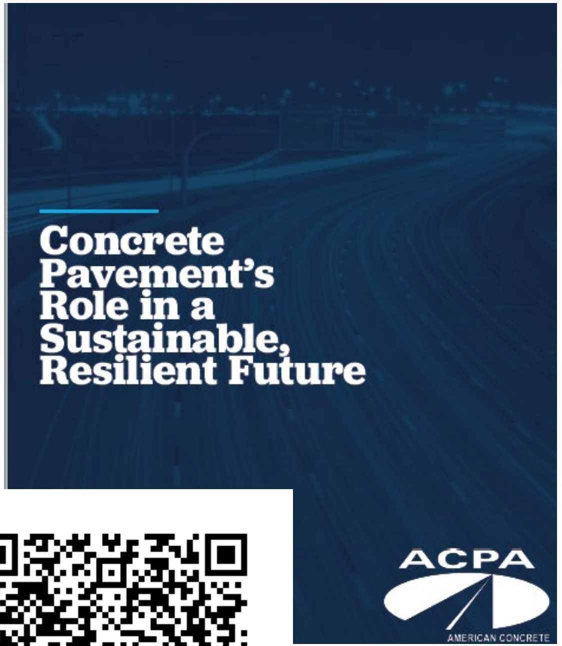
Achieving Sustainability and Resilience with Concrete Pavements



2023 Annual Concrete Conference

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AMERICAN CONCRETE PAVEMENT ASSOCIATION

Concrete Pavement Sustainability – Environmental Impacts

- We start to quantify!
- EPDs a good starting point.

ENVIRONMENTAL IMPACTS

Declared Product:
Mix 1618915 • Santa Clara Plant
A4GRC 658 C+S 30% BL AIR WR
Compressive strength: 5000 PSI at 28 days

Declared Unit: 1 m^3 of concrete

Global Warming Potential (kg CO_2-eq)	392
Ozone Depletion Potential (kg CFC-11-eq)	1.1E-5
Acidification Potential (kg SO_2-eq)	2.06
Eutrophication Potential (kg N-eq)	0.46
Photochemical Ozone Creation Potential (kg O_3-eq)	45.5
Abiotic Depletion, non-fossil (kg Sb-eq)	1.4E-6
Abiotic Depletion, fossil (MJ)	695
Total Waste Disposed (kg)	2.71
Consumption of Freshwater (m^3)	1.01

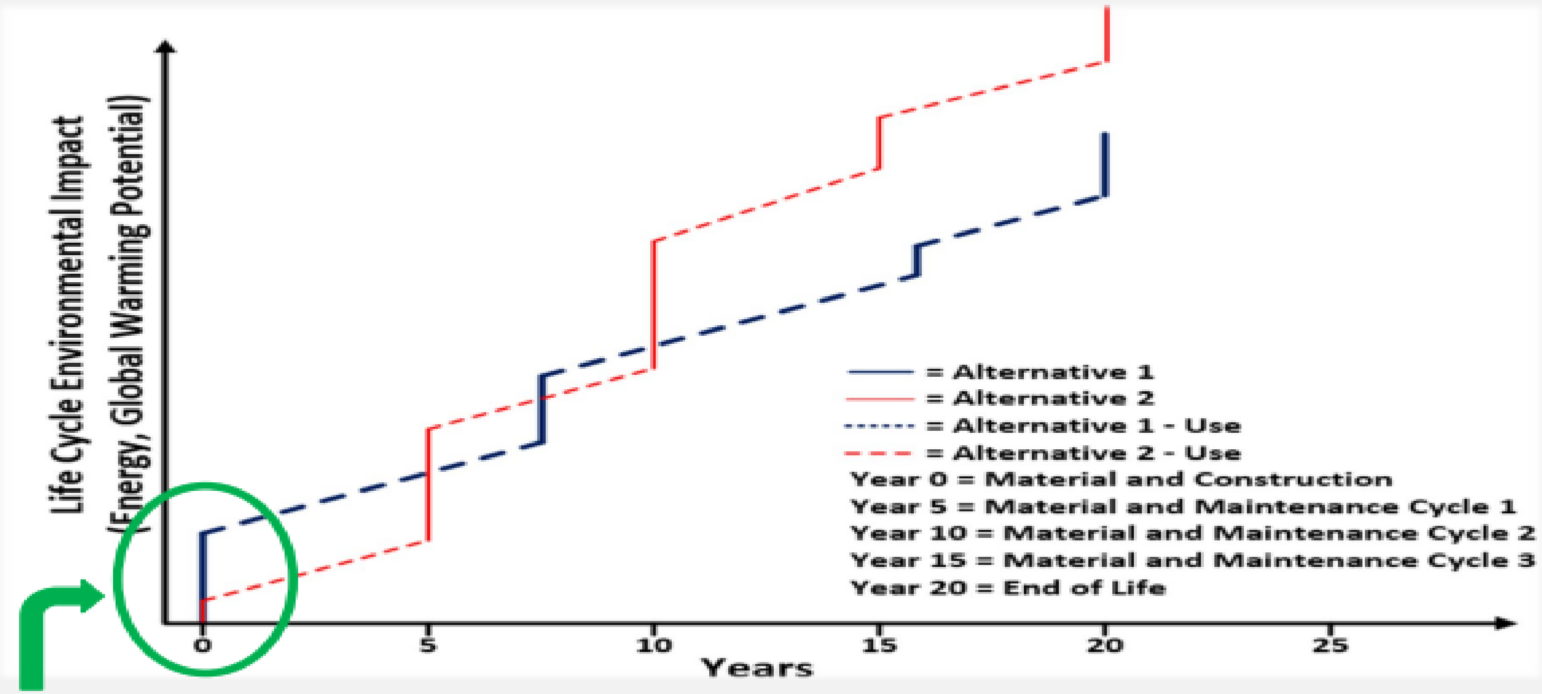
Product Components: crushed aggregate (ASTM C33), natural aggregate (ASTM C33), Portland cement (ASTM C150), slag cement (ASTM C989), batch water (ASTM C1602), admixture (ASTM C494), admixture (ASTM C260)

Table 8a. Sum … **(20.7-27.6 MPa) RMC produ**

					001-000-20-A	3001-4000-30-FA	3001-4000-40-FA	3001 4000 SL
Core Mandatory Impact Indicators								
GWP	kg CO_2e	261.19	426.75	426.75	365.48	332.37	297.41	32
ODP	kg CFC11e	7.84E-06	1.11E-05	1.11E-05	9.56E-06	8.73E-06	7.84E-06	1.01
AP	kg SO_2e	0.99	1.33	1.33	1.17	1.08	0.99	
EP	kg Ne	0.37	0.55	0.55	0.48	0.44	0.40	
POCP	kg O_3e	21.38	28.22	28.22	24.98	23.23	21.38	2
ADPf	MJ, NCV	1,522.19	2,229.70	2,229.70	1,921.20	1,754.51	1,578.49	1,85
ADPe	kg Sbe	2.44E-04	3.69E-04	3.69E-04	3.25E-04	3.02E-04	2.77E-04	2.94
FFD	MJ Surplus	143.16	180.58	180.58	162.85	153.28	143.16	17

WHERE DO EPDS FIT IN?

ABC Ready-Mix Environmental Impacts	
Serving Size: 1 cubic yard of concrete mix no. 123	
Global Warming Potential [kg CO_2 eq]	3.06×10^{3}
Ozone Depletion Potential [CFC-11 eq]	4.24×10^{-6}
Acidification Potential [kg SO_2 eq]	21.7
Eutrophication Potential [kg N eq]	9.25×10^{-2}
Photochemical Oxidant Creation Potential [kg O_3 eq]	30.7
TOTAL ENERGY DEMAND [MJ]:	1166
Non-renewable [MJ]	586
Renewable [MJ]	580



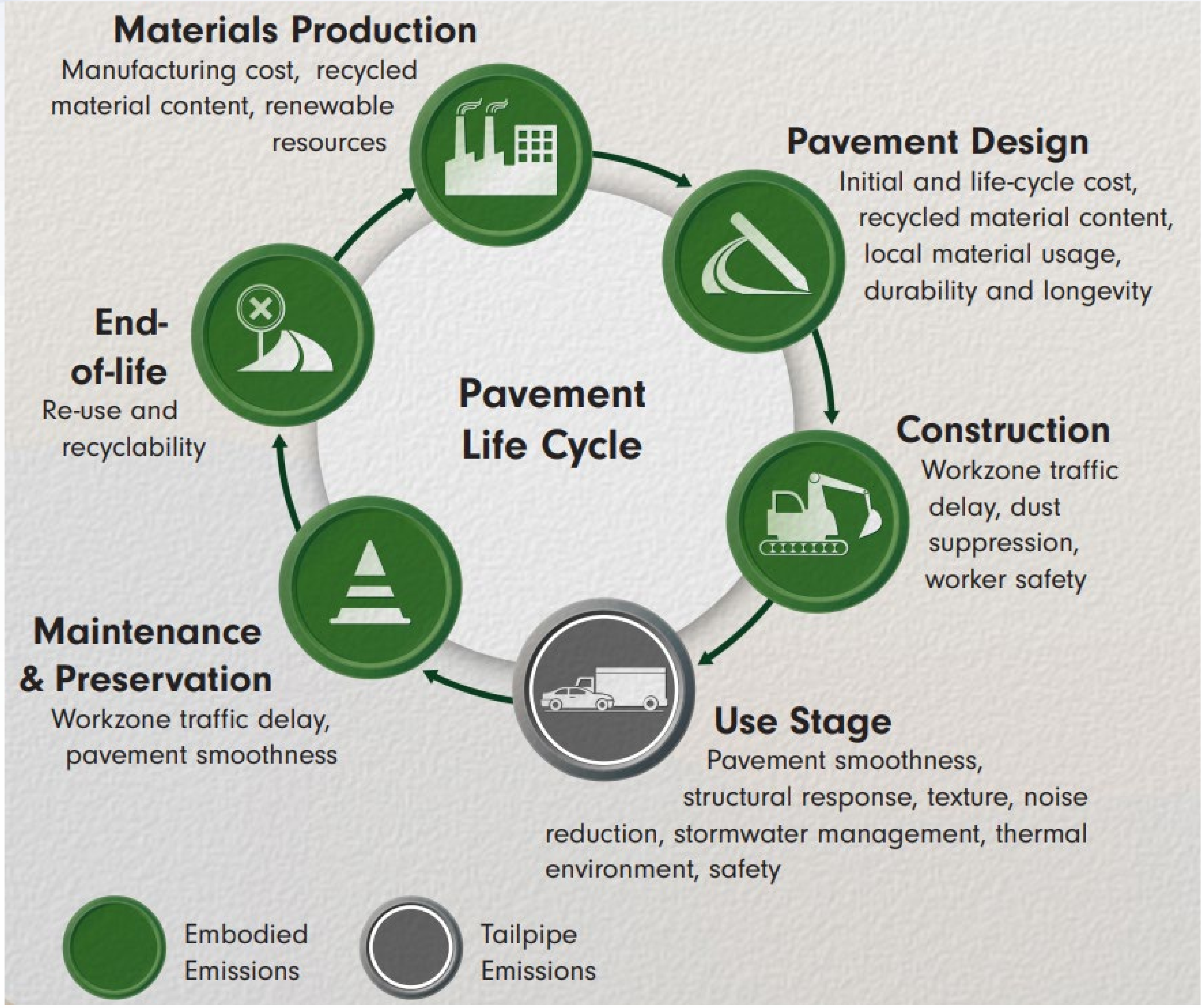
Supplier EPDs for materials

Product Stage			Construction Stage		Use Stage					End-of-Life Stage				Benefits & Loads
A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	C1	C2	C3	C4	D
Raw materials supply	Transport	Manufacturing	Transport	Installation	Use Stage	Maintenance	Repair	Replacement	Refurbishment	De-construction	Transport	Waste Processing	Disposal	Reuse, recovery, recycling potential

Projects

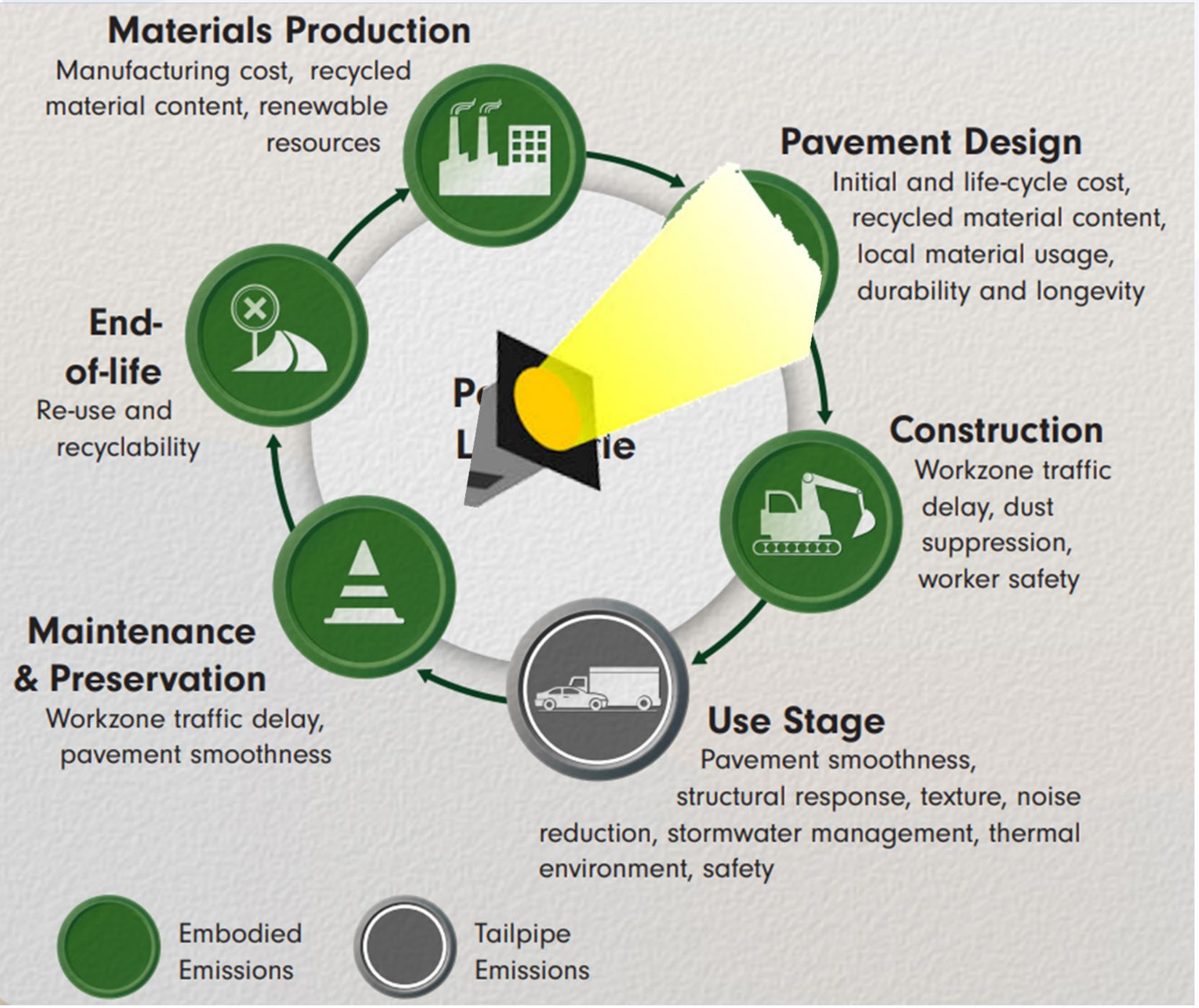
[Source: Jacquelyn Wong (CalTrans)]

Concrete Pavement Life Cycle



Source: FHWA - https://www.fhwa.dot.gov/infrastructure/climatechallenge/images/20211103_Emissions%20Infographic_508compl_toHPA.pdf

