CSHub MIT CONCRETE SUSTAINABILITY HUB

Introduction to the MIT Pavement LCA tool: Lessons learned

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National Concrete Consortium Meeting

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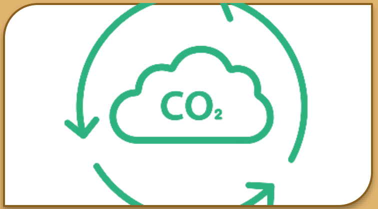
The CSHub is reshaping the way that stakeholders understand concrete as a solution within three contexts



Carbon - Neutral Industry

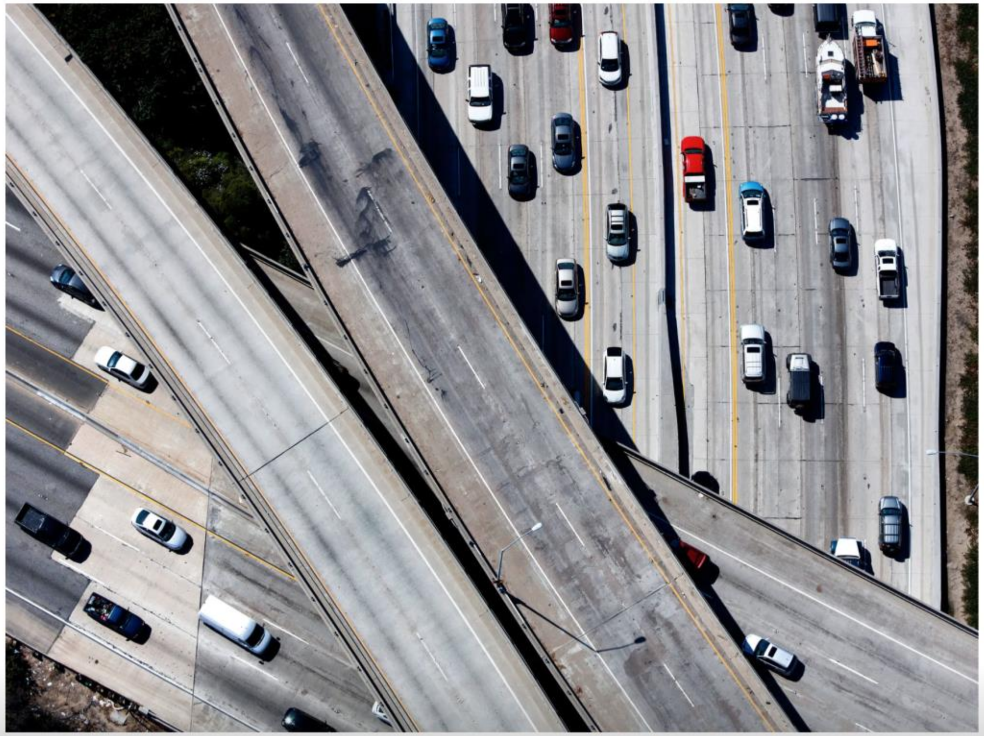
Sustainable Infrastructure

Resilient Cities

Pavement Life Cycle Assessment (LCA) is the key to reducing pavements' total carbon footprint

The Beguiling Science of Making Planet-Saving Pavement

Turns out it's not so easy to improve the way we produce the stuff beneath our feet.



Past efforts to combat the carbon footprint of pavement have shown an annoying tendency to backfire. Now, researchers are considering the full lifecycle of the stuff beneath our feet. PATRICK T. FALLON/BLOOMBERG/GETTY IMAGES

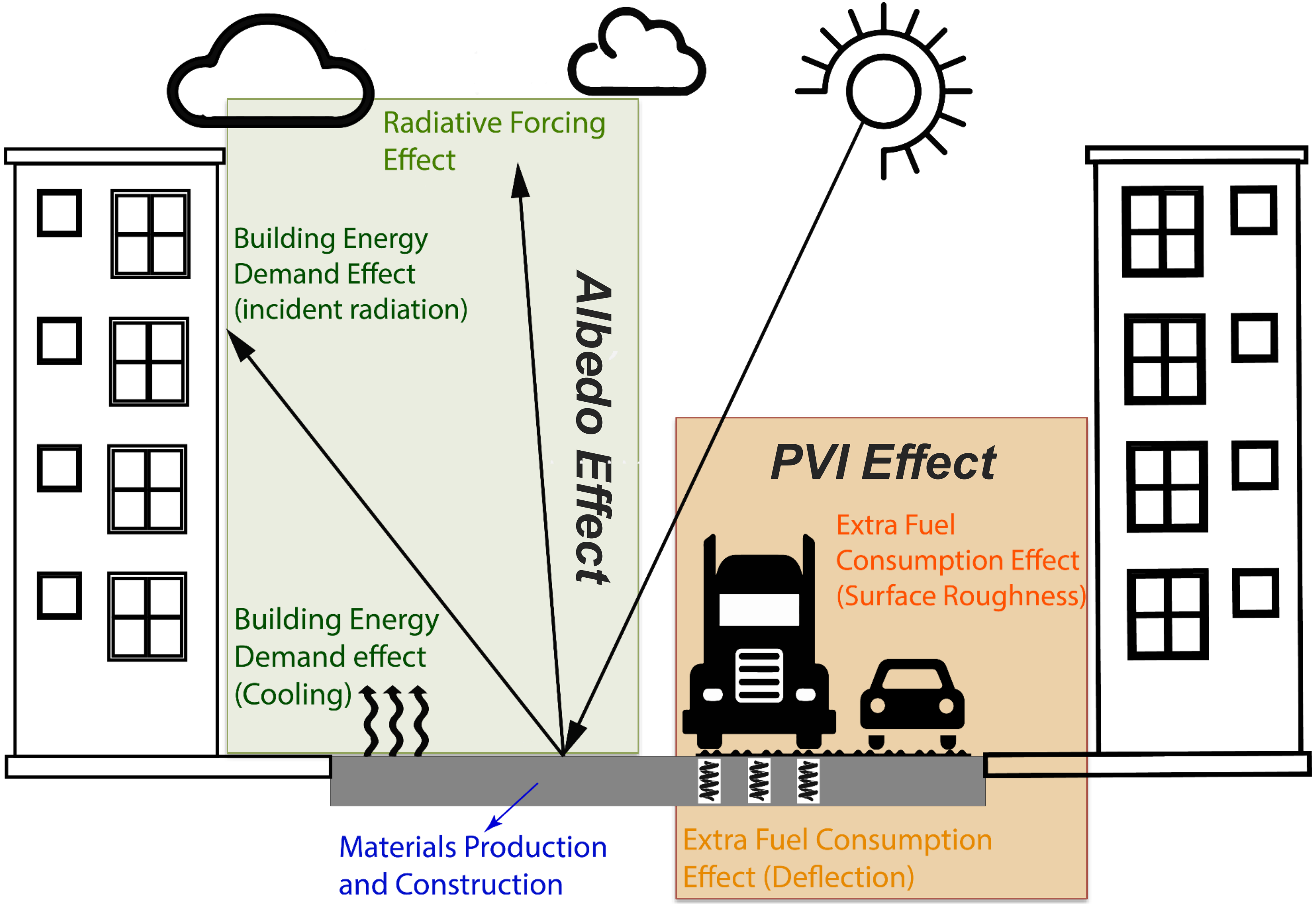
"A pavement composed of all-recycled materials sounds great,

until you consider that it requires more truck-driving construction workers to maintain it, and might need to be replaced in a couple of years instead of a handful…"

Source: https://www.wired.com/story/pavement-environment-science/

MIT CSHub

Pavement design and materials impact carbon emissions of vehicles and buildings

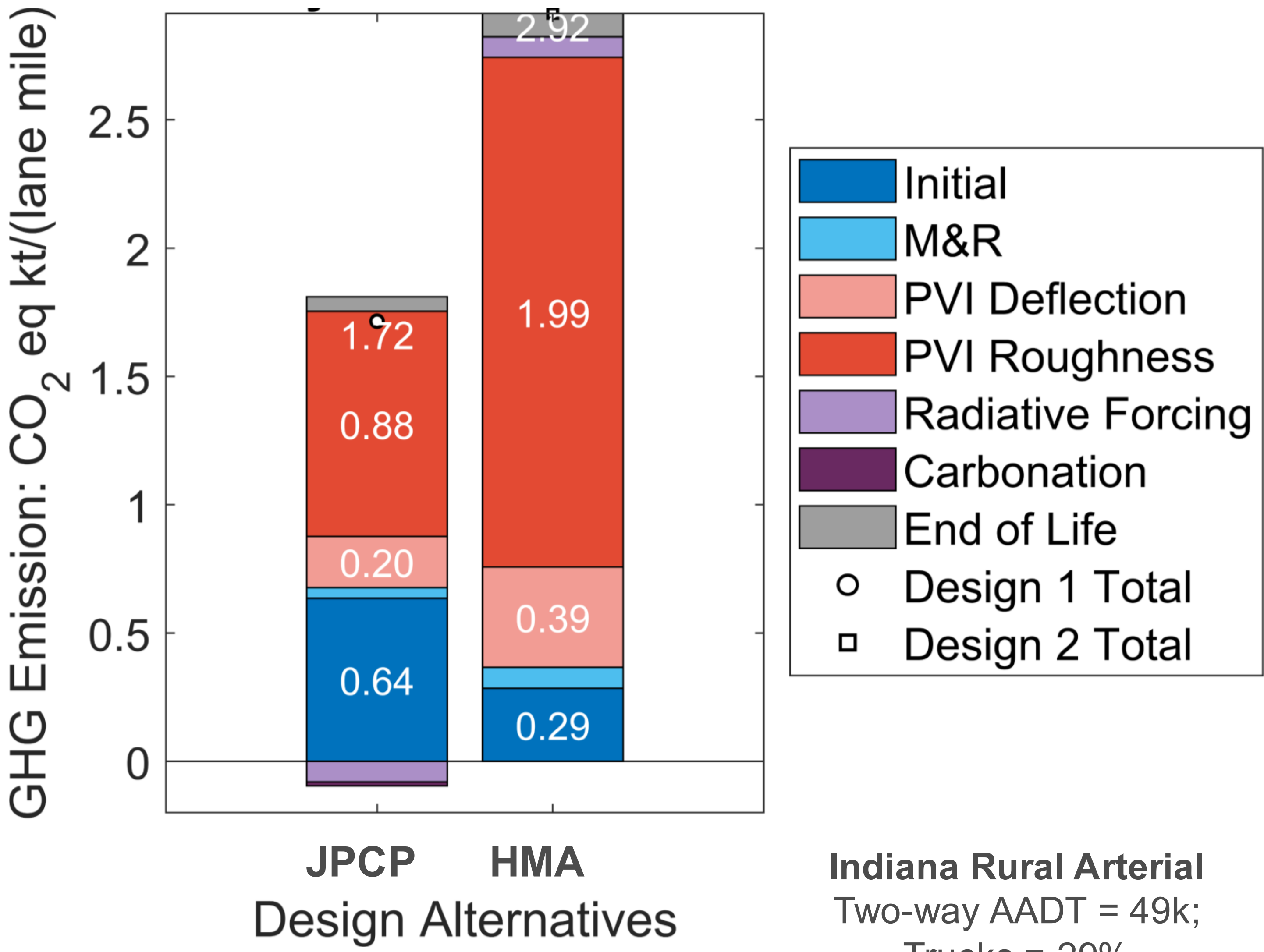


https://cshub.mit.edu/wp-content/uploads/2023/01/TopicSummary_ContextDependantLCA.pdf

Life cycle perspective matters: Use phase impacts can be the majority of total emissions

- Initial
  - Materials & construction
- M&R
  - Maintenance & repair
- Pavement vehicle interaction (PVI)
  - Emissions from excess vehicle fuel use from Deflection and Roughness
- Radiative forcing
  - Additional Reflection or absorption of solar energy
- Carbonation
  - Direct absorption of CO_2

Life-cycle GHG Emissions (per lane-mile)



Indiana Rural Arterial
Two-way AADT = 49k;
Trucks = 29%

Pavement LCA tool needs to be 1) easy to use (limited new data demands), 2) comprehensive, and 3) defensible

Gaps		Proposed solutions
Conducting pavement LCA is costly and labor intensive	→	Develop a **streamlined** pavement LCA framework
Pavement LCA requires extensive data	→	Leverage **publicly-available data**
The uncertainty associated with pavement LCA creates challenges in the decision-making process	→	Employ **probabilistic comparative analysis**

