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

FHWA is the source for all images unless otherwise noted.

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Federal Highway Administration

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October 24, 2023

U.S. Department of Transportation

Federal Highway Administration

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Abbreviations & Acronyms

U.S. Department of Transportation
Federal Highway Administration

- 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

U.S. Department of Transportation
Federal Highway Administration

- 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

U.S. Department of Transportation
Federal Highway Administration

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

Image Source: Adam Hand

DDIAPT Innovation Area:

Resource Responsible use of Materials for Flexible Pavement Systems

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Innovation Area	Task	Topic	Tech Brief or Report	FHWA Document
Resource Responsible use of Materials for Flexible Pavement Systems	B.1	High Reclaimed Asphalt Pavement (RAP) Mixtures	Resource Responsible Use of Reclaimed Asphalt Pavement in Asphalt Mixtures	FHWA-HIF-22-003
	B.1.2	Cold & Hot In-place Recycling	Asphalt Pavement Recycling Technologies	FHWA-HIF-23-036
	B.2	Reclaimed Asphalt Shingles (RAS) Modified Binders and Mixtures	Practices and Lessons Learned when Using Reclaimed Asphalt Shingles in Asphalt Mixtures	FHWA-HIF-22-001
	B.3	Asphalt Rubber-Modified Binders	Effective Use of GTR Modified Asphalt Binder in Asphalt Mixtures	FHWA-HIF-22-011
			Resource Responsible Use of Recycled Tire Rubber in Asphalt Pavements	FHWA-HIF-20-043

https://www.fhwa.dot.gov/pavement/recycling/

Cold & Hot In-place Recycling Methods

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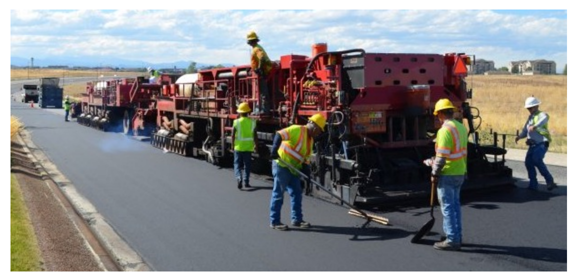
- Cold In-place Recycling
  - CIR
- Full Depth Reclamation
  - FDR
- Cold Central Plant Recycling
  - CCPR
- Hot In-Place Recycling
  - HIR



Images Source: Adam Hand

Objectives

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

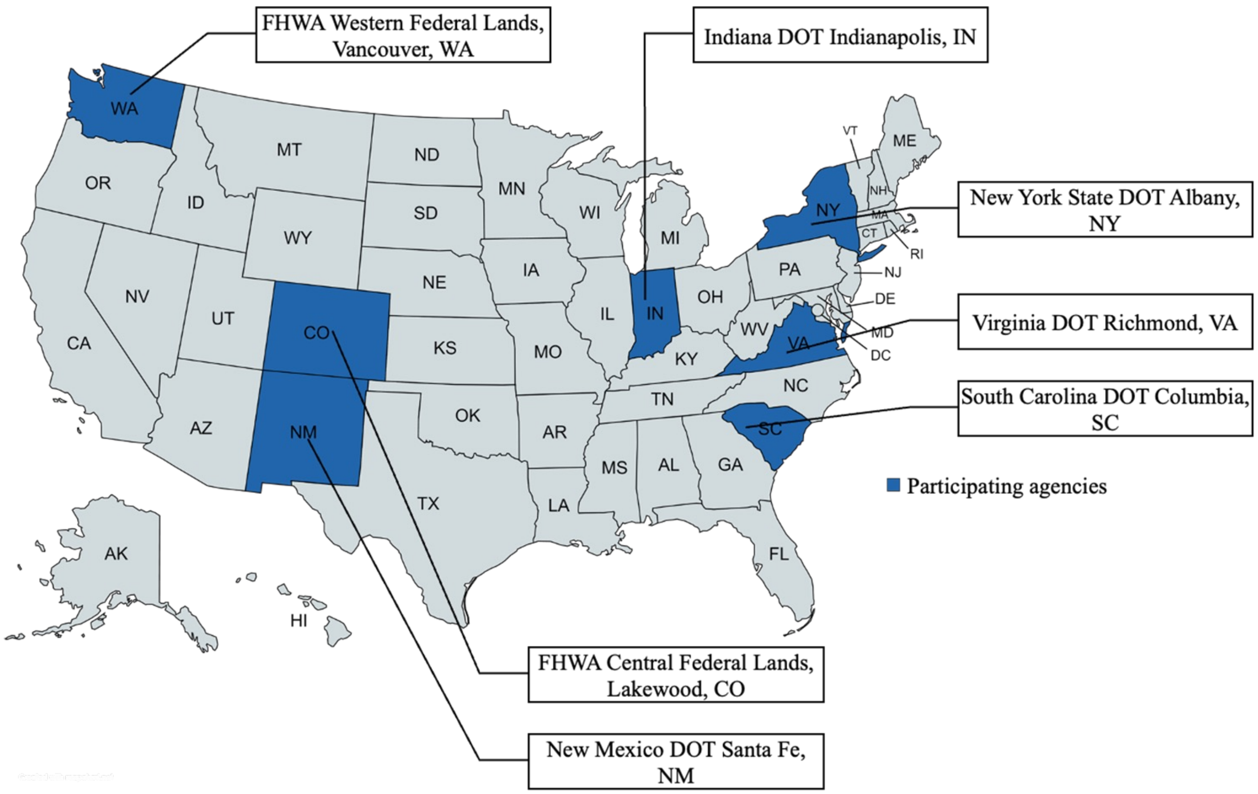

Image Source: University of Nevada Reno

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Participating Agencies

- 6 agencies
  - FLH
  - INDOT
  - NMDOT
  - NYSDOT
  - SCDOT
  - VDOT
- Virtual site visits and interviews

