

IMPROVING CONCRETE PAVEMENT SUSTAINABILITY

Thinking Beyond the Materials

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Much of the Current Sustainability Focus is on EPDs, Reducing “Embodied Emissions” & using Low Carbon Construction Materials

ENVIRONMENTAL PRODUCT DECLARATION
Mix 1618915 • Santa Clara Plant

This Environmental Product Declaration (EPD) reports the impacts for 1 m³ of ready mixed concrete mix, meeting the following specifications:

- ASTM C94: Ready-Mixed Concrete
- UNSPSC Code 30111505: Ready Mix Concrete
- CSA A23.1/A23.2: Concrete Materials and Methods of Concrete Construction
- CSI Division 03-30-00: Cast-in-Place Concrete

COMPANY
CEMEX
10100 Katy Freeway, Suite 300
Houston, TX 77043

PLANT
Santa Clara Plant
1555 Russell Avenue
Santa Clara, CA 95054

EPD PROGRAM OPERATOR
ASTM International
100 Barr Harbor Drive
West Conshohocken, PA 19428

DATE OF ISSUE
12/03/2020 (valid for 5 years until 12/03/2025)

ISO 21930:2017 Sustainability in Building Construction — Environmental Declaration of Building Products: serves as the core PCR
PCR for Concrete, NSF International, February 2019 serves as the sub-category PCR

Sub-category PCR review was conducted by Thomas P. Gloria • Industrial Ecology Consultants

Independent verification of the declaration, according to ISO 14025:2006: Internal external

Third party verifier: Thomas P. Gloria (t.gloria@industrial-ecology.com) • Industrial Ecology Consultants

For additional explanatory material
Manufacture Representative: Hernan Jose Perez Rodriguez (hernan.jose.perez@cemex.com)
Software Tool: CarbonCLARITY Suite, EPD Generator • Verification
LCA & EPD Developer: Climate Earth (support@climateearth.com)

SANTA CLARA
1555 Russell Avenue
Santa Clara, CA 95054
910-941-3200

ENVIRONMENTAL IMPACTS	
Declared Product: Mix 1618915 • Santa Clara Plant A4GRC 658 C+S 30% BL AR 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)	1.16E
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 C23), Portland cement (ASTM C150), slag cement (ASTM C989), batch water (ASTM C1602), admixture (ASTM C494), admixture (ASTM C260)

Additional detail and impacts are reported on page three of this EPD

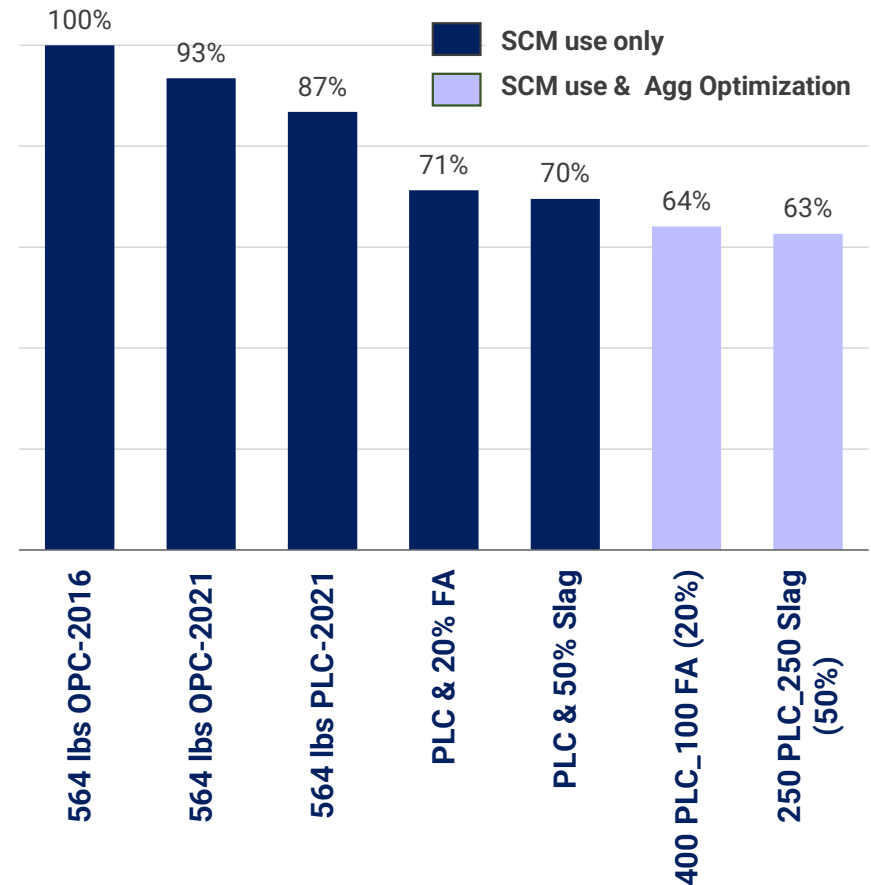
Environmental Product Declarations (EPDs)

aka a Type III environmental declaration

Buy Clean Policies

Procurement policy for the purchase of low carbon materials

Low CO₂ Concrete Mix Designs



Cement & Concrete are not the end products

Cement is used to make concrete.

Concrete is used to make the:

- Homes
- Buildings
- Hospitals
- Schools
- Bridges
- Pavements & other infrastructure
- Etc.

...that make our lives & society better.

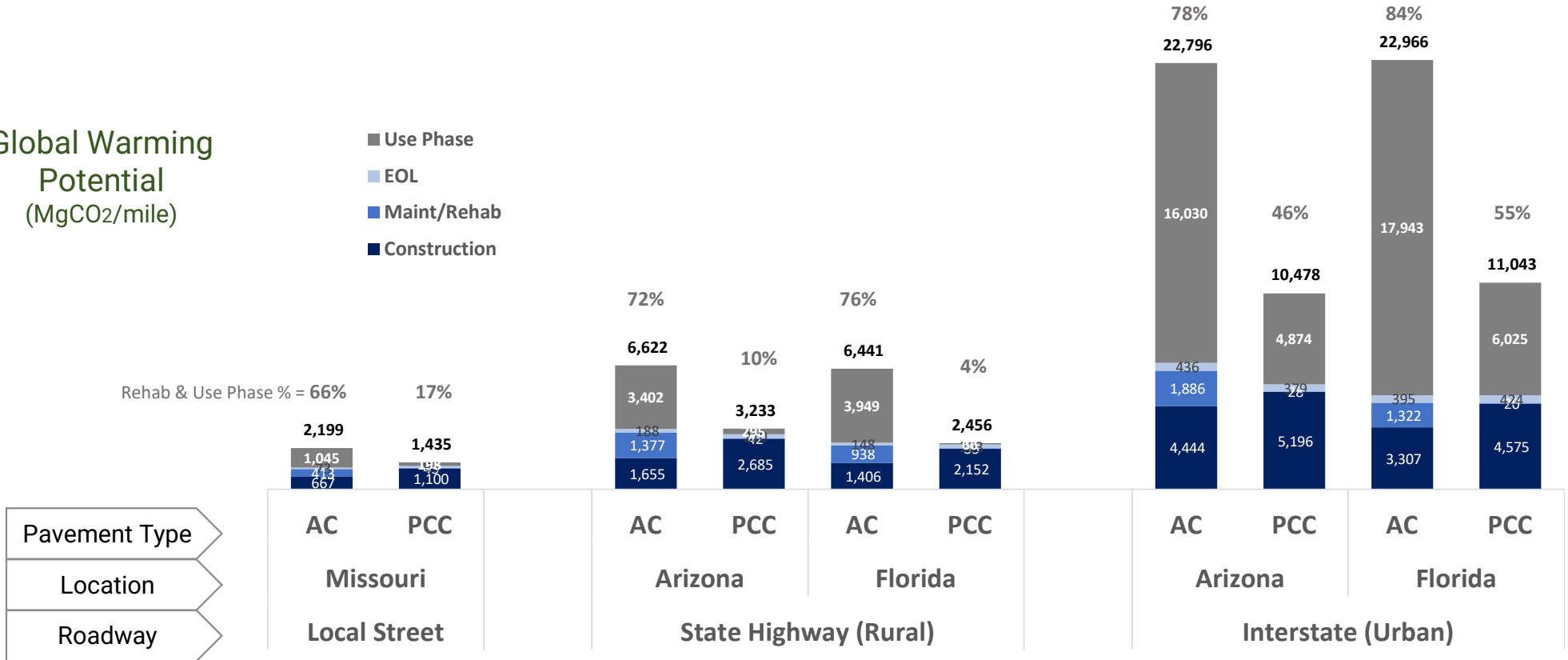


A Pavement's GWP is Impacted by what Happens After Initial Construction

The "Use Phase" can drive the Pavements Sustainability Profile

Global Warming Potential
(MgCO₂/mile)

- Use Phase
- EOL
- Maint/Rehab
- Construction



Sources: Role of the use phase and pavement-vehicle interaction in comparative pavement life cycle assessment as a function of context, Journal of Cleaner Production, <https://doi.org/10.1016/j.jclepro.2019.05.009> "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), lightening, carbonation and albedo (asphalt = baseline)

Strategies to Lower a (Concrete) Pavement's Life Cycle CO2

Improving Designs

- **Optimizing Concrete Mix Designs**

Improving concrete mix design by using Portland Limestone Cements; increasing use supplementary cementitious materials like slag, fly ash, silica fume, and other additives; improving aggregate gradation, etc.

