Practices and Lessons Learned
For Cold and Hot In-place Recycling

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• None of the AASHTO and ASTM specifications mentioned in this presentation are required under Federal requirements.
Abbreviations & Acronyms

- AASHTO – American Association of State Highway and Transportation Officials
- ARRA – Asphalt Recycling and Reclaiming Association
- CCPR – Cold Central Plant Recycling
- CIR – Cold In-place Recycling
- DDIAPT – Demonstration and Deployment of Innovative Asphalt Pavement Technologies
- DOT – Department of Transportation
- FDR – Full-depth Reclamation
- FHWA – Federal Highway Administration
- FLH – Federal Lands Highway
- GTR – Ground Tire Rubber
- HIR – Hot In-place Recycling
- HMA – Hot Mix Asphalt
- INDOT – Indiana DOT
- IS – Information Series
- ITS – Indirect Tensile Strength
- ME – Mechanistic Empirical
- NAPA - National Asphalt Pavement Association
Abbreviations & Acronyms

- NCHRP - National Cooperative Highway Research Program
- NMDOT – New Mexico DOT
- NP – National Park
- NYSDOT – New York State DOT
- PCR – Pavement Condition Rating
- PG – Performance Grade
- PM – Polymer Modified
- QA – Quality Assurance
- QC - Quality Control
- QCP – Quality Control Plan
- RAP - Reclaimed Asphalt Pavement
- RAS - Recycled Asphalt Shingles
- SCDOT – South Carolina DOT
- TSR – Tensile Strength Ratio
- UCS – Unconfined Compressive Strength
- VDOT – Virginia DOT
Outline

- Introduction and Background
- Performance, Sustainability, Cost
- Project Selection
- Pavement and Mix Designs
- Production
- Summary

Image Source: Adam Hand

U.S. Department of Transportation
Federal Highway Administration
DDIAPIT Innovation Area:
Resource Responsible use of Materials for Flexible Pavement Systems

<table>
<thead>
<tr>
<th>Innovation Area</th>
<th>Task</th>
<th>Topic</th>
<th>Tech Brief or Report</th>
<th>FHWA Document</th>
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<tr>
<td>Resource Responsible use of Materials for Flexible Pavement Systems</td>
<td>B.1</td>
<td>High Reclaimed Asphalt Pavement (RAP) Mixtures</td>
<td>Resource Responsible Use of Reclaimed Asphalt Pavement in Asphalt Mixtures</td>
<td>FHWA-HIF-22-003</td>
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<td></td>
<td>B.1.2</td>
<td>Cold &amp; Hot In-place Recycling</td>
<td>Asphalt Pavement Recycling Technologies</td>
<td>FHWA-HIF-23-036</td>
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<td>B.2</td>
<td>Reclaimed Asphalt Shingles (RAS) Modified Binders and Mixtures</td>
<td>Practices and Lessons Learned when Using Reclaimed Asphalt Shingles in Asphalt Mixtures</td>
<td>FHWA-HIF-22-001</td>
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<td>B.3</td>
<td>Asphalt Rubber-Modified Binders</td>
<td>Effective Use of GTR Modified Asphalt Binder in Asphalt Mixtures</td>
<td>FHWA-HIF-22-011</td>
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<td>Resource Responsible Use of Recycled Tire Rubber in Asphalt Pavements</td>
<td>FHWA-HIF-20-043</td>
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https://www.fhwa.dot.gov/pavement/recycling/
Cold & Hot In-place Recycling Methods

- Cold In-place Recycling
  - CIR
- Full Depth Reclamation
  - FDR
- Cold Central Plant Recycling
  - CCPR
- Hot In-Place Recycling
  - HIR

Images Source: Adam Hand
Objectives

• Learn details of positive State DOT practices.
• Collect and communicate experiences, lessons learned and performance information.
• Identify gaps for creation of research needs statements.
Participating Agencies

- 6 agencies
  - FLH
  - INDOT
  - NMDOT
  - NYSDOT
  - SCDOT
  - VDOT

- Virtual site visits and interviews
Federal Lands Highway Divisions
Scope

• CIR, CCPR, FDR & HIR
• Kick-off/planning meeting
• 2 or 3 - day virtual visits
• Agency reports
• Summary report
• FHWA TechBrief
• Webinar
### Agency Use of Technologies

#### Recycling Technologies Used

<table>
<thead>
<tr>
<th>Item</th>
<th>FLH</th>
<th>INDOT</th>
<th>NMDOT</th>
<th>NYSDOT</th>
<th>SCDOT</th>
<th>VDOT</th>
</tr>
</thead>
<tbody>
<tr>
<td>CIR</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>CCPR</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>V. Limited</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>FDR</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>HIR</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
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#### Years of Experience