Federal Lands Highway Divisions

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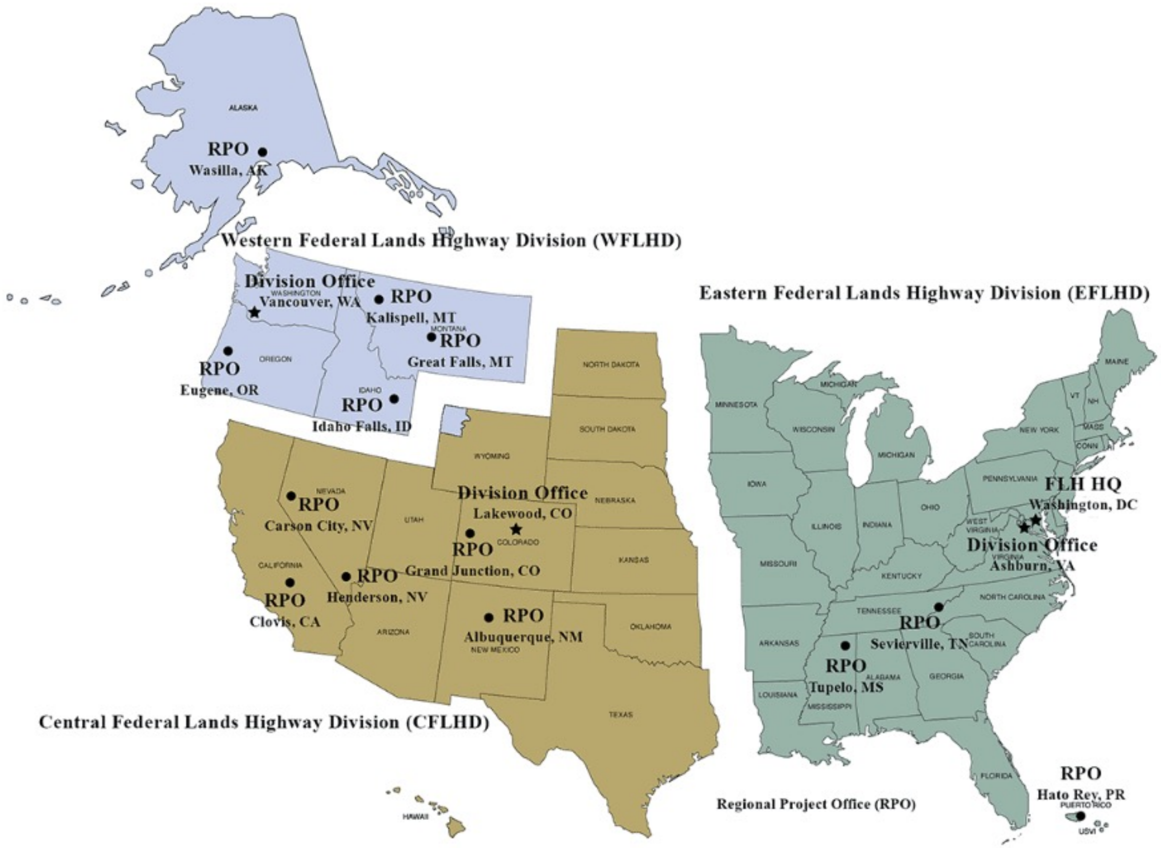

Scope

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- 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

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Recycling Technologies Used

Item	FLH	INDOT	NMDOT	NYSDOT	SCDOT	VDOT
CIR	Yes	Yes	Yes	Yes	No	Yes
CCPR	Yes	Yes	Yes	V. Limited	No	Yes
FDR	Yes	Yes	Yes	No	Yes	Yes
HIR	No	No	Yes	Yes	No	No

Years of Experience

Item	FLH	INDOT	NMDOT	NYSDOT	SCDOT	VDOT
CIR	50	5-10	3	20^+	n/a	10^+
CCPR	15	5-10	8	5^+	n/a	10^+
FDR	40	5-10	9	n/a	7	13^+
HIR	50	n/a	20^+	15^+	n/a	n/a

Agency Use of Technologies

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Percentage of Recycling Program

Item	FLH[1]	INDOT	NMDOT	NYSDOT	SCDOT	VDOT
CIR	6% (5%)	38%	10%	50 to 65%	0%	20%
CCPR	6% (5%)	12%	40%	<1%%	0%	18%
FDR	88% (80%)	50%	50%	0%	100%	62%
HIR	0%	0%	n/a	35 to 50%	0%	0%

[1]≈10% of FLH Recycling in RAP Millings

Outline

U.S. Department of Transportation
Federal Highway Administration

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- **Performance, Sustainability, Cost**
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Data collection vehicle for roadway condition

