

USING DESIGN AND LIFE-CYCLE ANALYSES TO SUPPORT COLD RECYCLING DECISIONS

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University of California Pavement Research Center, UC Davis

3rd International Workshop on Asphalt Recycling Technologies

September 21 - 22, 2026



Outline



- Introduction and background
- Cold recycling in agency practice
- California analysis tools
- Case study
- Way forward

Introduction

- Cold recycling: proven strategy, many publications, lots of “reinvention of the wheel”
- Relatively slow implementation as standard practice
- Many barriers to implementation in the US:
 - Siloed development of terminology, guidance, and specifications
 - Agency policy and practice
 - Uncordinated research with often contradictory findings and recommendations
 - Unsupported marketing claims
 - Lack of federal leadership

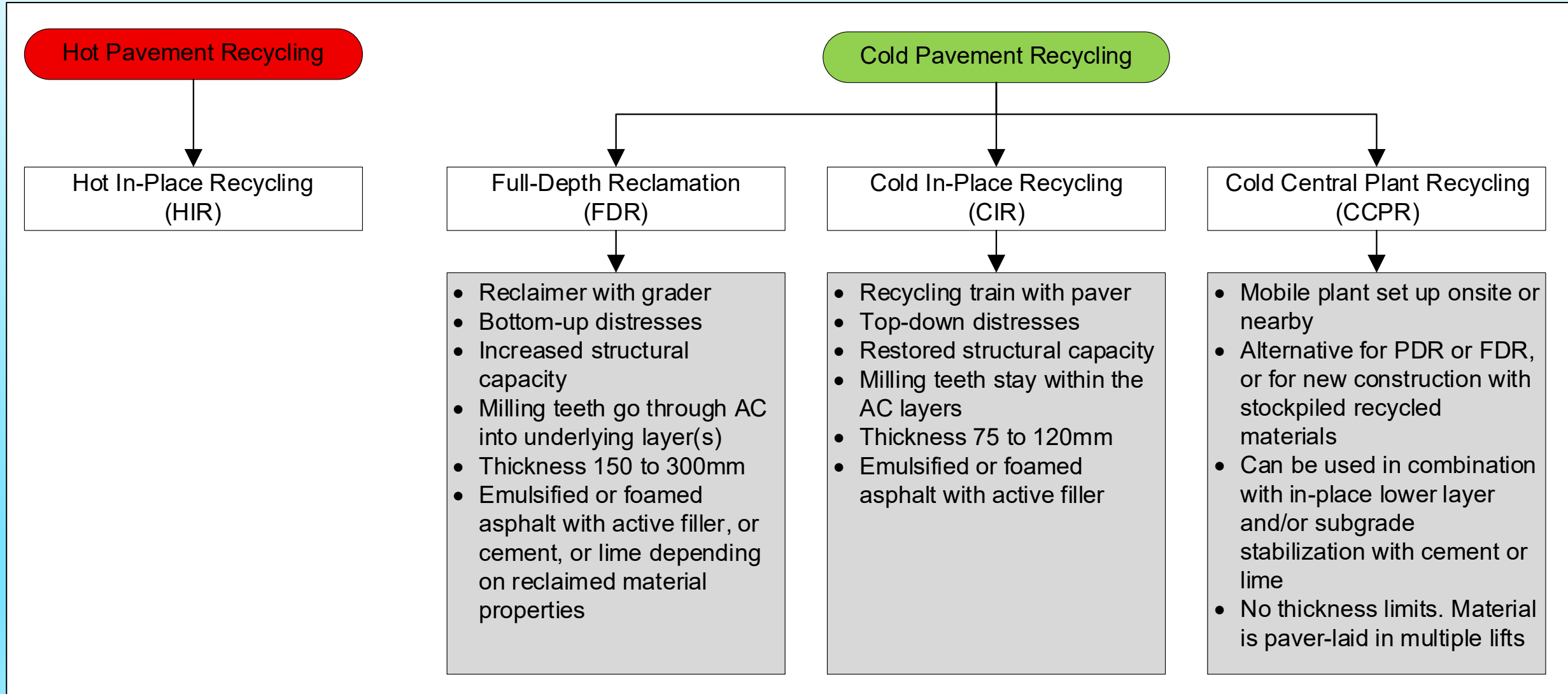


Evolution of Cold Recycling

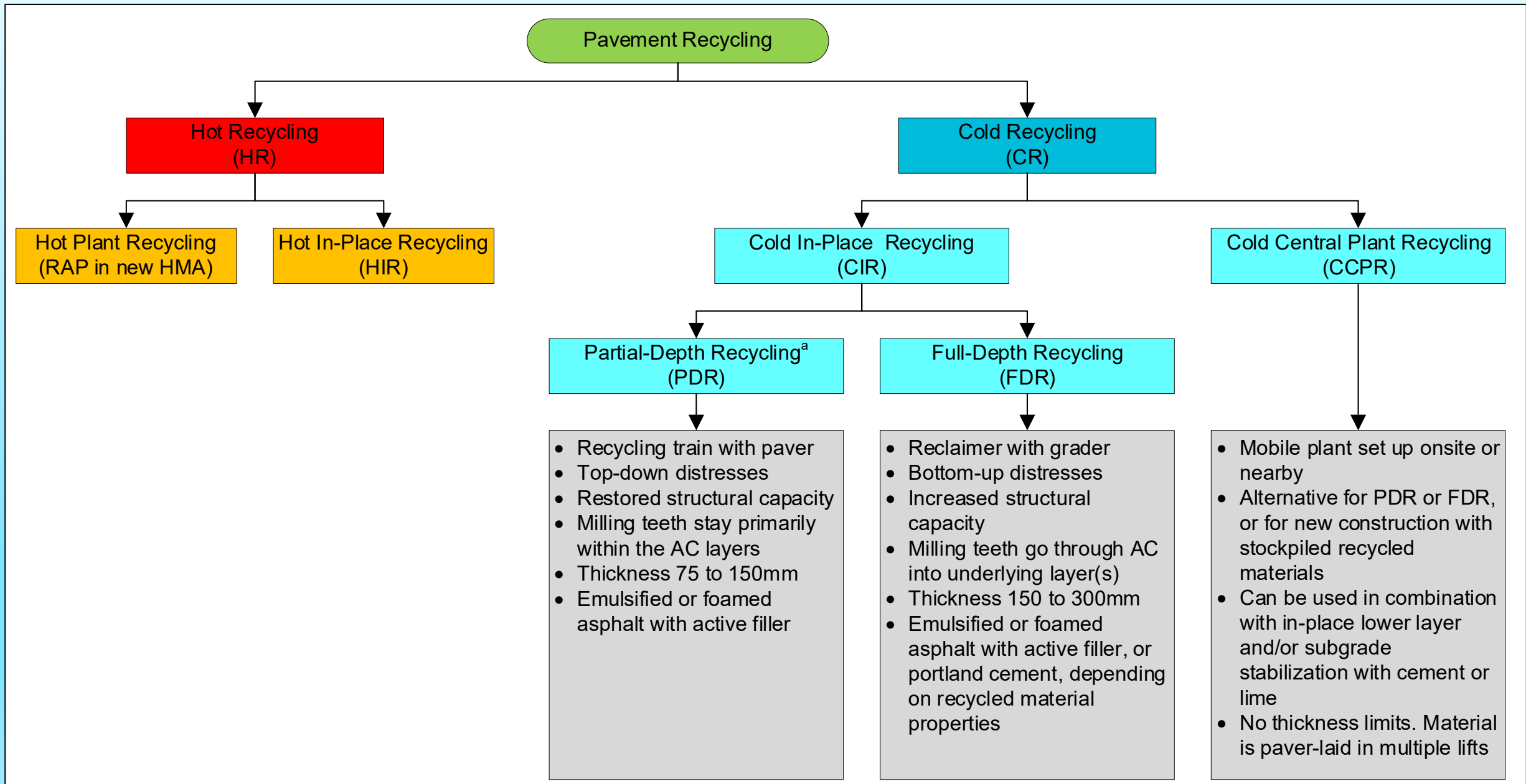
- Cold recycling started with modification of machines originally developed for other purposes:
 - Soil stabilizers for FDR
 - Focus on “rehabilitation”
 - Milling machines for CIR/PDR
 - Focus on “maintenance”
- Development was incremental and independent as were terminology, stabilizer choice, mix design methods, and specifications
- Latest generation of machines developed specifically for CR (in-place and central plant)
 - Efforts to also standardize stabilizer choice, testing, and specification approaches for CR
 - Some choices now left to contractor