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<th>SCDOT</th>
<th>VDOT</th>
</tr>
</thead>
<tbody>
<tr>
<td>CIR</td>
<td>50</td>
<td>5-10</td>
<td>3</td>
<td>20+</td>
<td>n/a</td>
<td>10+</td>
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<tr>
<td>CCPR</td>
<td>15</td>
<td>5-10</td>
<td>8</td>
<td>5+</td>
<td>n/a</td>
<td>10+</td>
</tr>
<tr>
<td>FDR</td>
<td>40</td>
<td>5-10</td>
<td>9</td>
<td>n/a</td>
<td>7</td>
<td>13+</td>
</tr>
<tr>
<td>HIR</td>
<td>50</td>
<td>n/a</td>
<td>20+</td>
<td>15+</td>
<td>n/a</td>
<td>n/a</td>
</tr>
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</table>
**Agency Use of Technologies**

**Percentage of Recycling Program**

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<tr>
<th>Item</th>
<th>FLH¹</th>
<th>INDOT</th>
<th>NMDOT</th>
<th>NYSDOT</th>
<th>SCDOT</th>
<th>VDOT</th>
</tr>
</thead>
<tbody>
<tr>
<td>CIR</td>
<td>6% (5%)</td>
<td>38%</td>
<td>10%</td>
<td>50 to 65%</td>
<td>0%</td>
<td>20%</td>
</tr>
<tr>
<td>CCPR</td>
<td>6% (5%)</td>
<td>12%</td>
<td>40%</td>
<td>&lt;1%%</td>
<td>0%</td>
<td>18%</td>
</tr>
<tr>
<td>FDR</td>
<td>88% (80%)</td>
<td>50%</td>
<td>50%</td>
<td>0%</td>
<td>100%</td>
<td>62%</td>
</tr>
<tr>
<td>HIR</td>
<td>0%</td>
<td>0%</td>
<td>n/a</td>
<td>35 to 50%</td>
<td>0%</td>
<td>0%</td>
</tr>
</tbody>
</table>

¹=10% of FLH Recycling in RAP Millings
Outline

1. Introduction and Background
2. Performance, Sustainability, Cost
3. Project Selection
4. Pavement and Mix Designs
5. Production
6. Summary

Data collection vehicle for roadway condition
Performance & Sustainability

• “A total of 40 agencies responded... Most cold recycling programs pave less than 50 lane-miles per year. Cold recycling is frequently used on roadways with annual average daily traffic (AADT) under 10,000, but more experienced agencies use cold recycling on roadways with AADTs between 10,000 and 25,000.”

• “The reported service life of cold recycled pavements ranges from 20 to 34 years when the cold recycled mix is used in conjunction with an overlay. The service life is somewhat shorter and more variable when chip seals are used as the wearing surface. Poor drainage can reduce the service life by 30% or more.”

• “Cold recycling with an overlay can reduce the cost of a project by 40% to 60% compared to a conventional mill and fill. Greenhouse gas emissions can be reduced by about 50% compared to a conventional mill and fill.”


The use of a synthesis is not a Federal requirement.
Performance & Sustainability

Additional Resources:

• 2010 Robinette and Epps: LCCA & LCA Benefits (TRR 2179, 2010)

• 2015 FHWA: Towards Sustainable Pavement Systems
  https://www.fhwa.dot.gov/pavement/sustainability/ref_doc.cfm

• 2019 Gu et al: CIR & CCPR vs. New HMA, Energy consumption reduced 56-64% & GHG reduced 39-46%
  Journal of Cleaner Production 208 (2019) 1513e1523

• 2022 Amarh et.al: 10 VDOT rehabilitation projects including (CIR), CCPR, & FDR, HMA; pavement recycling projects used for interstate reconstruction and primary route restorative maintenance yielded lower global warming (GW) than non-recycling approaches.
  Transportation Research Record 2022, Vol. 2676(6) 75–86

Image Source: Transportation Research Record, 2022, Vol. 2676(6) 75–86
INDOT FDR Projects

• FDR vs. Conventional Rehabilitation Structural Performance

• 40-70% Cost Savings

Image Source: Indiana Department of Transportation
FLH: CIR Cost and Performance

The Economics....