Performance & Sustainability

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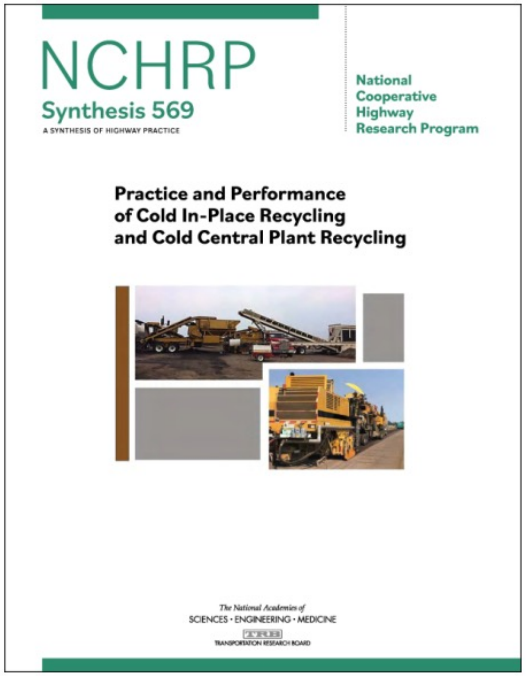
- *"A total of 40 agencies responded… Most cold recycling programs pave less than 50 lane-miles per year. Cold recycling is frequently used on roadways with annual average daily traffic (AADT) under 10,000, but more experienced agencies use cold recycling on roadways with AADTs between 10,000 and 25,000."*

- *"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."*

https://nap.nationalacademies.org/catalog/26319/practice-and-performance-of-cold-in-place-recycling-and-cold-central-plant-recycling



The use of a synthesis is not a Federal requirement.

Performance & Sustainability

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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

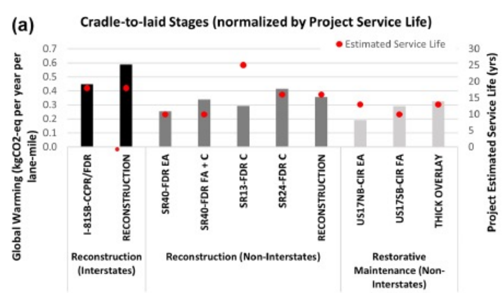
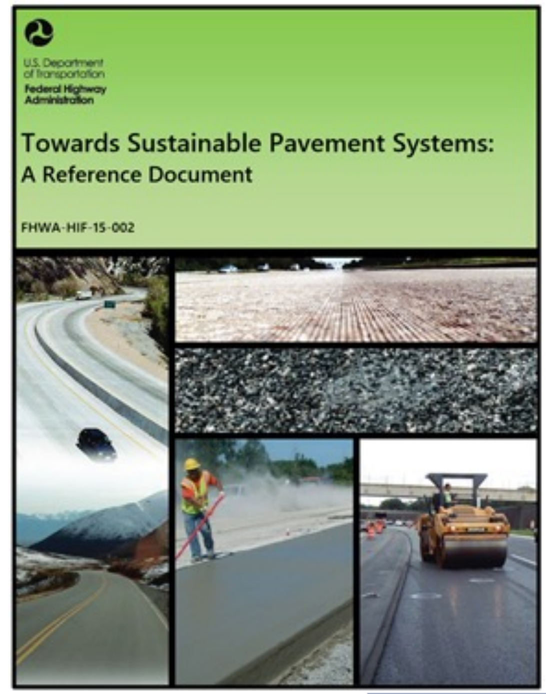