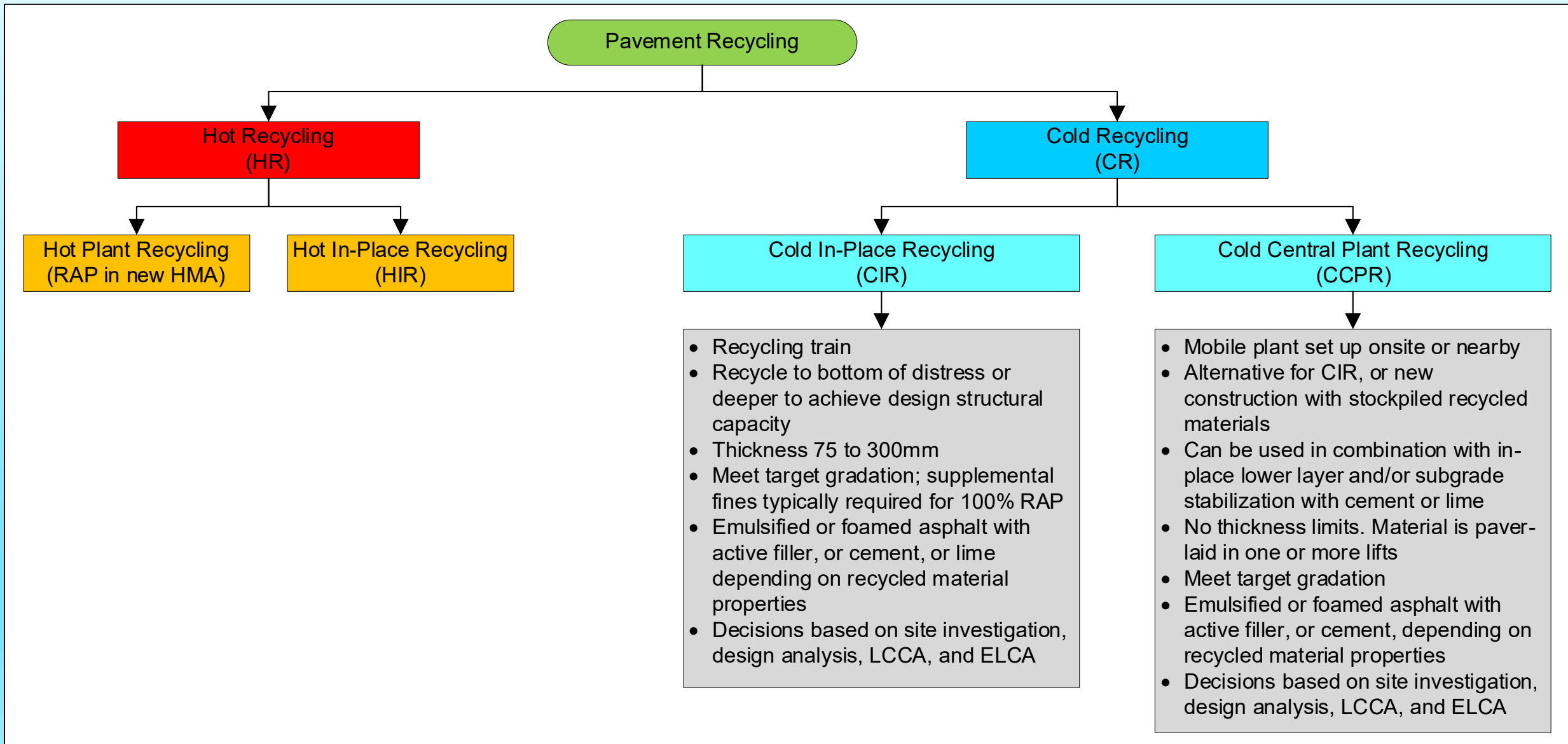
“Old” Terminology (still widely used)



Revised to Better Reflect Processes/Agency Practice



Future Terminology Based on New Developments?