- **Optimizing Pavement Designs**

Optimizing can remove "over design" to lowers the Environmental Impact of the Pavement System and it allows one to look at different features it improve the pavement's long-term performance, which can reduce life-time CO2 emmsions.

- **Improving Resilience and Durability**

Durable, resilient pavements need less repair; withstand storms, fires and other natural disasters better, and reduce future rehabilitation and reconstruction activities (and associated traffic disruptions)

Reducing Use Phase Impacts

- **Improving Fuel Efficiency**

Fuel consumption of trucks on concrete is improved because concrete pavements are stiffer and stay smoother longer.

- **Increasing the Pavement's Albedo**

Concrete's light color and higher albedo increases Radiative Forcing Impacts & lowers Urban heat Island impacts

- **Take advantage of Carbonation**

Carbonation is the reabsorption CO2 into concrete. Once absorbed, CO2 is not re-released, which reduce Concrete's overall CO2

OPTIMIZING DESIGNS



There are Many Design Features that can be used on Concrete Pavements

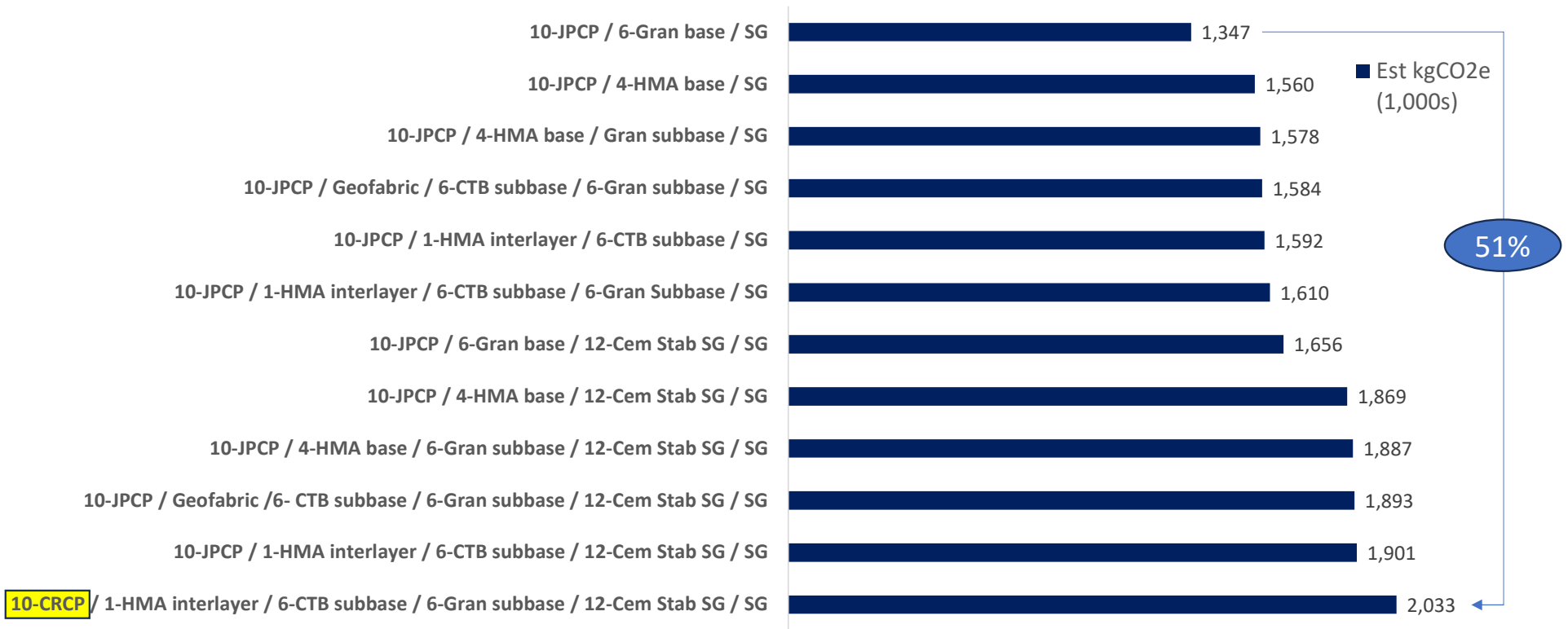
Each Design Feature must balance Performance and Cost (both initial & long term)

Feature	Benefit or Options
Concrete Pavement Type	Jointed, Jointed reinforced, Continuously reinforced, RCC, Overlays
Optimize Thickness	Reduces overdesign, lowers costs and environmental impact
Joint Spacing	Shorter joints reduces curling & warping stresses (& thickness) but does increase joint sawing and dowel costs
Use >13 ft Widened Lanes	Shifts loading to “interior loading” (reduces thickness)
Dowels / Increase Dowel Size / No Dowels	Increases load transfer, reduces bearing stress reduces faulting
Change Shoulder Design	Tied Concrete vs AC vs RCC; reduced /tapered thickness; no dowels; different mix, etc. (improves edge support)
Optimized aggregate gradation	Reduces cement content, creates denser mix, less shrinkage
Use different concrete mixes	Mainline vs shoulder mixes, 2-layer construction
Change base type	Granular vs asphalt treated vs cement treated, reduce thickness, dense graded vs permeable; subgrade / chemical stabilization
Use single 1/8”-wide single saw cut and filled (not sealed)	Removes second sawing operation and reduces noise
Use Longitudinal tining or Next Generation Concrete Surface (NGCS)	Reduces noise

“Features” have a significant impact on performance, cost & GWP

Pavement Structure has a Large Impact on the Initial Pavement CO2

Estimated Material CO2 for a 10-inch Concrete Pavement with different base types



Need to account for the performance differences that these structures will provide

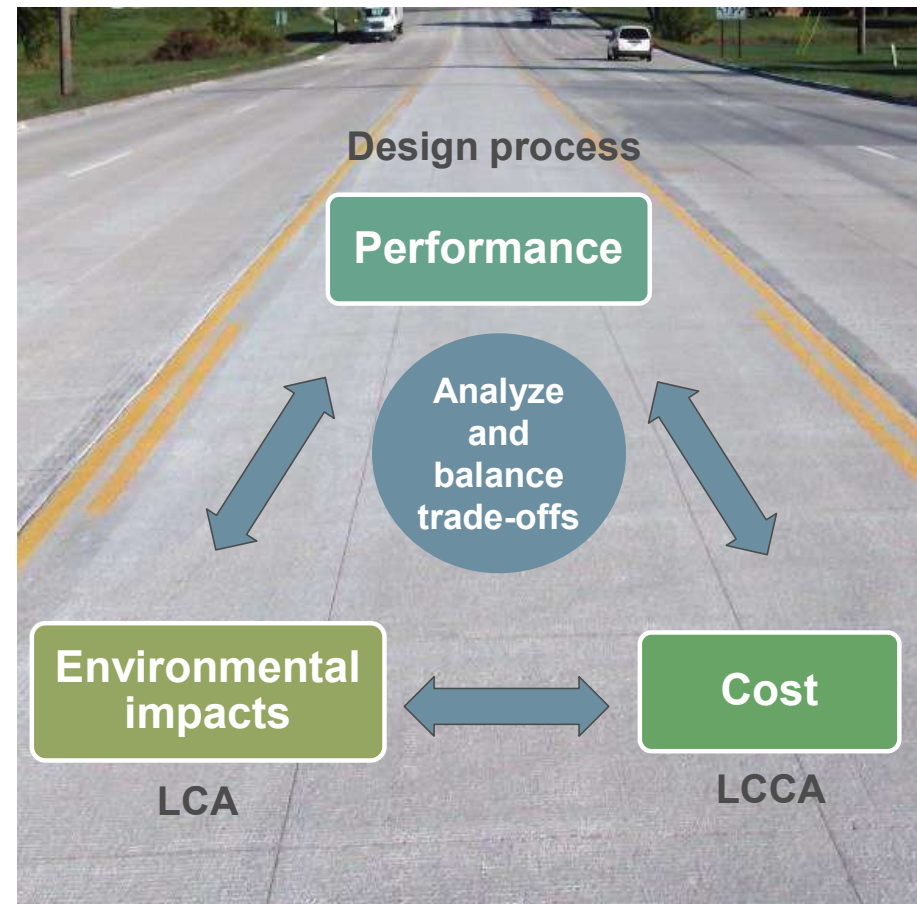
Pavement = 1 mile, 4 lanes (2 12-ft lanes / direction), no shoulders. CO2 / GWP values for materials based on IW Average EPDs (cement, concrete, & steel); EC3 median values (asphalt); EU Ecoinvent (aggregate); or representative company EPDs (lime, geogrids and geofabrics)

Tools for Optimizing Designs of a Pavement System

TOOLS

- 1 AASHTO Pavement-ME Design Procedure**
Predicts pavement performance over the analysis period
- 2 Life Cycle Cost Analysis (LCCA)**
Determines which pavement design is most cost effective over the analysis period
- 3 Life Cycle Assessment (LCA)**
Determines which pavement design is most “sustainable” over the analysis period

Combining performance with the LCCA / LCA allows designers to make trade-offs that balances costs, sustainability, & performance over the full life cycle



Pavement-ME is the Most Advanced Design Procedure

Covers a wide range of applications, including nearly all new & rehabilitation options
Can account for new and diverse materials and various failure mechanisms

State-of-the practice design procedure based on advanced models & actual field data collected across the US and Canada

- Adopted by AASHTO in 2011
- Calibrated to more than 2,400 asphalt & concrete pavement test sections, ranging in ages up to ~40+ years

Based on mechanistic-empirical principles that account for site specific:

- Traffic
- Climate
- Materials
- Proposed structure (layer thicknesses and features)