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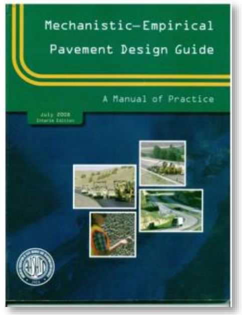
Surrogate modeling offers an efficient method for implementing AASHTO MEPDG pavement design in LCA

Pavement ME

Time Consuming

Extensive Inputs



Needs Licence

Complicated

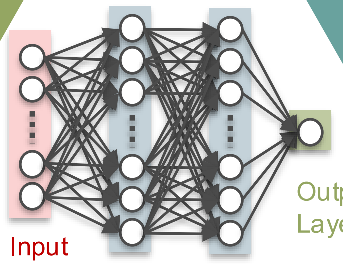
Analysis

Surrogate Modeling

Artificial Neural Networks

Fast

Sensitive Inputs



Standalone

Simple

Design and Analysis

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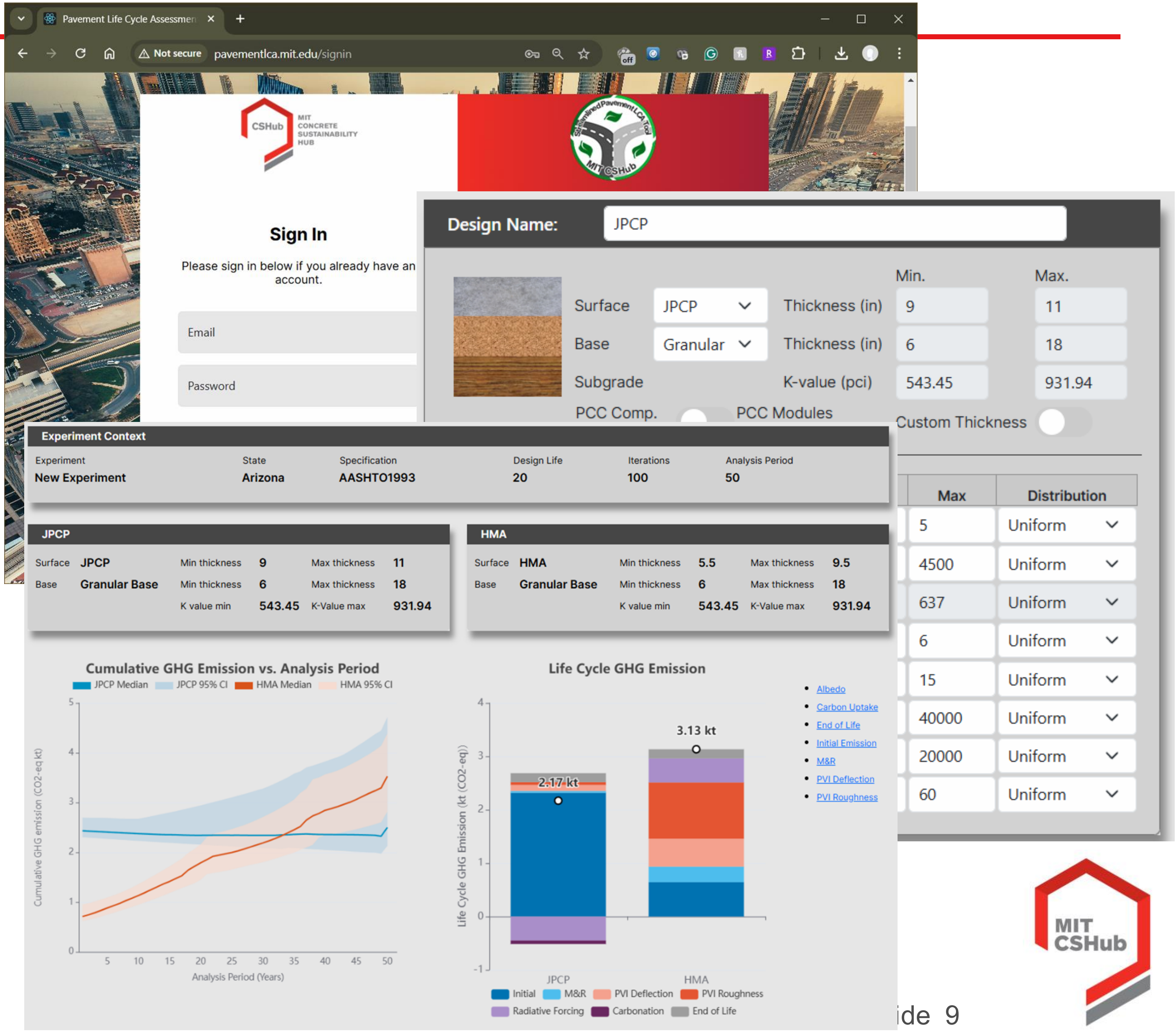
New Tools Will Make Getting Your Evaluations Easier and Faster

CSHub Lifecycle Tool is NOW Live and Ready for Testing

- http://pavementlca.mit.edu/
  - Use your laptop. The site is not yet optimized for phones.
- You can run an analysis with as little information as
  - State
  - Road class (Functional system such as interstate, collector, …)
  - Traffic level (High, medium, low)



Step One: Define Context (Where is this road? & What does it do?)

Input Data

Pavement Contexts

- Geographical Location
- Climatic Conditions
- Traffic

Climate

State	California
Annual Precipitation Days	40
Precipitation Threshold (in./hr)	0.1
Solar Radiation	221.52

Function and Reliability

Urban-Rural Class	Urban
Functional System	Interstate
Reliability	Medium

Traffic Content

Traffic Volume	High
Truck Percentage	High
Traffic Direction	Two-way
Traffic Speed	Medium
Traffic Growth	Medium
Number of Lanes	4
Pavement Length (mile)	1
Lane Width (ft)	12
Shoulder Type	Tied PCC
Shoulder Width (ft)	10

Detailed Traffic Data

Save and Next

Data sources: FHWA and NASA

Traffic parameters can be refined further if available

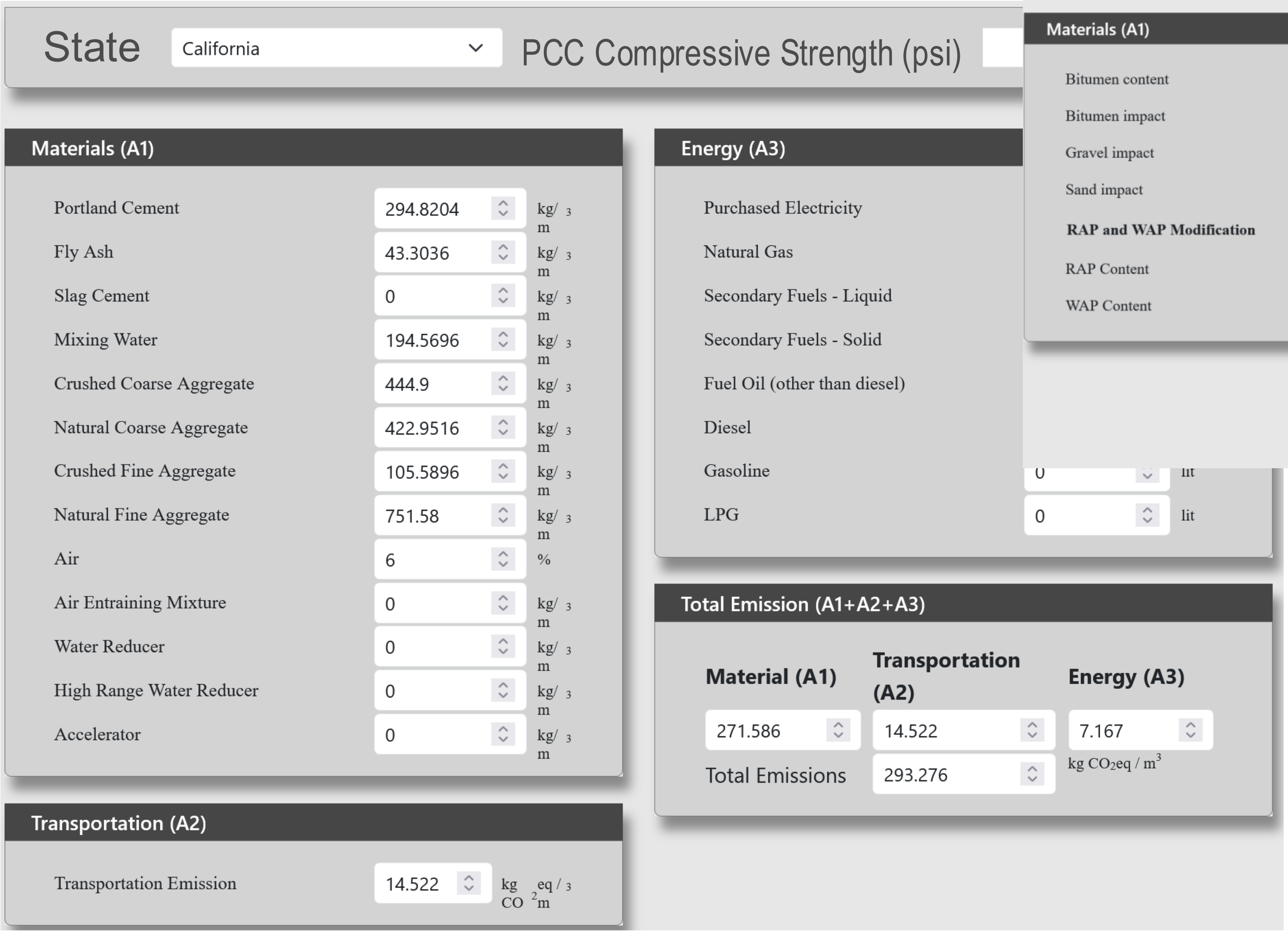
Context Parameters

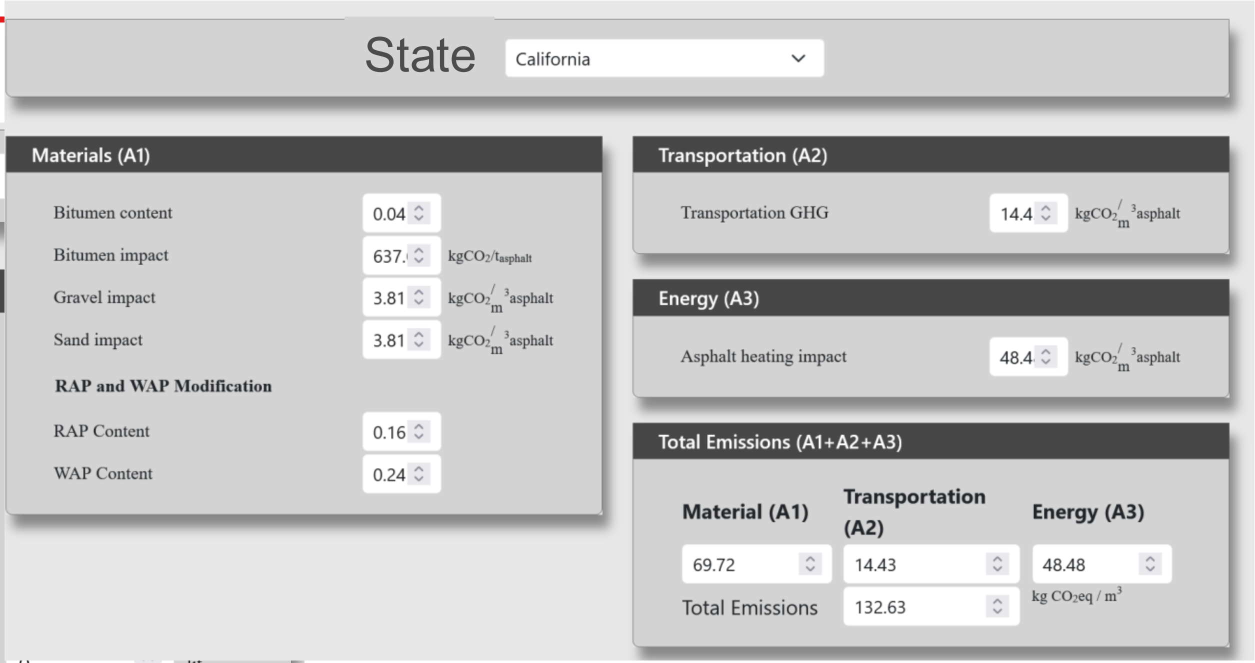
Parameters	Min.	Mean	Max.	Distribution
AADT per Lane	15900	18700	21500	Uniform
AADT All Lanes	63500	74800	86000	Uniform
Truck Percentage (%)	9	11	12	Uniform
AADTT per Lane	1430	2000	2580	Uniform
AADTT All Lanes	5722.2	8026	10329.12	Uniform
Traffic Growth (%)	1	1.5	2	Uniform
Traffic Speed (mph)	55	60	65	Uniform
Reliability (%)	90	92.5	95	Uniform