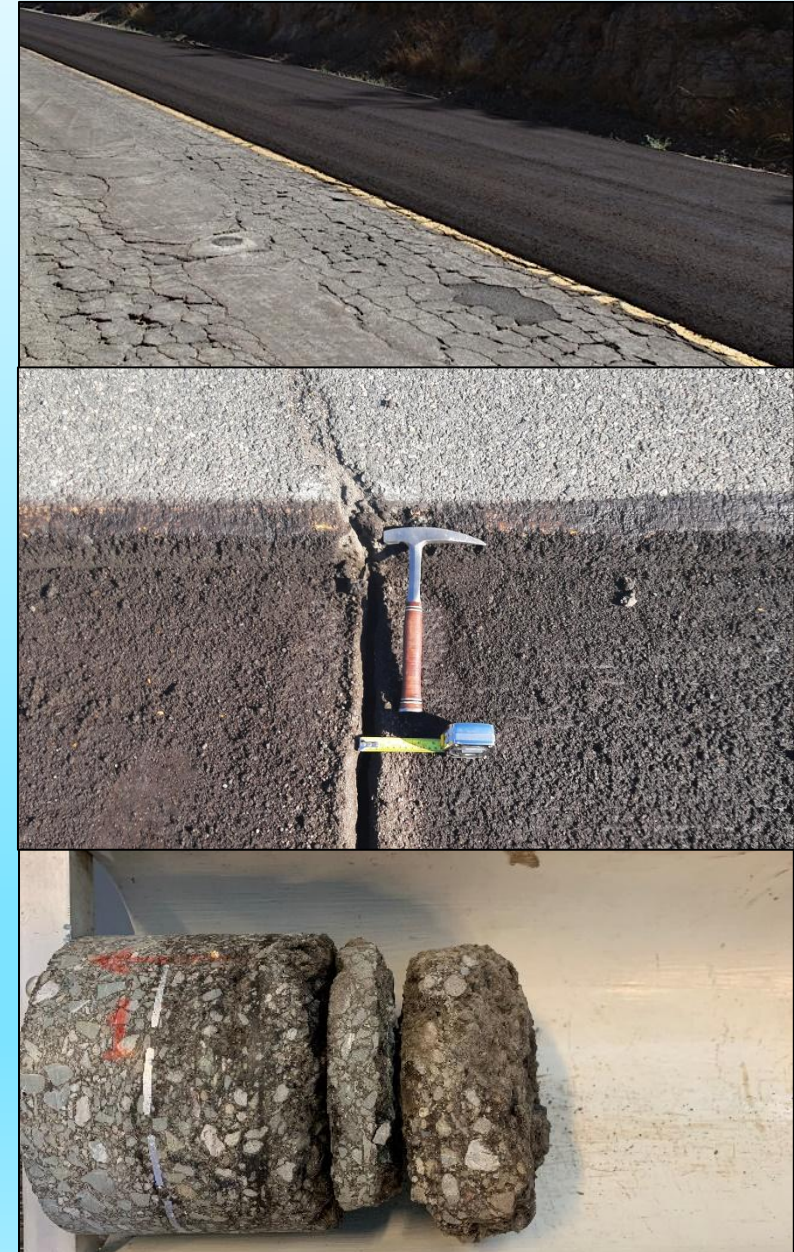
Outline



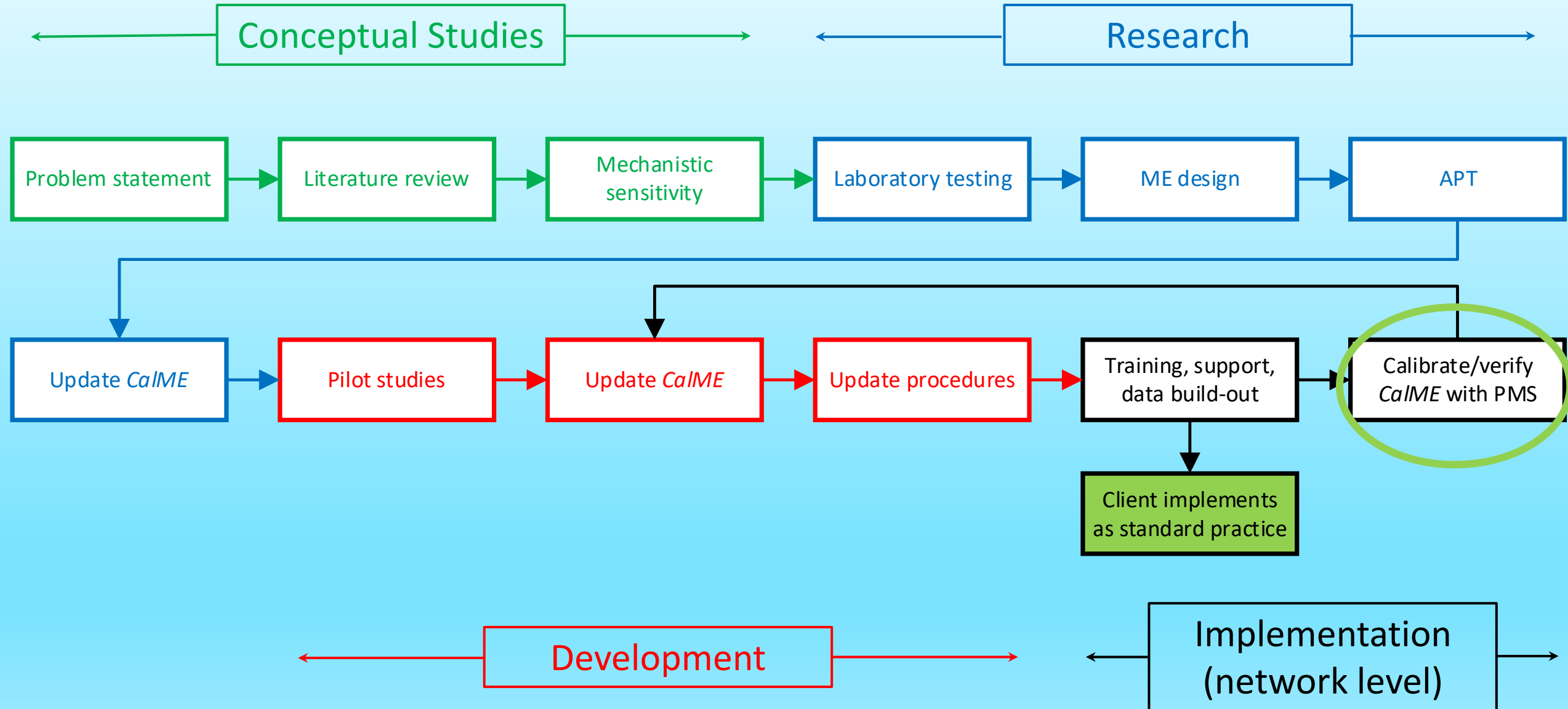
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Cold Recycling in Agency Practice

- Historically, agencies only used remove and replace strategies
 - Exponential increase in cost/user delay with increasing depth
 - Clear difference between “maintenance” and “rehabilitation”
 - Depth restrictions for maintenance
 - Different design requirements and funding sources
 - Continue with “maintenance” until rehabilitation is awarded
 - Cover the problem
- Introduction of cold recycling
 - CIR or PDR was put in the “maintenance” box
 - FDR was put in the “rehabilitation” box
 - Same design approach and restrictions as remove and replace
 - Major barrier to implementation?
- Policies have generally not been updated to use cold recycling effectively
 - Has led to inappropriate recycling choices and poorer than expected performance



Cold Recycling Research Roadmap



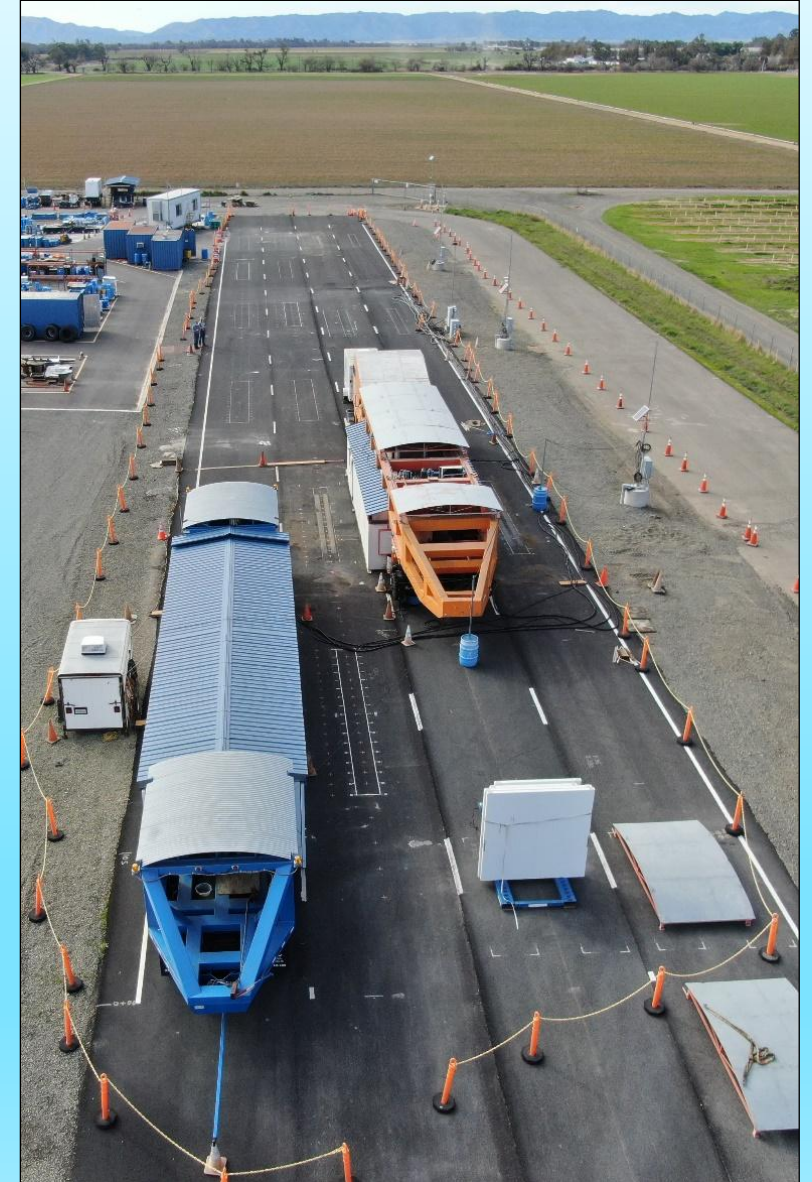
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California Analysis Tools