Image Source: Transportation Research Record, 2022, Vol. 2676(6) 75–86



INDOT FDR Projects

- FDR vs. Conventional Rehabilitation Structural Performance

- 40-70% Cost Savings

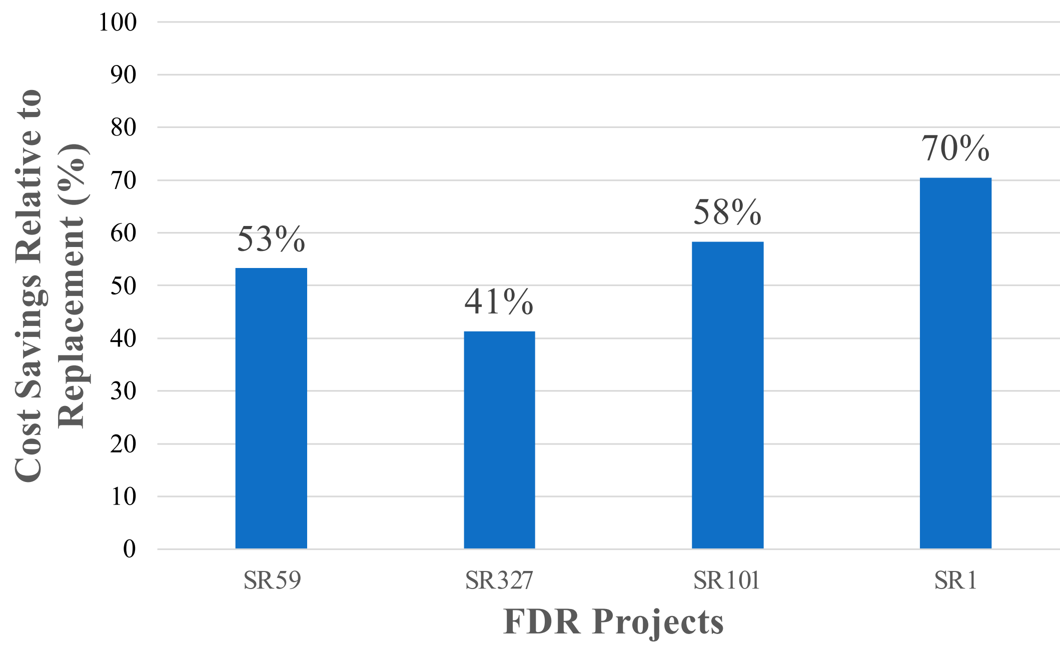
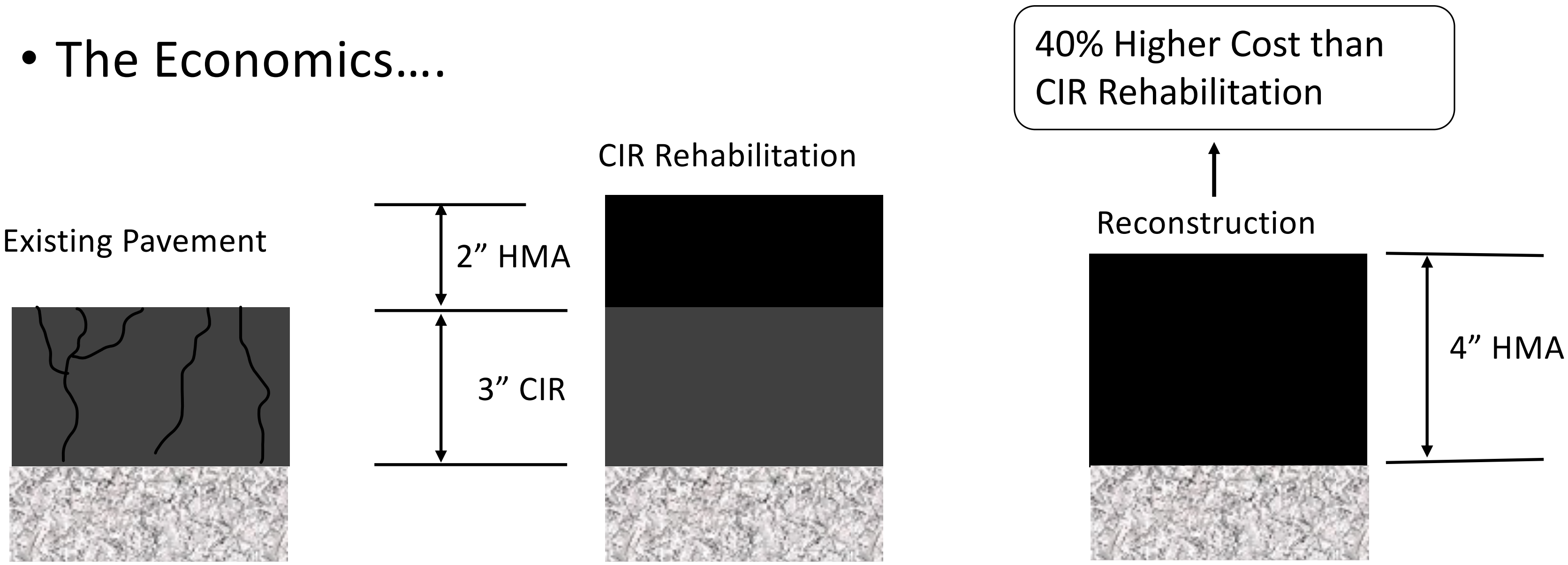


Image Source: Indiana Department of Transportation

FLH: CIR Cost and Performance

- The Economics….



Performance – Washington Road Tahoe National Forest, CA

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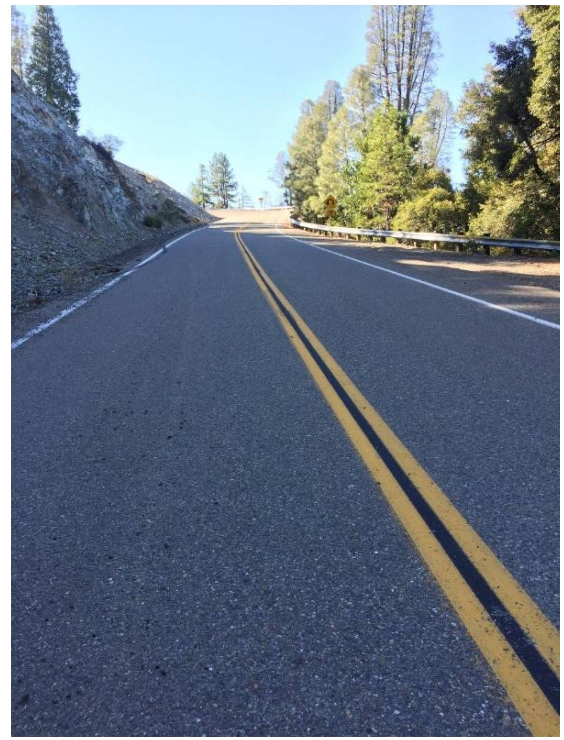
2009 – under construction