- Existing Pavement
- 2" HMA
- 3" CIR

CIR Rehabilitation

Reconstruction
- 40% Higher Cost than CIR Rehabilitation
- 4" HMA
Performance – Washington Road
Tahoe National Forest, CA

2009 – under construction

2019 – 10 years old
Performance – Ice House Road
El Dorado National Forest, CA

22 years old

31 years old
Performance – Rocky Mountain National Park, CO

1982 CIR

After 26 years!
Outline

- Introduction and Background
- Performance, Sustainability, Cost
- Project Selection
- Pavement and Mix Designs
- Production
- Summary
Project/Recycling Technology Selection Criteria

• Some Examples:
  • FLH
    • https://highways.dot.gov/federal-lands/specs
  • INDOT
    • https://www.in.gov/dot/div/contracts/design/Part%206/Chapter%20602%20-%20Project%20Categories%20and%20Pavement%20Types.pdf
  • NYSDOT
    • https://www.in.gov/dot/div/contracts/design/Part%206/Chapter%20602%20-%20Project%20Categories%20and%20Pavement%20Types.pdf
  • FHWA Tech Brief: Overview of Project Selection Guidelines for Cold In-place and Cold Central Plant Pavement Recycling
Project Selection: Possible Characteristics of a Good Candidate

• End of service life.
• Minor patching.
• Fatigue cracking.
• 3-inch depth minimum.
Project Selection: Possible Characteristics of a Poor Candidate

• Road geometry: grade and curves.
• Less than 3 inches.
• Geotextile in milling depth.
• Need to tie into existing structures.
Project Selection: Field Investigation

Average Distance between Borings: 2674 feet
Average Thickness of Pavement: 4.2 inches
Controlling Thickness: 3.6 inches

<table>
<thead>
<tr>
<th>Boring No.</th>
<th>Station</th>
<th>Distance Between Borings (ft)</th>
<th>Pavement Depth (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SG03-45</td>
<td>2059+70</td>
<td>2640</td>
<td>3.8</td>
</tr>
<tr>
<td>SG03-46</td>
<td>2086+10</td>
<td>2700</td>
<td>4</td>
</tr>
<tr>
<td>SG03-47</td>
<td>2113+10</td>
<td>2640</td>
<td>3.6</td>
</tr>
<tr>
<td>SG03-48</td>
<td>2139+50</td>
<td>2680</td>
<td>4.2</td>
</tr>
<tr>
<td>SG03-49</td>
<td>2166+30</td>
<td>2676</td>
<td>5</td>
</tr>
<tr>
<td>SG03-50</td>
<td>2193+06</td>
<td>2680</td>
<td>3.6</td>
</tr>
<tr>
<td>SG03-51</td>
<td>2219+86</td>
<td>2654</td>
<td>4.5</td>
</tr>
<tr>
<td>SG03-52</td>
<td>2246+40</td>
<td>2760</td>
<td>4</td>
</tr>
<tr>
<td>SG03-53</td>
<td>2274+00</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>
INDOT Pavement Treatment Selection

**OVERLAY**
- Based on Project Conditions; Pavement Recycling is Being Considered for Overlay
- Distress Trigger: Striping, Top-Down Cracking, or Other Distress that Would be Suitable for CRP and/or Overlay

**FULL-DEPTH**
- Based on Project Conditions; Pavement Recycling is Being Considered for Full-Depth
- Distress Trigger: Bottom-Up Cracking and Distress Requiring Full-Depth Patching are Observed
- Conventional Fix Trigger: Treatment is Set to be Reconstruction or Requires > 50% Full-Depth Patching

**ALTERNATIVES**
- Cement FDR (Include 50% Subgrade)
- Cement FDR (Include 50% Subgrade)
  - COPR Base Lift (If Suggested) Multi-Lift HMA Overlay

**PAVEMENT RECYCLING TREATMENT SELECTION**

Figure 602-1A

Source: Indiana DOT

https://www.in.gov/dot/div/contracts/design/Part%206/Chapter%20602%20-%20Project%20Categories%20and%20Pavement%20Types.pdf
Outline

- Introduction and Background
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Structural Pavement Design

- AASHTO 1993: FLH, NMDOT, SCDOT, VDOT (rehab)
- AASHTOWare Pavement™ ME Design: INDOT, NYSDOT, VDOT (new)