- Three primary tools
 - *CalME*: mechanistic-empirical design analysis
 - *eLCAP*: environmental life cycle analysis
 - *RealCost-CA*: life cycle cost analysis
- Based on phased pavement research studies
 - Laboratory, APT, and long-term field performance (visual, coring, and FWD)
- Integrated and use standard databases
- Pre-populated with basic input data



CalME: CALTRANS Mechanistic-Empirical Structural Analysis Program for Flexible Pavements

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Useful Links

- Caltrans
- UCPRC
- CalME v3.DD001.3 (August 2020)

Members role

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Project ID Cold recycling test track

Trial Title Lane 3 CCPR over FDR

Project Location

District 3

County Placer

Route 80

Direction West

PM Start 0.100

PM End 4.000

No. Lanes 3

Project Length: 3.900 mi Lane Miles: 13.486 Avg #lanes: 3.46

Traffic Count Information

Location	Location Description	AADT	AADTT	% Trucks
1.953-1.975		87,500	4,871	5.6

Climate

Climate Zone Inland Valley

Suggested Inland Valley

Design Lane Traffic Loads

Load Distribution (WIM Station) Group1a

Suggested Group1b

Growth Rate (From First Year) 0.0 %

First Year Axles / Design Lane 12,324,877

First Year Trucks / Design Lane 4,294,143

Design Life 40 yrs Total ESALs 125,888,553 TI 16.0

Create a Trial Structure

(Using Design Life and TI)

Subgrade CL

Generate

Error Message Summary

Pavement Structure

Update Modulus for the Selected Layer Type Using Unconfined Compressive Strength (UCS): MPa

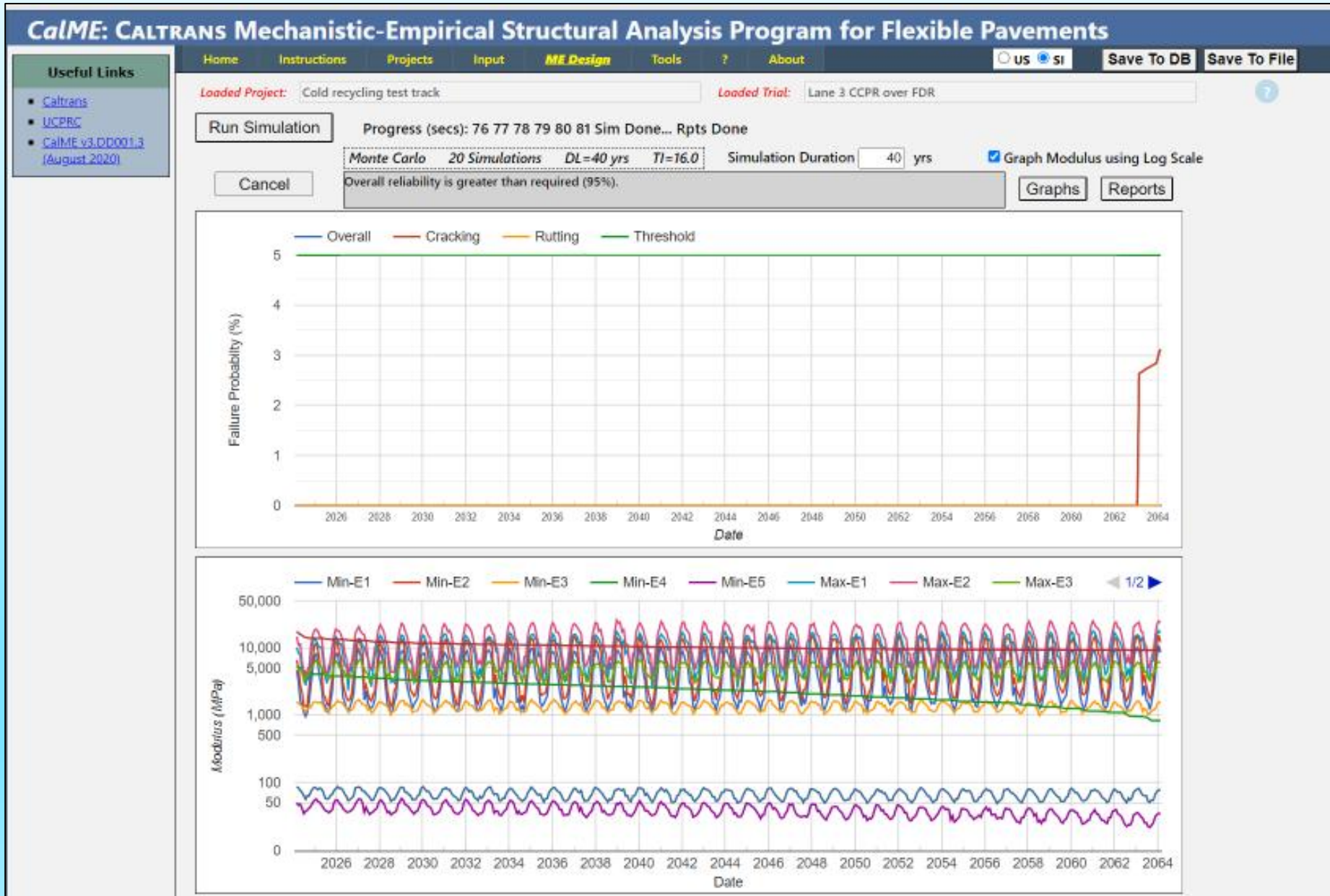
☐ TS->CSS
 ☐ TS->LS5
 ☐ CTB-Class B
 [Apply](#)
[Delete All](#)

#	Old	Layer Type	Age (d)	Material	Thickness (mm)	Modulus-E (MPa)	R-value	GF	Cost (\$/m3)	Actions
1		HMA	90	2020 Standard HMA Type A Mix with PG 64-10 Binder and up to 15% RAP for non-PRS Projects	60	6,516.2	N/A	1.64	0.00	Edit Delete Insert
2		HMA	90	2020 Standard HMA Type A Mix with 25% RAP for non-PRS Projects	60	8,326.1	N/A	1.38	0.00	Edit Delete Insert
3		CCPR	90	CCPR-FA with 2020 Standard FDR-FA Properties	180	2,999.9	N/A	N/A	0.00	Edit Delete Insert
4		FDR	N/A	2020 Standard FDR-C	300	10,000.2	N/A	1.70	0.00	Edit Delete Insert
5		Subgrade	N/A	2020 Standard CL	∞	68.0	16	N/A	0.00	Edit Delete Insert

[Add Layer](#)
[Add 2 Layers](#)
[Add 3 Layers](#)
[Add 4 Layers](#)
[Add 5 Layers](#)

For CL Subgrade, AB-min is 150 or Equiv.

