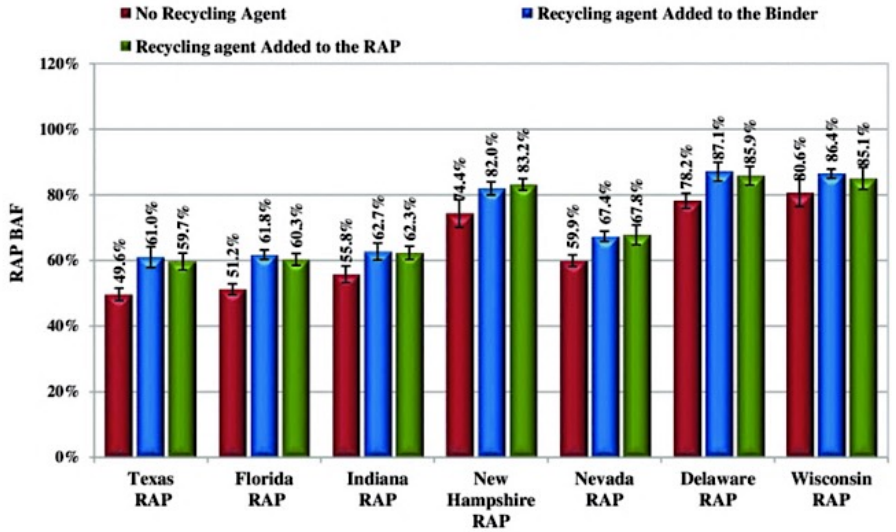
Review of RAP Binder Availability Factors (BAF)

NCHRP 9-58 Phase II – Epps Martin, et al. 2023

- BAF was estimated by measuring amount of RAP binder content coating virgin aggregates after blending.



Effect of mixing temperature



Effect of Adding RA

- Mixing temperature had a significant impact on coating BAF when going from 140 to 150°C
- Using Recycling Agents (RA) increased the BAF by 5-10%, especially for stiff RAP.

NCHRP 9-65 (NCAT & TTI)

Reviewed Source: Beirgi, et. al., 2024

- One of **most comprehensive studies** on high RAM durability improvement strategies
- Tested Various strategies with **Northeastern RAP and RAS**, and **Southern RAP**.

Summary of results and scoring visualization is not by study authors:

NCHRP 9-65 Strategies Studied	Northeast RAP	Southern RAP	Southern RAP	Northeast RAP + RAS
	High RAP	Low RAP	High RAP	
Improved ΔTc	↓	↔	↑	N/A
Polymer (PMA)	N/A	↔	↔	N/A
Softer Binder	↑	↑↑	↑↑	↔
BAF (Increasing Virgin AC)	↑↑	↔	↑	↑↑↑
Recycling Agent (RA)	↑↑↑	↑	↑↑↑	N/A

- A number of “Hybrid” strategies also showed promising results, such as combining BAFs, with Soft binders or PMA

Methods used to Study Binder Availability

Mitigating actions while maintaining RAP binder replacement:

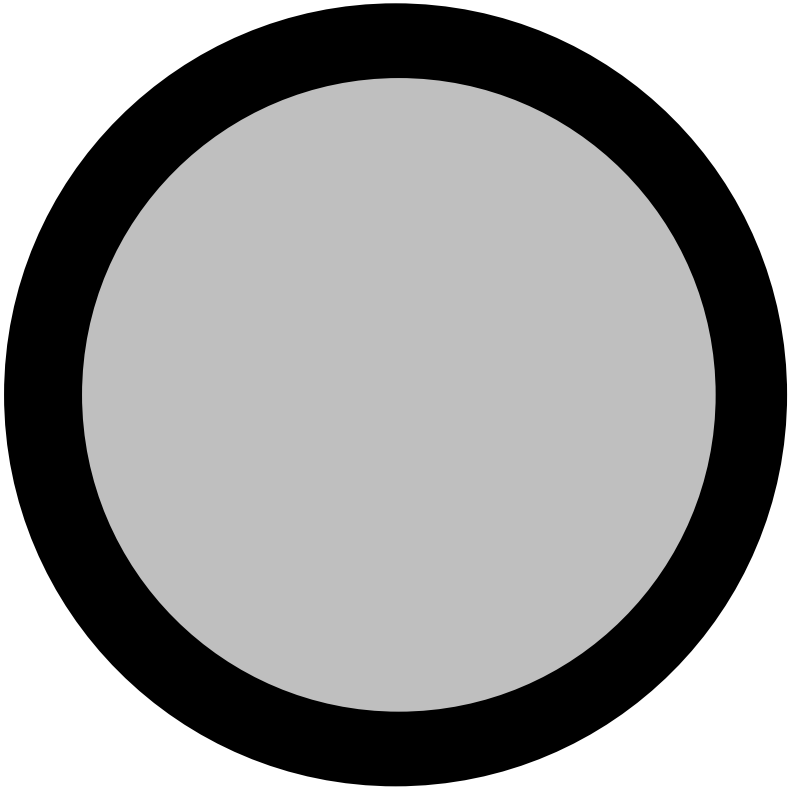
- Soft binder
- Recycling Agents

Mitigating actions by reducing RAP binder replacement:

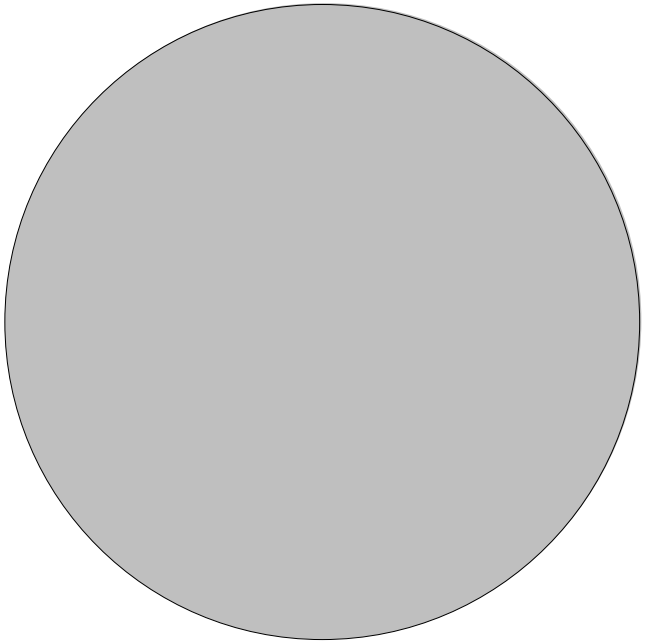
- Increasing virgin binder content (Binder availability factors, regressing air voids, increasing VMA)
- Decreasing RAP content in mix

Factors to Consider on RAP Binder Availability

Perception on Binder Film Thickness



Typical “idealized” Representation of binder film on aggregate in literature



More proportional representation of ~10µm binder film on a #4 aggregate

Factors to Consider on RAP Binder Availability

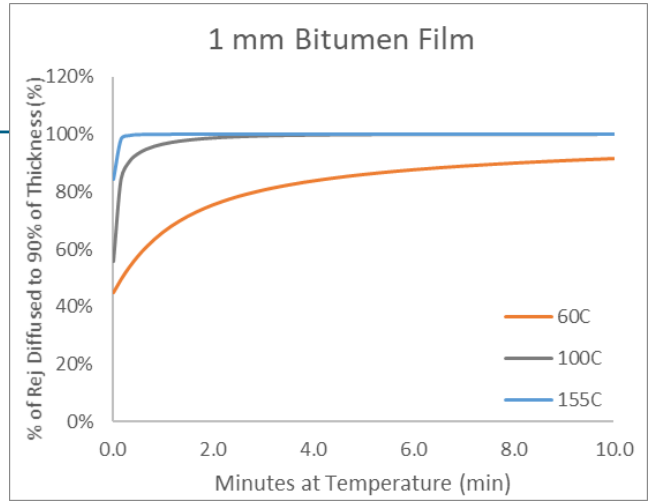
RA – RAP Binder Diffusion Rates

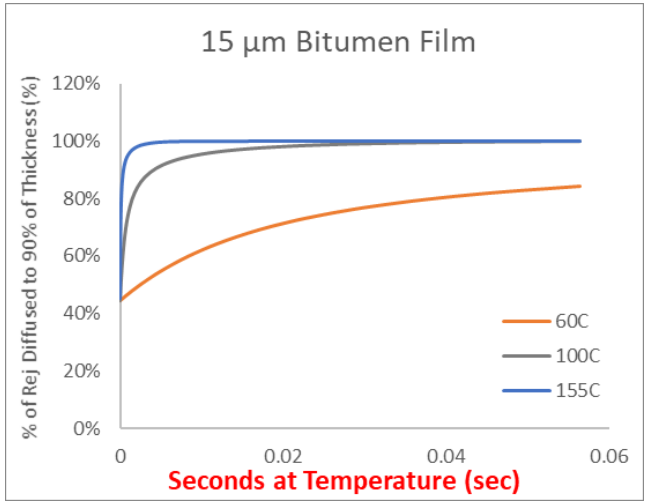
- Time required for Rejuvenator impact is governed by the diffusion time through the asphalt binder film thickness.
  - Total asphalt binder film thickness is in the order of 5-15 µm.
  - Addition of the rejuvenator directly to the RAP instead of into the virgin bitumen changes the diffusion path length by 5-10 µm.

- For a rejuvenator with sufficient diffusivity at mixing temperatures full diffusion in the film will take less than a minute.