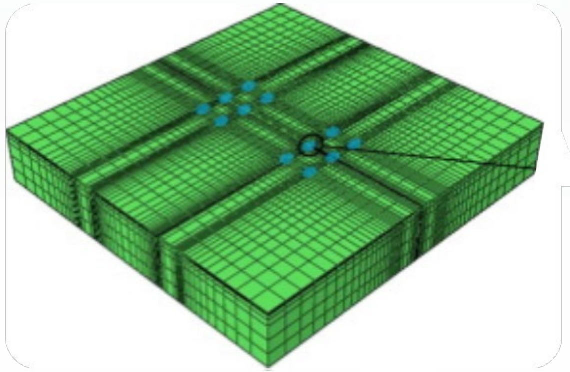
Concrete Pavement Life Cycle



- Design Phase
  - Most flexibility
  - Evaluate options
  - “Optimized” designs

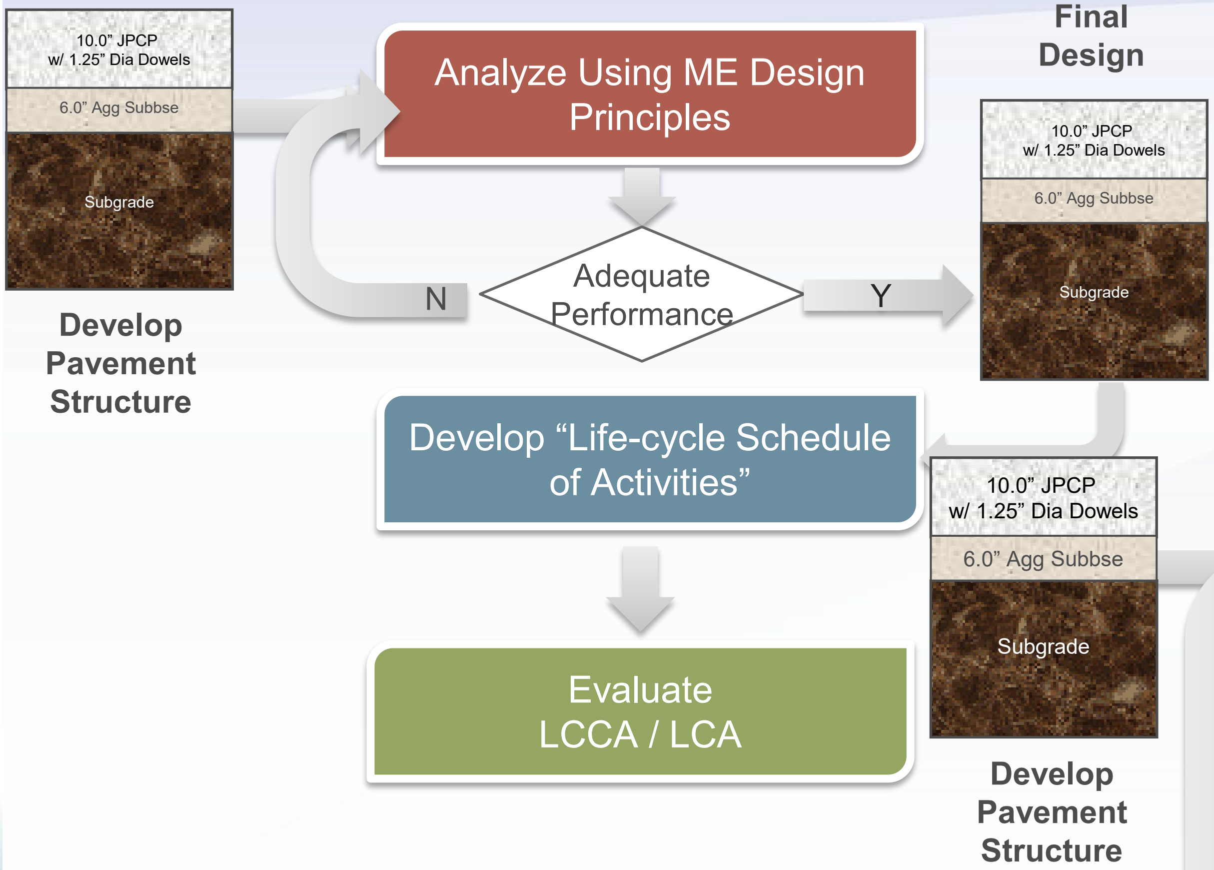
Concrete Pavement Life Cycle – Design Phase

- Use the best available design tools
  - Pavement ME Design
  - *PavementDesigner.org*
- Long-life Pavements
  - Low hanging fruit (double life = ½ CO_2)
- Concrete overlays
  - Capitalize on equity already in pavement
  - Long-life and low-carbon design solution
- OPTIMIZE!!!

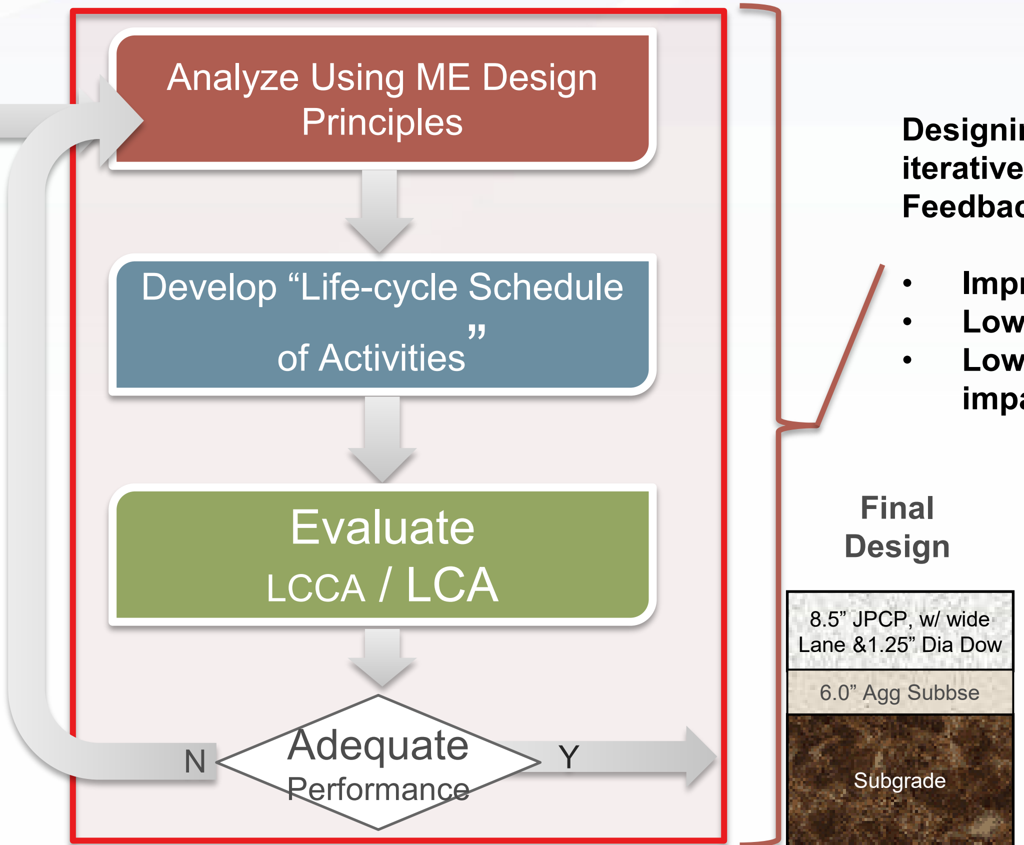


Optimize Pavement Designs

Traditional Design Process



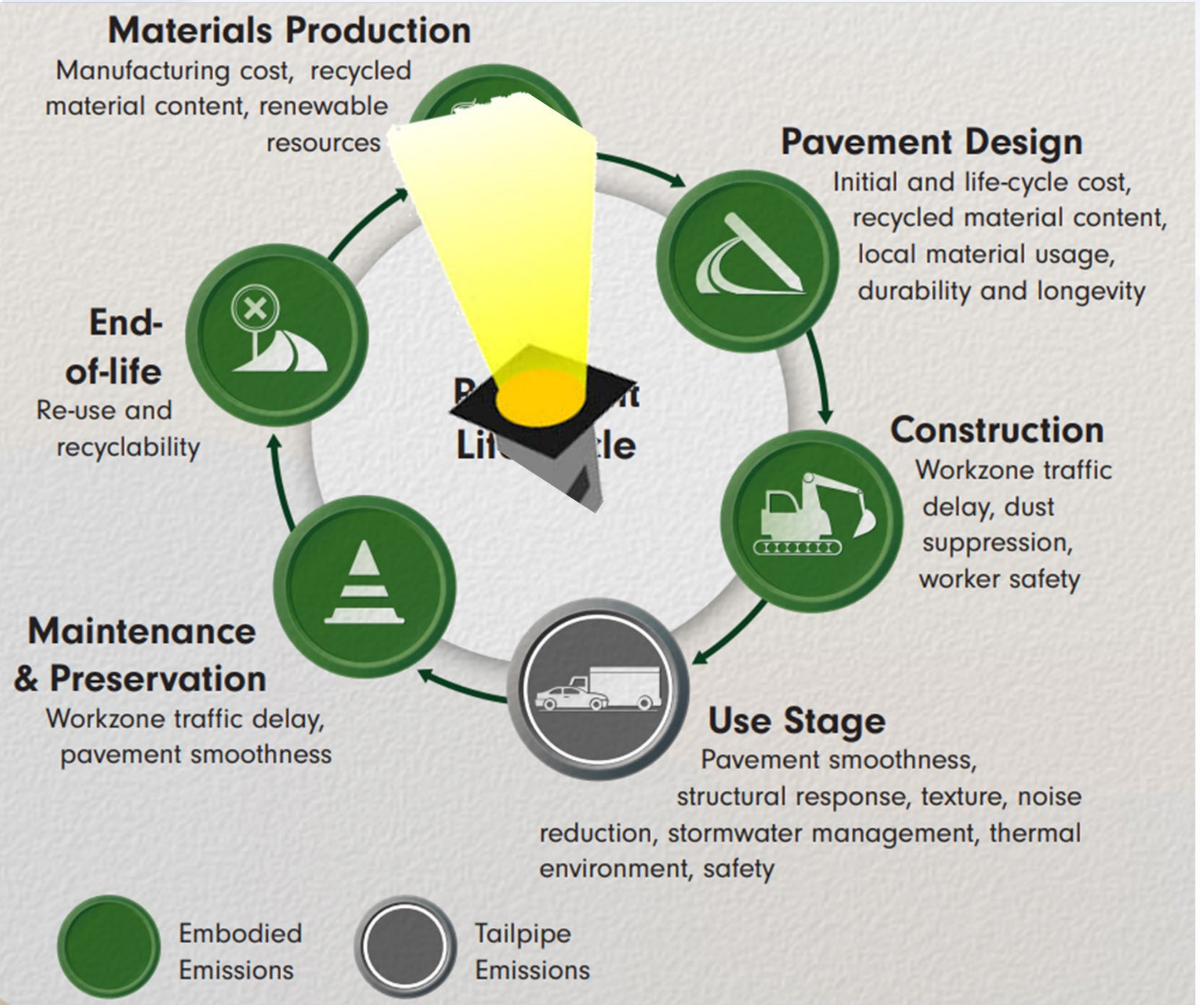
Optimized Design Based on Life Cycle Thinking



Designing pavements in an iterative procedure provides a Feedback Loop

- **Improves performance**
- **Lowers cost**
- **Lowers environmental impacts**

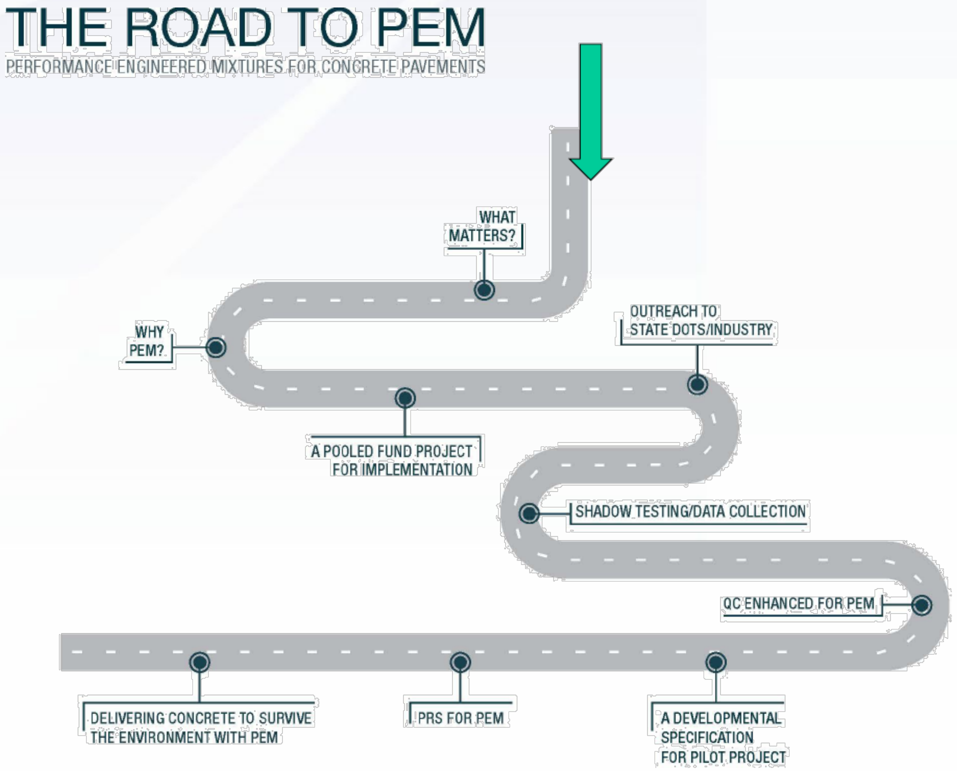
Concrete Pavement Life Cycle



- Materials Phase
  - EPDs live here!
  - PCA's Road Map
  - PLC
  - Performance Engineered Mixtures (PEM)
  - Recycling
  - New technologies and materials!