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eLCAP™: environmental Life Cycle Assessment for Pavements Tool

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Useful Links

- Caltrans
- UCPRC

Members role

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Loaded Project: Workspace project title-516

Loaded Trial: Workspace trial title-516

Project Location

District

County

Route

Direction

```
..... PM Start .....
```

..... PM End

3

Yolo

128

East

None

5 000

None

7.00

0000

Climate Zone: Inland Valley

Project Length: 1.986 mi

Lane Miles: 1.986

Avg #lanes: 1.00

Error Message Summary

● Cross Section

○ Activities

Life Cycle Event 

Date: Activity N/A

LSI=0.000

TW=12.00

RSI=0.000

[LSI] Embankment Left-Slope	[LupS] Left Unpaved Shoulder Width (ft)	[LpS] Left Paved Shoulder Width (ft)	[TW] Traveled Way Width (ft)	[RpS] Right Paved Shoulder Width (ft)	[RupS] Right Unpaved Shoulder Width (ft)	[RSI] Embankment Right-Slope	Actions
0.0000	0.000	0.000	12.000	0.000	0.000	0.0000	Edit

Traffic Segment Information at Center of Project (Single Direction)

PM Boundaries	AADT	AADTT	%Trucks	WIM		1st Year Design Lane (2026)		Tl ₂₀	Axles/Truck	Last Traffic Survey	
				Group	Spectrum	Trucks	ESALs			Year	%Growth
5.900 - 6.132	1,100	69	6.28	Group1a	Spectrum1	45,997	33,711	9.1	2.870	2012	5.9

Outline



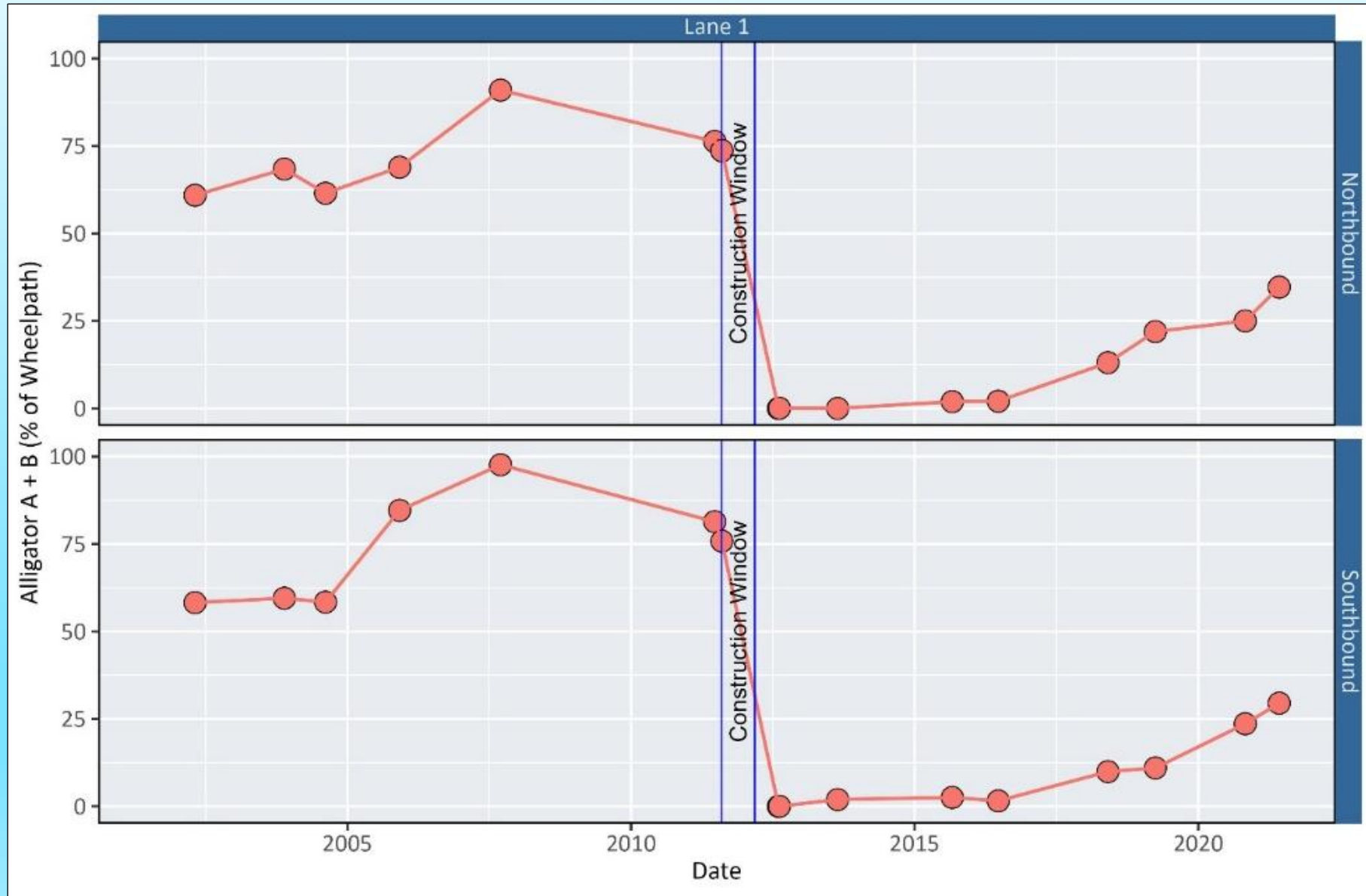
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Case Study Example

- 2-lane road (78 lane kms), 2.5m ESALs over a 20-year design
- Rehabilitated in 2012 with a 60mm mill and 100mm overlay
 - Road had extensive fatigue cracking
 - Empirical R-Value design used
- Reflected distresses started reappearing in 2018
 - *CalME analysis on rehab design predicted 5% wheelpath cracking after 5 years, 10% after 7 years, and 25% after 10 years*
- Various maintenance interventions to address issues