<table>
<thead>
<tr>
<th>Item</th>
<th>FLH</th>
<th>INDOT</th>
<th>NMDOT</th>
<th>NYDOT</th>
<th>SCDOT</th>
<th>VDOT</th>
</tr>
</thead>
<tbody>
<tr>
<td>CIR</td>
<td>0.28-0.30</td>
<td>75-100ksi</td>
<td>0.35</td>
<td>n/a</td>
<td>n/a</td>
<td>0.35</td>
</tr>
<tr>
<td>CCPR</td>
<td>0.25-0.30</td>
<td>75-100ksi</td>
<td>0.35</td>
<td>n/a</td>
<td>n/a</td>
<td>0.35</td>
</tr>
<tr>
<td>FDR AC</td>
<td>0.20-0.25</td>
<td>75-100ksi</td>
<td>0.30</td>
<td>n/a</td>
<td>n/a</td>
<td>0.25</td>
</tr>
<tr>
<td>FDR PC</td>
<td>0.15-0.22</td>
<td>75-100ksi</td>
<td>n/a</td>
<td>n/a</td>
<td>0.26</td>
<td>0.25</td>
</tr>
</tbody>
</table>

1 NYSDOT typically very thick pavements, so no formal structural design is performed.
2 VDOT used aggregate base thickness multiplied by 1.26 for CCPR in AASHTOWare Pavement™ ME Design.

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CIR Requires a Riding Surface

Surface with:
• Asphalt pavement.
  • Use a tack coat.
  • Double chip seal.
## CIR Materials Selection – Binders & Active Fillers

<table>
<thead>
<tr>
<th>Item</th>
<th>FLH</th>
<th>INDOT</th>
<th>NMDOT</th>
<th>NYSDOT</th>
<th>VDOT</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Binders</strong></td>
<td>Engineered Emulsion</td>
<td>Emulsion</td>
<td>Engineered Emulsion</td>
<td>Emulsion, PM Emulsion, PG64S-22 Foamed Asphalt</td>
<td>Emulsion or Foamed Asphalt</td>
</tr>
<tr>
<td><strong>Active Filler</strong></td>
<td>Portland Cement or Lime Slurry</td>
<td>Portland Cement Allowed</td>
<td>Portland Cement or Lime</td>
<td>1% Portland Cement</td>
<td>Portland Cement</td>
</tr>
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</table>

Terminology...binder, stabilizing agent, active fillers
## CIR Mix Design

<table>
<thead>
<tr>
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<th>NMDOT</th>
<th>NYSDOT</th>
<th>VDOT</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Compactor</strong></td>
<td>Gyratory-35</td>
<td>Gyratory-30</td>
<td>Gyratory-30</td>
<td>Gyratory-30</td>
<td>Marshall-75</td>
</tr>
<tr>
<td><strong>Foamed</strong></td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>Indirect Tensile Strength &amp; TSR or Retained Marshall Stability</td>
<td>Indirect Tensile Strength &amp; TSR, Half-Life</td>
</tr>
</tbody>
</table>

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Outline

- Introduction and Background
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- Production
- Summary
Quality Control & Acceptance

6 Core Elements of a QA Program

- Agency Acceptance
- Dispute Resolution
- Independent Assurance
- Contract Quality Control
- Lab Qualification
- Technician Qualification

Common Production QC Measurements

- Binder.
- Moisture.
- Gradation top size.
- Density.
- Thickness.
- Curing.
## Curing & Opening to Traffic

<table>
<thead>
<tr>
<th>Item</th>
<th>FLH</th>
<th>INDOT(^1)</th>
<th>NMDOT</th>
<th>NYSDOT</th>
<th>VDOT</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Traffic</strong></td>
<td>0 for 2 hours</td>
<td>-</td>
<td>0 for 2 hours</td>
<td>-</td>
<td>0 for 2 hours</td>
</tr>
<tr>
<td><strong>Moisture</strong></td>
<td>(\leq 2.5%)</td>
<td>(\leq 3.0%)</td>
<td>(\leq 3.0%)</td>
<td>-</td>
<td>(\leq 50%) of optimum moisture</td>
</tr>
<tr>
<td><strong>Content</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>content</td>
</tr>
<tr>
<td><strong>Time</strong></td>
<td>Cover within 14 days</td>
<td>(\geq 3) days or 10 days without rainfall</td>
<td>(\geq 3) days</td>
<td>Emulsion (\geq 10) days; Foamed Asphalt (\geq 3) days</td>
<td>-</td>
</tr>
</tbody>
</table>

\(^1\)Greater than 3 days and less than 3.0% moisture or cured 10 days without rainfall.
Objective: The objectives of this research are to develop (1) time-critical tests for asphalt-treated CIR, FDR, and CCPR materials and (2) a guide specification using these tests for process control and product acceptance that provides the agency with a basis for determining when the pavement can be opened to traffic and surfaced.
NCHRP Project 09-62 Phase III – Field Trials MnROAD

**SHORT-PIN RAVELING TEST (SPRT)**

Apply pressure on the weight to keep the plate flush with the surface and rotate the torque wrench slowly at a constant rate over a 4 second period.