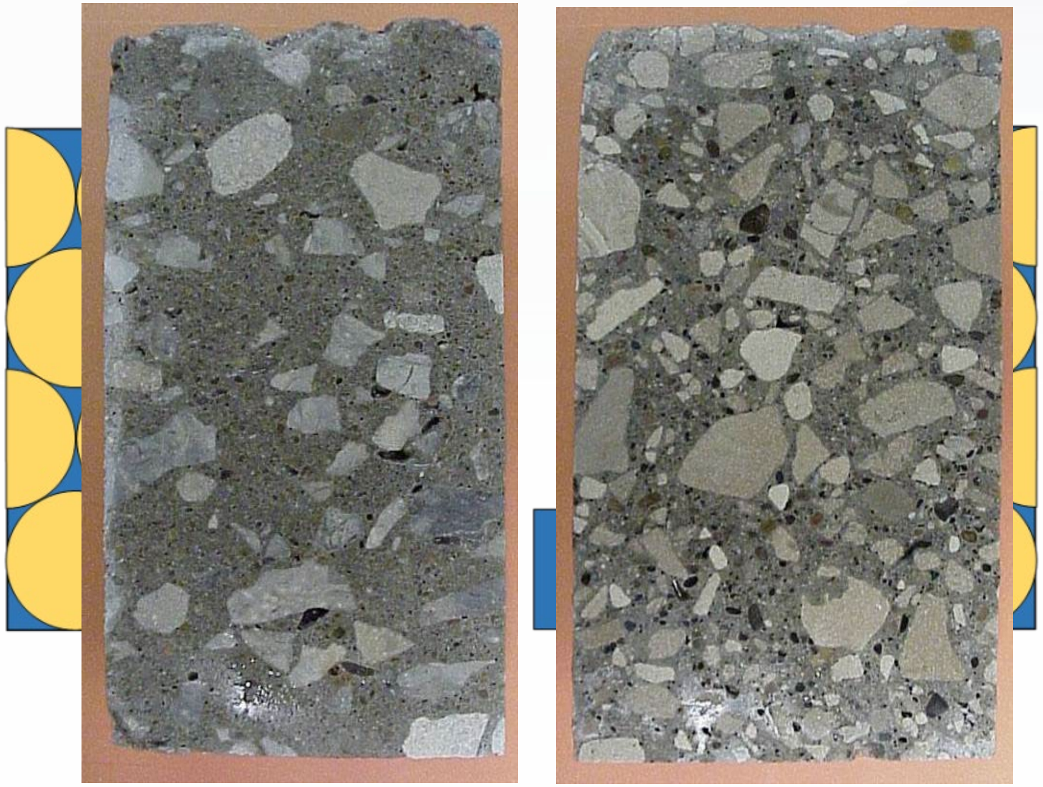
Optimizing Mix Designs

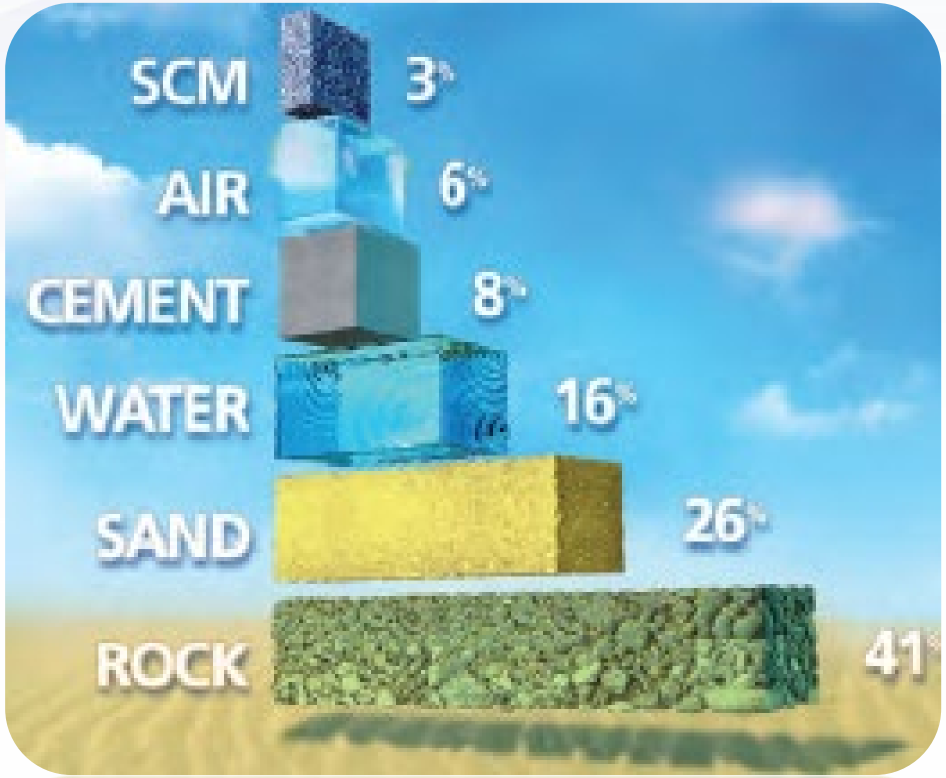
- Performance Engineered Mixtures (PEM)



Optimizing Mix Designs

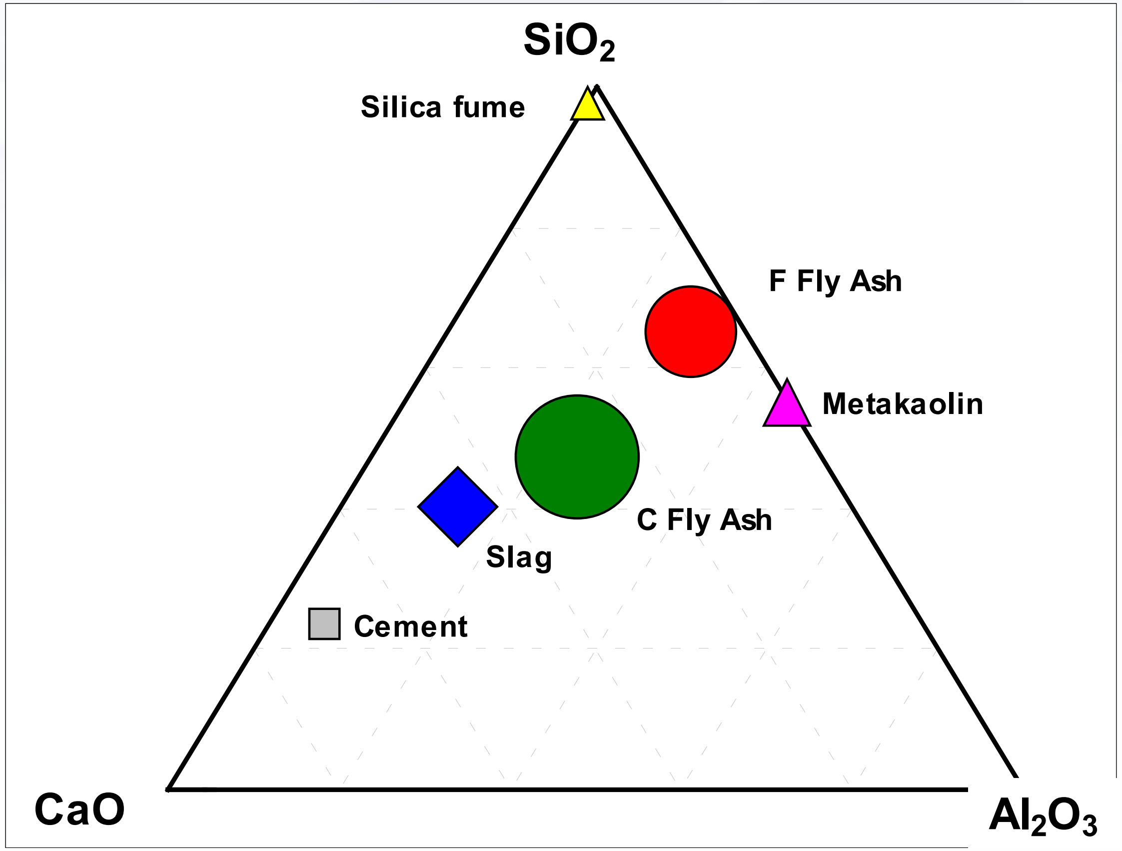
- Performance Engineered Mixtures (PEM)
  - Optimized cement gradations lead to optimized cementitious contents





Concrete Pavement Life Cycle – Materials Phase

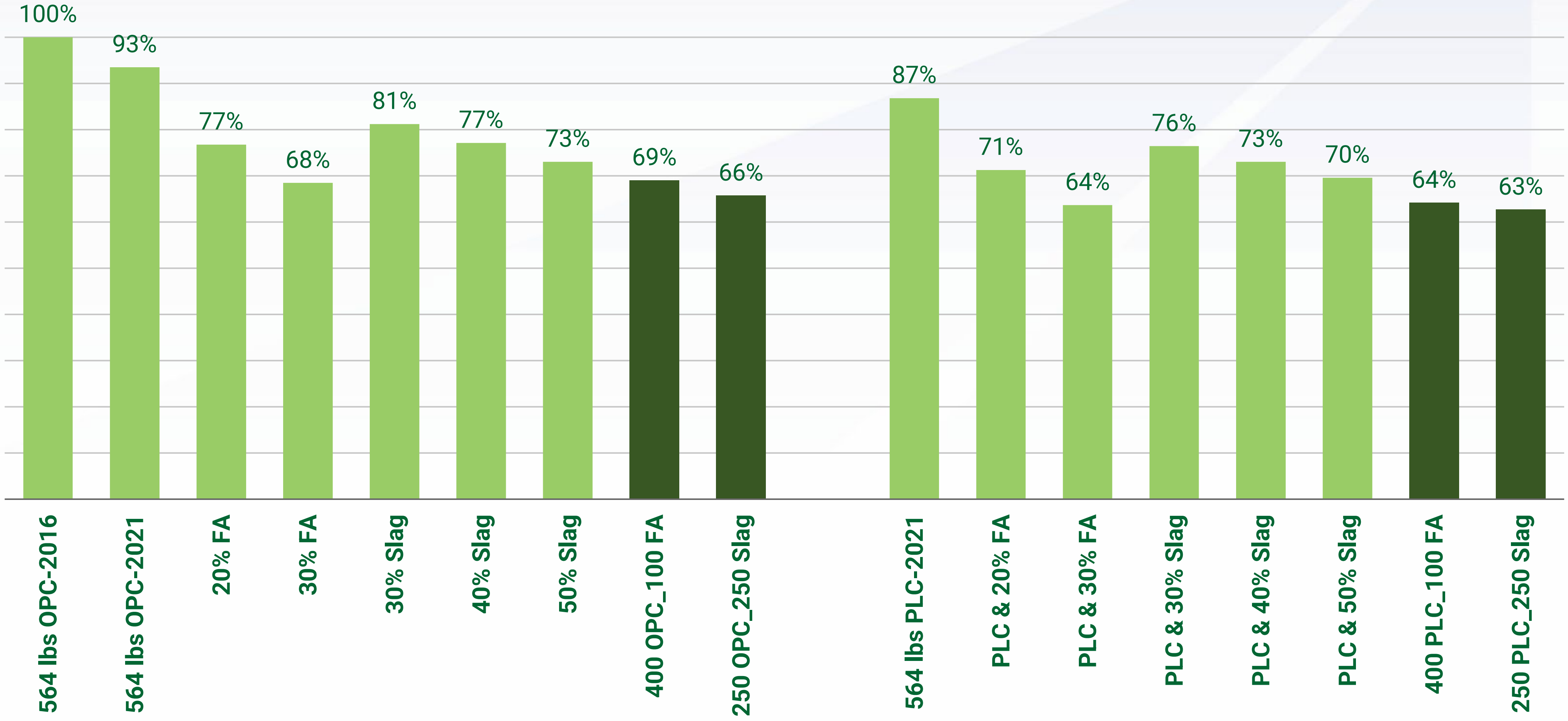
- Performance Engineered Mixtures (PEM)
  - Optimized use of SCMs
    - Enhance performance
    - Increase longevity
    - Reduce disposal headaches
    - Ternary combinations



Optimizing Mix Designs

Using SCMs and optimizing concrete mix designs lowers CO_2 of the mix

Using Portland Limestone Cements lowers the CO_2 impacts some more



GWP - global warming potential

For standard six sack (564lb/cy) Mix; Assumed Slag shipping Distance = 10,500 miles (*Rizhao to FL)*

Concrete Pavement Life Cycle – Materials Phase

- New SCMs and ACMs
  - Reclaimed coal ash
  - Natural pozzolans
  - Calcined clay
  - Ground glass
  - Carbon injection

Use Innovative Low-Carbon Cementitious Materials

- Test sections recently constructed at MNRoad
  - Assess CO_2 savings
  - Measure performance under traffic
  - 16 sections
    - Control and optimized mixtures
    - Reclaimed fly ashes
    - Geopolymers
    - Carbon injection
    - Innovative SCMs

Concrete Pavement Life Cycle – Materials Phase

- Recycling
  - Reduced virgin material
  - Eliminates disposal
  - 140 M Tons Annually

Top 10 Recycled

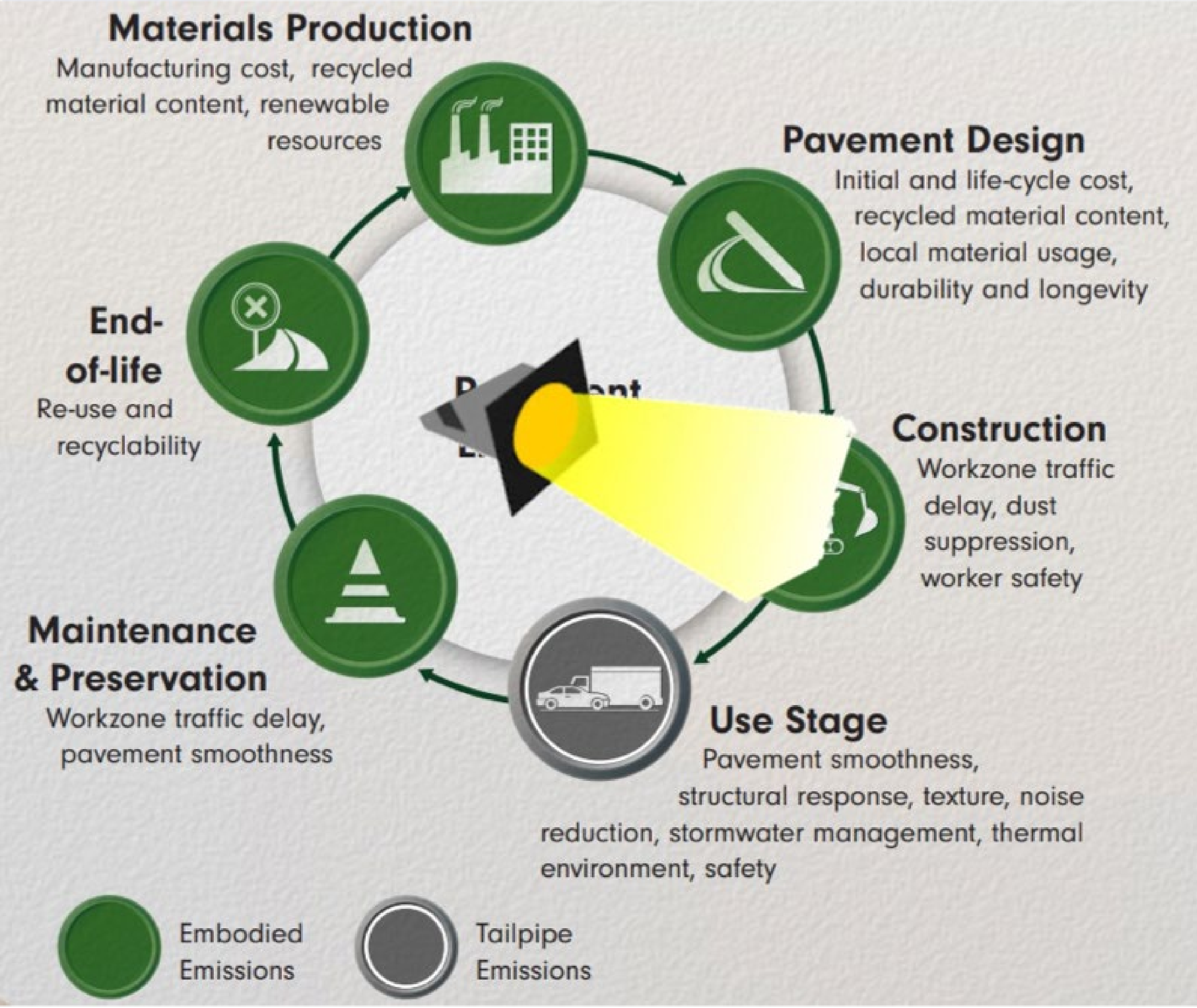
1. Concrete
2. Steel
3. Aluminum
4. Plastic (PET)
5. Newspapers
6. Corrugated Cardboard
7. Plastics (HDPE)
8. Glass
9. Mixed Papers
10. Used Motor Oil