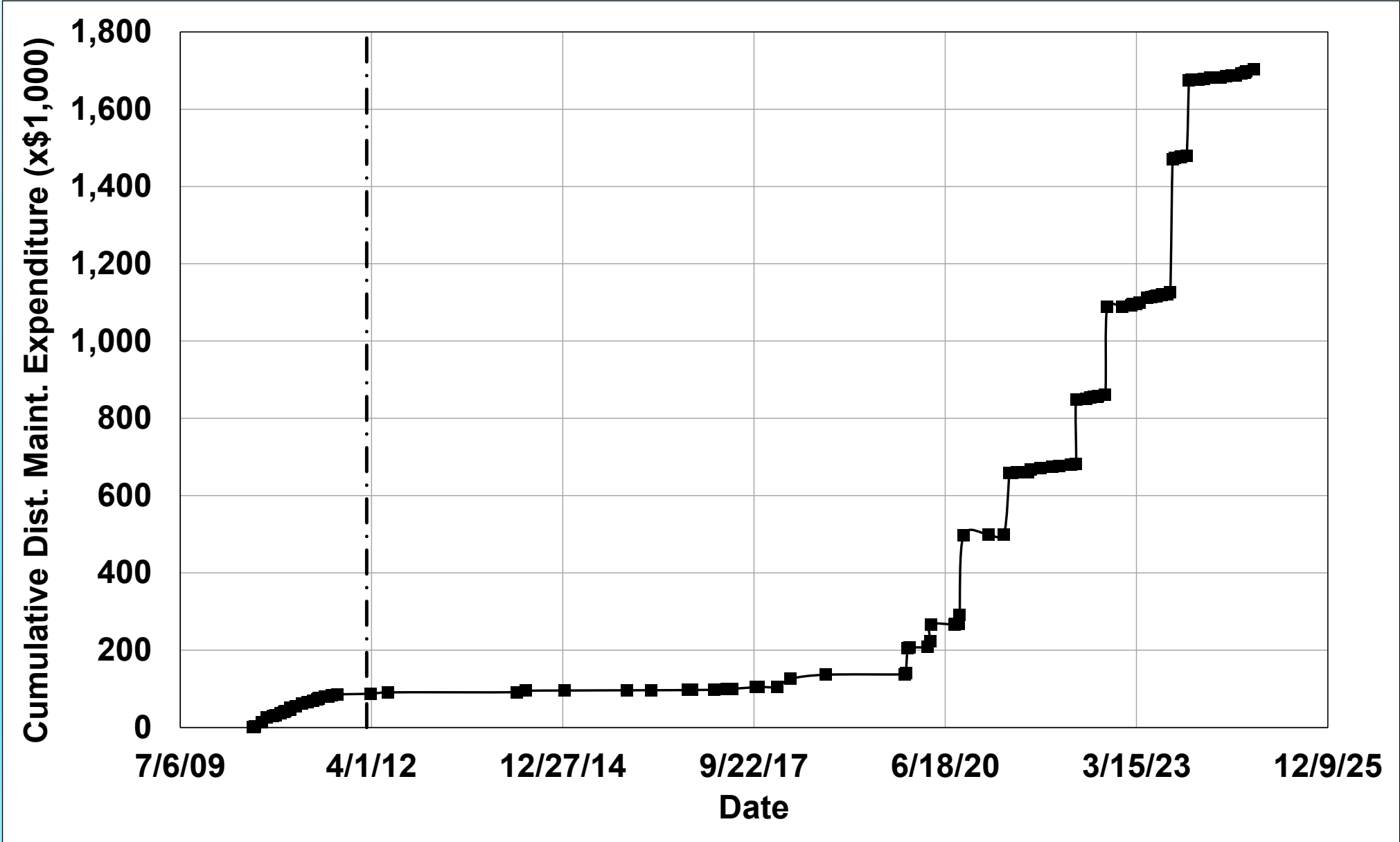
PMS Data (*CalME* is calibrated with PMS data)



2023 Site Investigation



Maintenance Expenditure



Analysis

- 5 maintenance options investigated until rehabilitation is scheduled again
 - Mill and overlay
 - Wheelpath patch with overlay (180mm)
 - PDR with overlay (75, 105, 120, 165, 195mm)
 - To assess leaving distresses below PDR
 - PDR + supplemental fines with overlay
 - Optimized cold recycling (300mm CR)
 - PDR depth restrictions are 100mm/120mm
 - FDR currently not permitted as maintenance
- All options had same 60mm HMA overlay



Analysis Assumptions

- 20-year design, 40-year analysis period
- Failure criteria set at 5% wheelpath cracks or 10mm rut
- Alternative repeated at end of life or 5 years after construction if fails early
- Seal coat at 12-year intervals if option has not reached failure criteria
- 3.2% discount rate for LCCA

CalME: CALTRANS Mechanistic-Empirical Structural Analysis Program for Flexible Pavements

Home Instructions Projects **Input** ME Design Tools ? About US SI Save To DB Save To File

Project ID: IPR Guide Examples Trial Title: Guide Example #1

Project Location

District	County	Route	Direction	PM Start	PM End	No. Lanes
3	Yolo	16	West	None 0.000	None 5.000	1

Project Length: Lane Miles: Avg #lanes:

Traffic Count Information

Location	Location Description	AADT	AADTT	% Trucks
0.632-2.800		350	35	9.9

Climate

Climate Zone: Inland Valley Suggested Inland Valley

Design

Select Load Dist: HMA (ation) Group1a RHMA-G suggested Group1a Growth: FDR (ear) 5.5 % First Year: PDR (ane) 9,437,939 First Year: CCPR (ane) 3,288,297

Design: LCB Total ESALs: 73,160,254 TI: 15.0 (rounded)

Pavement

Update: AB CTB-Class A CTB-Class B ATPB AS TS Subgrade

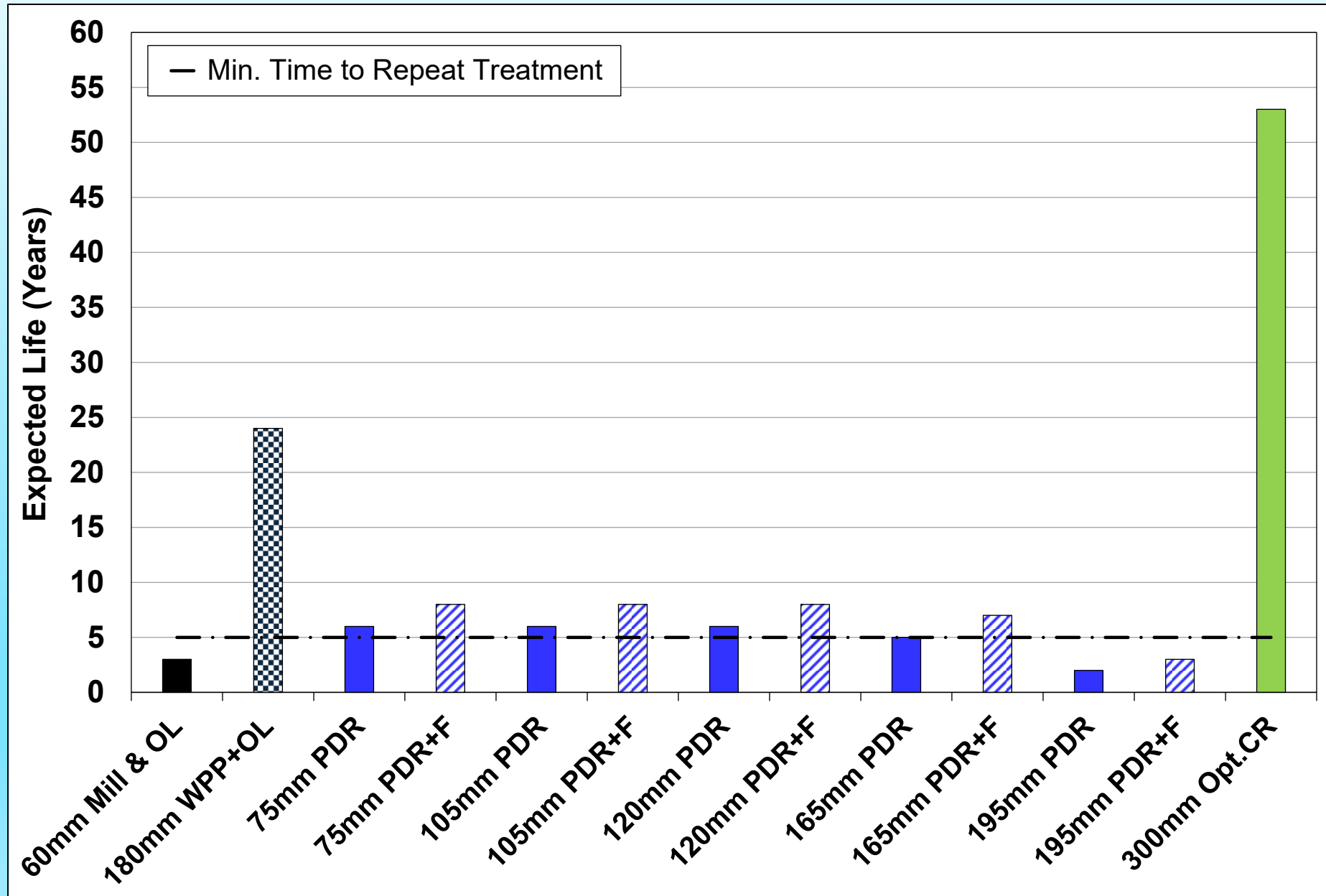
Selected Layer Type Using Unconfined Compressive Strength (UCS): 300 psi TS->CSS TS->LSS CTB-Class B Apply Delete All