Data source: FHWA

Step Two: Define materials (including mix design, if desired)

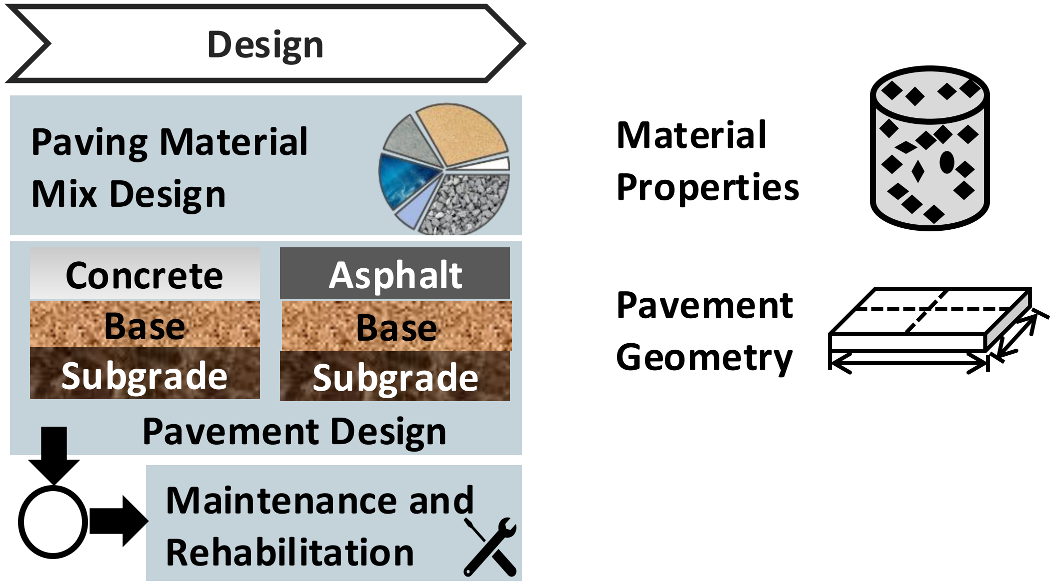
What is this road made of?





Data sources: NRMCA and NAPA

Step Three: Define the pavement design and Specify maintenance and repair treatment actions



Maintenance and Rehabilitation (M&R) Schedule

Timing (years)			Material	
Min	Max	Treatment Type	Removal	Addition
33	38	100% Diamond Grinding w/ Full Depth Re	3	3
0	0	Unspecified	0	0
0	0	Unspecified	0	0
0	0	Unspecified	0	0
0	0	Unspecified	0	0
0	0	Unspecified	0	0

Design Name: JPCP

			Min.	Max.
Surface	JPCP	Thickness (in)	11.5	13.5
Base	Granular	Thickness (in)	6	21
Dowel Bar		Dowel diameter (in)	1.5	1.5
Subgrade		K-value (pci)	212.49	1089.4

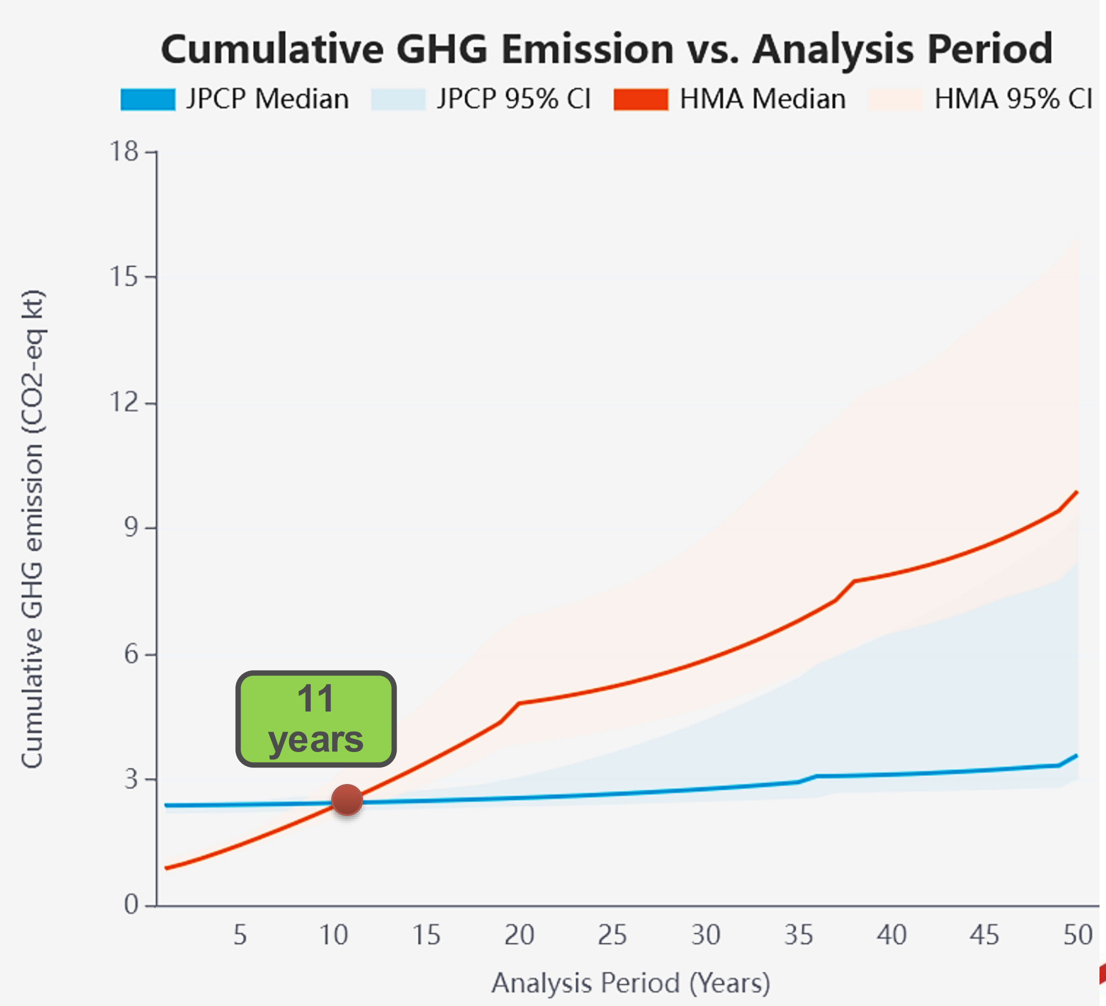
PCC Comp. Strength (psi) | PCC Modules of Rupture (psi): MR | Custom Design

Parameters	Min	Mean	Max	Distribution
PCC Elastic Modulus (10^6 psi)	3	4	5	Uniform
PCC Comp. Strength (psi)	3500	4000	4500	Uniform
PCC Modules of Rupture (psi)	562	600	637	Uniform
Coefficient of Thermal Expansion (10^-6 in/in/F)	4	5	6	Uniform
Joint Spacing (ft)	15	15	15	Uniform
Base Resilient Modulus (ESB): psi	20000	30000	40000	Uniform
Subgrade Resilient Modulus (MR): psi	8000	14000	20000	Uniform
Depth to Rigid Foundation (ft)	6	8	10	Uniform

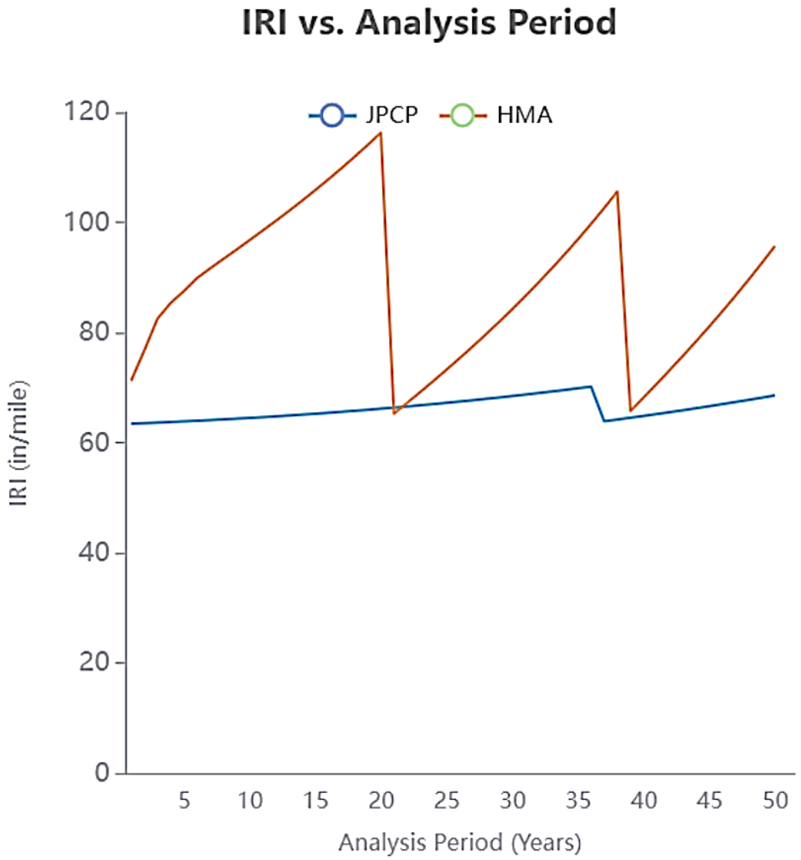
Case study of a California interstate highway:
Time-dependent GHG emission profile

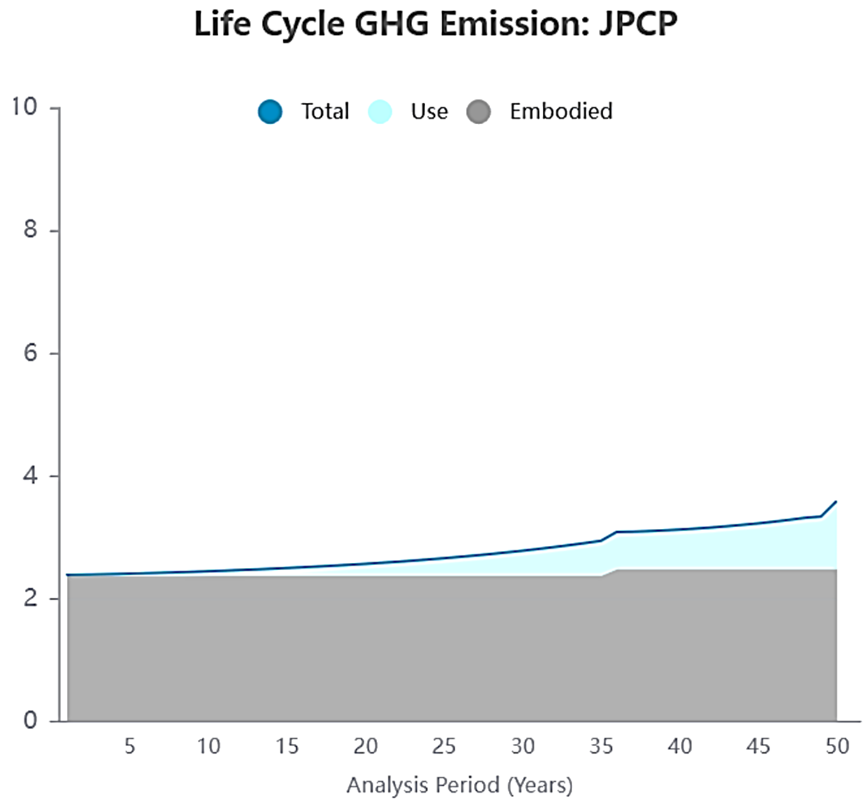
Parameters	Value
State	California
Traffic System	Urban-Interstate
AADT (two-way)	74,800
Truck Percentage	11%
Segment Length	1 mile