National Concrete Pavement Technology Center

Iowa State University
Institute for Transportation

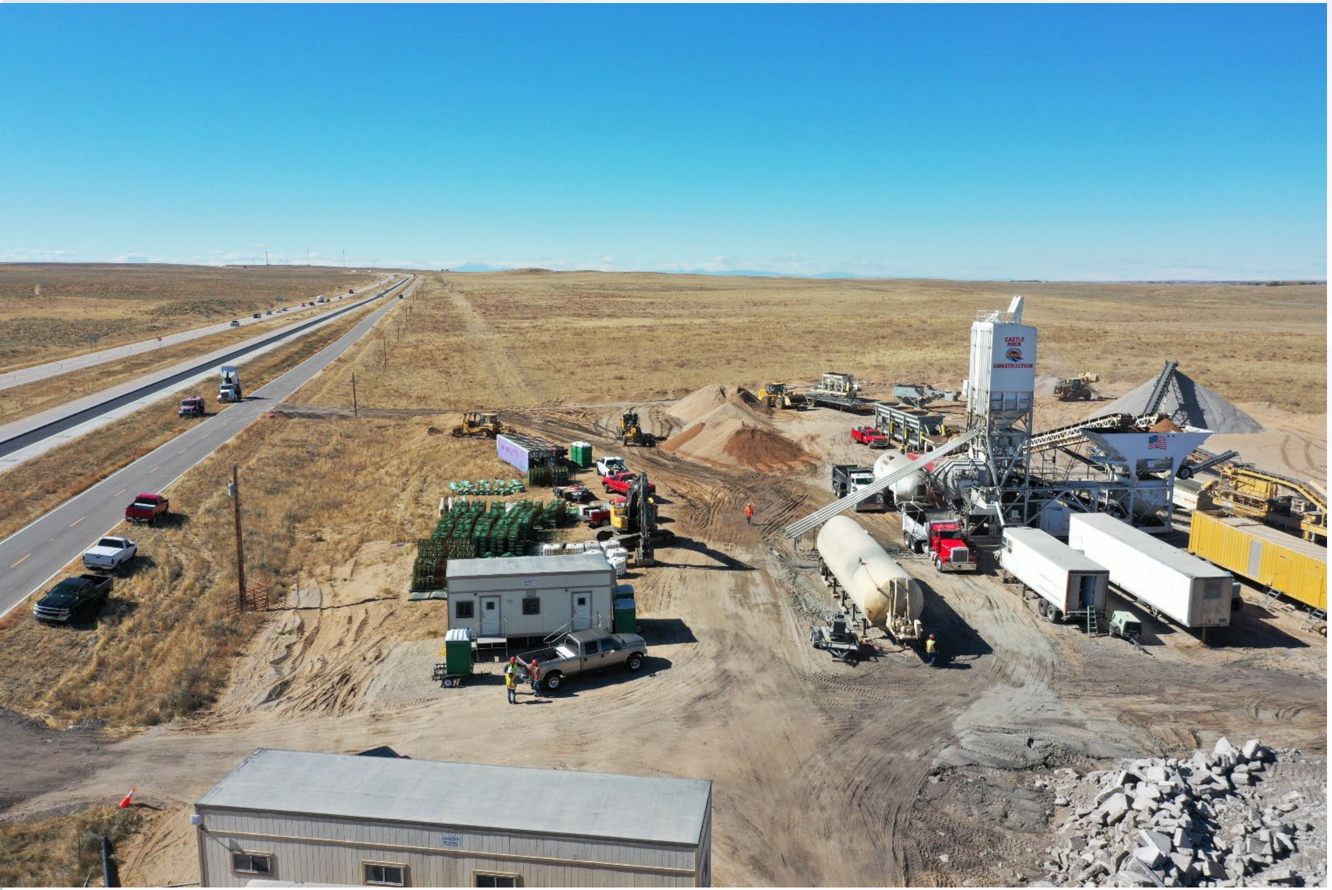
Cavalline

Concrete Pavement Life Cycle – Construction Phase



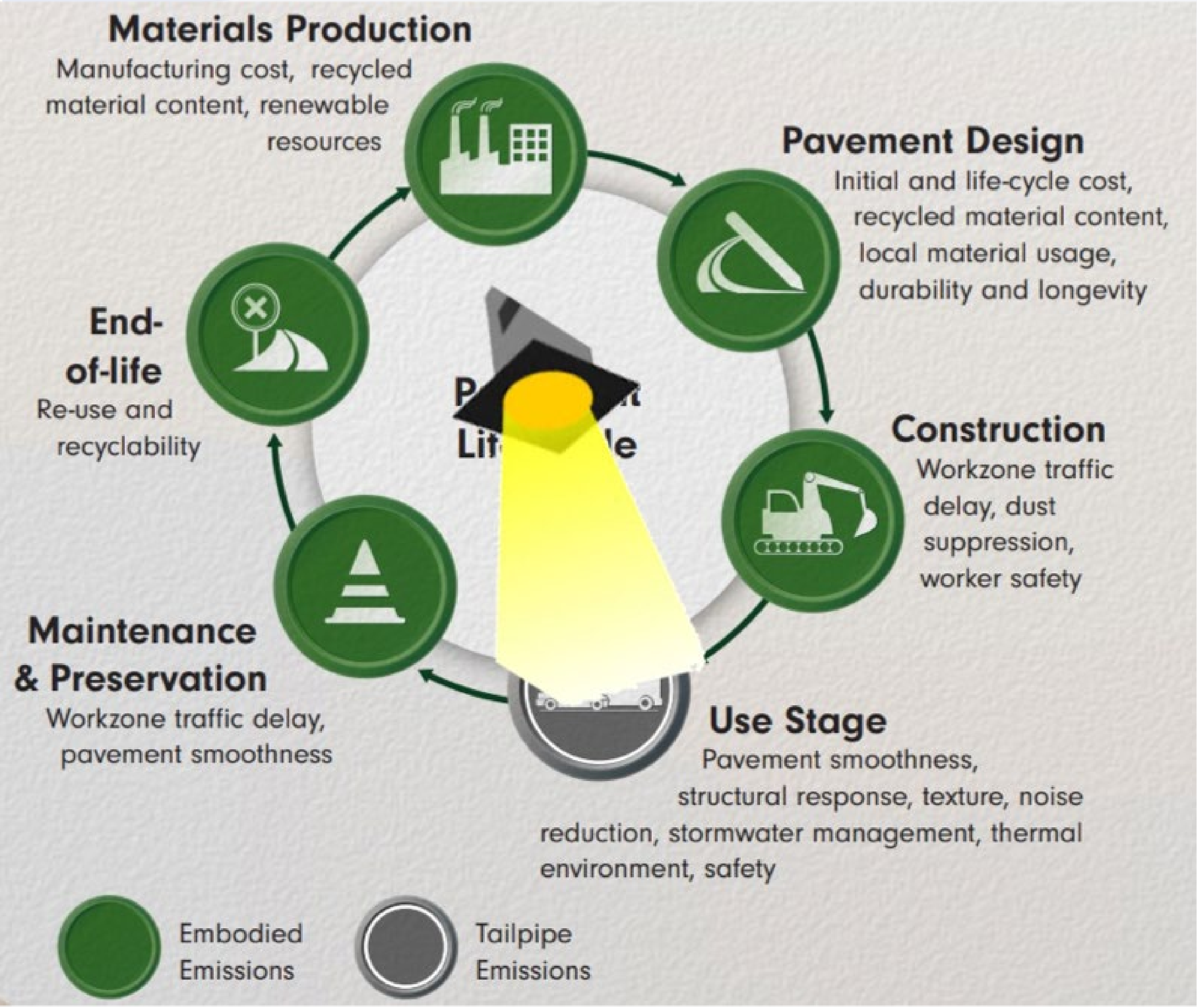
- Construction Phase
  - Optimized construction planning
  - Reduced transportation
  - Recycling… again!
  - Implementation of renewable fuels

Concrete Pavement Life Cycle – Construction Phase



- Construction Phase
  - Optimized construction planning
  - Reduced transportation
  - Recycling… again!
  - Construction equipment improvements

Concrete Pavement Life Cycle – Use Phase



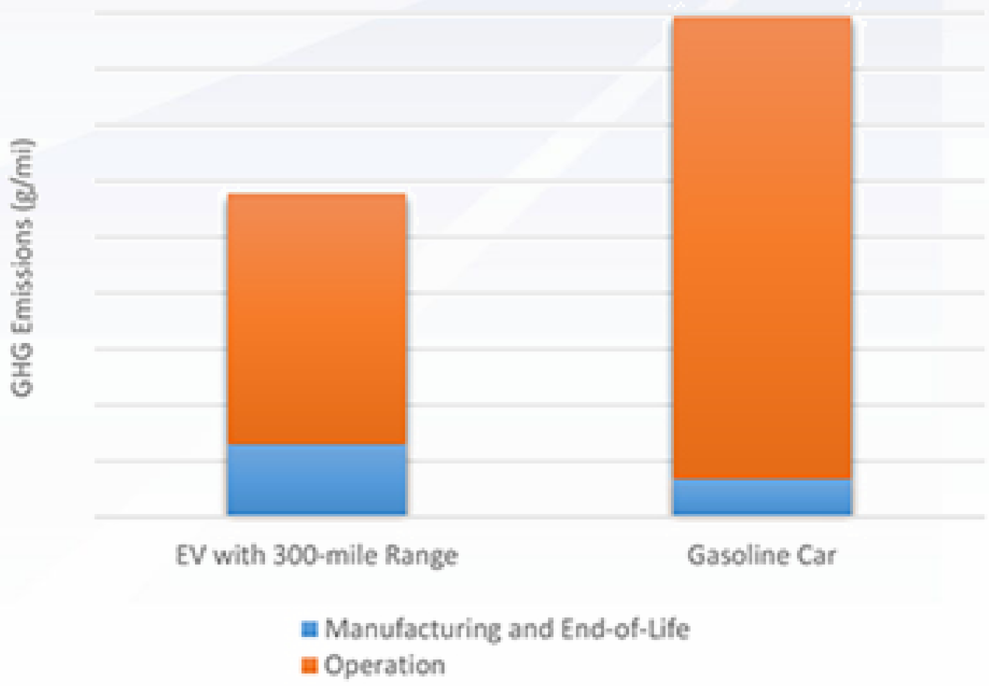
- Use Phase
  - Pavement Vehicle Interactions (PVI)
  - Albedo
  - Urban heat island
  - Lighting
  - Carbonation / Sequestration

Use Phase – Why is it important?

Tesla Model S - Electric

Audi A7 – Gas Powered

Lifecycle GHGs for an Electric Vehicle and Gasoline Car



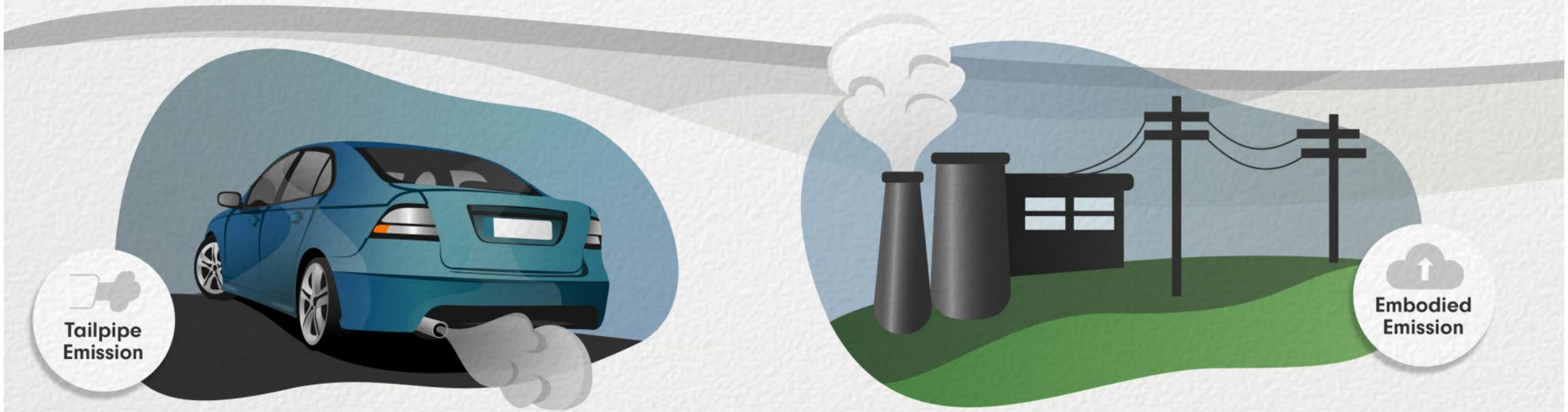
None of the CO2 reductions from EVs materialize until well past embodied stage

Source: https://www.epa.gov/greenvehicles/electric-vehicle-myths

Concrete Pavement Life Cycle – Use Phase

EMISSIONS FROM HIGHWAY TRANSPORTATION SYSTEMS

A Look Beyond the Tailpipe



What are tailpipe emissions?

Tailpipe emissions are pollutants from exhaust gases discharged from vehicles equipped with an internal combustion engine. Tailpipe emissions incurred during the use stage of the pavement life cycle are considered operational emissions.

What are embodied emissions?

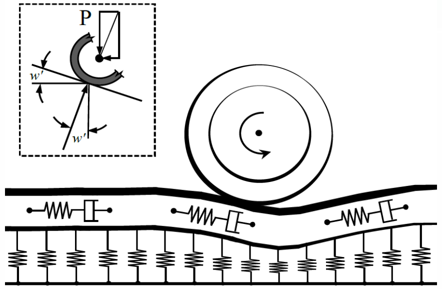
Embodied emissions include emissions from manufacturing, material transport, construction, maintenance, and disposal of transportation infrastructure building materials. Embodied emissions of greenhouse gases (GHG) are also known as embodied carbon.

Reducing Use Phase Impacts – PVI

Pavement Vehicle Interaction (PVI) Impacts the Excess Fuel Usage (EFC)

- Pavement texture:
  - The micro-surface of the pavement “grabs” the tire, which increases friction and lowers fuel efficiency.
  - Tire industry. Critical for safety. Tire-pavement contact area

- Roughness/smoothness*:
  - Higher roughness “bounces” the cars and increases fuel usage
  - Absolute value = vehicle dependent.
  - Changes / evolves over time: material specific



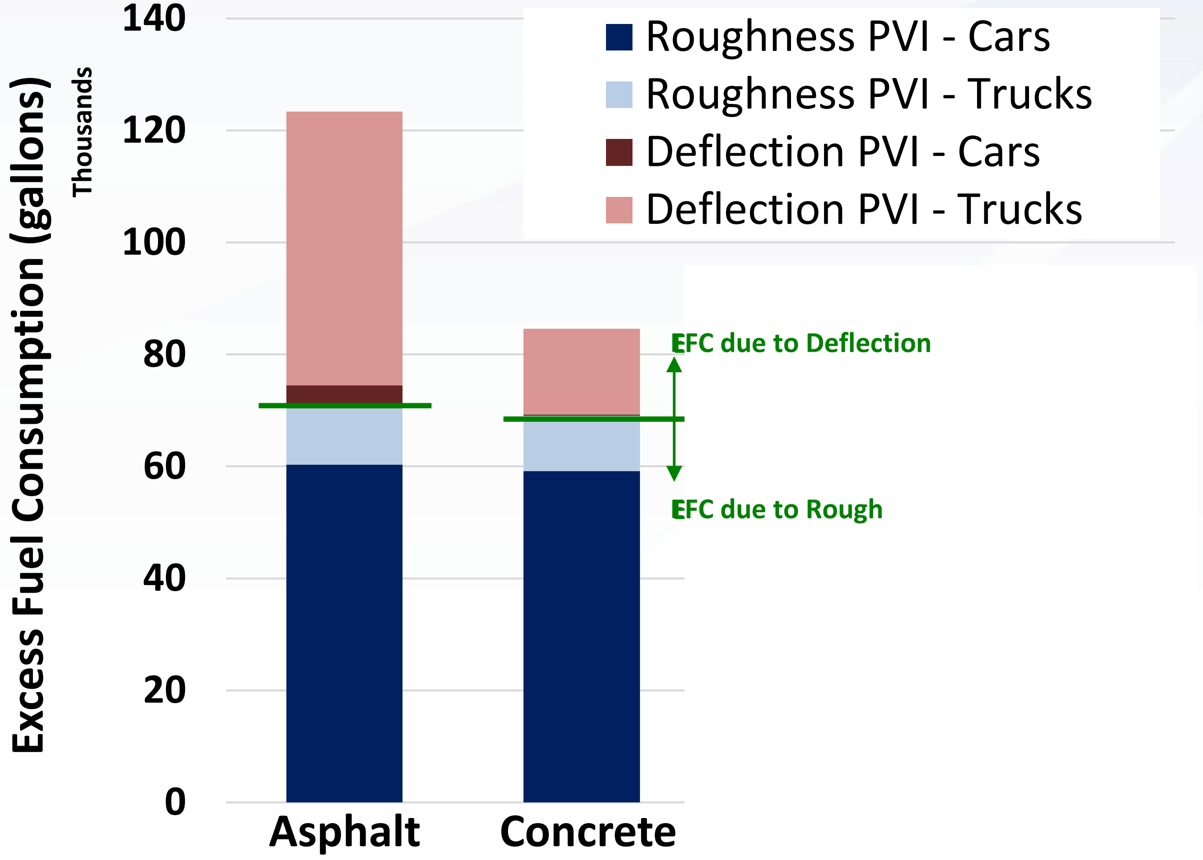
- Deflection/dissipation induced PVI**:
  - Vehicle deflects the pavement and vehicle drives up a hill
  - Pavement Design Parameters (materials, stiffness & thickness) matter
  - Speed and temperature dependent, especially for inter-city pavement systems

*Zaabar, I., Chatti, K. 2010. Calibration of HDM-4 Models for Estimating the Effect of Pavement Roughness on Fuel Consumption for U.S. Conditions. Transportation Research Record: **Journal of the Transportation Research Board**, No. 2155. Pages 105-116.