Provides estimates of performance during the analysis period

- Can match rehabilitation activities to performance



New Pavement

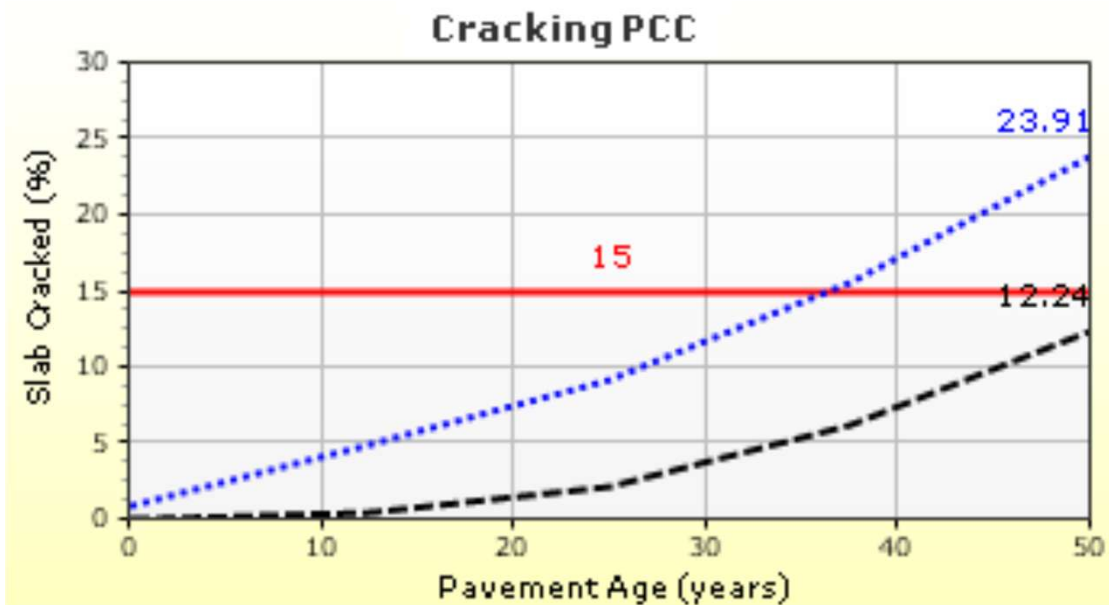
- Asphalt Concrete (AC)
- Jointed Plain Concrete Pavement (JPCP)
- Continuously Reinforced Concrete Pavement (CRCP)

Overlays & Restoration

- AC over AC
- AC over JPCP / CRCP (w/ & w/o fracture)
- Bonded PCC over JPCP / CRCP
- Unbound PCC over JPCP / CRCP
- JPCP /CRCP over AC
- JPCP Restoration

Pavement-ME Defines a Specific Pavement's Performance

Predicting performance of key distresses allows for trade-off analysis with Life Cycle Analysis



Red Line – Predefined Distress Threshold Value. When major rehabilitation is needed (i.e. patching & DG or overlay).

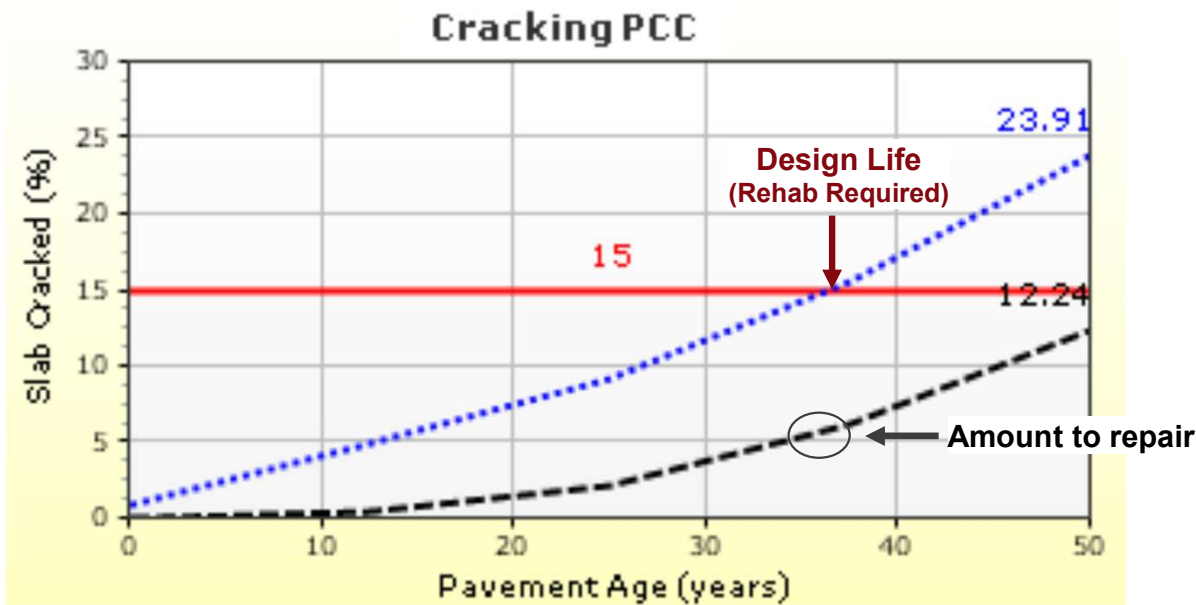
Black Dashed Line - The 50% Reliability (most likely) level of distresses predicted

Blue Dotted Line - The predicted distresses at the Specified Reliability Level (i.e. 90%). Designs are based on when this line hits the defined distress limit

Design life is when the Blue Reliability curve hits red Predefined Threshold Value (~33 years in this case)

Pavement-ME Defines a Specific Pavement's Performance

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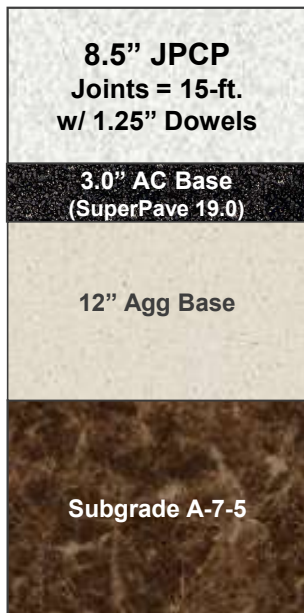
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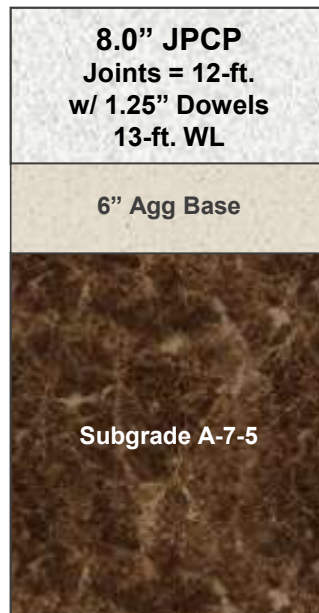
Design life is when the Blue Reliability curve hits red Predefined Threshold Value (~33 years in this case)

Pavement-ME Allows for Comparisons of Different Designs

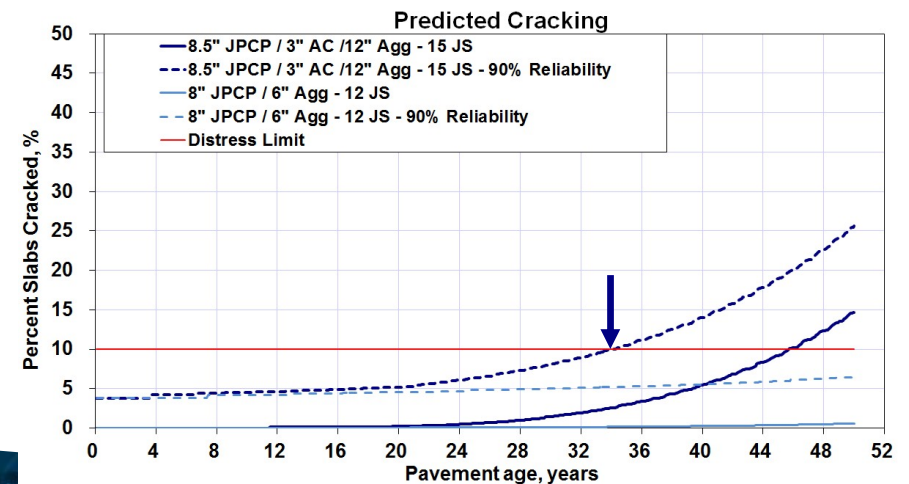
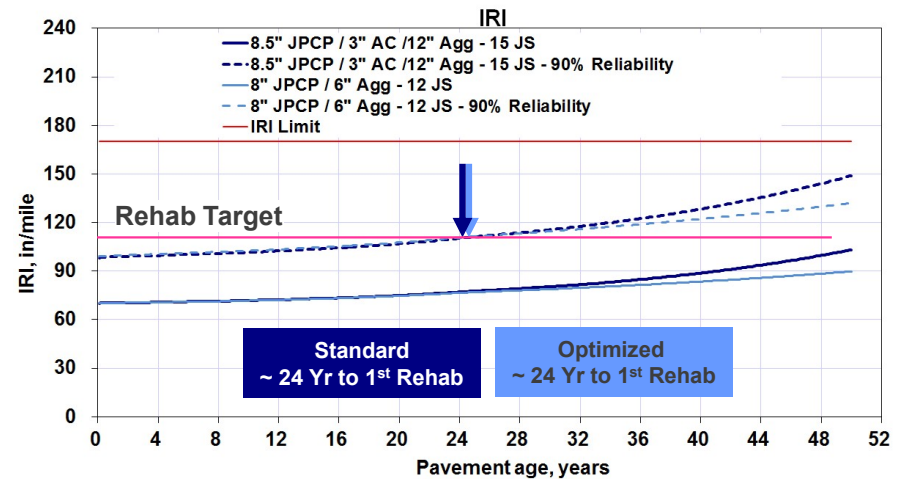
Original Concrete Design