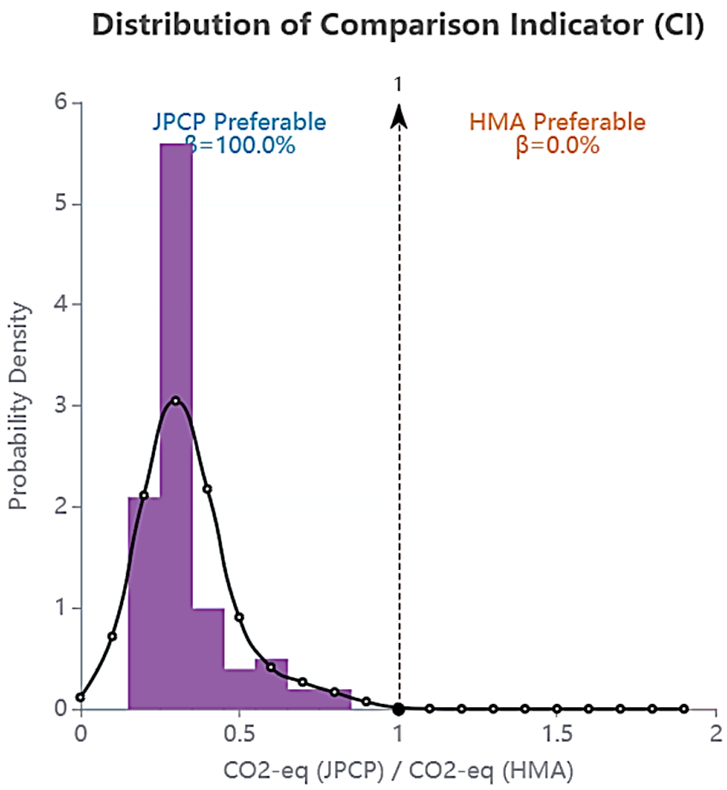
Pavement Design	
Design 1: JPCP • 12.5-in PCC • 1.5-in dowel bar • 13-in aggregate base • 12-ft slab width	**Design 2: HMA** • 9-in HMA • 13-in aggregate base • 12-ft slab width



Additional Results Detail the Pavement Performance Prediction and Provide Statistical Details on the Comparison



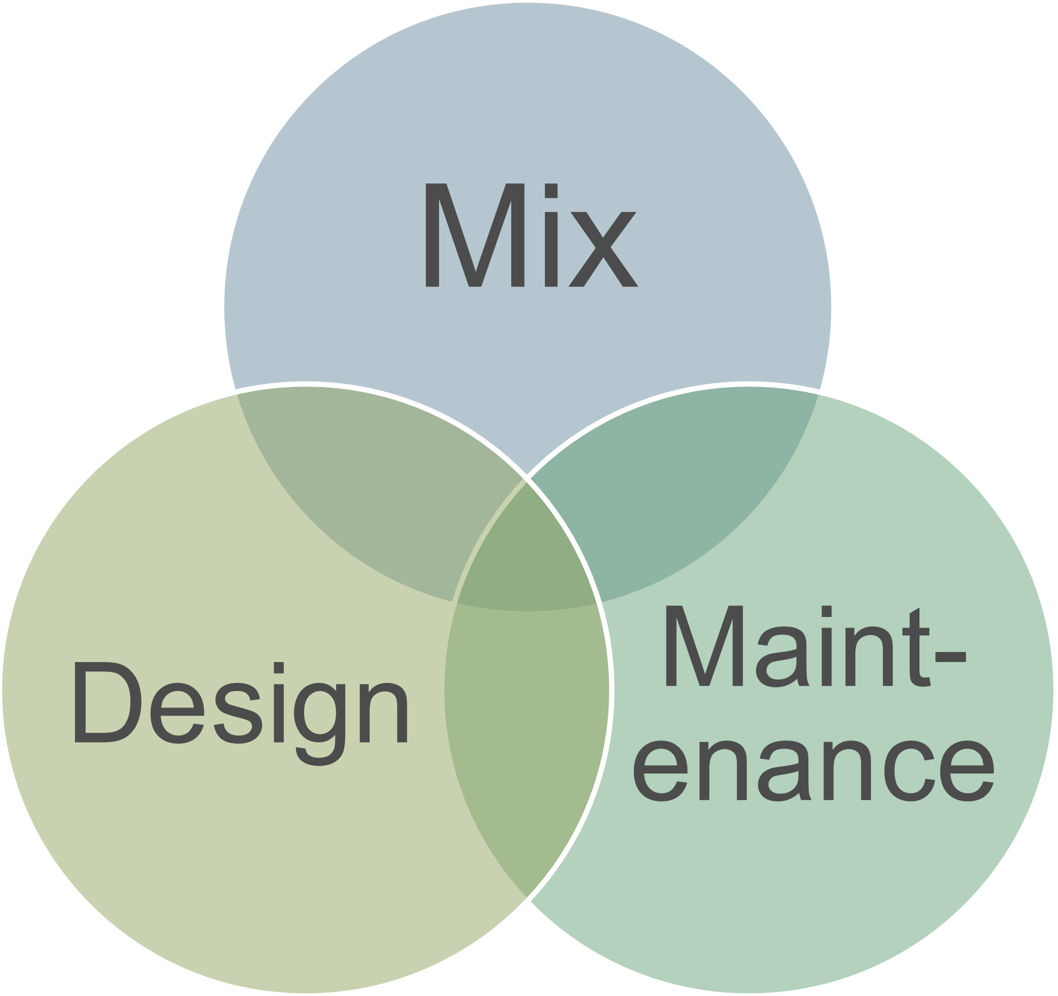




Significant Opportunities Still Exist to Improve Pavement Design and Maintenance

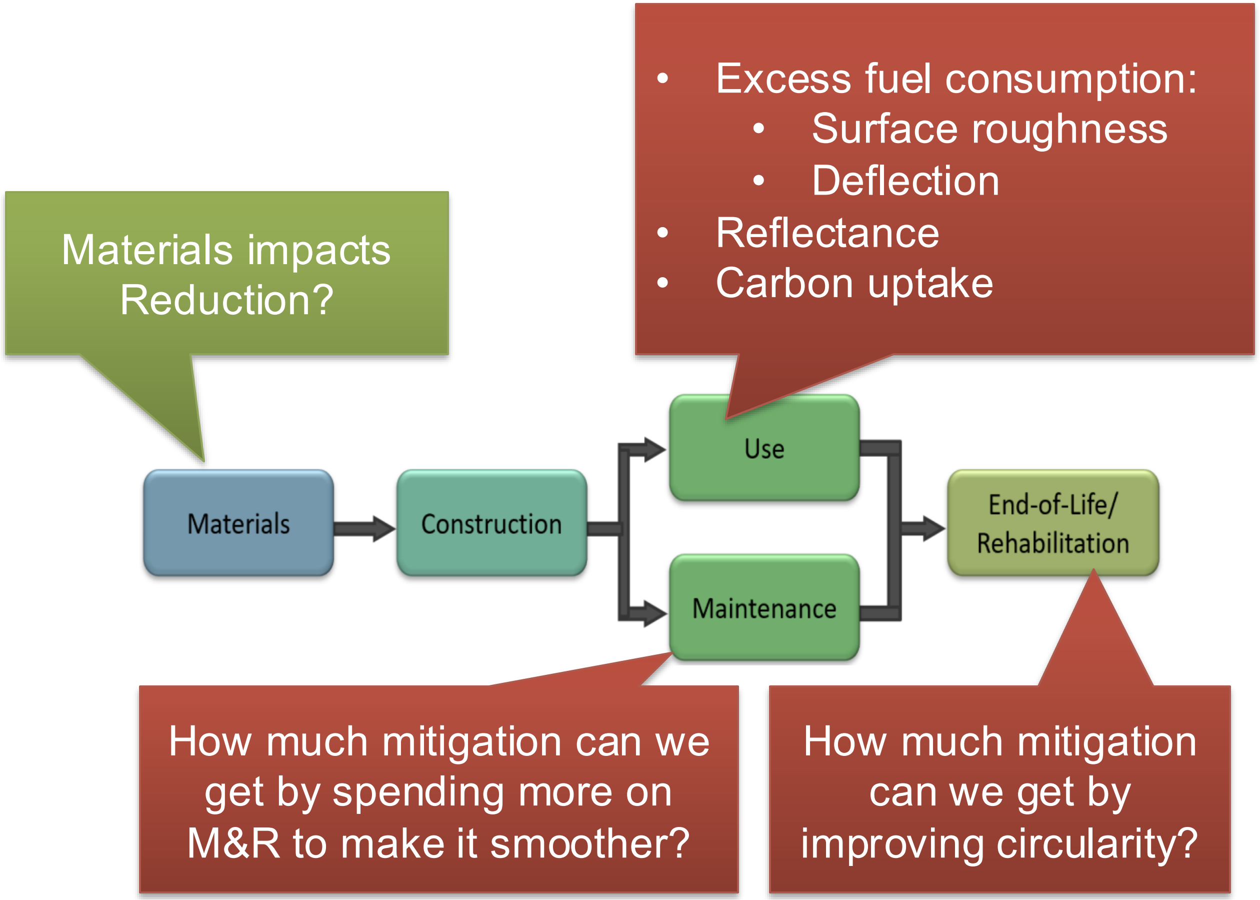
Current low-carbon policies target ONLY upfront emissions, missing opportunities to reduce impacts throughout lifecycle

Impacts can be Reduced Throughout the Lifecycle



Regulations around low-carbon concrete pavements address the upfront emissions, but the potential is extremely larger

Potential parts of the low-carbon policies:
1) Impact of Materials choice on the rest of the life cycle
2) Solutions for achieving low use and end-of-life emissions



Lifecycle Perspective Reveals Important Opportunities to Manage Emissions Through Design and Maintenance

- Case Study:
  - Roller Compacted Concrete
  - State Highway
  - Around Miami, FL

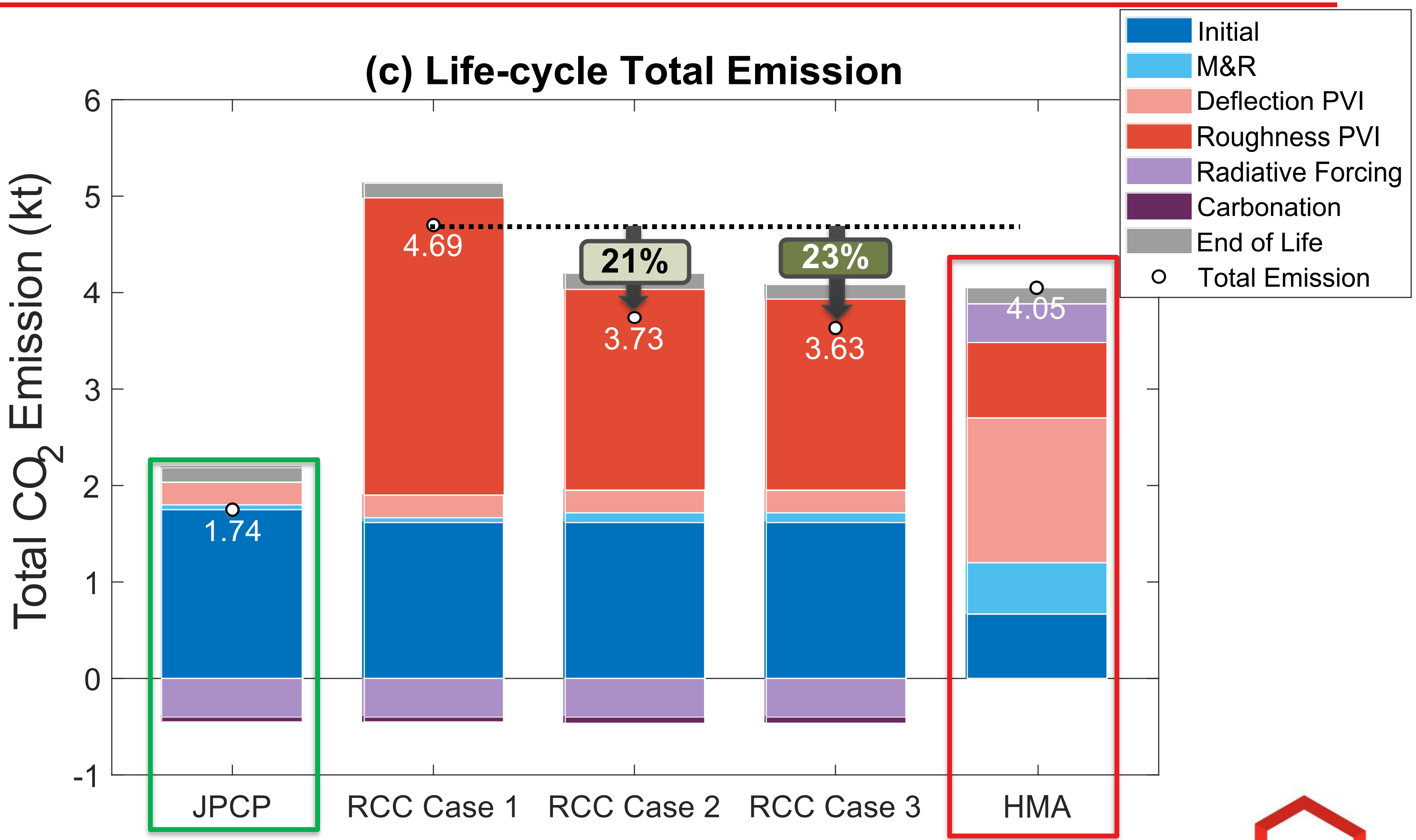
[Semix | What is Roller Compacted Concrete (RCC) ?]