Images Source: Adam Hand
NCHRP Final Test Suggestions

- Short Pin Raveling Test (SPRT)
  - Blows & Torque
- Long Pin Shear Test (LPST)
  - Blows and Torque

- Data Set

<table>
<thead>
<tr>
<th>Suggested Tests</th>
<th>Properties</th>
<th>Mean</th>
<th>Pooled σ</th>
<th>Threshold Value (Average of 3 Tests)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short-Pin Raveling Test (SPRT)</td>
<td>Number of Blows</td>
<td>8.4</td>
<td>0.8</td>
<td>7.1</td>
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<tr>
<td></td>
<td>Torque, ft-lb</td>
<td>24.3</td>
<td>2.5</td>
<td>20.2</td>
</tr>
<tr>
<td>Long-Pin Shear Test (LPRT)</td>
<td>Number of Blows</td>
<td>22.8</td>
<td>2.1</td>
<td>19.3</td>
</tr>
<tr>
<td></td>
<td>Torque, ft-lb</td>
<td>76.4</td>
<td>8.2</td>
<td>62.9</td>
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</tbody>
</table>

Objective: to produce proposed AASHTO Construction Guide Specifications for the application of CCPR and CIR in the standard five-part AASHTO format with supporting commentary. The specifications shall include plans for quality assurance and agree with current provisional material specifications and mix design practices for these treatments. The specifications shall enable specifying agencies to tailor their own specifications to the local conditions and environments.


The use of an NCHRP Report is not a Federal requirement.
Outline

- Introduction and Background
- Performance, Sustainability, Cost
- Project Selection
- Pavement and Mix Designs
- Production
- Summary
Suggested Practices from Participating Agencies

• Pre-Construction
  - Detailed treatment selection guide
  - Regularly updated specifications
  - Adequate site investigation
  - Representative samples
  - Pre-construction meetings (all SH 4-8 hours)

• Mix Design
  - Accredited labs
  - Leveraging engineered emulsions

• Production & Acceptance
  - Requiring QC Plans
  - Control or test strips for density
  - Proof rolling requirement
  - On-site technical representative
  - Monitor yield daily
  - Maintenance/traffic control while curing
  - Pay for binder as separate item

• Programmatic
  - Post-project/season stakeholder meetings
  - Collecting performance data
Lessons Learned from Participating Agencies

- Use large enough minimum project sizes
- **Without detailed site investigation variability can create issues**
- Adequate drainage is essential
- Don’t overlook geometric constraints (underpasses, drainage inlets, guardrail height, etc.)
- If significant changes in cross section (subgrade, mc, thickness), may require more than one mix design
- If correcting geometry (grades/cross slopes) be sure adequate recycled layer thickness
- Leave adequate pavement structure in-place
  - Do not include aggregate base in CIR
- Require mix designs and QCPs 30 days prior to production
- Recognize recycled layer “fluffs”
- In high moisture, portland cement helps with strength
Lessons Learned from Participating Agencies

- Night work, early season, cool temps, CIR emulsion breaking
- Change milling speed, moisture & temperature affect gradation & density
- Calibrate equipment
- Keep rollers back from paver on CIR, not like HMA

- Contractor and inspector experience with new technologies important
- HMA tech ≠ CIR tech
- Tack coats are helpful
- Post-project/season stakeholder meetings
References
# References

FHWA website at: https://www.fhwa.dot.gov/pavement/recycling/apiprt.cfm

Tech Brief.  
NHI 2-day training.  
Just in time videos.  
Checklist series.

## Asphalt Pavement In-place Recycling Technologies (APIPRT)

- **VIRGINIA CASE STUDY**, FHWA-HIF-19-078, 2020 (also available as a video)  
- **Overview of Project Selection Guidelines for Cold In-place and Cold Central Plant Pavement Recycling**, FHWA-HIF-17-042, 2018  
- **NHI APIPRT Training**  
  - NHI 131140 Hot In-place Recycling (web-based training)  
  - NHI 131142 Full Depth Reclamation (FDR) (web-based training)  
  - NHI 131030 Asphalt Pavement In-place Recycling Techniques  
  - Inspector Training for Cold In-place Recycling (web-based training)  
- **Pavement Preservation Checklist Series**  
  - **Hot In Place Asphalt Recycling Application**, FHWA-HIF-19-034  
  - **Cold In Place asphalt Recycling Application**, FHWA-HIF-19-035  
  - **Full Depth Reclamation Construction**, FHWA-HIF-19-038  
  - **Hot Cold and Green (and the 3Es)**
Thank You

Q & A

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