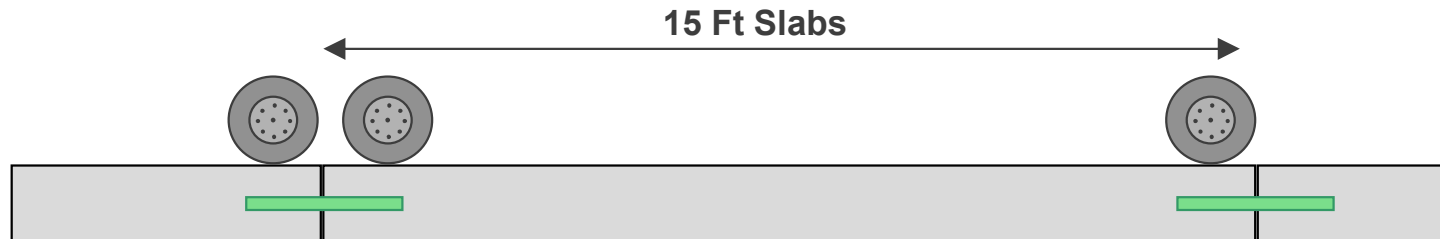
Optimized Concrete Design



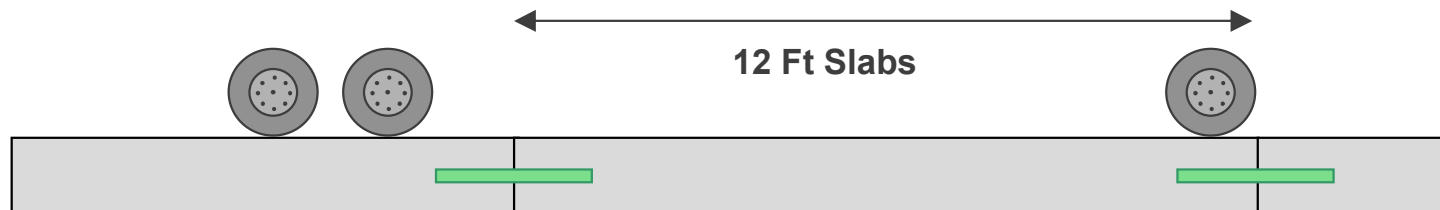
Pavement ME gives a repeatable, un-biased process that shows how a specific pavement design will perform



Shorter Joint Spacing Reduces Wheel Loads Stresses



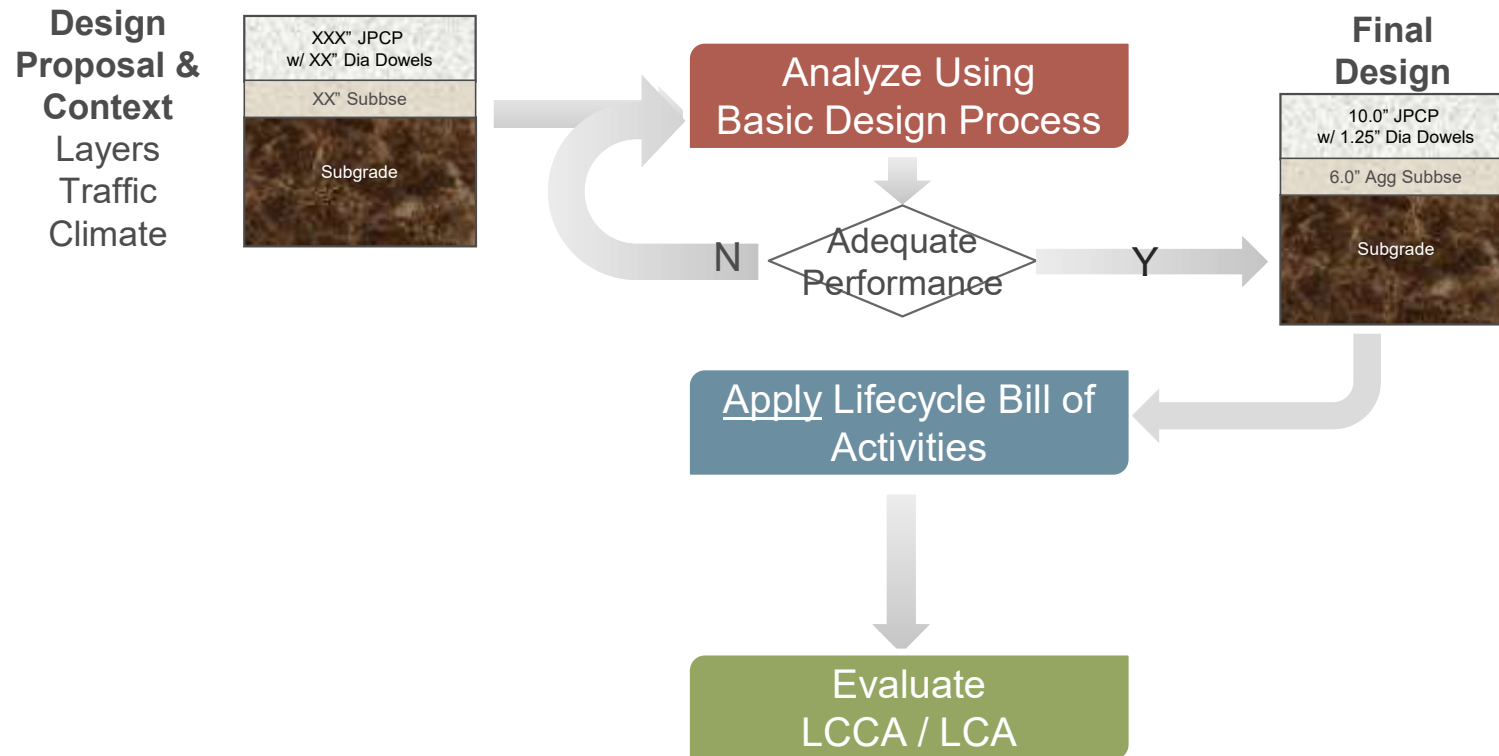
Loading the slab at each end creates additional top down stresses and causes earlier top down cracking



Reducing slab length means only one end is loaded by an axle, which reduces top down stresses and extends life

Currently Design is Done in a “Static” Mode

Designs are developed and then compared to select the final pavement design

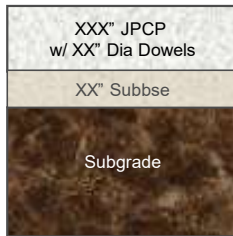


Doing a LCCA/LCA at the end misses opportunities to make design changes

Need to Link Design and Evaluation in an Iterative Process

Assures that performance, costs and CO2 impacts are representative of the actual pavement

Design Proposal & Context
Layers
Traffic
Climate



Analyze Using P-ME
Design Principles

Develop Lifecycle Bill
of Activities

Evaluate
LCCA / LCA

Adequate
Performance

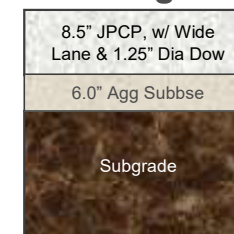
N

Y

Designing pavements in an iterative procedure provides a Feedback Loop

- Improves performance
- Lowers cost
- Lowers environmental impacts

Final Design



Route 67 in Ramona, Ca

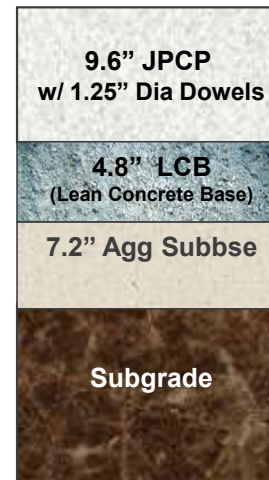
Falls within the *South Coast* CALTRANS climatic region

Route 67 in Ramona, CA (at Route 78 junction)

- Moderate volume road:
- 35-mph urban road
- 2 lanes in each direction (+ middle turn lane)
- 2 inner/2 outer shoulders
- Daily traffic: 23,400 (ADTT = 1,357)
- Initial ESAL = 335,000 / year
- 20-year Design Life / 55-year Analysis Period



CALTRANS Concrete Design



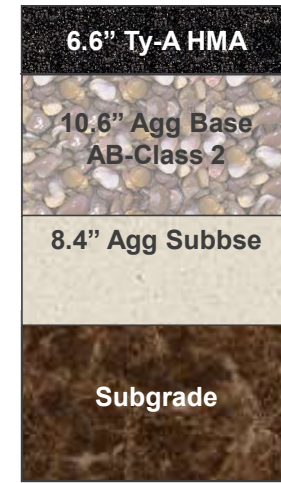
JPCP new construction:

Design life = 20-years

Maintenance Level = 1,2,3

- 2% Patch & DG at year 25,
- 4% Patch & DG at year 30
- 6% Patch & DG at year 40
- 3" Asphalt overlay in year 45
(10-year life)

CALTRANS Asphalt Design



HMA new construction:

Design life = 20-years

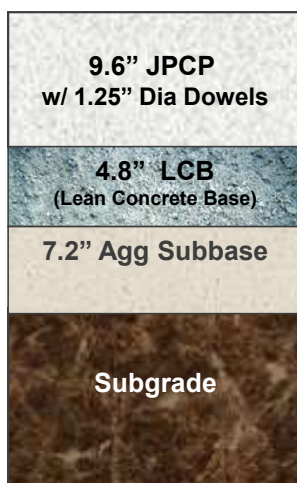
Maintenance Level = 1,2

- 3" AC Overlay in years 20,
- Mill / 4" ACOL in year 25
- Mill / 3" ACOL in year 35
- Mill / 4" ACOL in year 45
- Mill / 3" ACOL in year 50
(5-year life)

Estimated Cost and Environmental Impact for Standard Caltrans Pavement Designs

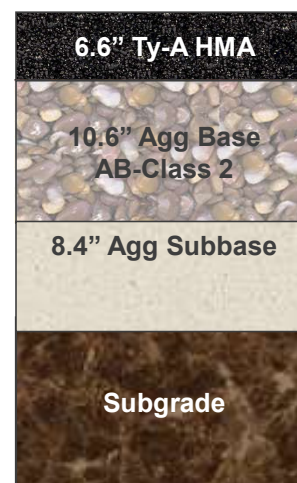
Route 67 - Ramona, CA

CALTRANS Concrete Design



	LCCA (NPV \$/mile)	LCA (tons CO ₂ e/mile)
Initial Const.	\$3,147,585	3,954
<i>Pavement</i>	\$2,229,803	2,860
<i>LCB</i>	\$644,902	781
<i>Agg Subbase</i>	\$272,880	313
Rehabilitation	\$911,663	479
Carbonation		(123)
PVI-Deflection		604
PVI-Roughness		1,912
Total	\$4,059,248	6,826

CALTRANS Asphalt Design



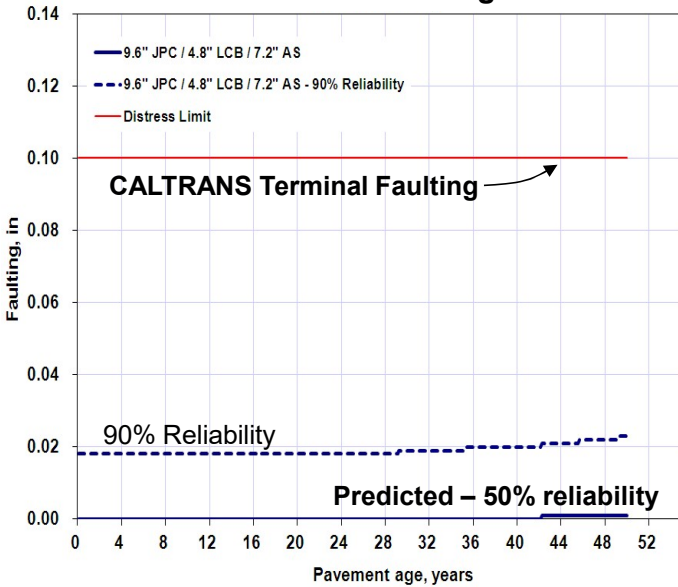
	LCCA (NPV \$/mile)
Initial Const.	\$2,278,102
<i>Pavement</i>	\$1,437,480
<i>AB-Class 2</i>	\$522,262
<i>Agg Subbase</i>	\$318,360
Rehabilitation	\$1,104,504
Total	\$3,382,606

Asphalt is 38% lower in Initial Costs and 20% lower in Life Cycle Costs

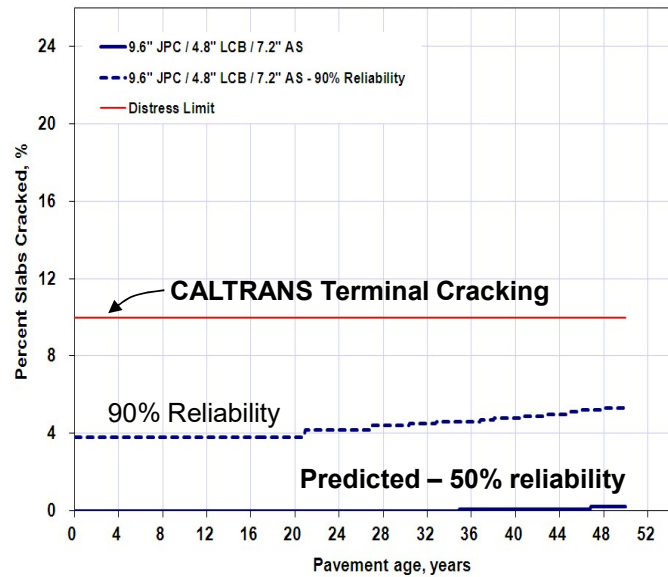
Route 67 Pavement-ME Predicted Performance is High

Faulting, Cracking, & IRI are well below terminal levels for the entire analysis period

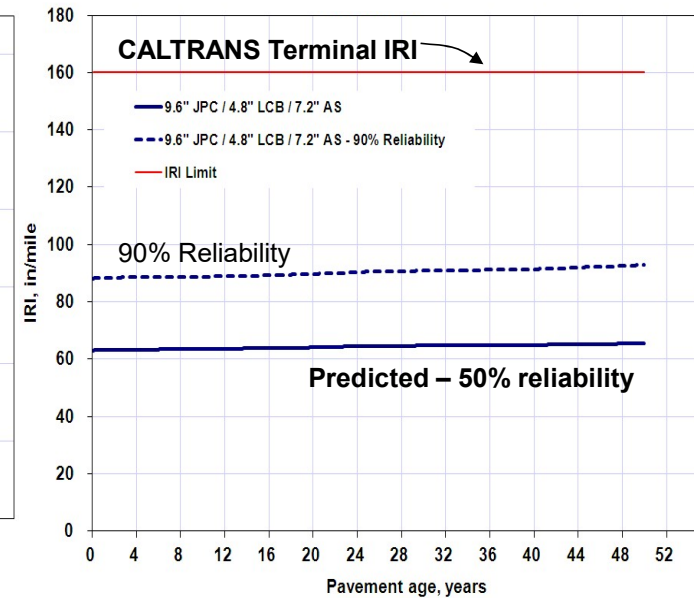
Predicted Faulting



Predicted Cracking



Predicted IRI



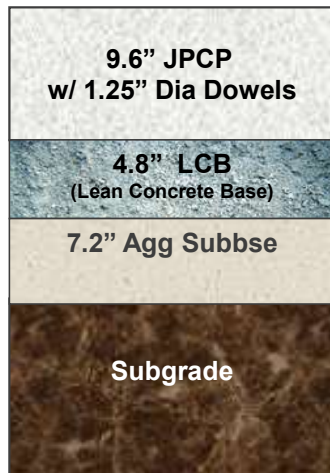
**Pavement is over-designed because it does not need rehabilitation for the entire 50-year analysis period
Creates the opportunity for project specific optimization**

Over-Design Creates the Opportunity for Optimization

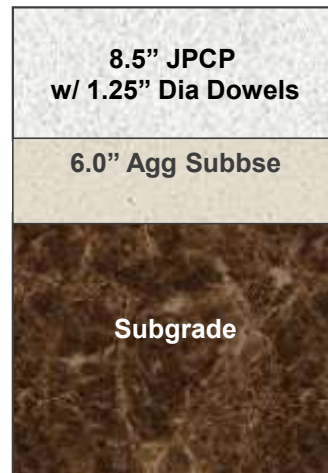
Each design feature needs need to balance performance, cost & environmental impact

Features Evaluated

CALTRANS Concrete Design



Optimized Concrete Design



- Iterated Concrete Thickness
 - 9.0"
 - 8.5"
 - 8.0
- Removed 4.8" Lean Concrete Base
 - Accounts for 20% of the initial construction costs & GWP
 - Performance history shows that aggregate bases have worked in similar applications
- Iterated Aggregate base thickness
- Develop rehabilitation activities based on Pavement-ME distresses

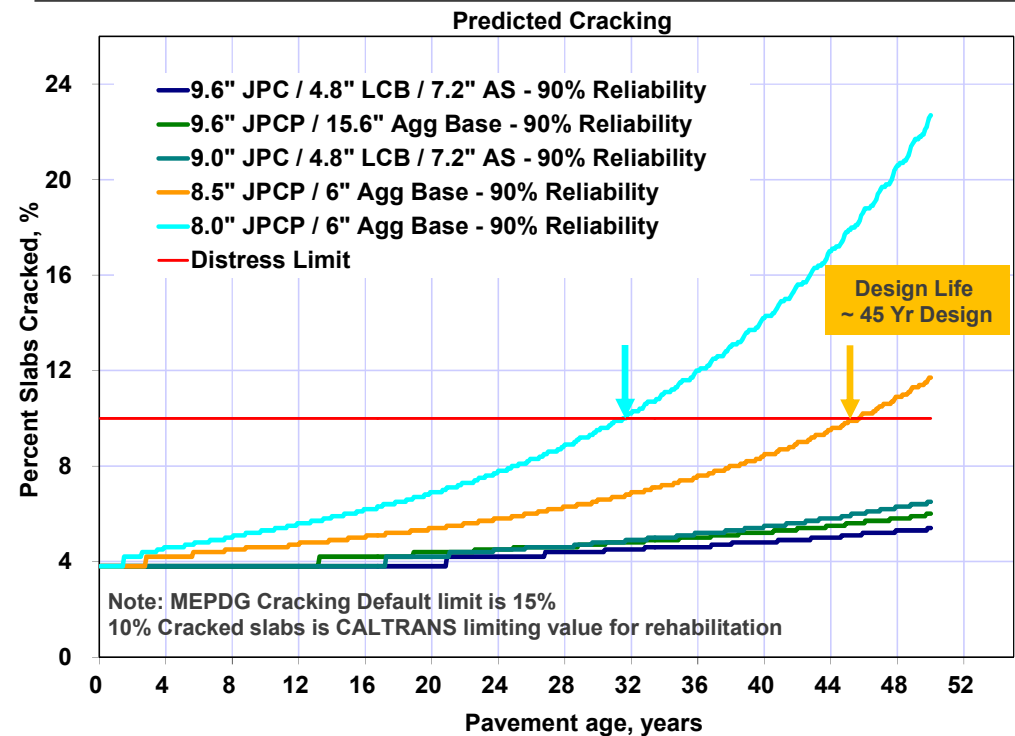
8.5" Jointed Plain Concrete Pvmnt w/ Dowels meets the Performance Criteria