- Traffic - State Highway (Rural)
  - Two-way Annual Average Daily Traffic (AADT) = 17,000
  - Truck percent (%): 6
  - Traffic Speed: 35-45 mph

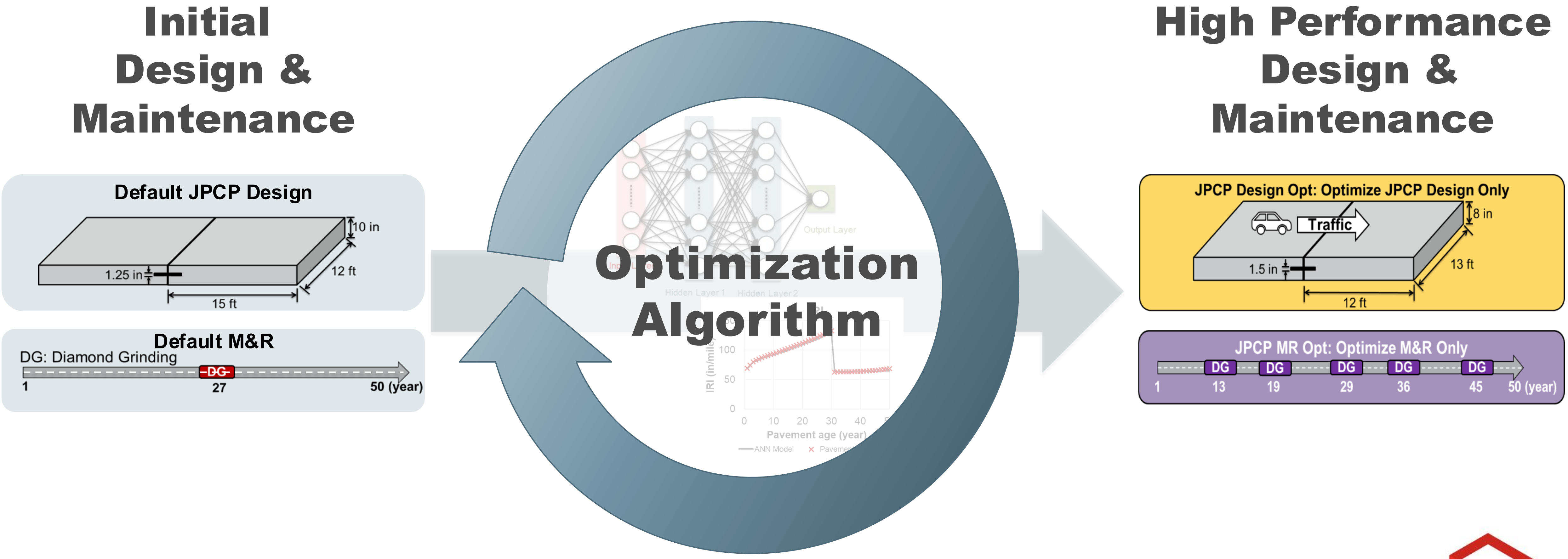
- Designs
  - JPCP
    - DG @ year 30
  - RCC
    - 1 – DG @ years 0 & 30
    - 2 – DG @ years 0, 15, & 30
    - 3 – DG @ years 0, 20, & 40

Scenario 1: Implementing Well-timed Diamond Grindings can Reduce Life-cycle GHG Emissions by up to 23%

M&R	Activities
RCC Case 1	DG and 5% FDR @ 30 year
RCC Case 2	DG and 5% FDR @ 15 and 30 years
RCC Case 3	DG and 5% FDR @ 20 and 40 years



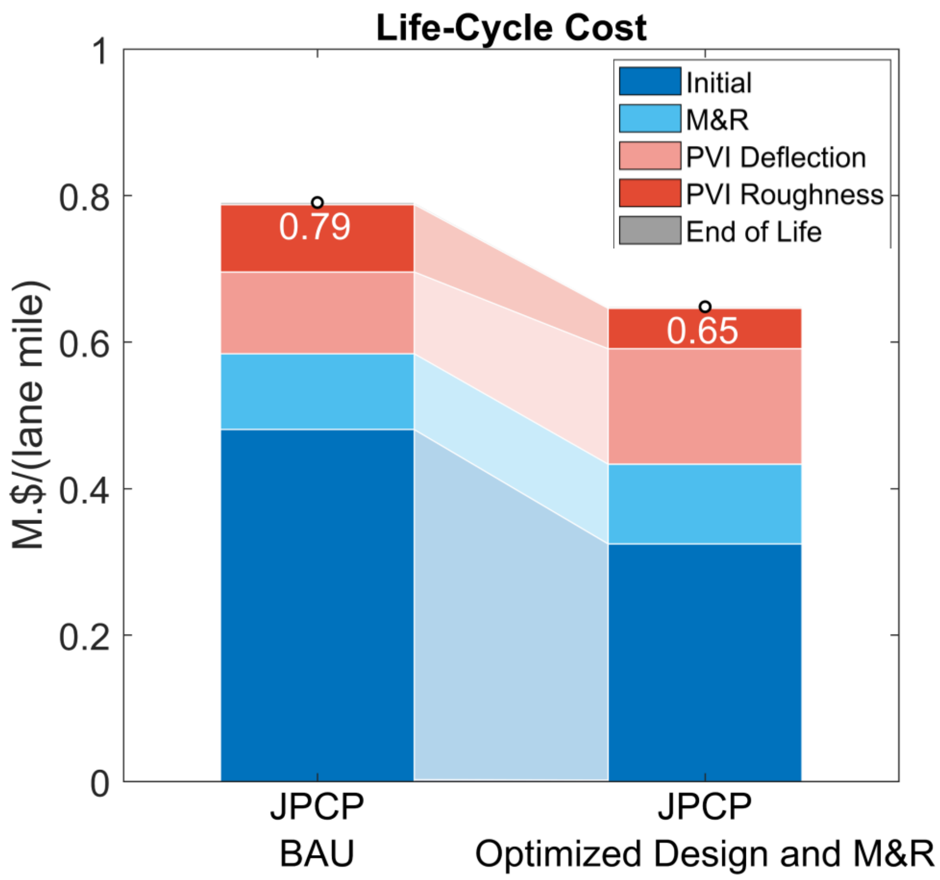
Using the MIT CSHub Rapid Performance Simulator, we can Converge on High-Performance Designs & Maintenance Plans

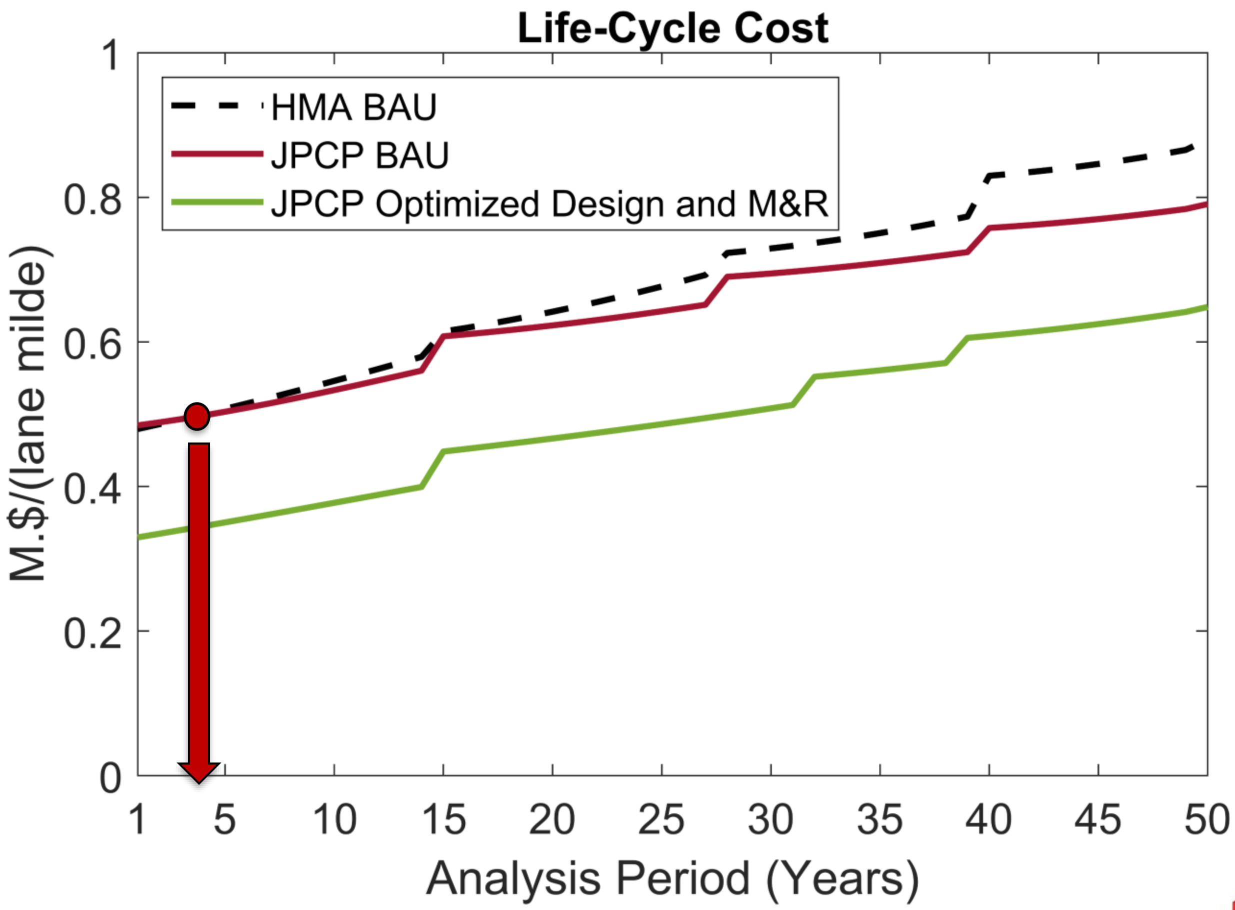


Opportunity to Reduce Pennsylvania JPCP Life-cycle GHG Emissions and Life-cycle Cost

Parameters	JPCP BAU	JPCP Optimized Design and M&R
PCC thickness (in)	12	9
Base type	4-in cement treated base with 6-in subbase	6-in aggregate base
Joint spacing (ft)	15	13
Slab width (ft)	12	13 (widened lane)
Shoulder type	Tied PCC	Tied PCC
Dowel bar diameter (in)	1.5	1.5
M&R schedule	• 100%DG and FDR @ 15 years • 100%DG and FDR @ 28 years • 100%DG and FDR @ 40 years	• 100%DG and FDR @ 15 years • 100%DG and FDR @ 32 years • 100%DG and FDR @ 39 years

Optimization of Design and Maintenance Reduces Lifecycle Costs of Concrete the Solution by ~20%