2019 – 10 years old

Performance – Ice House Road El Dorado National Forest, CA

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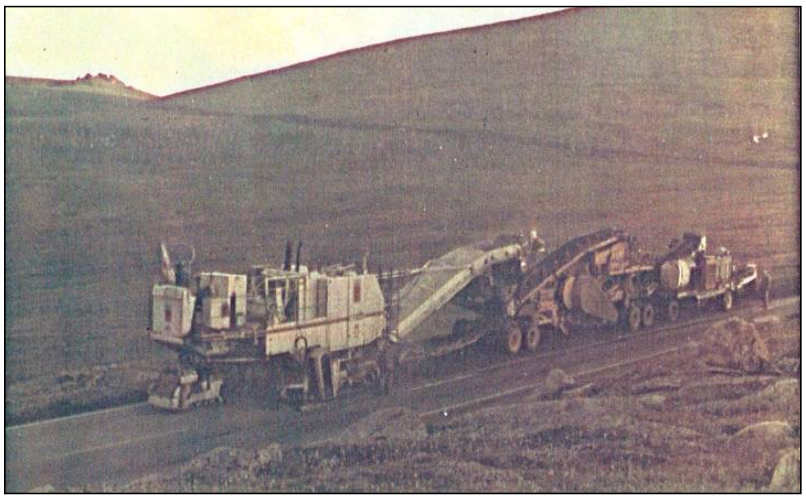
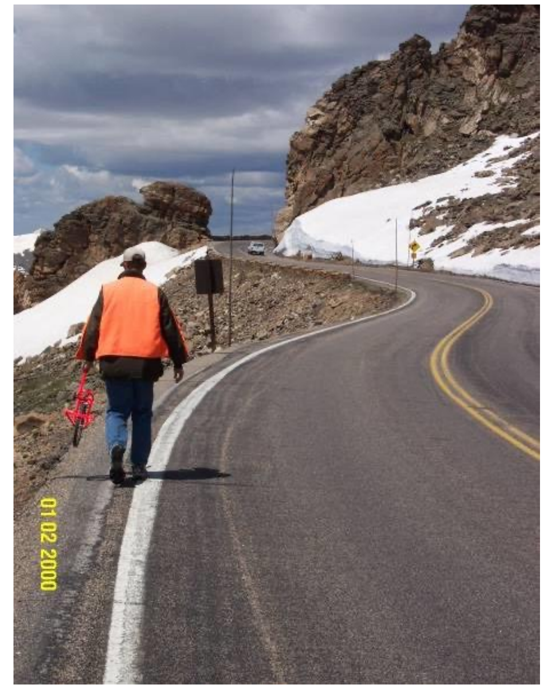
22 years old

31 years old

Performance – Rocky Mountain National Park, CO

1982 CIR





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After 26 years!

Outline

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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
    - https://www.fhwa.dot.gov/pavement/asphalt/pubs/hif17042.pdf

Project Selection: Possible Characteristics of a Good Candidate

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- End of service life.
- Minor patching.
- Fatigue cracking.
- 3-inch depth minimum.

Project Selection: Possible Characteristics of a Poor Candidate

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- Road geometry: grade and curves.
- Less than 3 inches.
- Geotextile in milling depth.
- Need to tie into existing structures.

Project Selection: Field Investigation

FEDERAL HIGHWAY ADMINISTRATION
VANCOUVER, WASHINGTON
GEOTECHNICAL SECTION
BORING LOG (English Units)

6 in H-S AUG
8 in H-S AUG
NQ CORE
HQ CORE
OTHER:

DEPTH (ft)	DESCRIPTION	GRAPHIC LOG	SAMPLE #	SAMPLE
	LATITUDE (DEGREES):48.67487800 LONGITUDE (DEGREES):-113.60747500			
0	Asphalt.			
0.5	Red to gray, silty fine to coarse SAND, some fine to coarse gravel, some clay, subangular to angular fragments, damp (SM) (BASE).			
2.0				

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

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

INDOT Pavement Treatment Selection

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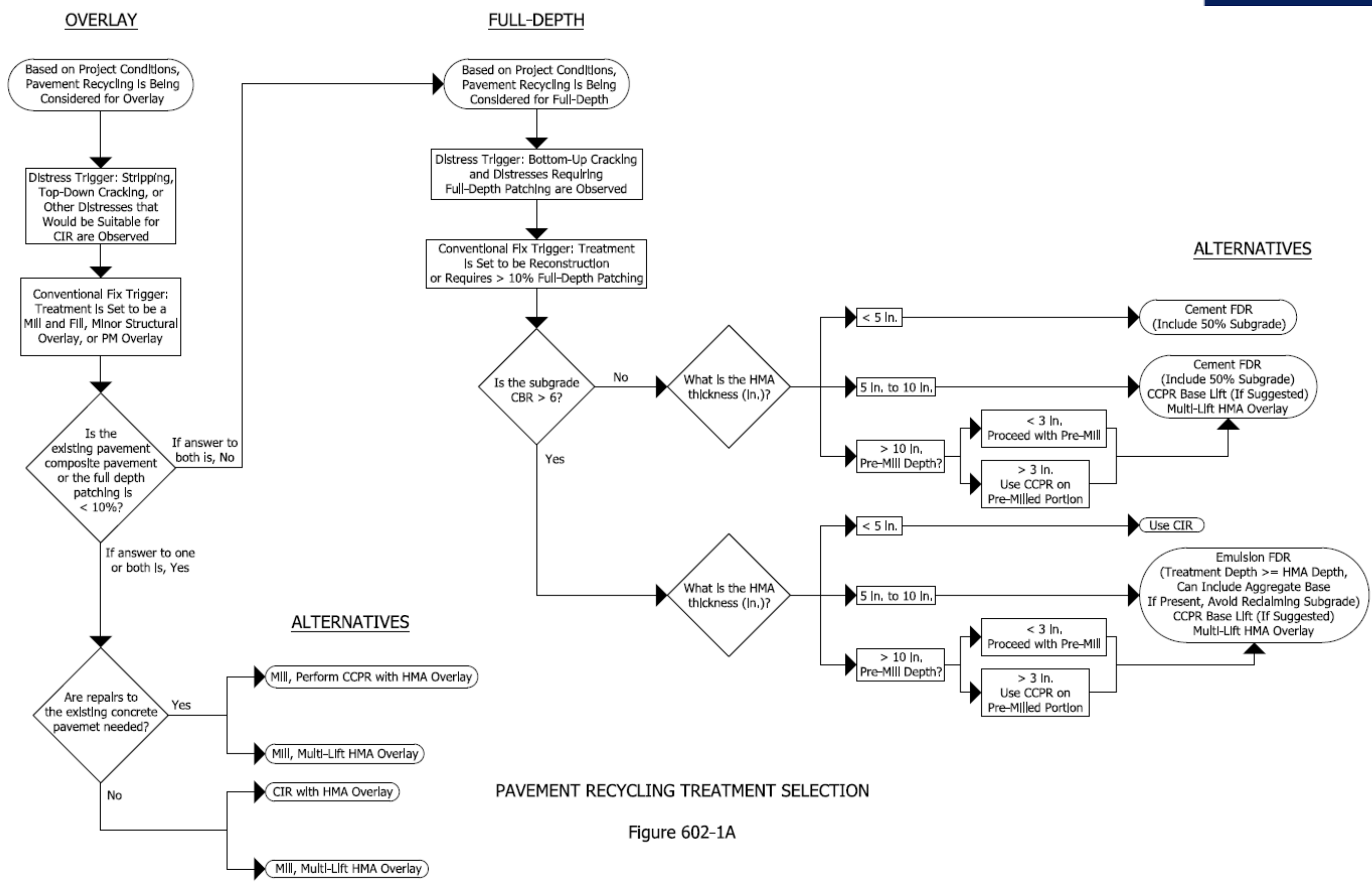