Good balance between long term performance and low cost / low GWP

- Performance curves show all the pavement options evaluated exhibited good performance
 - Cracking not an issue until the pavement is at 8.5-inch or less.
 - Faulting and IRI are well below unacceptable levels for all cases
- 8.0-inch pavement met the 20-year design life
- 8.5-inch JPCP design chosen as optimized design
 - Cracking hits terminal level at year 45
 - Good balance between long term performance (and a hedge against increased traffic) and low cost / low GWP

Optimization does not mean choosing the Thinnest (cheapest) Pavement
It's about selecting the Most Effective

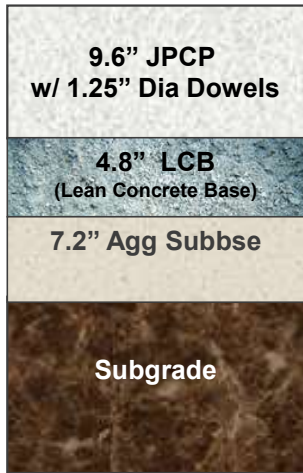
Pavement-ME Predicted Performance



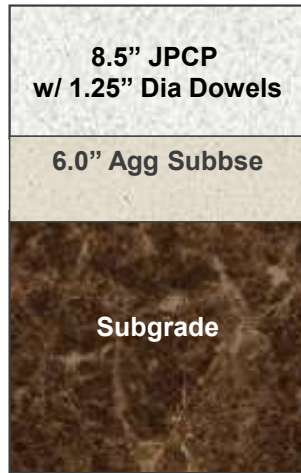
Arrows indicate year of predicted 1st rehabilitation for that given pavement

Project Specific Pavement Optimization Lowers Cost & Environmental Impact

CALTRANS Concrete Design



Optimized Concrete Design



	Original CALTRANS Schedule		Optimized Pavement-ME Design	
	LCA (tons CO ₂ e)	LCCA (NPV \$)	LCA (tons CO ₂ e)	LCCA (NPV \$)
Initial Const.	3,954	\$3,147,585	3,063	\$2,256,638
<i>Pavement</i>	2,860	\$2,229,803	2,803	\$2,021,307
<i>LCB</i>	781	\$644,902	--	--
<i>Agg Subbase</i>	313	\$272,880	260	\$235,331
Rehabilitation	479	\$911,663	54	\$315,798
Carbonation	(123)		(87)	
PVI-Deflection	604		704	
PVI-Roughness	1,912		2,110	
Total	6,826	\$4,059,248	5,844	\$2,572,437

Optimization reduced the initial construction GWP by 890 tons (22.5%) and the life cycle GWP by 980 tons (14.3%)

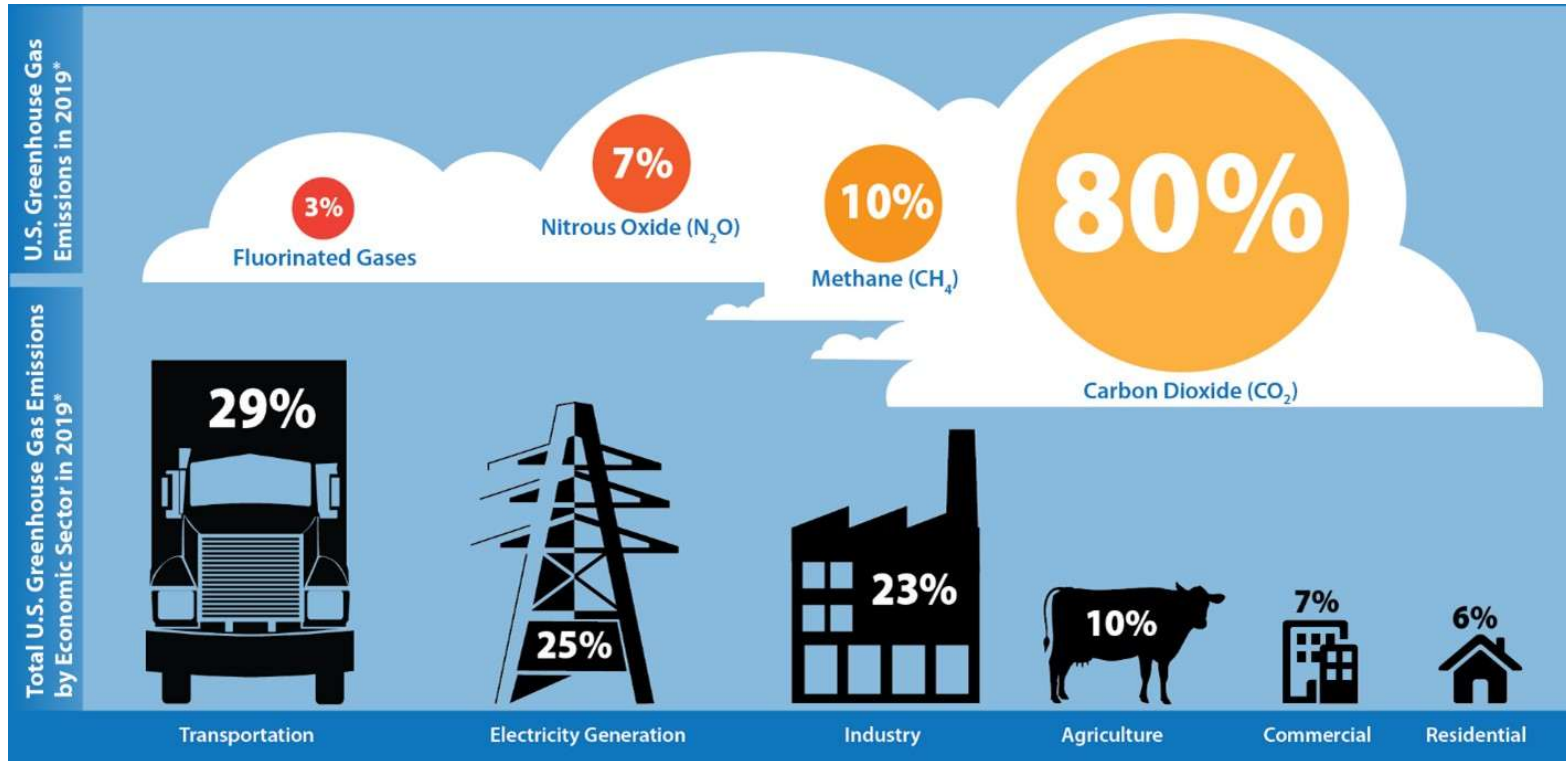
Optimization reduced the initial construction costs by \$890k (28.3%) and the life cycle cost \$1.48M (36.6%)

USE PHASE



Transportation is the Largest Source of GHG Emissions

Specifically, it's from the Vehicles that use Fossil Fuels on our Roadways



A 1 to 2% improvement in fuel efficiency due to better pavements can will have a bigger impact than materials.

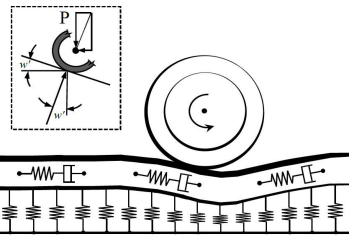
Agencies have big opportunity to reduce the Transportation Sector's GHG Emmsions by improving pavements

Pavement Vehicle Interaction Impacts the Excess Fuel Usage (EFC)



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

Every 10% decrease in IRI increases fuel usage by 1 to 2%



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

Stiffer pavements have 0.5 - 3% better fuel efficiency
Important in heavy truck corridors / high temperatures.



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

Rough surface texture increases fuel usage between 0.4 to 1.6%

*Zaabar, I., Chatti, K. 2010. Calibration of HDM-4 Models for Estimating the Effect of Pavement Roughness on Fuel Consumption for U.S. Conditions. TRR 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. TRR No. 2306. Pages 171-179.