** Akbarian M., Moeini S.S., Ulm F-J, Nazzal M. 2012. Mechanistic Approach to Pavement-Vehicle Interaction and Its Impact on Life-Cycle Assessment. Transportation Research Record: **Journal of the Transportation Research Board**, No. 2306. Pages 171-179.

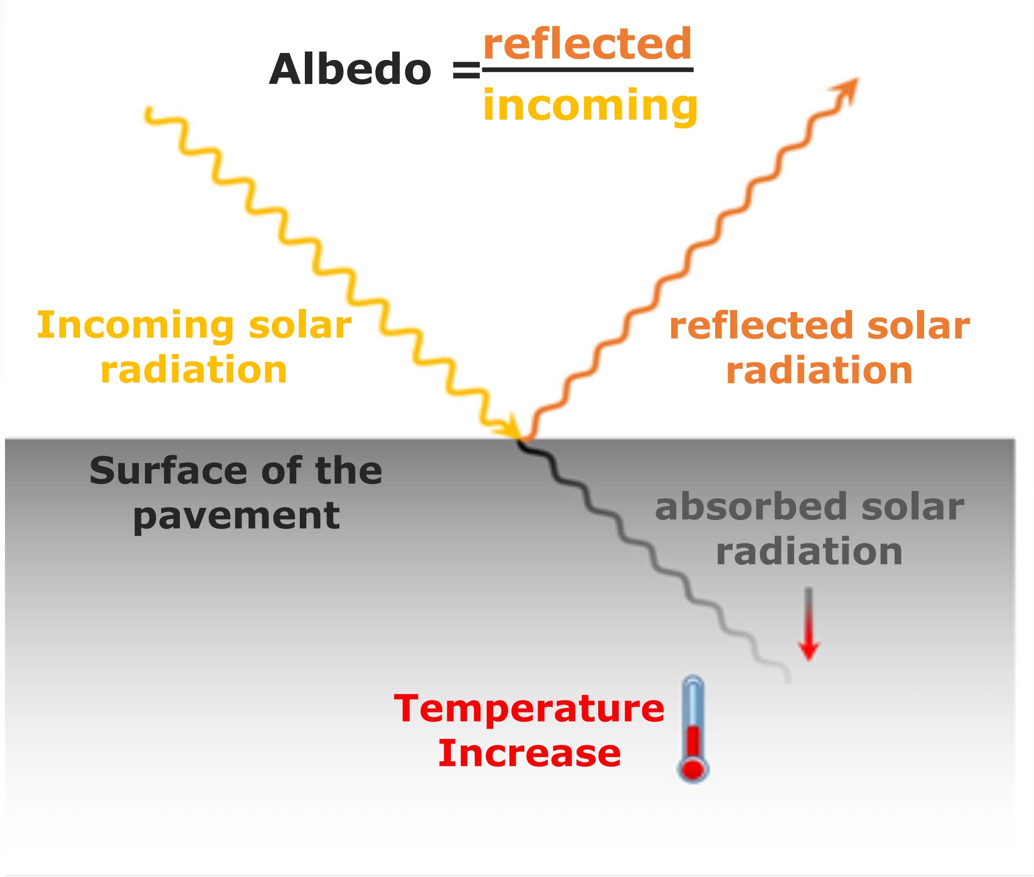
Concrete Pavement Life Cycle – Use Phase

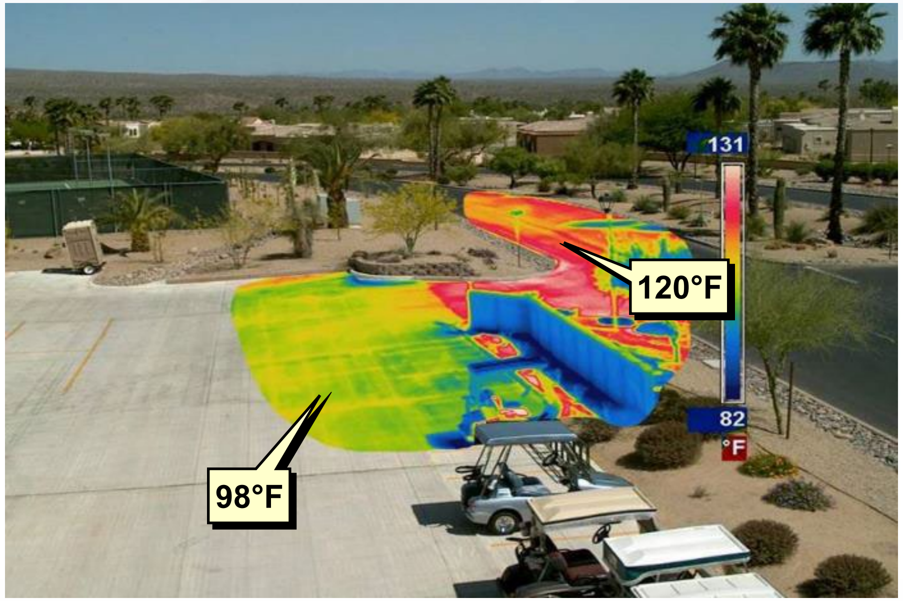
- Excess fuel consumption matters!



Reducing Use Phase Impacts – Albedo

- Albedo – The measure of solar energy reflected by surface





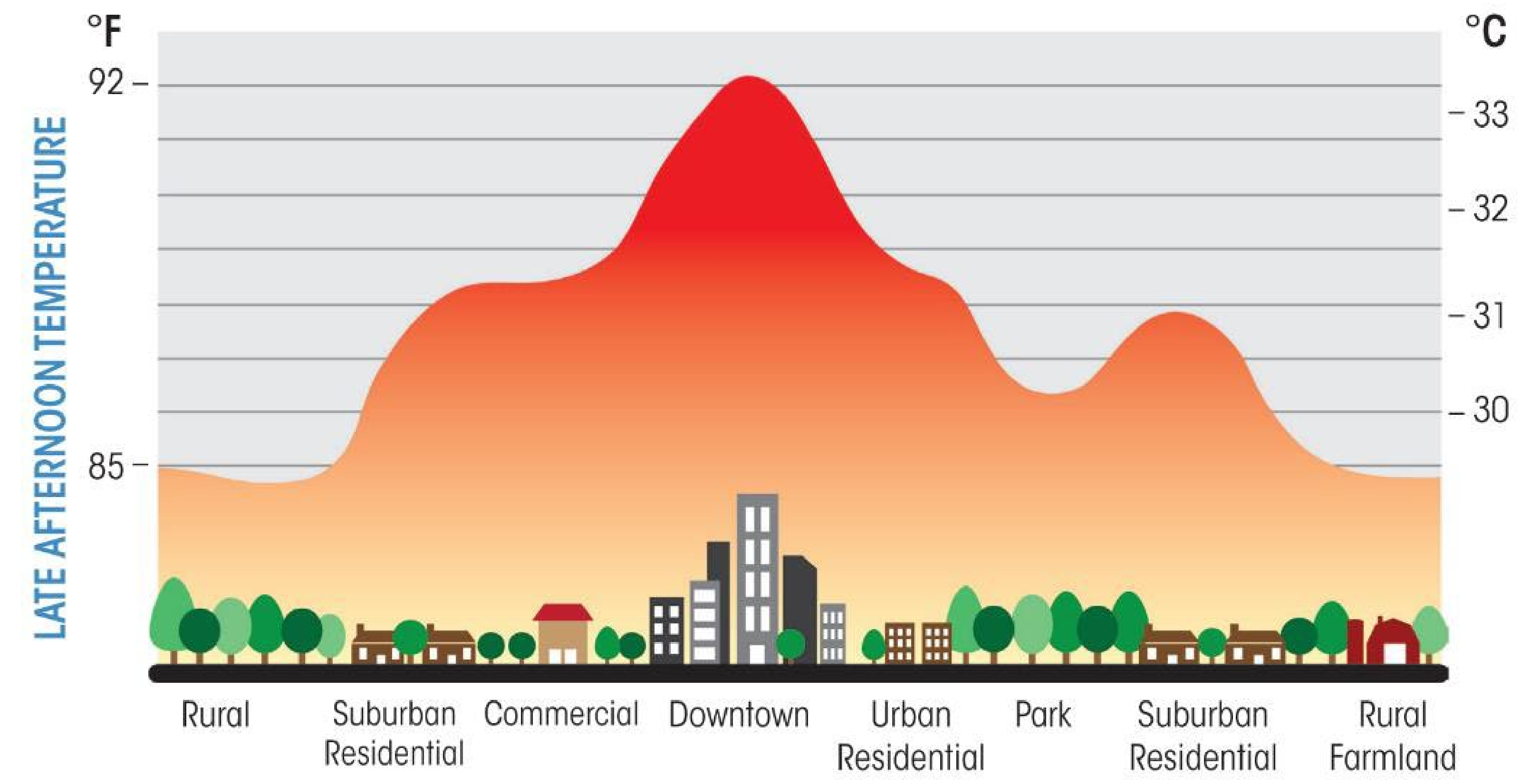
Albedo Values

- Concrete ≈ 0.40 (new) to 0.2 (old)
  Concrete with PLC &/or Slag ≈ 0.45 to 0.55
- Asphalt ≈ 0.05 (new) to 0.15 (old)
- Earth Avg ≈ 0.3 to 0.35

Reducing Use Phase Impacts – Urban Heat Island

- Concrete's high albedo reduces Urban Heat Island impact

Example of Heat Island effect



Increasing pavement albedo by 0.20 (asphalt to concrete) can reduce city temperatures by :

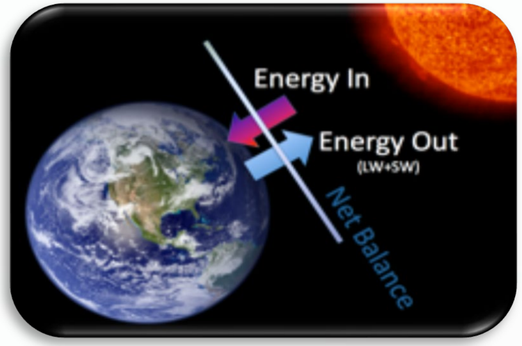
- **0.3° C (Boston)**
- **2.1° C (Phx)**

Sources:
http://www.cleanairpartnership.org/files/urbanheatisland.jpg
http://cshub.mit.edu/pavements/albedo

Concrete Pavement Life Cycle – Use Phase

Increasing pavement albedo is meaningful and low-cost and low risk endeavor to address climate change

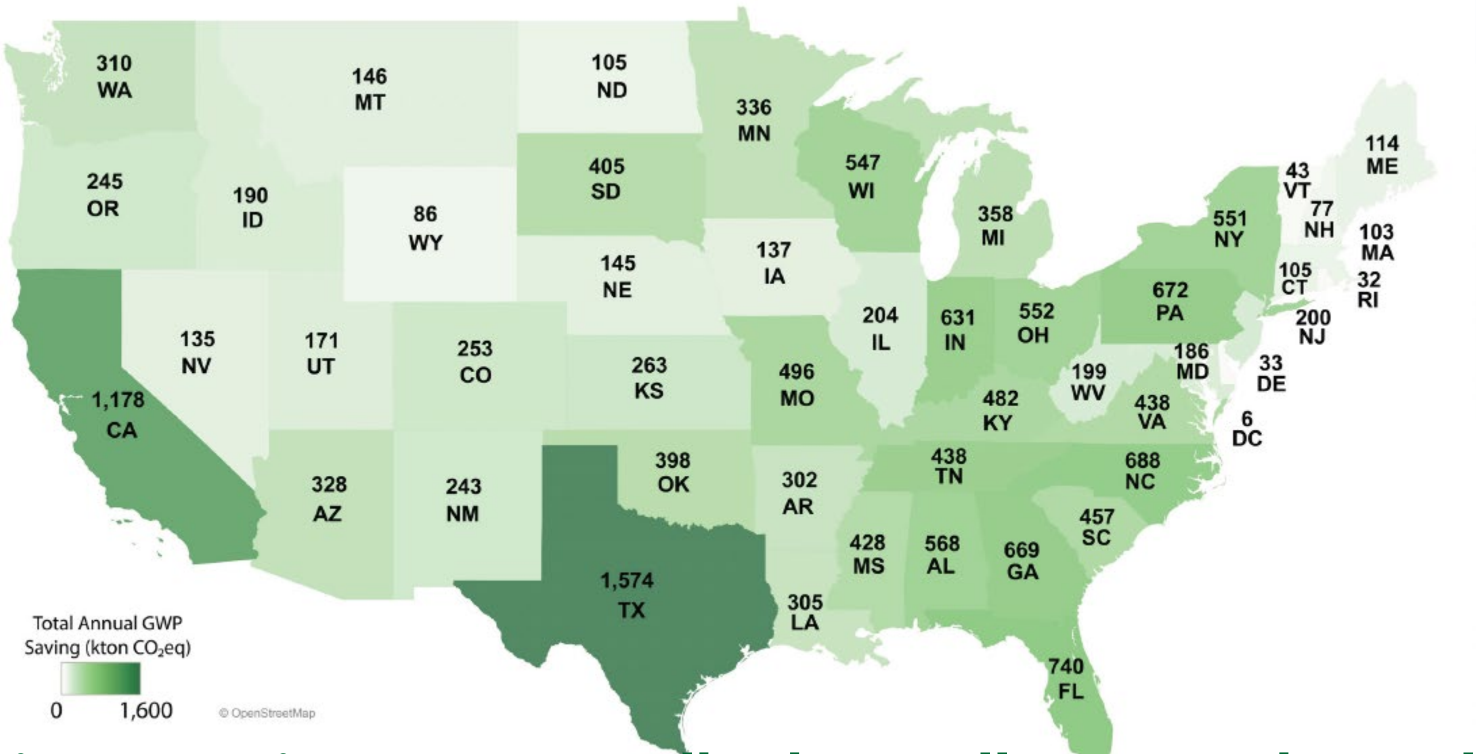
Earth's Energy Balance



Radiative forcing

Albedo improves the Earth's Energy Balance to create **Cooling Benefits**

Annual GWP savings due to increasing the surface reflectivity of all pavements across the continental U.S. (kton CO_{2eq})



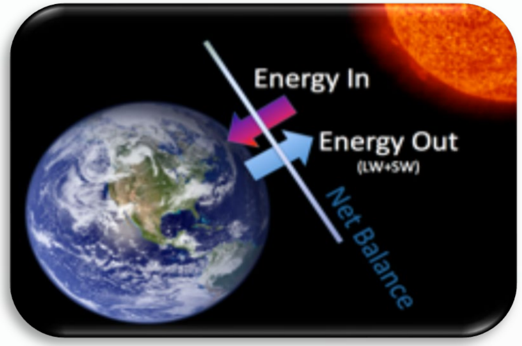
Sources:
http://www.cleanairpartnership.org/files/urbanheatisland.jpg
http://cshub.mit.edu/pavements/albedo