#	Old	Age (d)	Material	Thickness (ft)	Modulus-E (ksi)	R-value	GF	Cost (\$/ft3)	Actions
1		90	2020 Standard RHMA-G with PG 64-16 base binder for non-PRS Projects	0.20	627.9	N/A	N/A	0.00	Edit Delete Insert
2		90	2020 Standard HMA Type A Mix with PG 64-16 Binder and up to 15% RAP for non-PRS Projects	0.20	945.1	N/A	1.46	0.00	Edit Delete Insert
3		90	2020 Standard CCPR-EA or CCPR-FA	0.50	261.1	N/A	1.50	0.00	Save Cancel
4		28	2020 Standard CSS (Needs UCS)	1.00	1,000.0	N/A	N/A	0.00	Edit Delete Insert
5		N/A	2020 Standard SM	∞	21.5	37	N/A	0.00	Edit Delete Insert

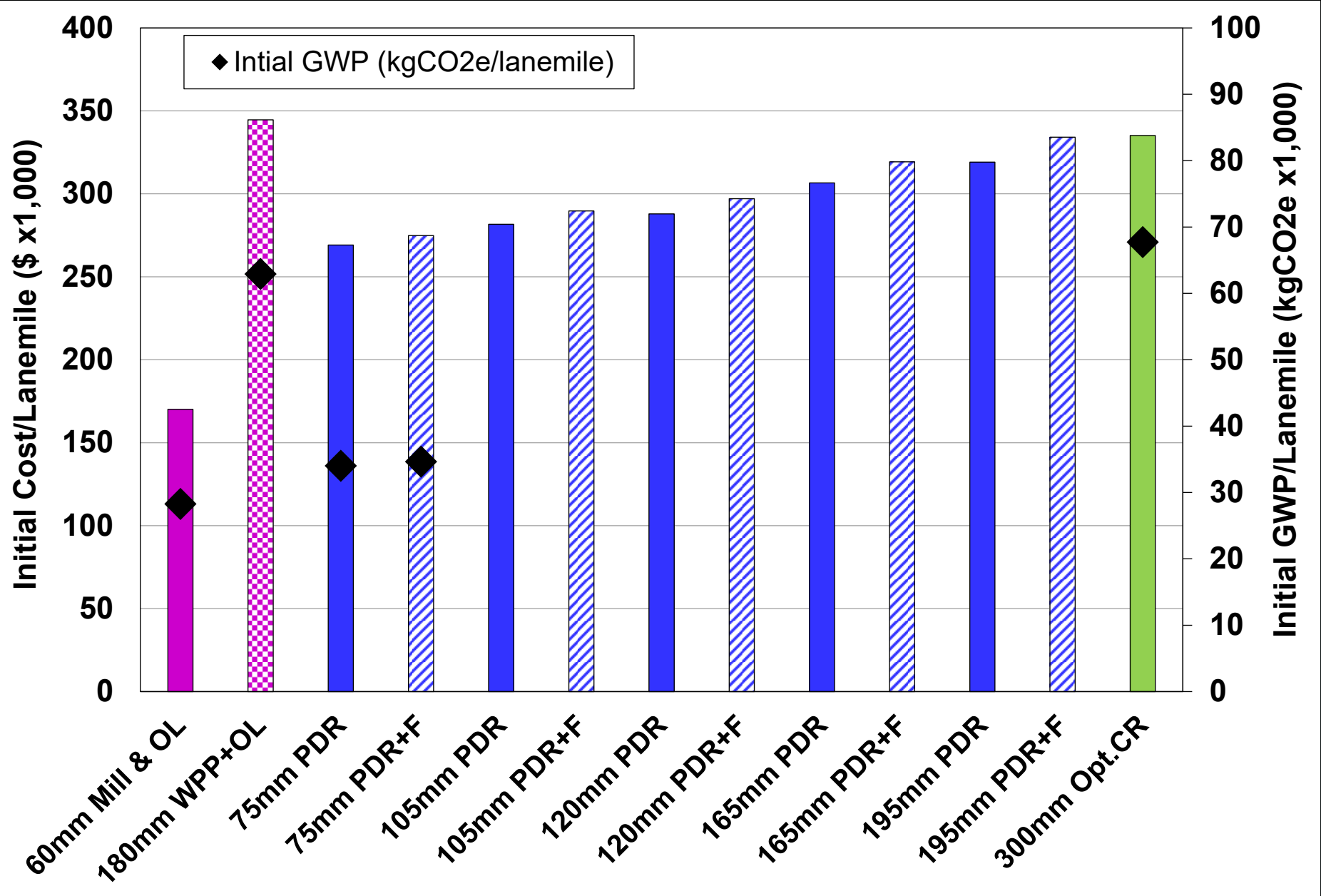
Add Layer Add 2 Layers Add 3 Layers Add 4 Layers Add 5 Layers Min thick: 0.25; Max thick: ∞