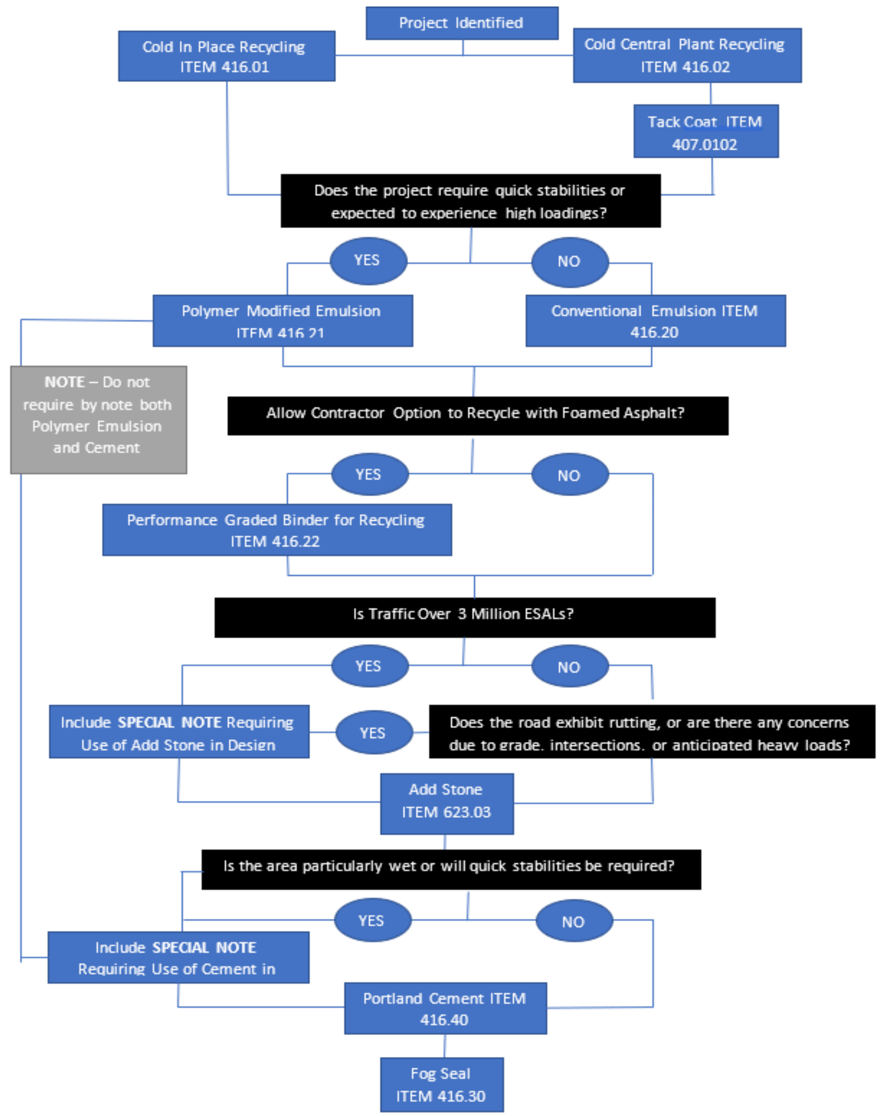
PAVEMENT RECYCLING TREATMENT SELECTION

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

NYSDOT



https://www.dot.ny.gov/divisions/engineering/design/dqab/cpdm

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Source: NYSDOT

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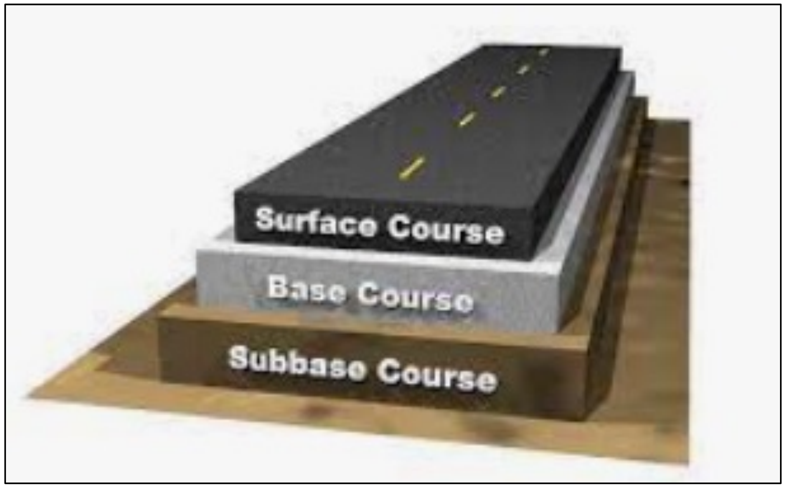

Structural Pavement Design

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

Item	FLH	INDOT	NMDOT	NYDOT	SCDOT	VDOT
CIR	0.28-0.30	75-100ksi	0.35	n/a[1]	n/a	0.35
CCPR	0.25-0.30	75-100ksi	0.35	n/a	n/a	0.35[2]
FDR AC	0.20-0.25	75-100ksi	0.30	n/a	n/a	0.25
FDR PC	0.15-0.22	75-100ksi	n/a	n/a	0.26	0.25

[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.

CIR Requires a Riding Surface

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Surface with:

- Asphalt pavement.
  - Use a tack coat.
- Double chip seal.

CIR Materials Selection – Binders & Active Fillers

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Item	FLH	INDOT	NMDOT	NYSDOT	VDOT
Binders	Engineered Emulsion	Emulsion	Engineered Emulsion	Emulsion, PM Emulsion, PG64S-22 Foamed Asphalt	Emulsion or Foamed Asphalt
Active Filler	Portland Cement or Lime Slurry	Portland Cement Allowed	Portland Cement or Lime	1% Portland Cement	Portland Cement

Terminology…binder, stabilizing agent, active fillers

CIR Mix Design

	FLH	INDOT	NMDOT	NYSDOT	VDOT
Compactor	Gyratory-35	Gyratory-30	Gyratory-30	Gyratory-30	Marshall-75
Emulsion	Indirect Tensile Strength & TSR	Marshall Stability & Retained Stability, Raveling	Indirect Tensile Strength & TSR Coating, Raveling	Indirect Tensile Strength & TSR or Retained Marshall Stability	Marshall Stability & Retained Stability