An increase in pavement albedo on all U.S. roads would reduce CO2-eq by 17.45 Mton per year due to radiative forcing—equivalent to ~ 4 million cars

Reducing Use Phase Impacts – Radiative Forcing

Increasing pavement albedo is meaningful and low-cost and low risk endeavor to address climate change

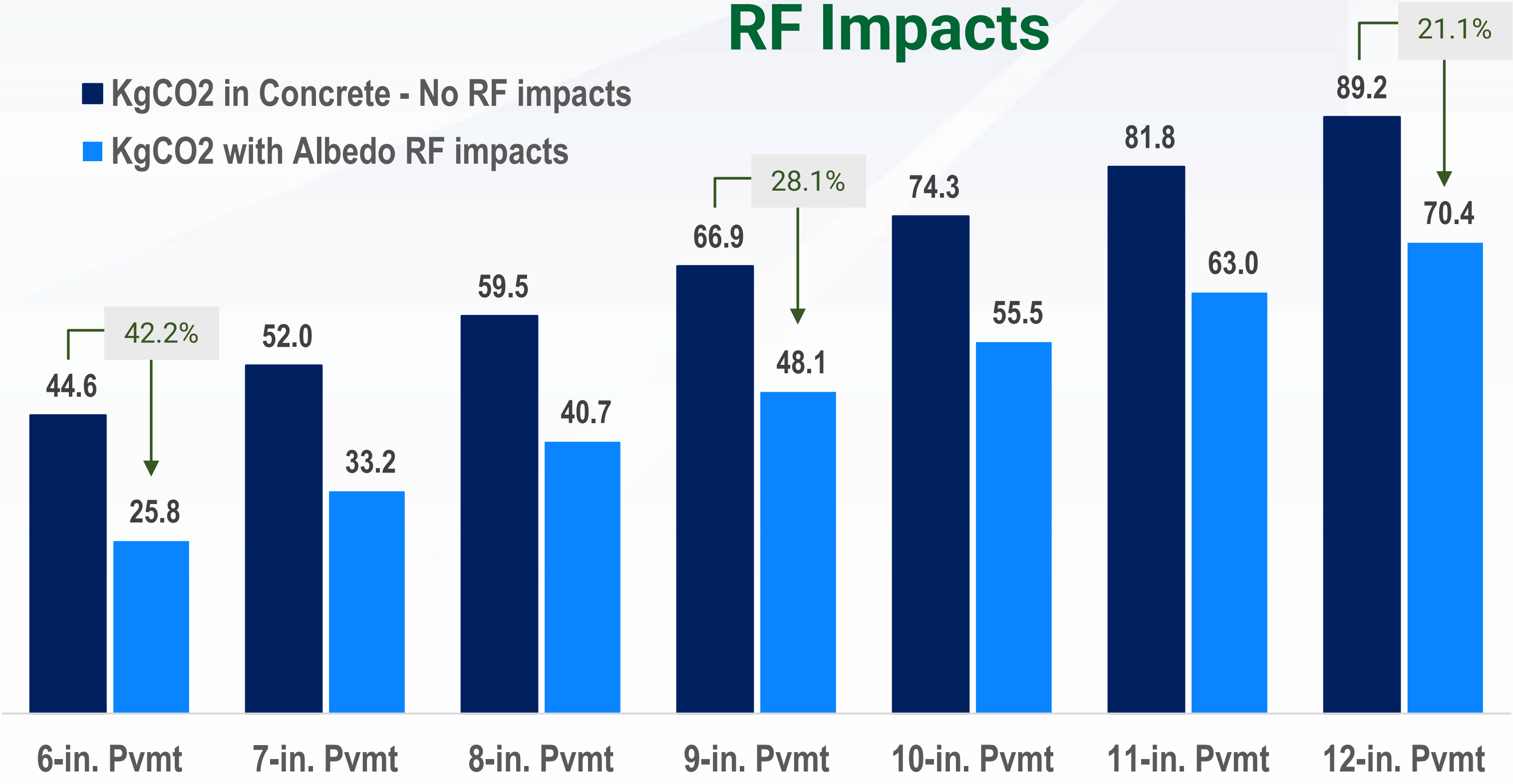
Earth's Energy Balance



Radiative forcing

Albedo improves the Earth's Energy Balance to create **Cooling Benefits**

KgCO2 in 1 SY of Pavement with & without RF Impacts



Sources:
http://www.cleanairpartnership.org/files/urbanheatisland.jpg
http://cshub.mit.edu/pavements/albedo

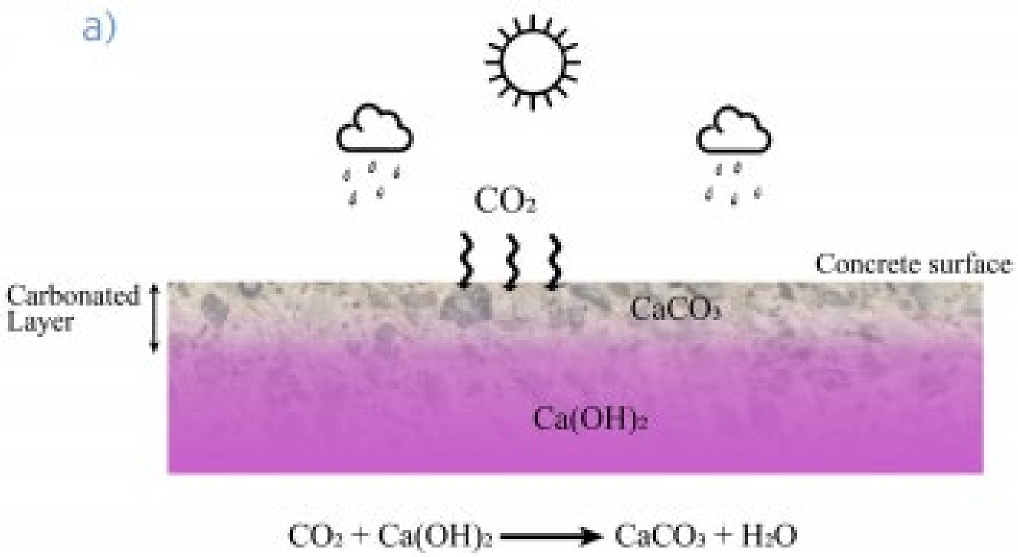
Over a 50-year period, albedo offsets <u>20% to 40%</u> of the production CO2 for the cement used in pavements (depends on thickness)

Reducing Use Phase Impacts – Carbonation

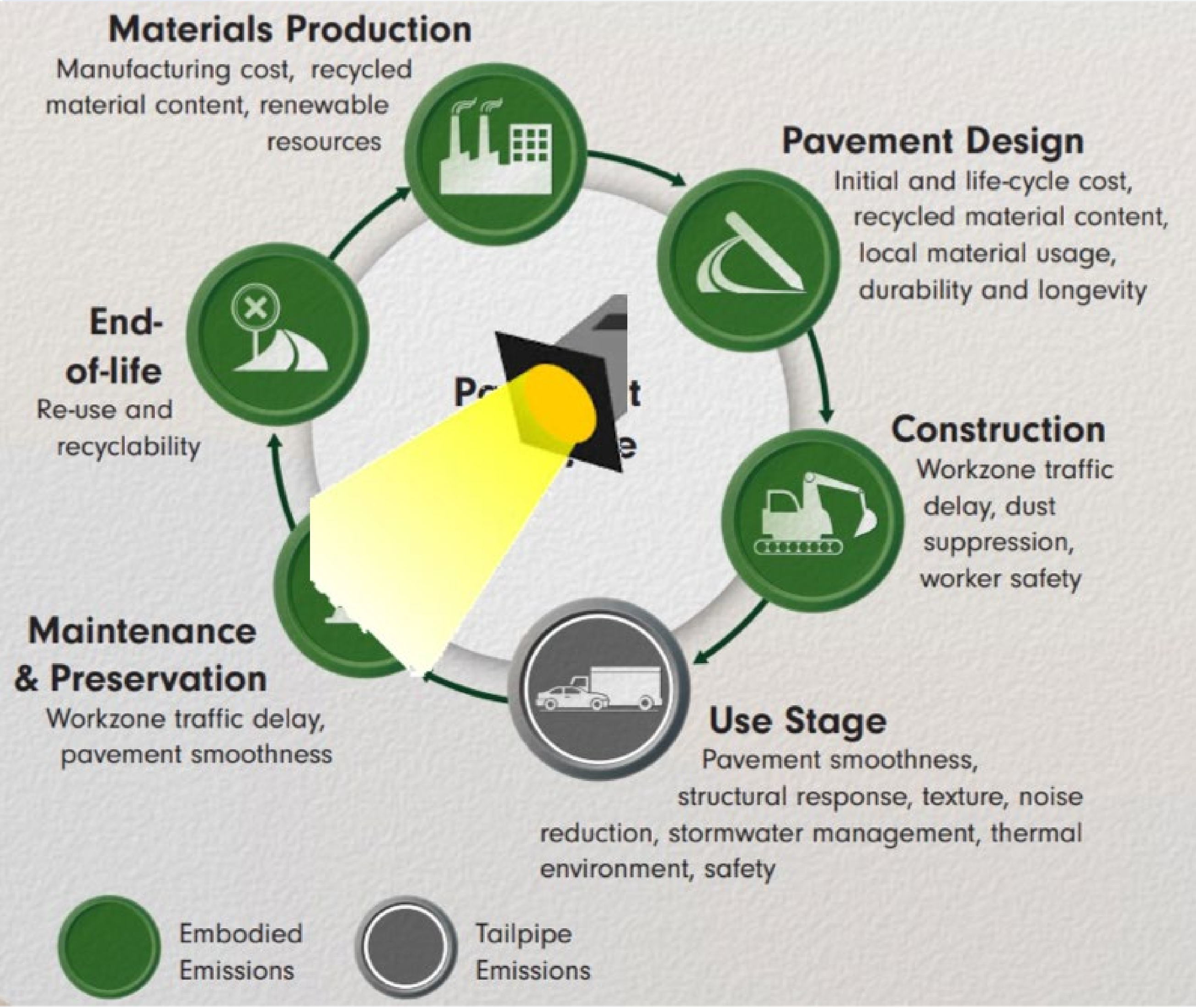
- Concrete – CO_2 Absorption
- Carbonation CO_2 reacts with calcium carbonate in concrete
- In US, concrete pavements could absorb about 2.8 million tons of CO2 30 years use
  - More in states w/ concrete pavements

https://news.mit.edu/2021/unravelling-carbon-uptake-concrete-pavements-0126

https://cshub.mit.edu/sites/default/files/images/0120%20Carbon%20Uptake%20Bri



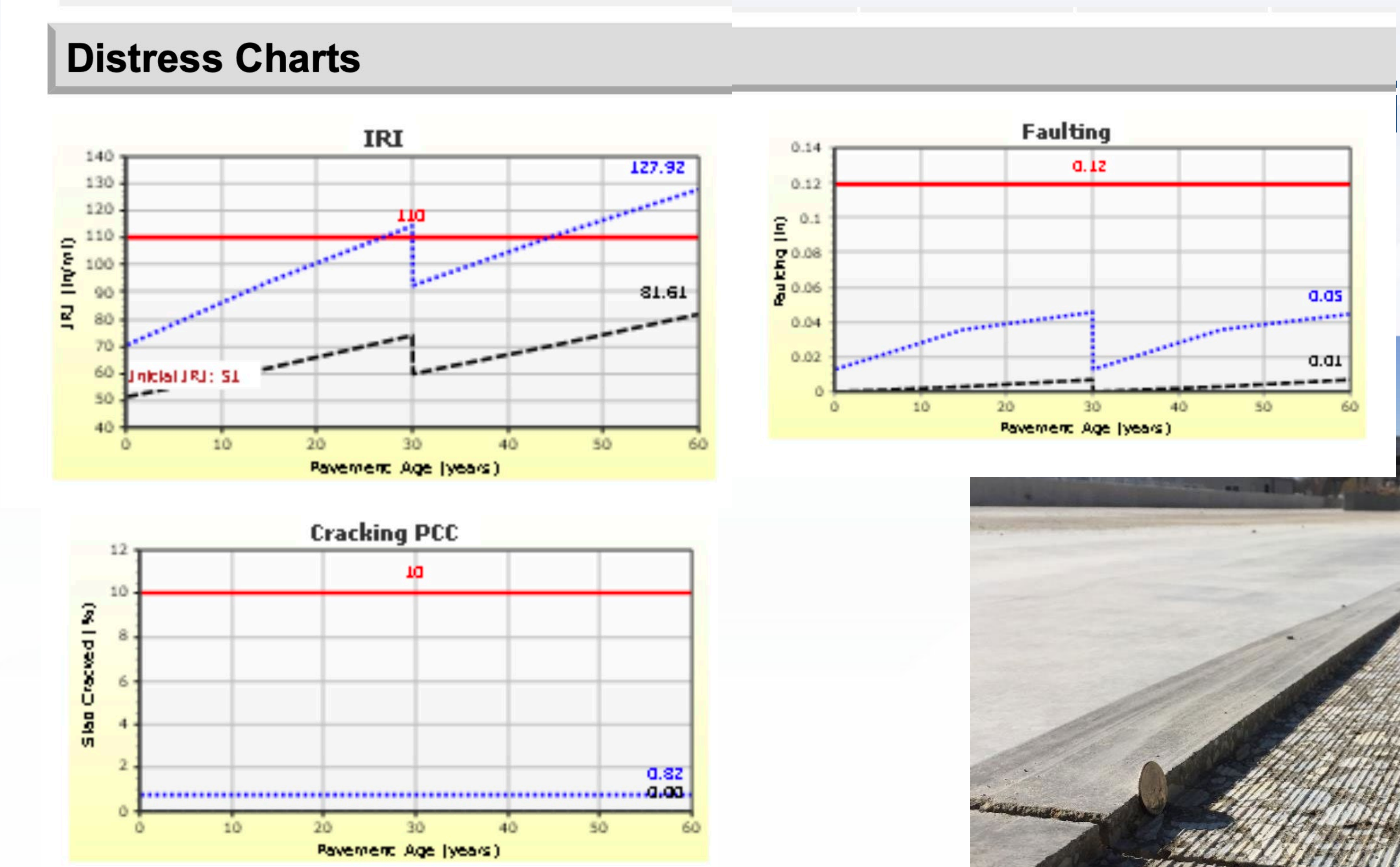
Concrete Pavement Life Cycle – M&R Phase



- Maintenance, Preservation, & Rehabilitation
  - Diamond grinding
  - Patching
  - Sealing
  - Overlays

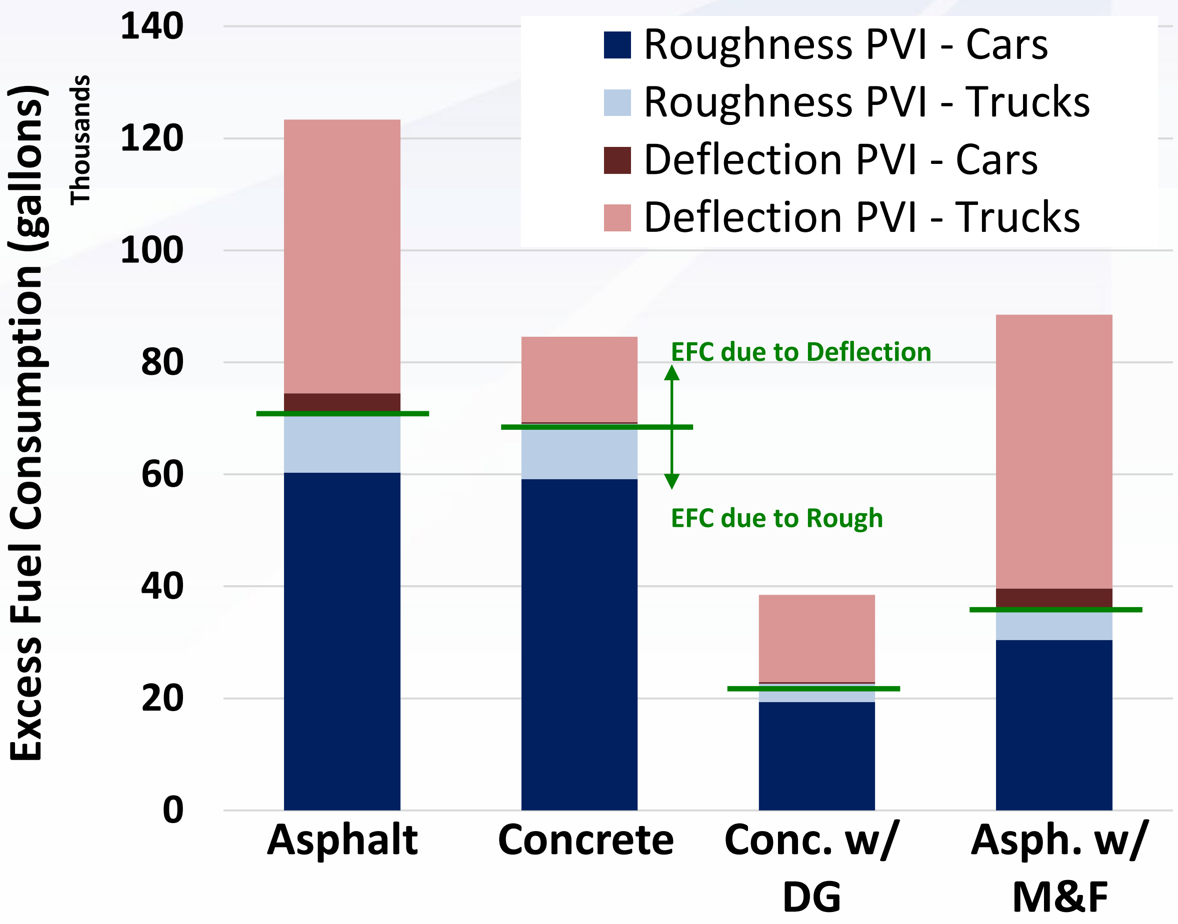
Concrete Pavement Life Cycle – M&R Phase

ify!