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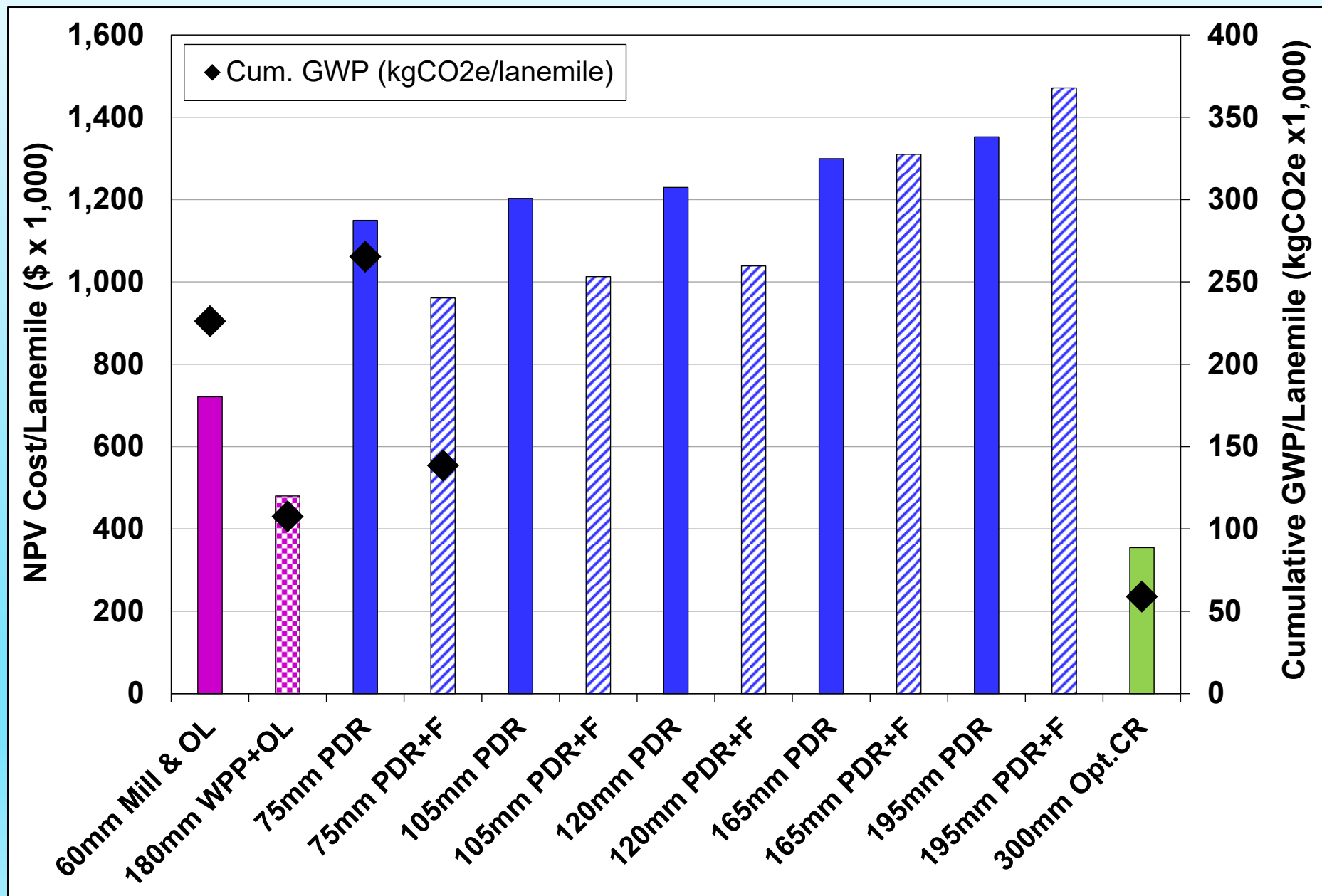
CalME Analysis: Expected life to reach 5% WP cracks



LCCA and LCA: Initial Cost



LCCA and LCA: NPV & Cumulative GWP



Analysis Summary for Optimized CR

- Summary of optimized CR choice
 - Expected life:
 - 53 years for optimized CR
 - 3 years for mill & overlay
 - 6 years for 105mm standard PDR
 - Initial cost:
 - OCR is 100% more than mill & overlay
 - OCR is 20% more than 105mm standard PDR
 - Life-cycle cost:
 - OCR is 50% less than mill & overlay
 - OCR is 70% less than 105mm standard PDR
 - Initial GWP:
 - OCR is 140% more than mill & overlay
 - OCR is 100% more than 105mm standard PDR
 - Life-cycle GWP:
 - OCR is 380% less than mill an overlay
 - OCR is 450% lower than 105mm standard PDR



Analysis Summary for Optimized CR

- Analyses are quick with the web-based tools
- Adding supplemental fines to 100% RAP mixes has benefits, but does not compare to optimized cold recycling
- Numerous other case studies completed to show benefits of different cold recycling strategies
- Layer coefficient design methods will not be accurate for this type of analysis



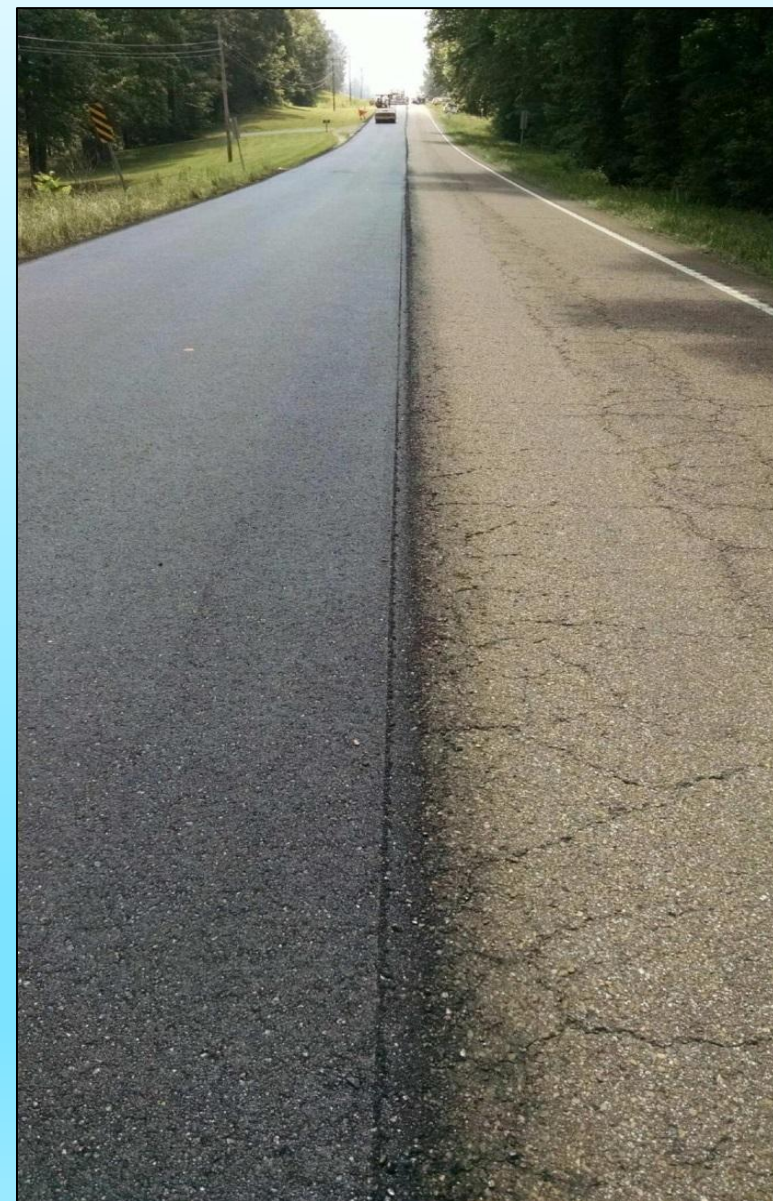
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Way Forward

- Keep doing what we are doing and expect a different outcome?
- Or, work with agencies and industry to show benefits of optimized cold recycling, and provide guidance on policy updates to accommodate it
 - Required changes are significant
 - Comfort zones may be tested 😊
 - Research must facilitate change and support implementation, not just continue to prove that CR “works”
 - Proving life-cycle cost savings, sustainability, and resilience are important factors
 - Quality analysis tools will be critical for agency decision makers and designers



Thank-you!



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