Foamed	n/a	n/a	n/a	Indirect Tensile Strength & TSR or Retained Marshall Stability	Indirect Tensile Strength & TSR, Half-Life

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Quality Control & Acceptance

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6 Core Elements of a QA Program

Common Production QC Measurements

- Binder.
- Moisture.
- Gradation top size.
- Density.
- Thickness.
- Curing.

Curing & Opening to Traffic

Item	FLH	INDOT[1]	NMDOT	NYSDOT	VDOT
Traffic	0 for 2 hours	-	0 for 2 hours	-	0 for 2 hours
Moisture Content	≤ 2.5%	≤ 3.0%	≤ 3.0%	-	≤ 50% of optimum moisture content
Time	Cover within 14 days	≥ 3 days or 10 days without rainfall	≥ 3 days	Emulsion ≥ 10 days; Foamed Asphalt ≥ 3 days	-

[1]Greater than 3 days and less than 3.0% moisture or cured 10 days without rainfall.

NCHRP Research Projects

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- NCHRP 09-62, Report 960 at: https://nap.nationalacademies.org/download/25971

NCHRP 09-62 [Completed]

Rapid Tests and Specifications for Construction of Asphalt-Treated Cold Recycled Pavements

Project Data	
Funds:	$999,737
Research Agency:	Virginia Transportation Research Council
Principal Investigator:	Brian Diefenderfer
Effective Date:	6/1/2017
Completion Date:	8/31/2022
Comments:	Publication pending

- 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.

https://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=4190

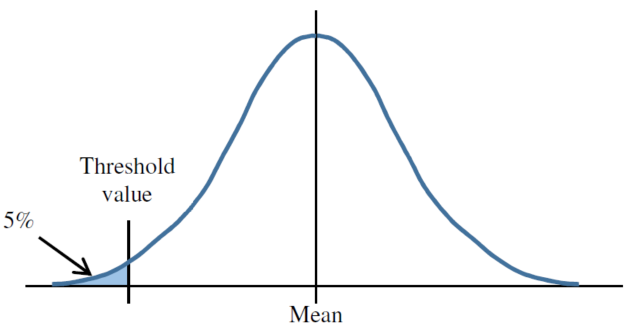
The use of an NCHRP Report is not a Federal requirement.