On Which to Focus on Depends on the Context

Example: 1000 Vehicles, Speed = 55 mph, Temperature = 86°F, Baseline IRI = 40 in/mi

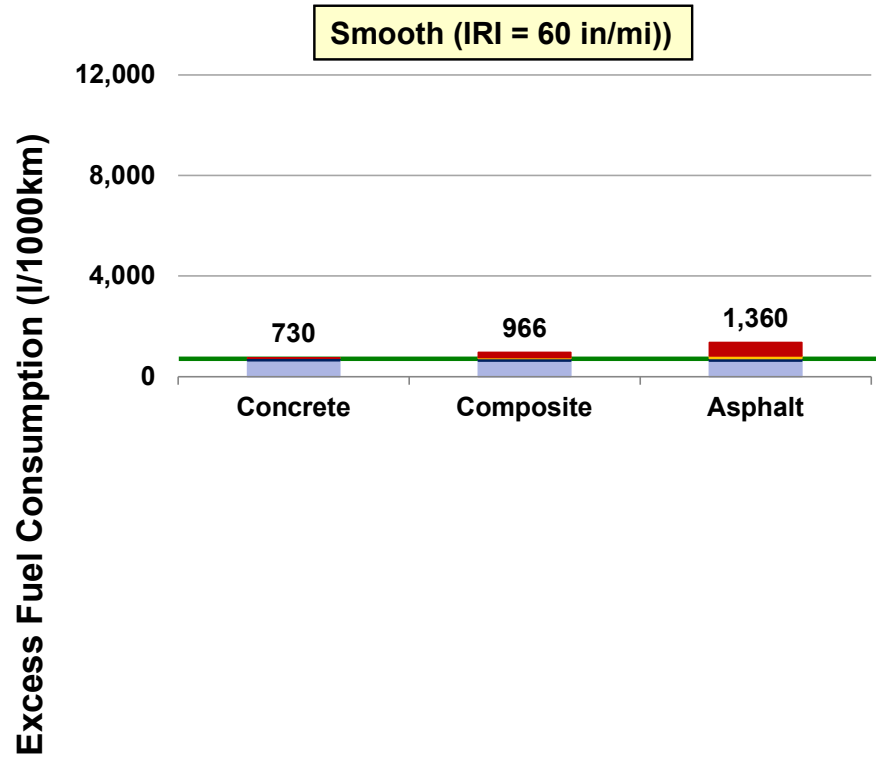


On Which to Focus on Depends on the Context

Example: 1000 Vehicles, Speed = 55 mph, Temperature = 86°F, Baseline IRI = 40 in/mi

5% Trucks (50 trucks)

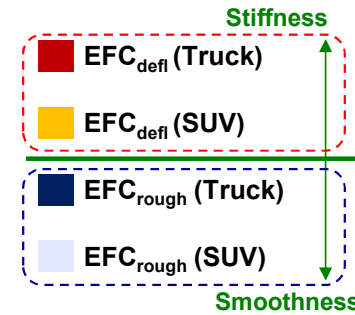
30% Trucks (300 trucks)



Rough (IRI = 180 in/mi)

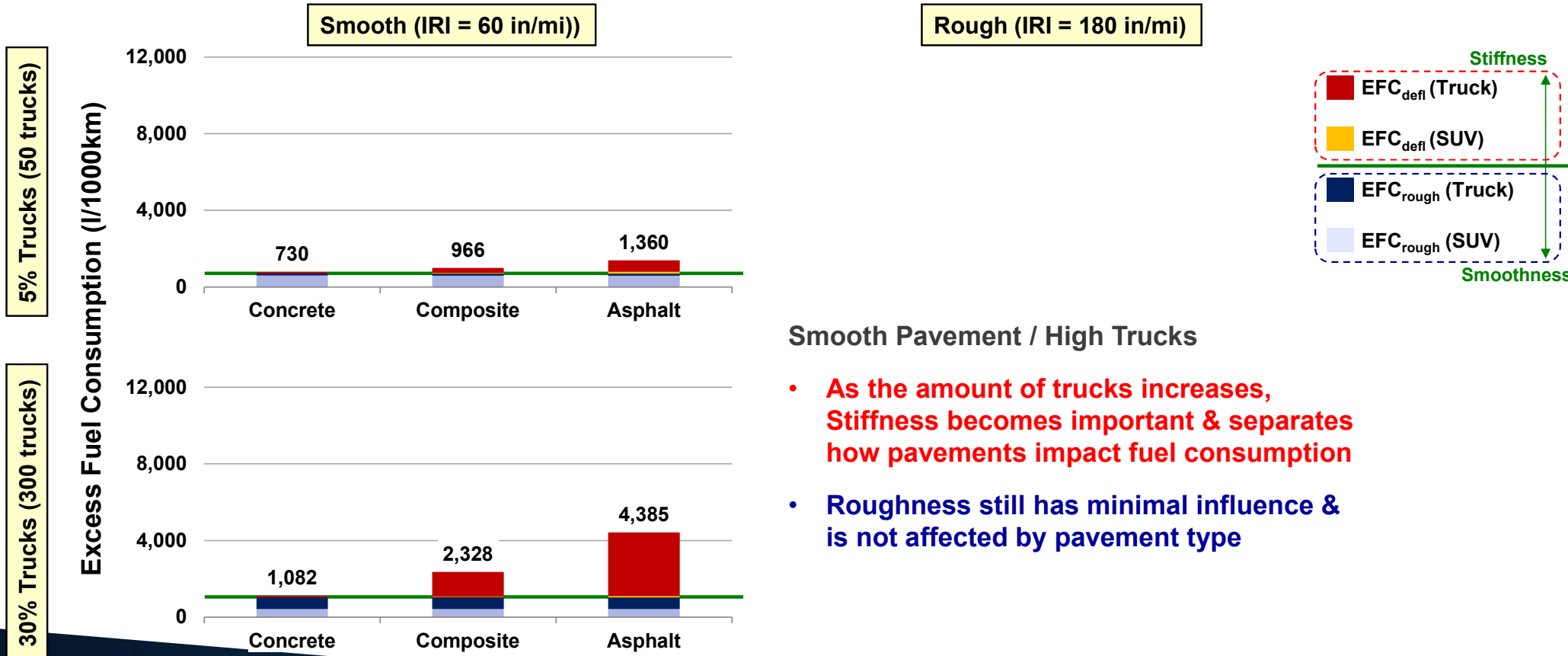
Smooth Pavement / Low Trucks

- Stiffness & pavement type influences fuel consumption somewhat (few heavy loads)
- Roughness has minimal influence & is the same for all pavement types



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Example: 1000 Vehicles, Speed = 55 mph, Temperature = 86°F, Baseline IRI = 40 in/mi

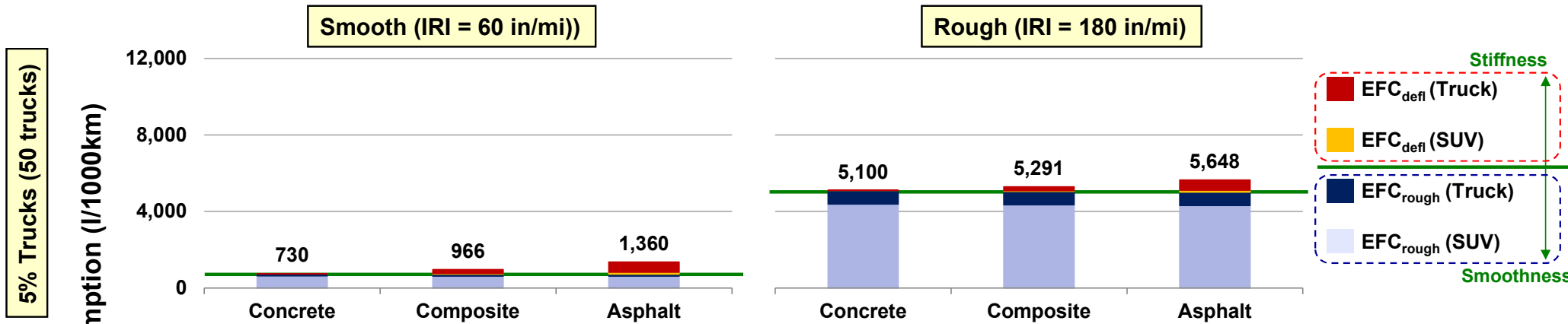


Smooth Pavement / High Trucks

- **As the amount of trucks increases, Stiffness becomes important & separates how pavements impact fuel consumption**
- **Roughness still has minimal influence & is not affected by pavement type**

On Which to Focus on Depends on the Context

Example: 1000 Vehicles, Speed = 55 mph, Temperature = 86°F, Baseline IRI = 40 in/mi



5% Trucks (50 trucks)

30% Trucks (300 trucks)

Excess Fuel Consumption (l/1000km)

Rough Pavement / Low Trucks

- Roughness induced fuel consumption dominates, but is the same for all pavement types (e.g. it is a function of how well the pavement is maintained)
- Stiffness & pavement type influences fuel consumption somewhat, but there are few heavy loads so not a big impact

On Which to Focus on Depends on the Context

Example: 1000 Vehicles, Speed = 55 mph, Temperature = 86°F, Baseline IRI = 40 in/mi

Smooth (IRI = 60 in/mi)

Rough (IRI = 180 in/mi)