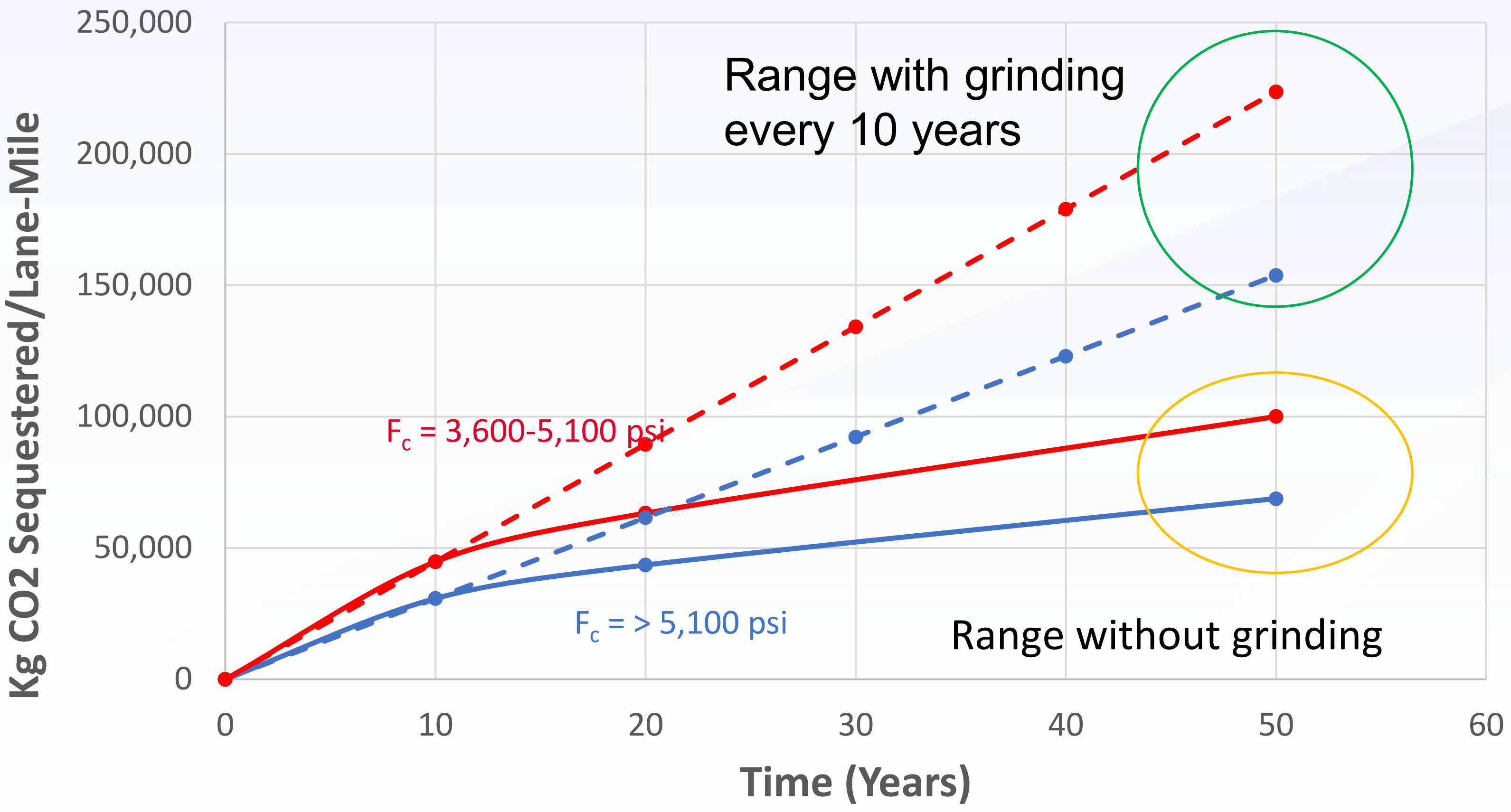
Reducing Use Phase Impacts – With Preservation

- Build & Maintain Smoother Pavements
  - Improved Maintenance activities that keep a Pavement smooth over its lifetime
  - Build Pavements that stay smoother longer
- Build "Stiffer" Pavements
  - Concrete's inherent higher stiffness means it lower structural PVI impacts



Reducing Use Phase Impacts – With Preservation

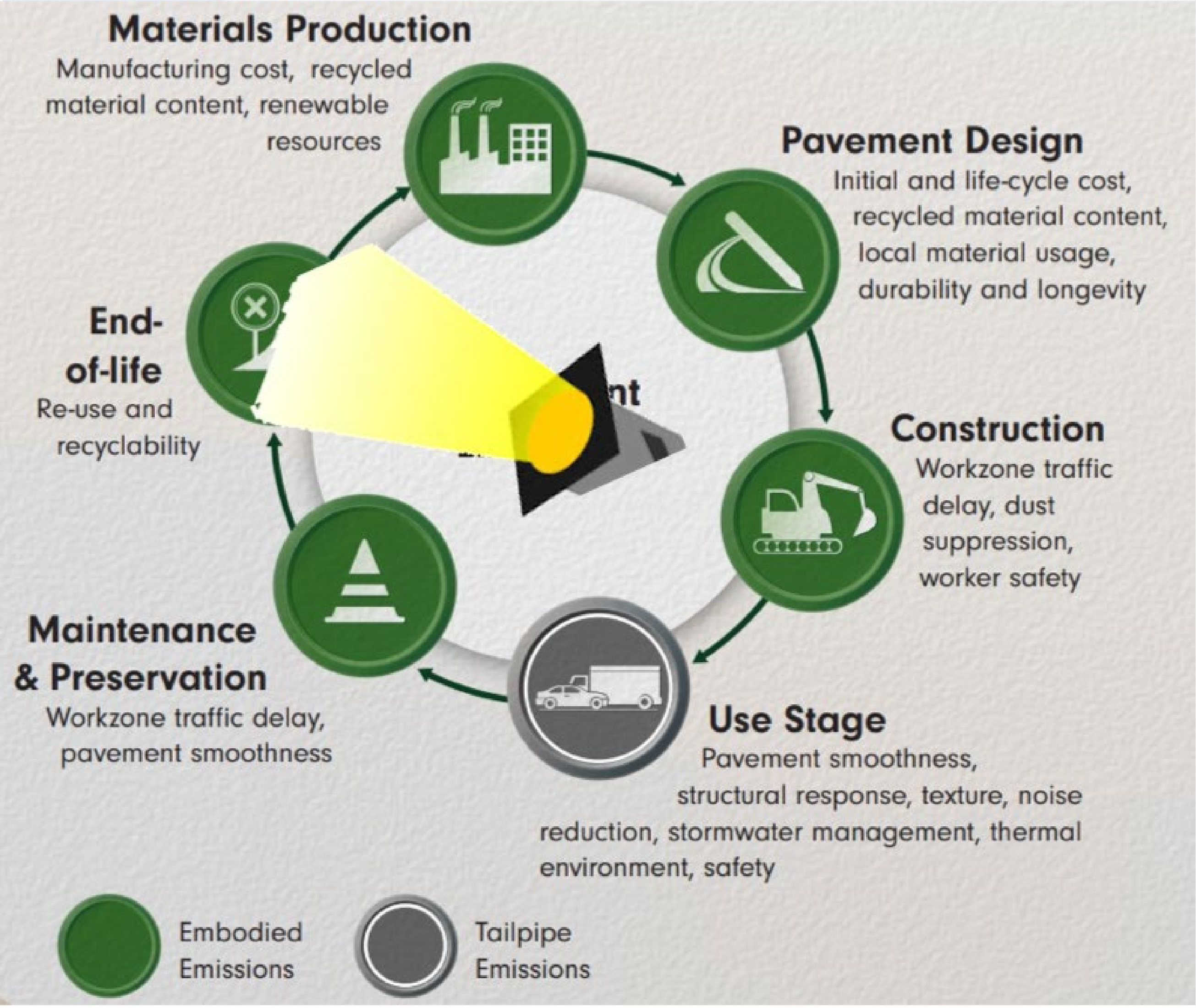
CO2 Sequestered Over Time per Lane-Mile with Diamond Grinding



Additional Diamond Grinding also improves vehicle fuel efficiency due to improved smoothness and increases Albedo resulting in even greater GHG reductions

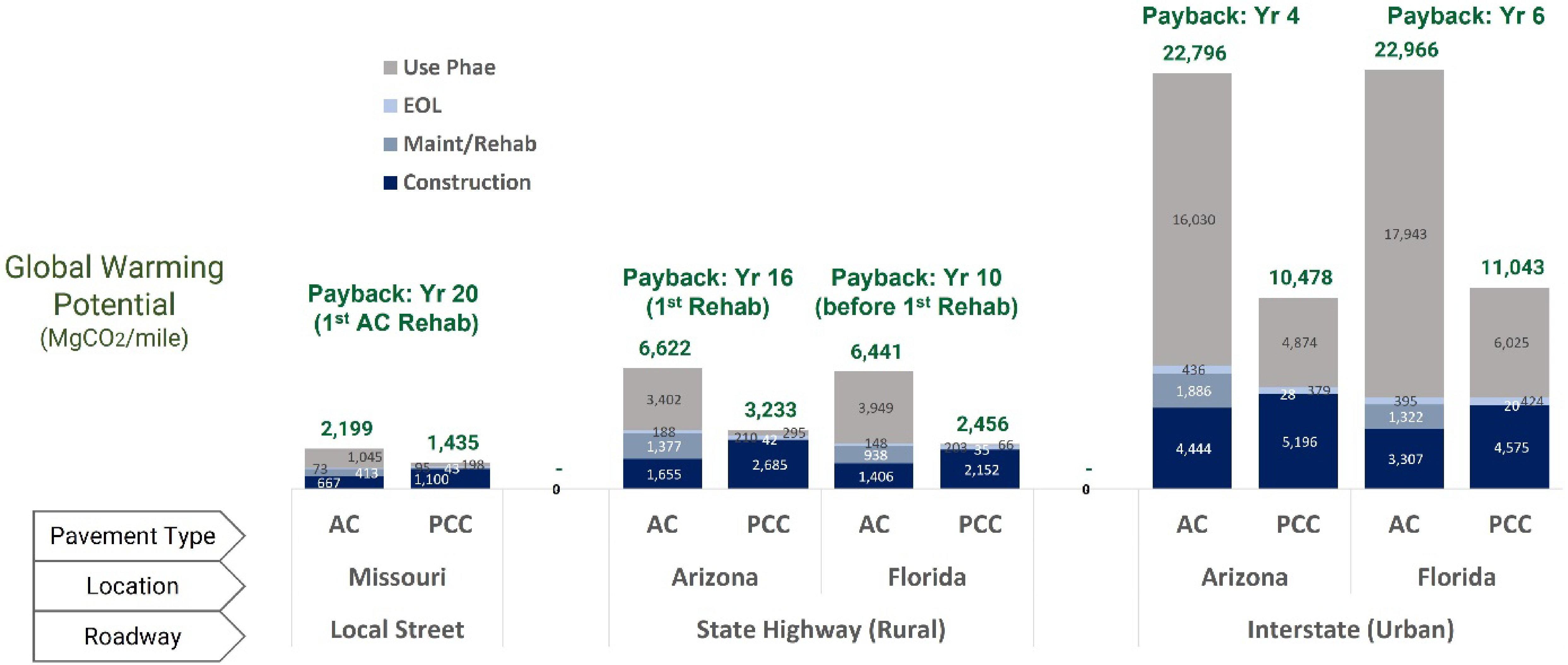
Source: Information courtesy of Tom Van Dam, NCE

Concrete Pavement Life Cycle – EOL Phase



- End of Life Phase
  - Overlay
  - Re-Use
  - Recycle
  - Start over
  - Begin with the end in mind
  - Permanent pavement structures

Getting the Full Picture



- Sources: MIT Concrete Sustainability Hub. *Scenario Analysis of Comparative Pavement Life Cycle Assessment Using a Probabilistic Approach* and *Supplementary Information for Comparative Pavement Life Cycle Assessment and Life Cycle Cost Analysis*
- Total GWP by phases for 1 mile of pavement with Design life = 30 years and analysis period = 50 years. Use phase includes Pavement Vehicle interaction (Fuel efficiency) and Albedo