NCHRP Project 09-62 Phase III – Field Trials MnROAD

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



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

https://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=4190

NCHRP Research Projects

U.S. Department of Transportation
Federal Highway Administration

- NCHRP 14-43, Web-only Document 363 at: https://www.trb.org/Publications/Blurbs/182965.aspx

NCHRP 14-43 [Final]

Construction Guide Specifications for Cold Central Plant Recycling and Cold In-Place Recycling

Project Data	
Funds:	$250,000
Research Agency:	National Center for Asphalt Technology
Principal Investigator:	Benjamin Bowers
Effective Date:	5/26/2020
Completion Date:	8/31/2022
Comments:	Report Published as NCHRP Web-Only-Document 363

- 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.

https://apps.trb.org/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=4755

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

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Suggested Practices from Participating Agencies

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- 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

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- 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

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- 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

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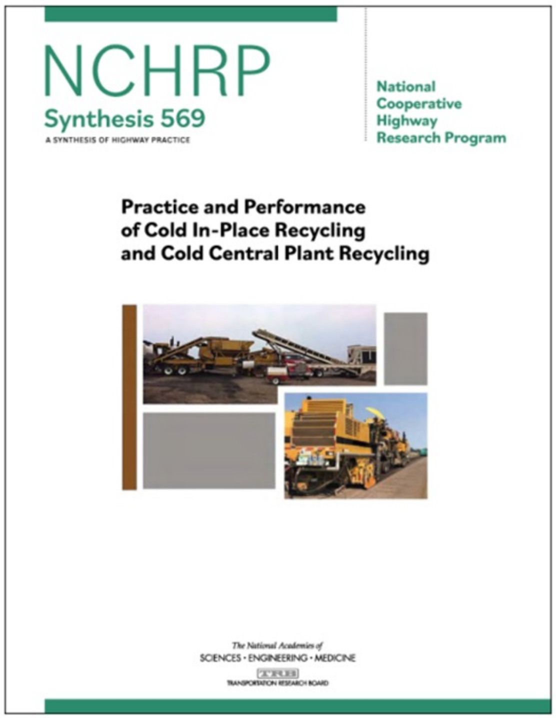
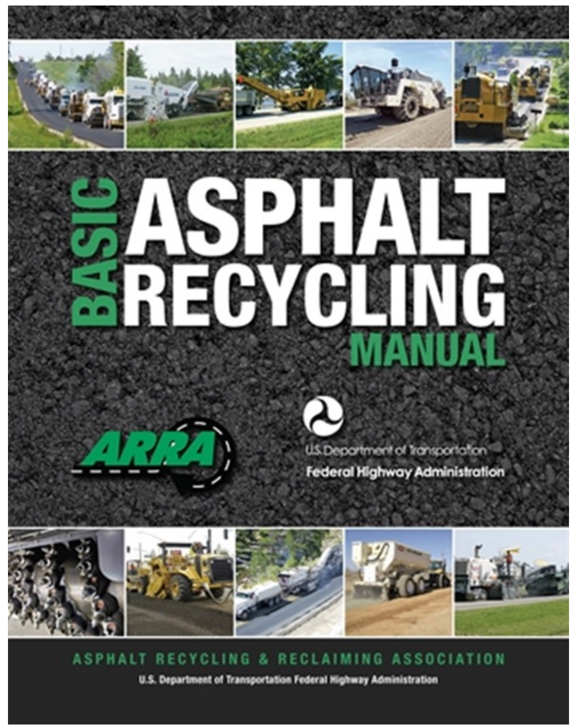
Federal Highway Administration





TechBrief

The Asphalt Pavement Technology Program is an integrated, national effort to improve the long-term performance and cost effectiveness of asphalt pavements. Managed by the Federal Highway Administration through partnerships with State highway agencies, industry, and academia, the program's primary goals are to reduce congestion, improve safety, and foster technology innovation. The program was established to develop and implement guidelines, methods, procedures, and other tools for use in asphalt pavement materials selection, mixture design, testing, construction, and quality control.

U.S. Department of Transportation
Federal Highway Administration

Office of Asset Management, Pavements, and Construction

FHWA-HIF-17-042

February 2018

Overview of Project Selection Guidelines for Cold In-place and Cold Central Plant Pavement Recycling

This Technical Brief provides project selection guidelines for the cold recycling techniques of cold in-place and cold central plant recycling. The Tech Brief intends to aid the user in properly selecting candidate projects for using cold pavement recycling. Significant improvements in cold recycling technologies have been made since the 2000s, including improvements in engineering, construction equipment, and test methods, together with improved mix designs, resulting in improved reliability of performance of the final product.

Introduction

Various in-place recycling techniques have been used to rehabilitate and maintain pavements in the United States since the 1930s. Two events of the 1970s rekindled interest in asphalt recycling: the petroleum crisis and the development of large-scale cold planing equipment with easily adjustable milling teeth.

In recent years, the economics and supply of petroleum and high quality natural aggregates have increased the need for cost-effective alternatives to virgin paving materials. Two in-place recycling alternatives include cold in-place recycling (CIR) and cold central plant recycling (CCPR). These methods provide owner agencies with cost effective and sustainable methods to repair their aging asphalt pavements. When applying the **right treatment** to the **right road** at the **right time**, and when properly designed, specified and constructed, these methods can result in cost savings of 30 to 50 percent compared to conventional asphalt operations, thus allowing for more miles of improved roadways from the associated cost savings. In addition, CIR and CCPR have been shown to accelerate project delivery and mitigate construction traffic congestion while including improvements in the overall sustainability of operations.

In spite of economically and environmentally effective technologies being available for decades, many owner agencies

1

References

U.S. Department of Transportation
Federal Highway Administration

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

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

Thank You

Q & A

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