Typical diffusion rates from the literature (for rejuvenators):

$D = 2x10^{-10}$ to $3x10^{-10}$ m^2/s at 150C From molecular dynamics (Xiao, et. al., 2017 – Wuhan University)
$D = 4x10^{-10}$ to $7x10^{-10}$ m^2/s at 150C, Experimentally derived (Cong, et. al., 2016 – Chang'an University)
$D = 1x10^{-11}$ to $5x10^{-11}$ m^2/s at 60C, from microscopy/FTIR (Su, et. al., 2016 – Shenzhen University)
$D = 2x10^{-11}$ to $6x10^{-11}$ m^2/s at 140C, Experimentally derived (Karlsson & Isacsson, 2003 – KTH)
$D = 2x10^{-12}$ to $4x10^{-12}$ m^2/s at 140C, for binder Experimentally derived (Yousefirad, et. al., 2014 – U. of Wisconsin)

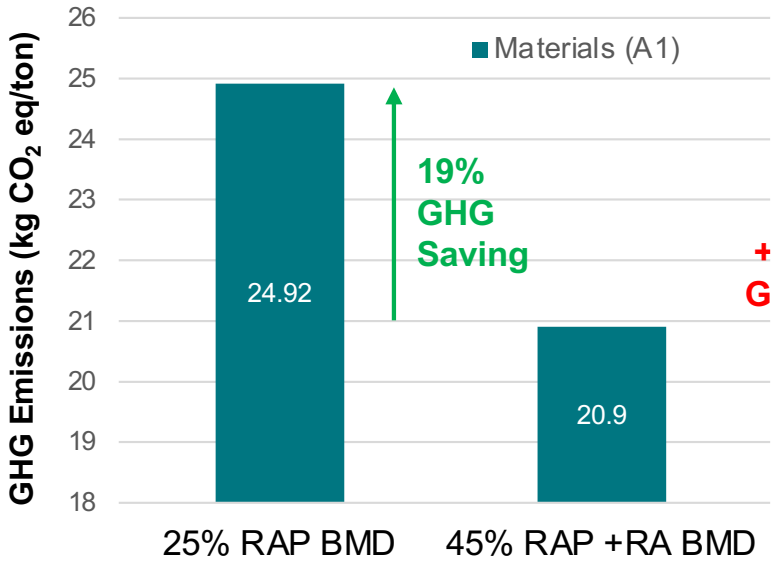




Factors to Consider on RAP Binder Availability

Carbon Footprint and GHG – *MNROAD 2018 Test Track Example*

- Are we giving back what we could have saved?



Project	Description	RAP %Mix	BMD
MNROAD	PG58-28 25% RAP	25	5.1%
MNROAD	PG58-28 45% RAP	45	5.1% + RA

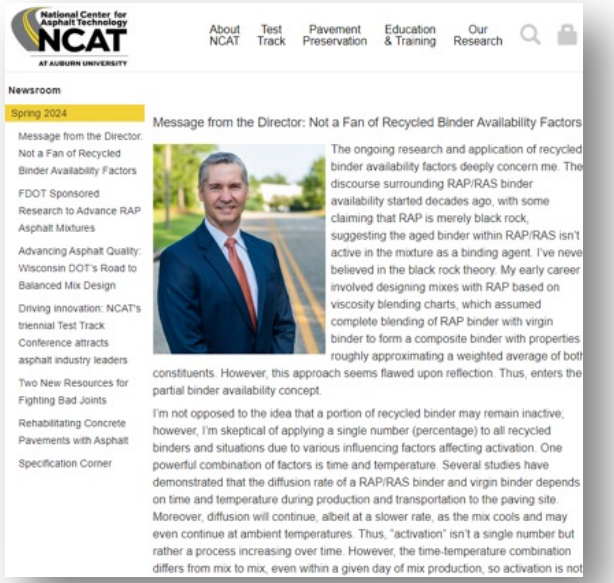
Factors to Consider on RAP Binder Availability

From Dr. Randy West (2024): Message from the Director: Not a Fan of…

- Limiting Factors for usefulness of BAFs:
  1. Ignores variable impact of “time” and “temperature” during production from mix to mix and plant to plant
  2. Not all RAP is the same (**age, depth of milling, original mix type, prior pavement preservation applications**)
  3. Fails to fully capture potential of recycling agents (RA)

- **More effective approach:** Incorporate **performance testing** in mix design

- *“This is where the promise of balanced mix design shines—allowing the results of mix performance tests to guide decisions, acknowledging the intricate interactions of materials that defy simple predictions.”*



Conclusions and Summary

There are multiple strategies available to mix designers to accommodate RAP Binder at a High Performance

- Many studies have shown that the **functional contribution** of RAP binder to a mix is less than 100% by different measures
- Multiple strategies have shown promise in accommodating RAP binder functionality:
  - **Increasing virgin binder** (e.g. Binder Availability Factors (BAF), VMA increases, regressed voids, lowering RAP limit)
  - **Maintaining RAP binder replacement** (e.g. Using Recycling Agents, softer binder grades)
- Factors such as RAP variability and production parameters (time/temperature) should be considered.
- Strategies requiring increased virgin binder may negatively impact the potential sustainability savings from recycling

Acknowledgements

- Jenna Kelly (Cargill) – for GHG calculations using NAPA Emarald Eco

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  - Professor Cassie Castorena (NCSU)
  - Professor Amy Epps and Dr. Edith Arambula (Texas A&M / TTI)

- All views and conclusions presented in this review are that of the presenters, and do not necessarily reflect that of the researchers and authors mentioned in this presentation.


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