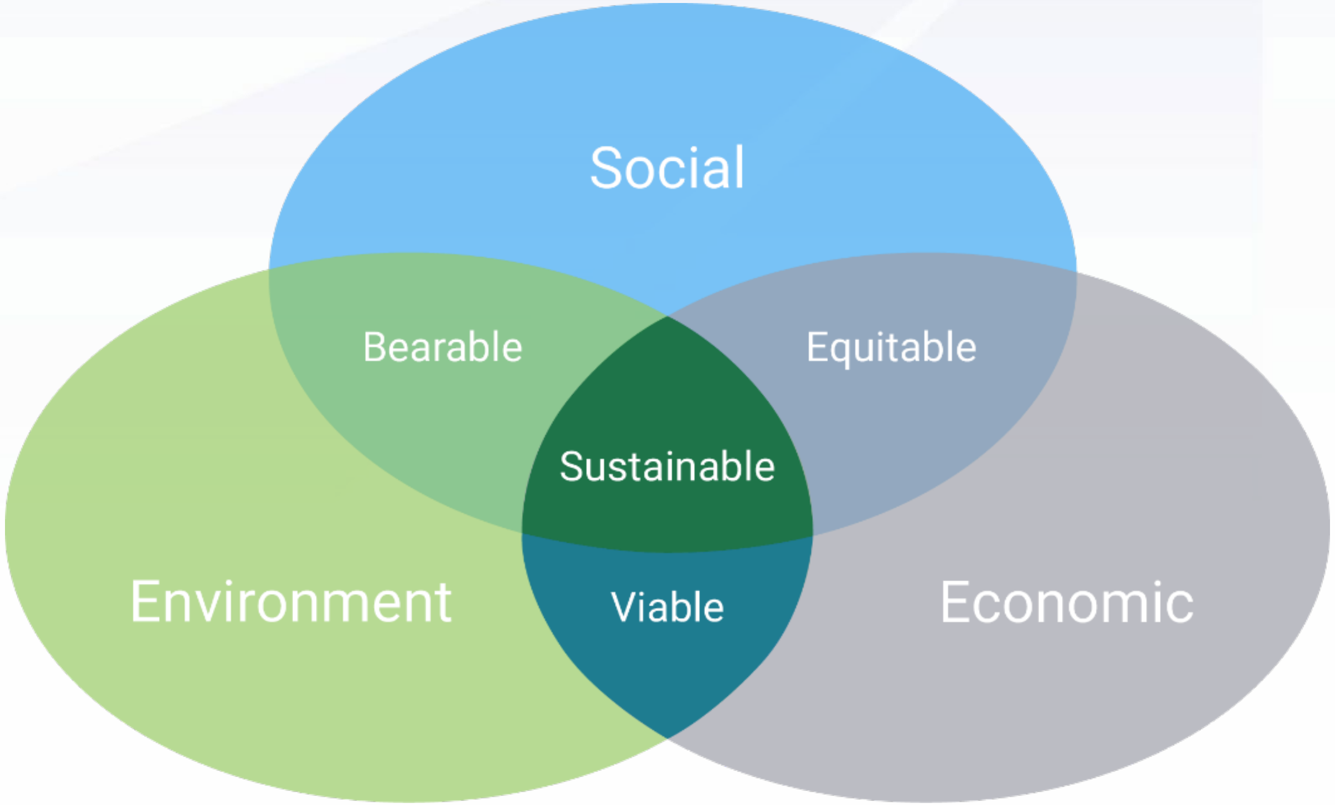
Focus on where we can make the greatest impacts

- Design and Materials Phase
  - Most flexibility
  - Optimizing pavement designs
  - Reducing cement's carbon footprint
  - Optimizing mix designs
  - Improving resilience and durability
- Use Phase
  - Typically largest impacts
  - Improving fuel efficiency
  - Increased pavement albedo
  - Take advantage of carbonation
  - Optimize with proper preservation

Re-Focusing Sustainability

- Meeting the needs of today without compromising future generations' ability to meet their own

Sustainable practices are simply good engineering



Adding in the need for resilience!

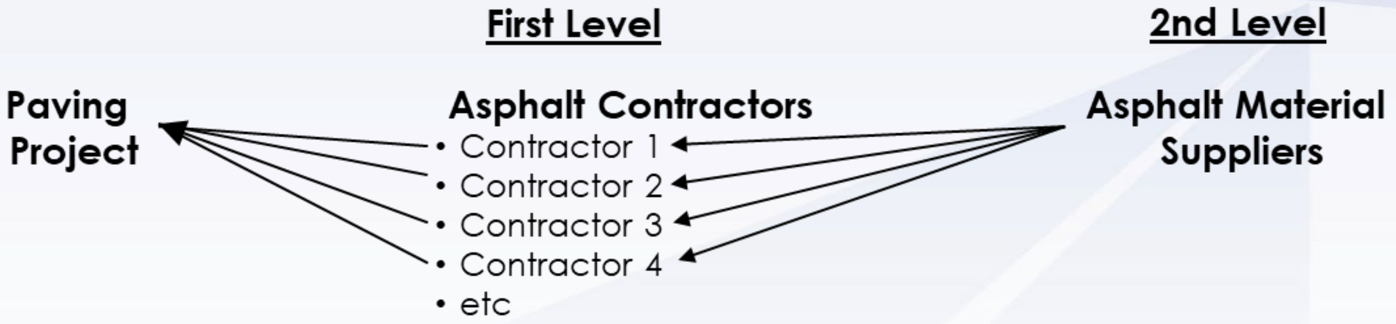
Concrete Sustainability – Economic Impacts

- Costs are easy… right?
- Two healthy pavement industries competing results in:
  - Reduced costs for both alternatives
  - Improved quality
  - Forces innovation and technology improvements
  - Improved overall sustainability

The Impact of Competition

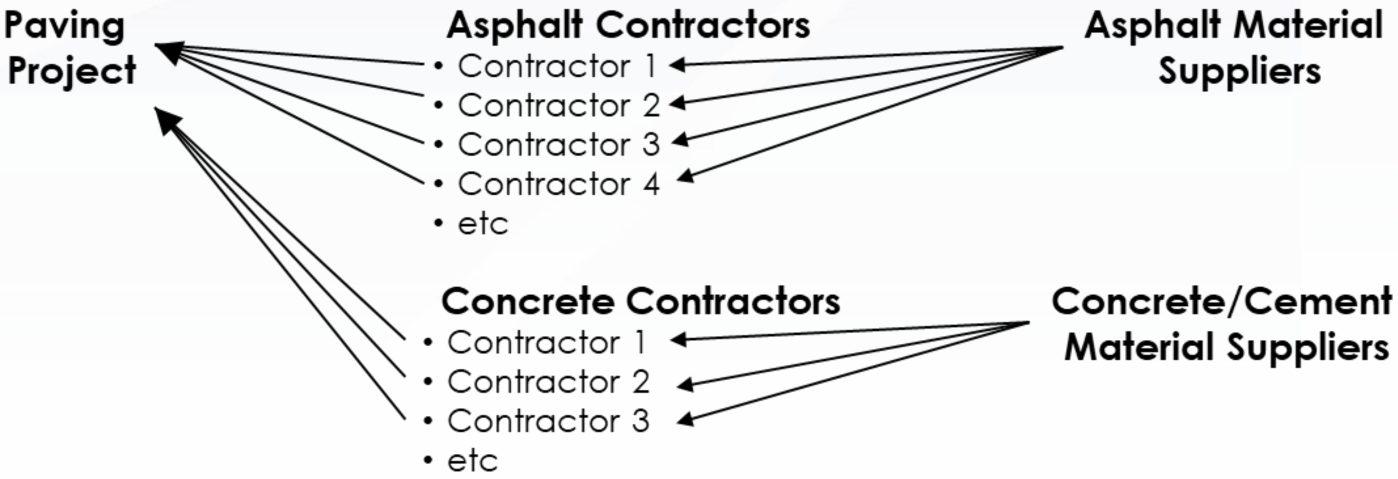
Intra-Industry (Contractor) Competition

Competition Between firms that pave with the same material



Inter-Industry (Industry) Competition

Competition between firms that pave with different material substitutes

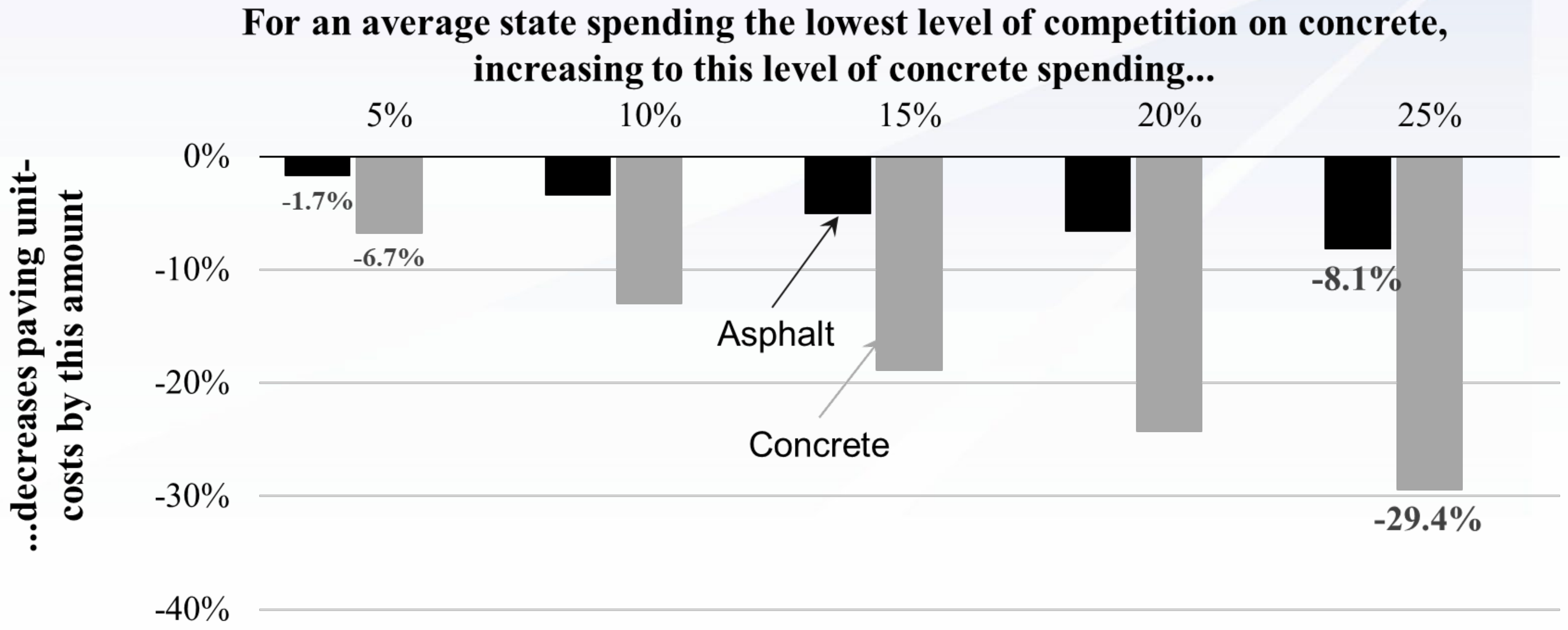


Contractor competition does not assure competition takes place at all levels of the supply chain

The Impact of Competition

INTER-INDUSTRY COMPETITION LOWERS UNIT COSTS

Allows Highway Agencies to do More with their Budgets



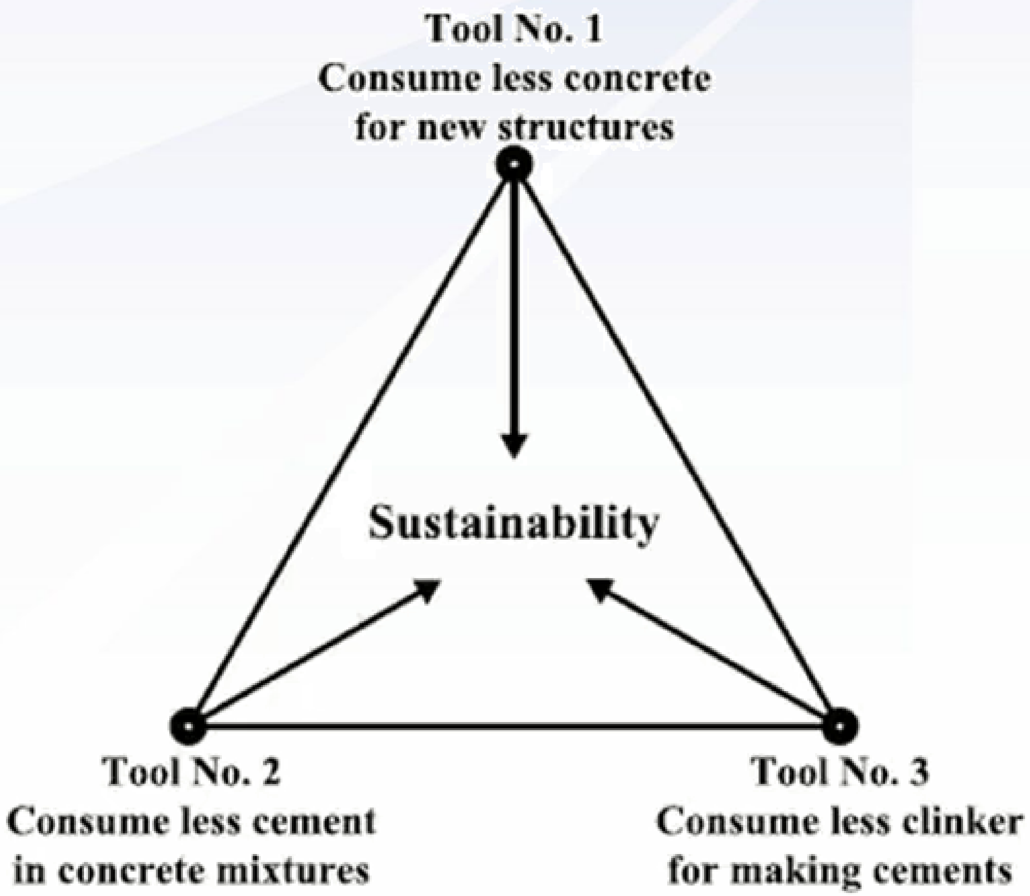
States with high industry competition pay ~ 8% and 29% less for asphalt and concrete pavements respectively vs. states with the low competition (increasing competition between contractors only lowers cost ~ 5%)

Concrete Sustainability – Social Impacts

- Safety
- Performance
  - Traditional – cracking, faulting, roughness
  - Modern – excess fuel consumption, albedo, urban heat island
- Equity

Sustainability… What can we do RIGHT NOW?!

- Embrace the life cycle perspective
- Optimize the amount of concrete used
- Optimize the amount of cement in concrete mixtures
- Consume less clinker for making cements
- Utilize healthy competition



[Source: Mehta, CI February 2009]

Re-Focusing Sustainability

- Meeting the needs of today without compromising future generations' ability to meet their own

Sustainable practices are simply good engineering

Adding in the need for resilience!

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- NRMCA
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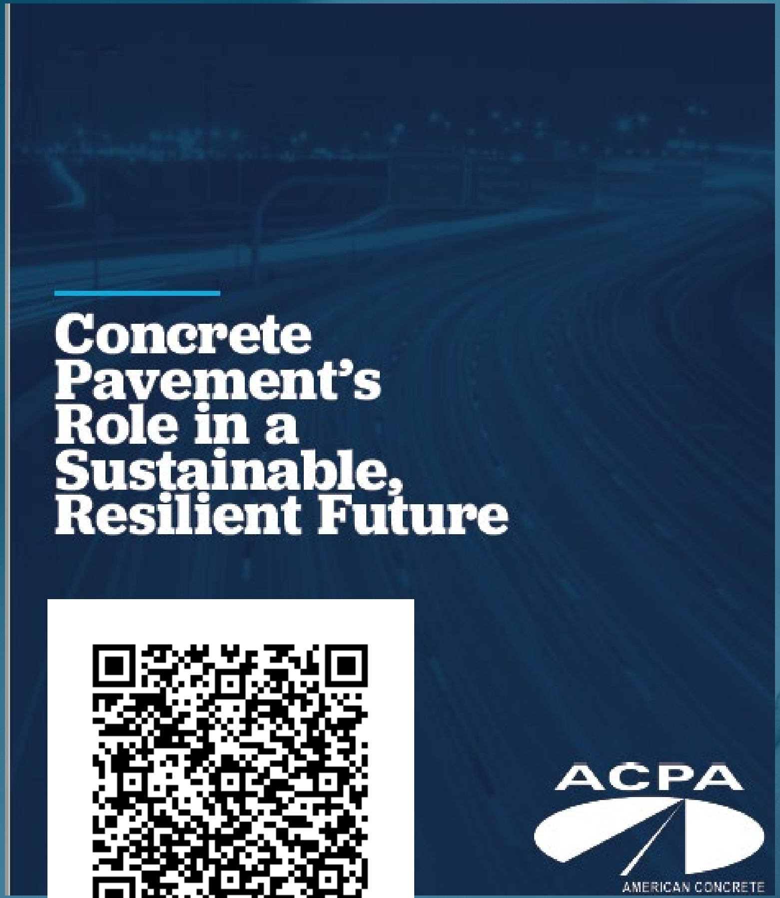

Thank you!

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