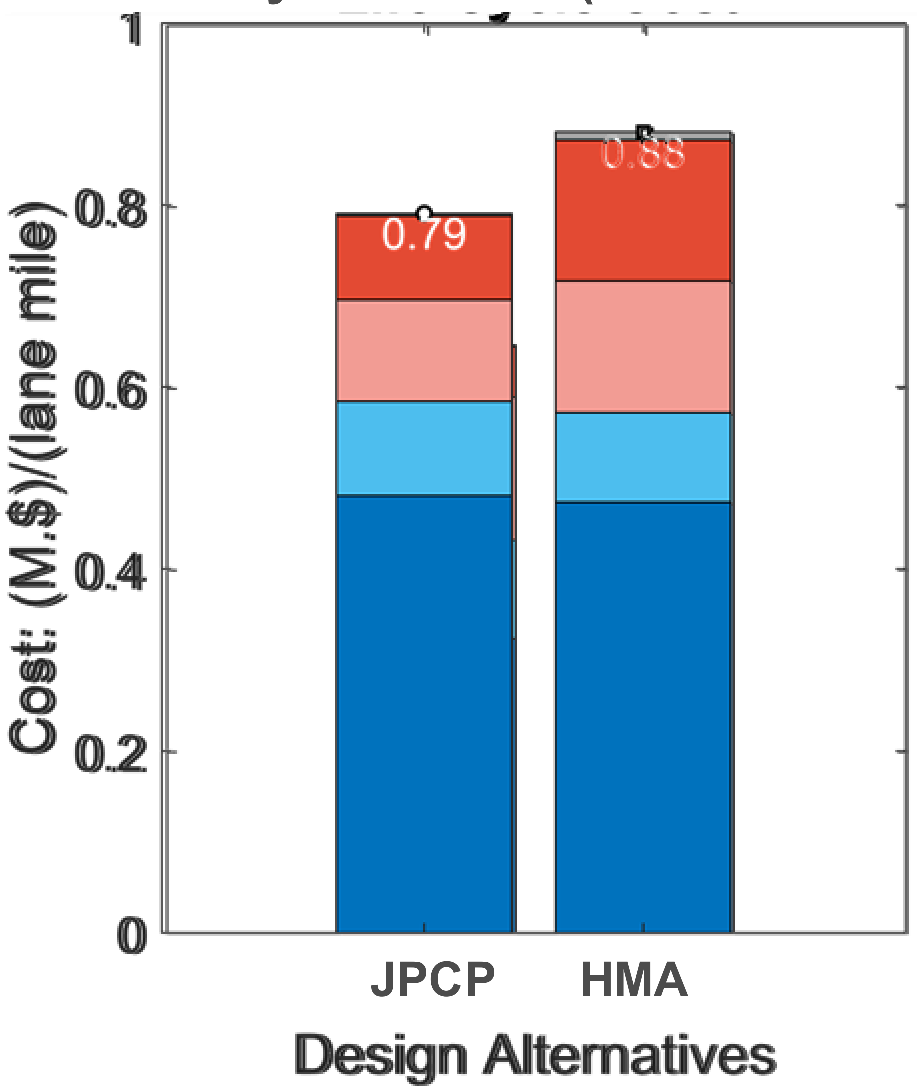




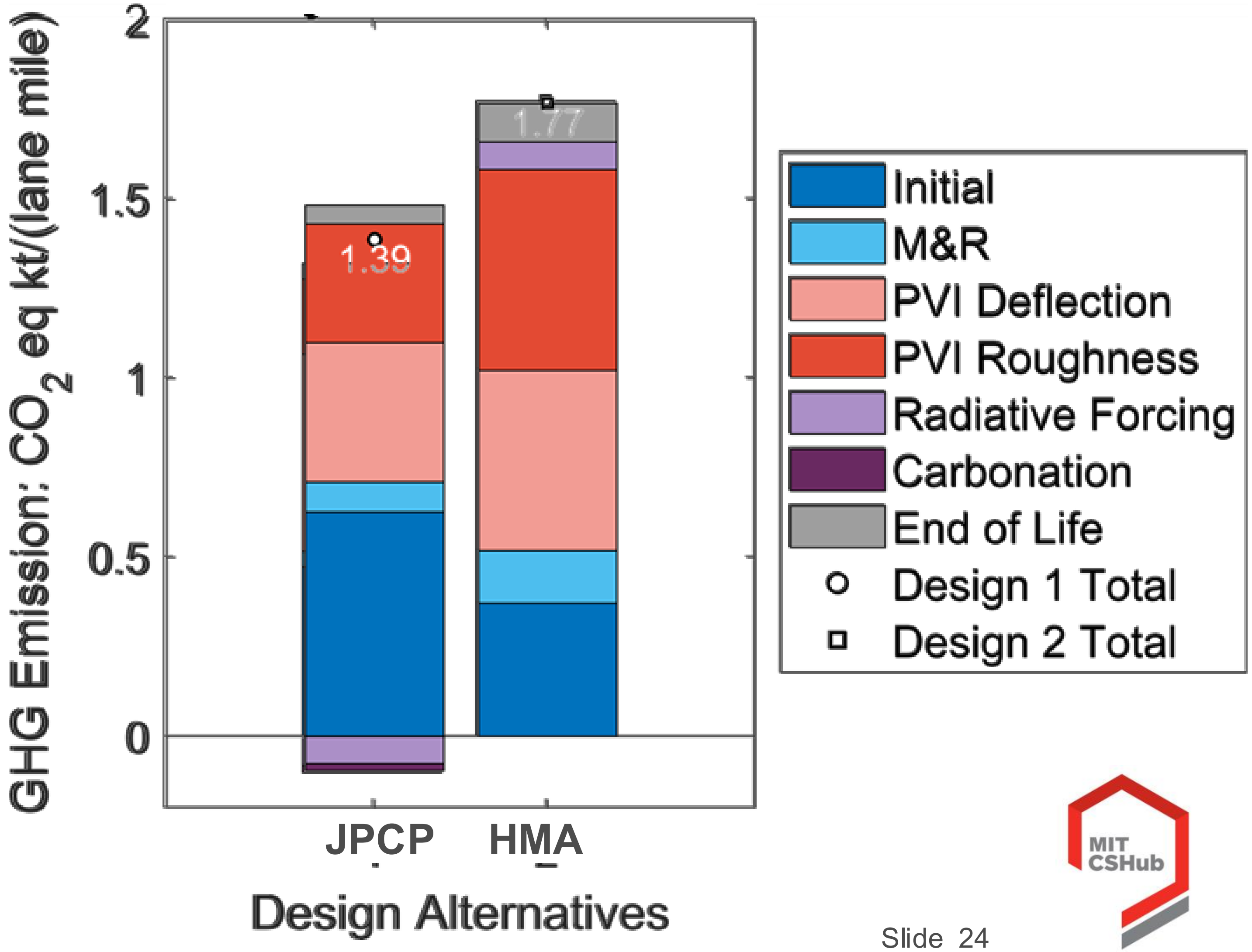
Smarter Design and Maintenance Make Concrete Solutions More Compelling

PA Rural Interstate
Two-way AADT = 37k;
Trucks = 29%

Life-cycle **COST** (M$/ lane-mile)



Life-cycle **GHG Emissions** (CO_2/ lane-mile)



To Reduce Maximize the Value of Concrete Pavements, Consider Materials, Design, & Maintenance

Remove prescriptive specifications

- Encourage innovation in mix design
- Select low-carbon concrete mixes

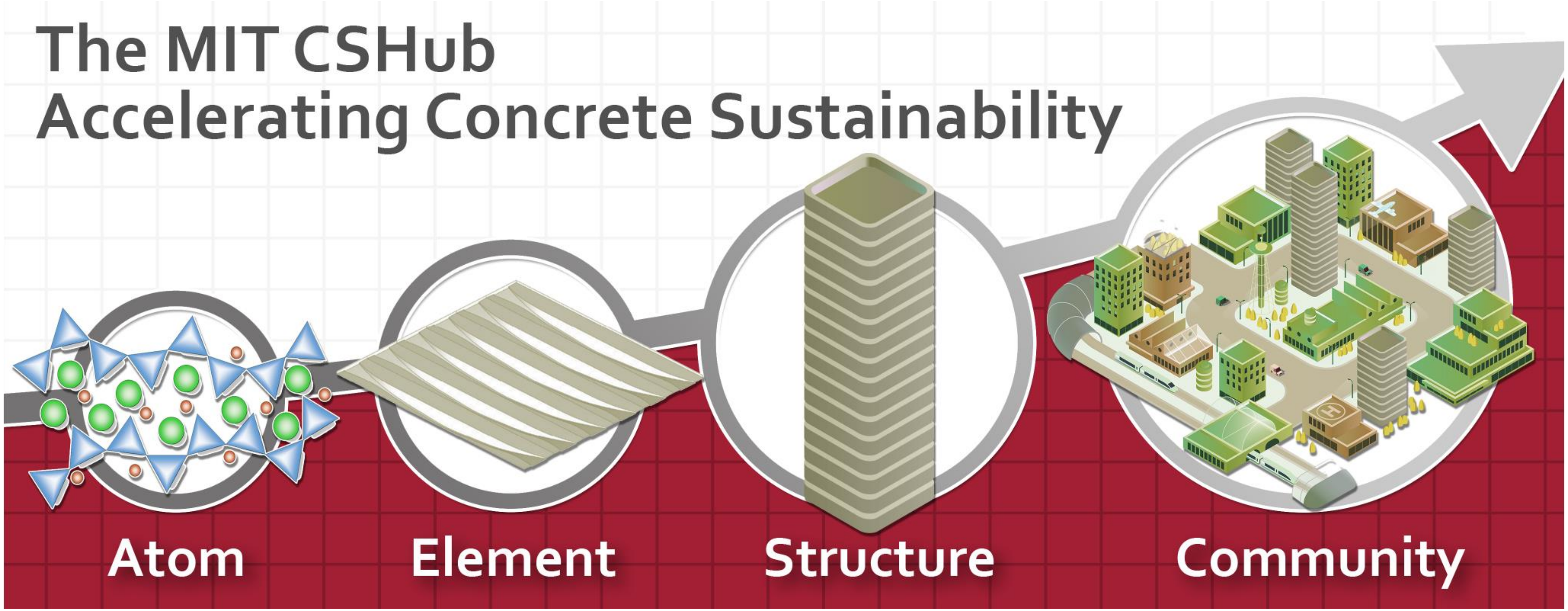
Optimize Pavement Design

- Right-size pavement thickness & dowel bar size
- Where possible, opt for…
  - Wider lanes
  - Shorter joint spacing
  - Tied shoulders

Optimize Pavement Maintenance & Rehabilitation

Implement flexible asset management

Thank you



The MIT CSHub
Accelerating Concrete Sustainability
Atom
Element
Structure
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Questions?

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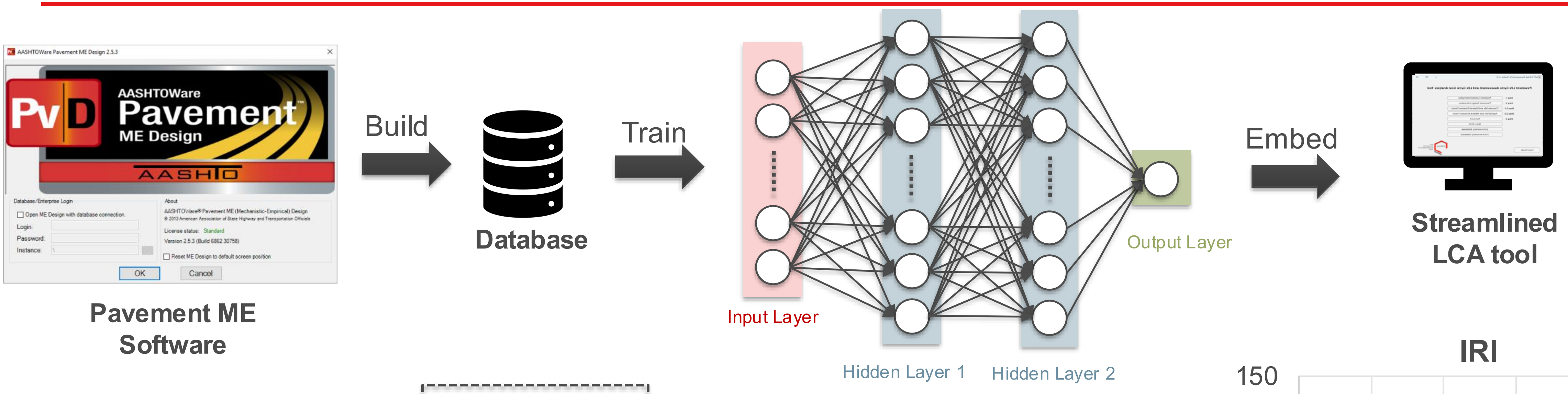
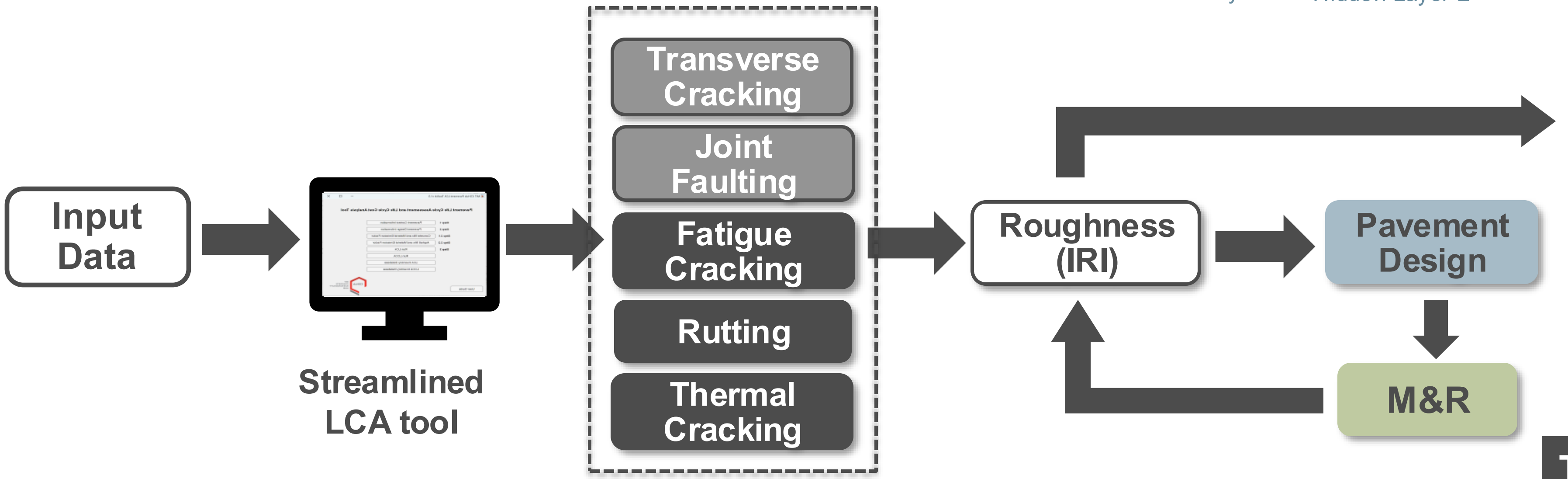
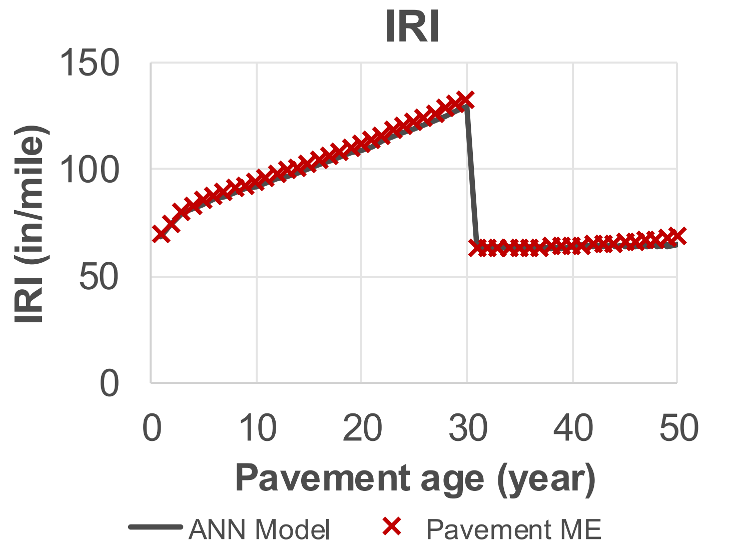
Surrogate models of Pavement ME reduce computational time without loss of accuracy

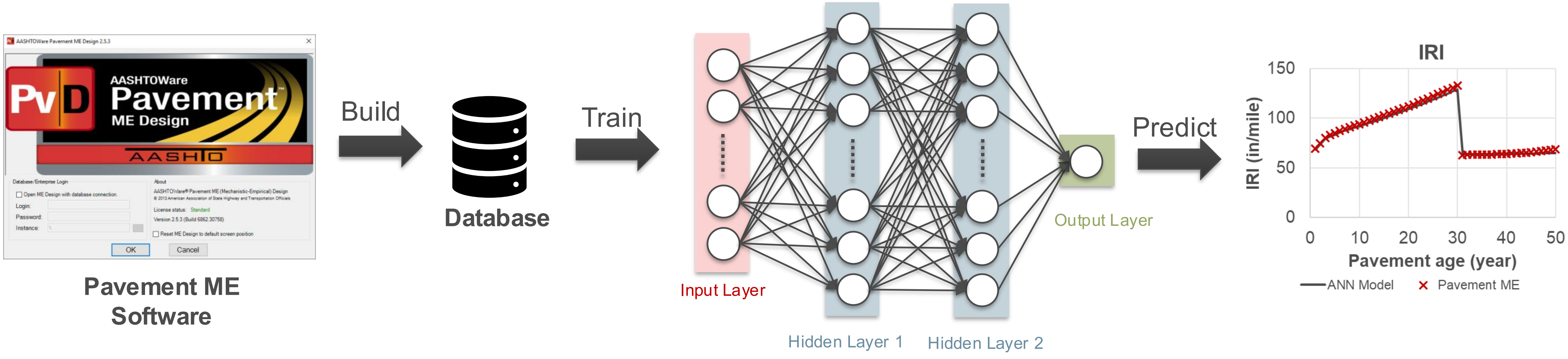




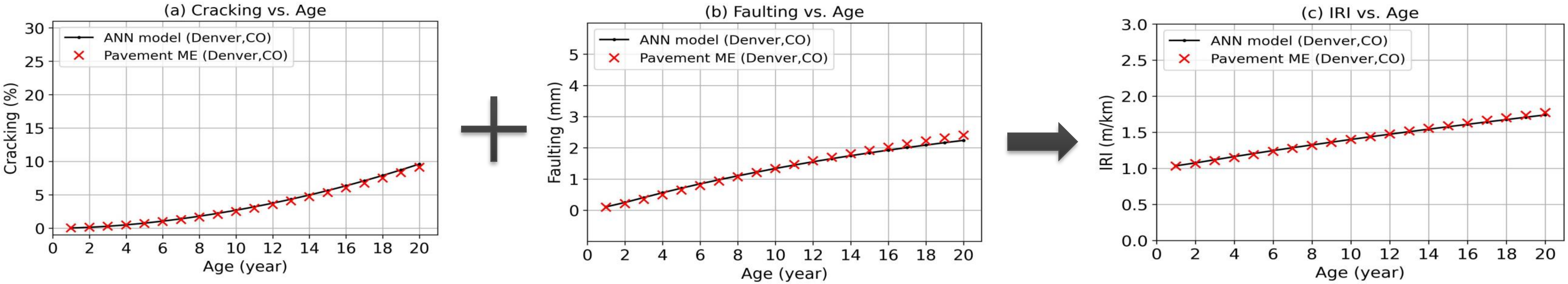


Tool	ANN Model	Pavement ME
Time	0.02 sec	10 mins

Rapid Pavement Performance Simulator Offers an Efficient Method for AASHTO MEPDG-based Pavement Design in LCA/LCCA



Model Fidelity is High



Fatigue Cracking (Total)

Joint Faulting

IRI

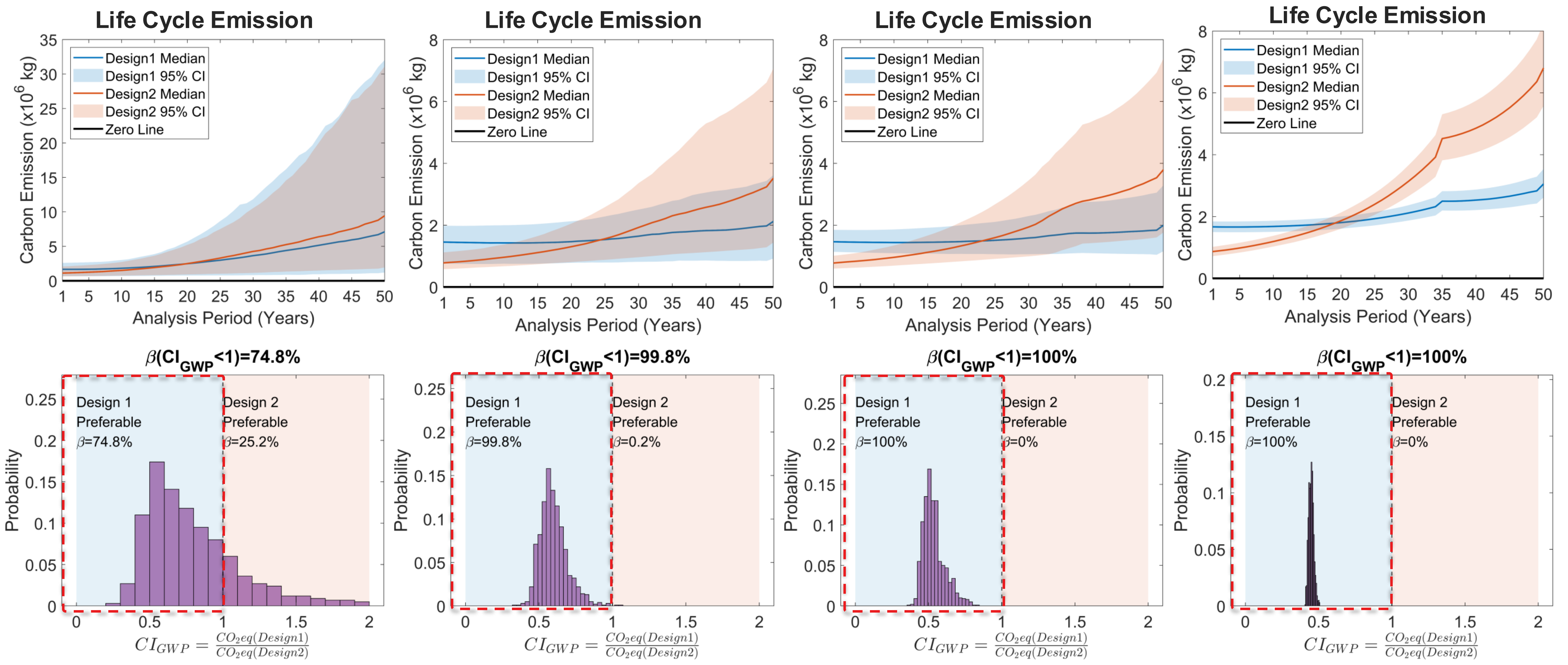
The structured data specifications streamline the LCA, enabling it to accommodate data inputs at any level

Pavement Features		M1 (+)	M2 (++)	M3 (+++)	M4 (++++)
		Underspecification Level			
Traffic System		Arizona	Arizona: Urban	Arizona: Urban-Minor Arterial	Arizona: Urban-Minor Arterial with medium truck volume
Pavement Structures and Material Properties	Design 1	PCC Base Subgrade	Standard Grade Concrete Granular Base Granular Material	M25 Concrete AASHTO Standard Soil Silt-Sand Subgrade	fc’ = 3,800 psi A-1-b: MR=38,000 psi A-2-6: MR=26,000 psi
	Design 2	Asphalt Base Subgrade	HMA Granular Base Granular Material	High stiffness HMA AASHTO Standard Soil Silt-Sand Subgrade	E=350,000 psi A-1-b: MR=38,000 psi A-2-6: MR=26,000 psi
M&R	M&R				
	Design 1	$M\&R \times 1$	Minor Repair — 28-40 year	DG and FDR — 32-38 year	100%DG and 5% FDR — 35
	Design 2	$M\&R \times 1$	Minor Repair — 28-40 year	AC Mill and Fill — 32-38 year	3-in AC Mill and Fill — 35

Least Specific Data → **Most Specific Data**

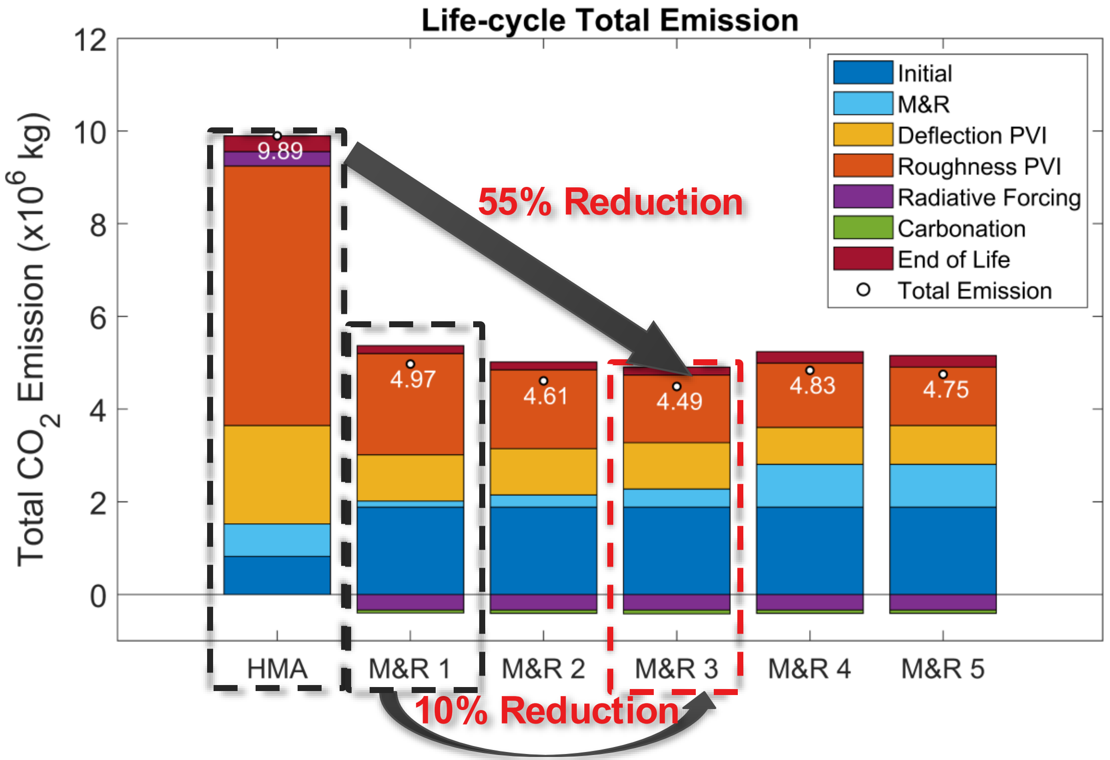
Level M2 data specification is sufficient for making statistically defensible decision for urban roads in Arizona

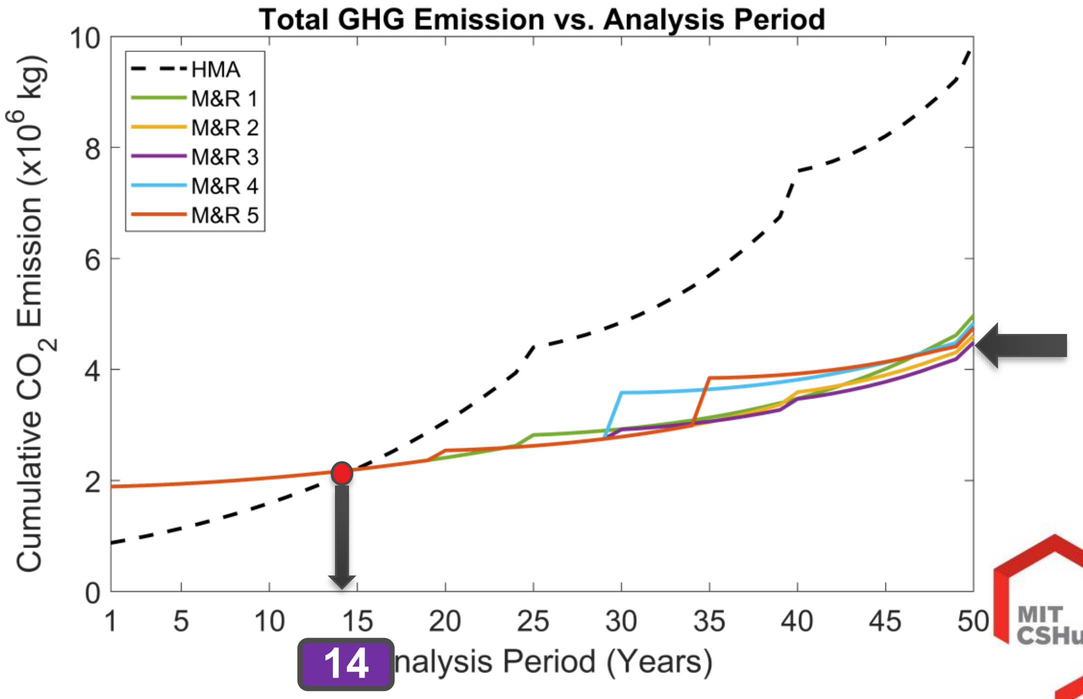
Underspecification Level			
M1 (+)	M2 (++)	M3 (+++)	M4 (++++)



Combined JPCP Design and M&R Optimization can reduce 55% life cycle GHG emission compared to HMA alternative

JPCP M&R Optimization	Activities
M&R Schedule 1 (original)	100% Diamond Grind (DG) with 5% Full Depth Replacement (FDR) @ **25** year
M&R Schedule 2	100% DG with 5% DG @ **20** and **40** year
M&R Schedule 3	100% DG with 5% DG @ **20**, **30**, and **40** year
M&R Schedule 4	100% DG with 5% DG @ **20** and **Bonded 4-in PCC Overlay** @ **30** year
M&R Schedule 5	100% DG with 5% DG @ 20 and **Bonded 4-in PCC Overlay** @ **35** year



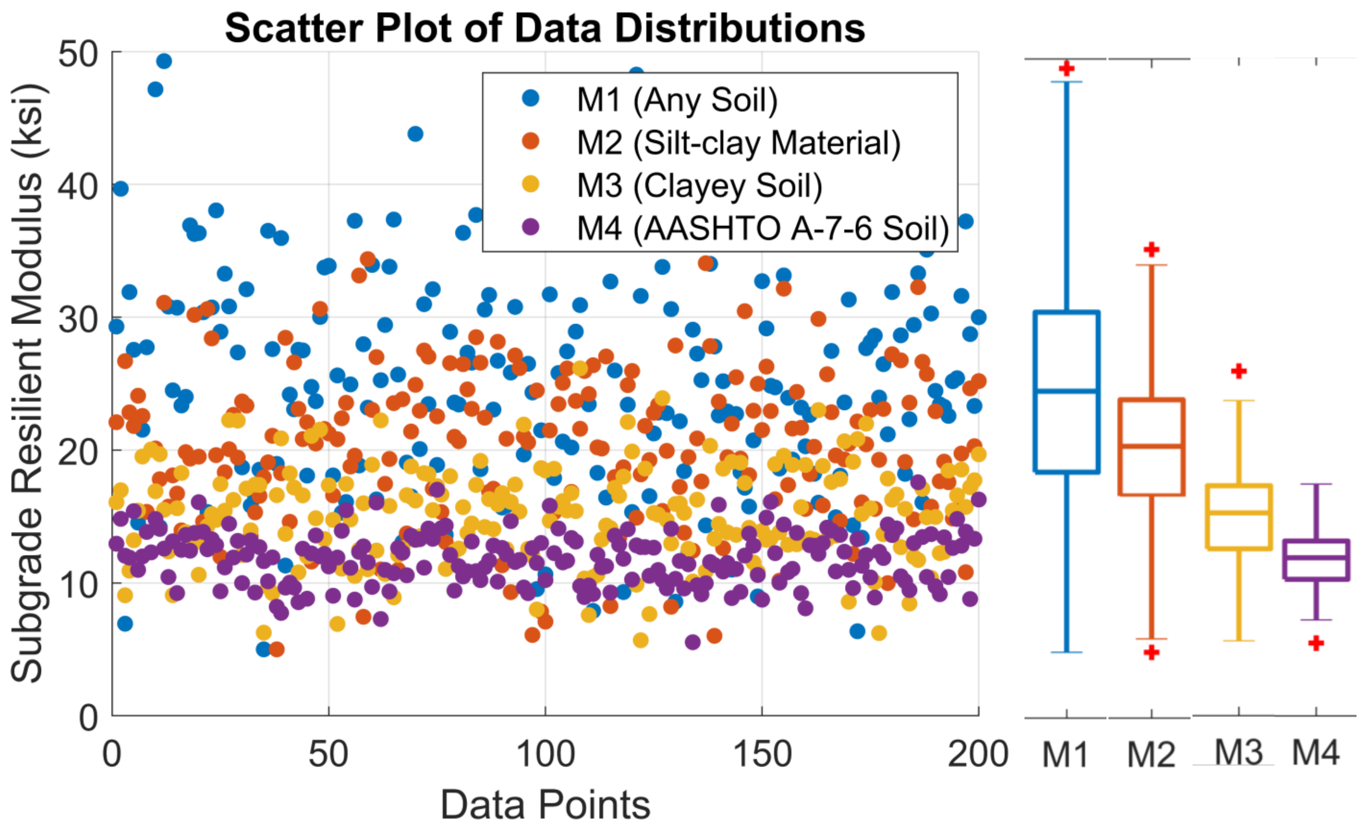


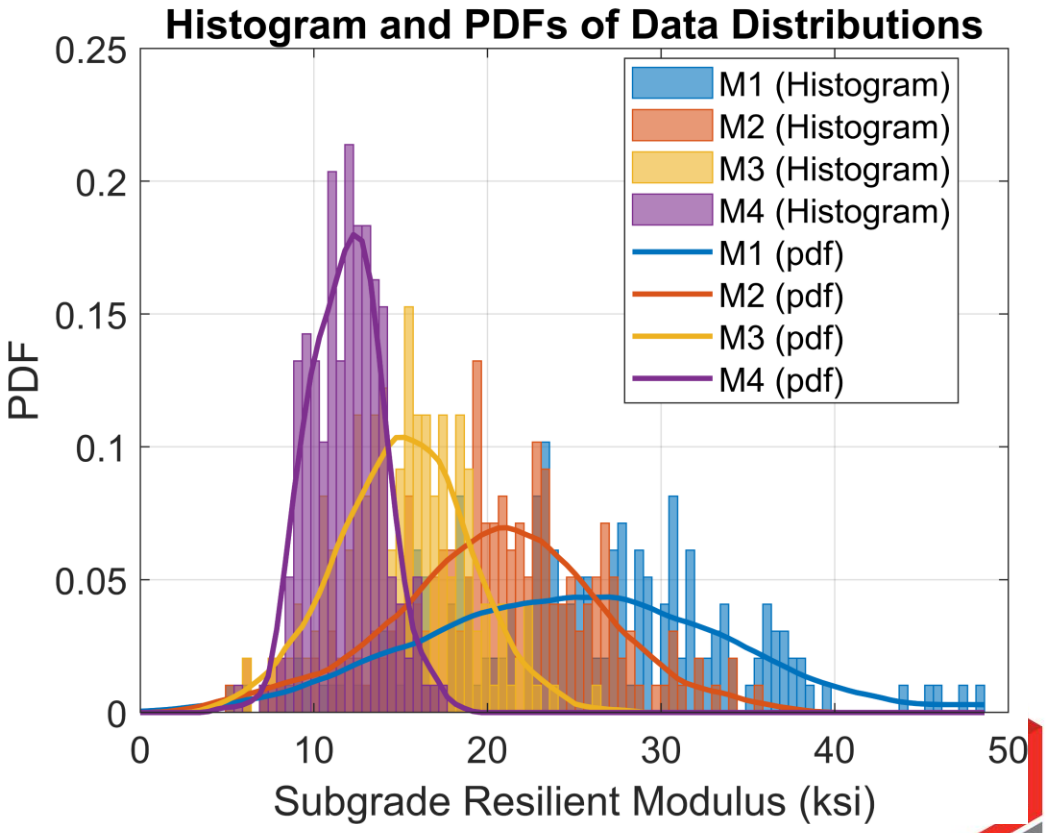
Structured data specification can accommodate any data level

Underspecification Level			
M1 (+)	M2 (++)	M3 (+++)	M4 (++++)

General details with broad variation

Specified details with limited variation of options





CSHub streamlined pavement LCA framework incorporates and tracks the life cycle emissions of pavements capturing different GHG sources