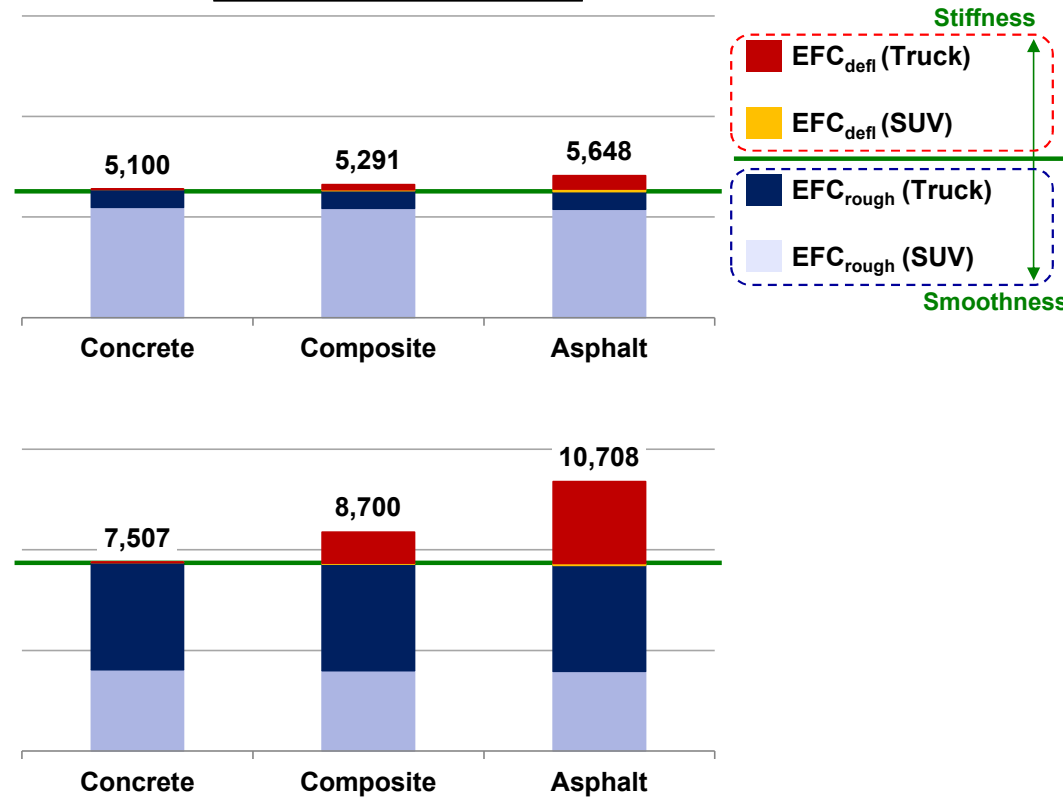
5% Trucks (50 trucks)

30% Trucks (300 trucks)

Excess Fuel Consumption (l/1000km)

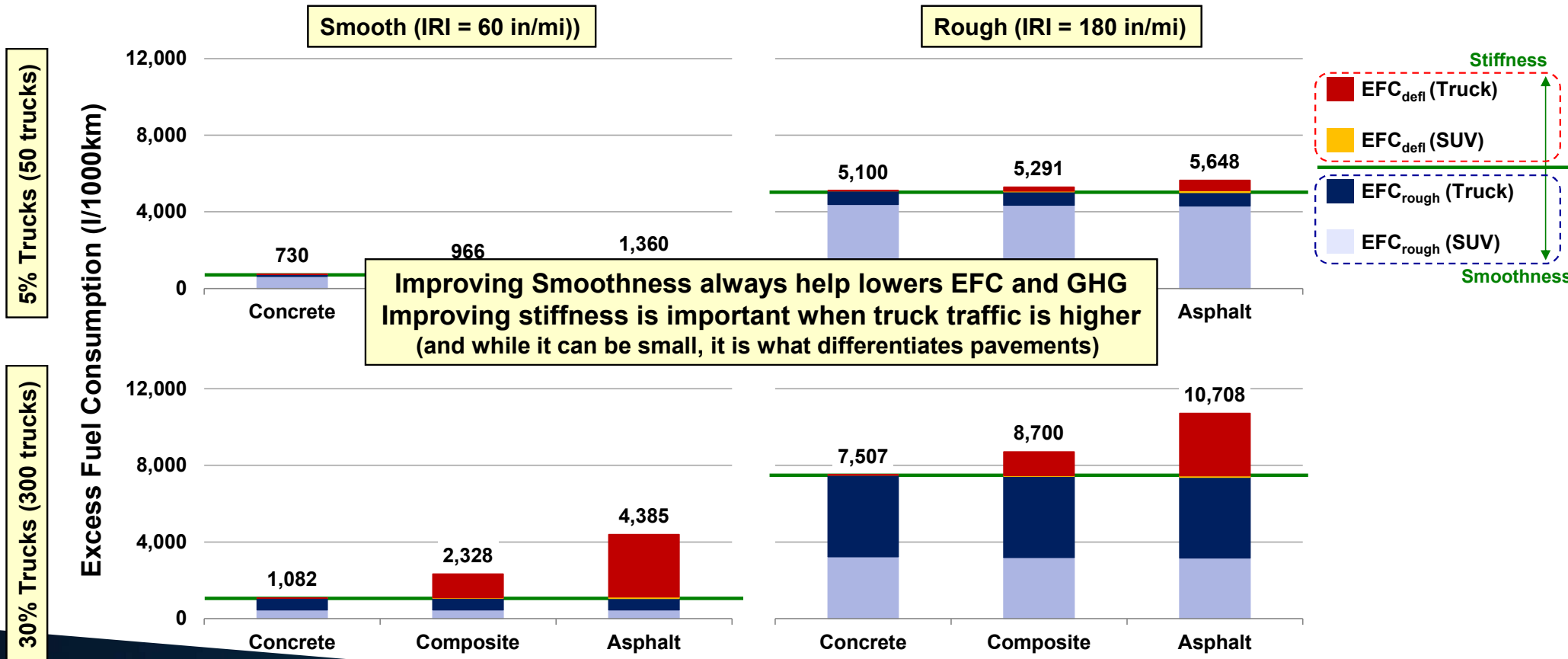
Rough Pavement / High Trucks

- With increasing number of trucks, stiffness again becomes important & separates pavements
- Roughness induced fuel consumption remains high for all pavement types

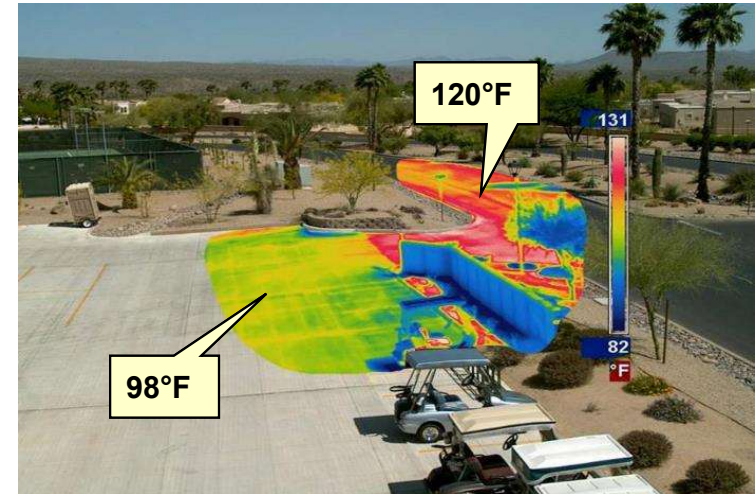
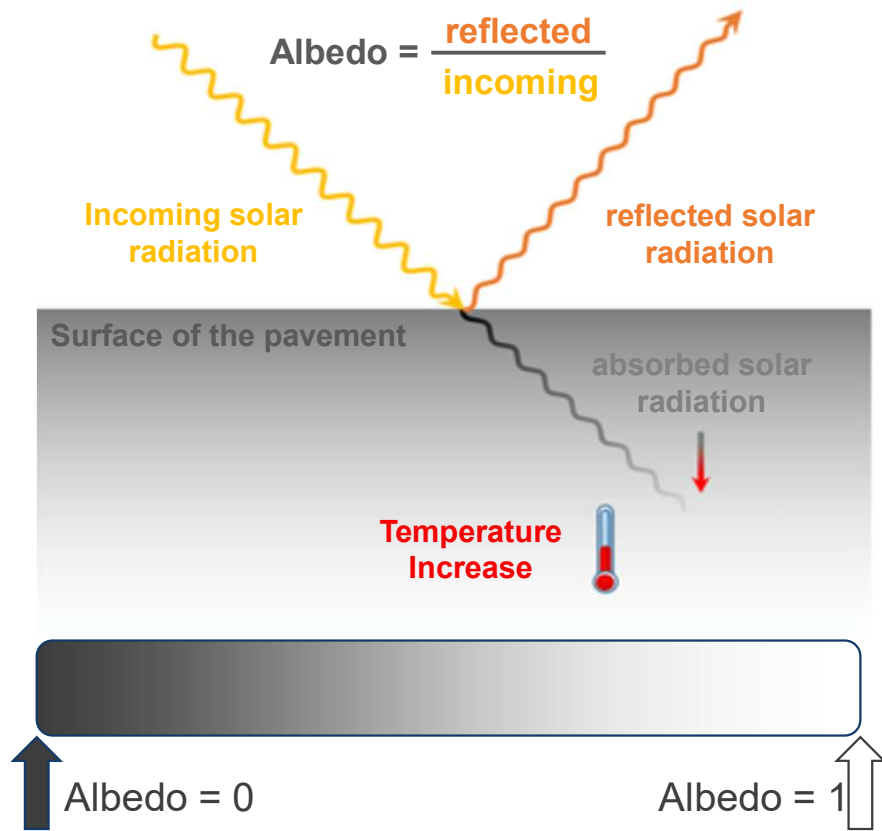


On Which to Focus on Depends on the Context

Example: 1000 Vehicles, Speed = 55 mph, Temperature = 86°F, Baseline IRI = 40 in/mi



Albedo – the Measure of Solar Energy Reflected by Surface



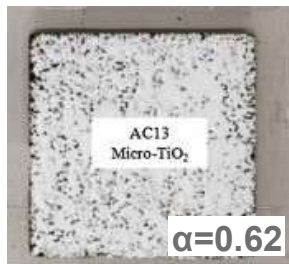
Albedo Values

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

There are Many Ways to Change the Albedo of Pavements

One Easy Way is to change Pavement Types

1) Reflective coatings



Chen et al. (2019)

2) Reflective Aggregates



Levinson and Akbari (2002)



3) Alternative binders



Boriboonsomsin, K., & Reza, F. (2007).

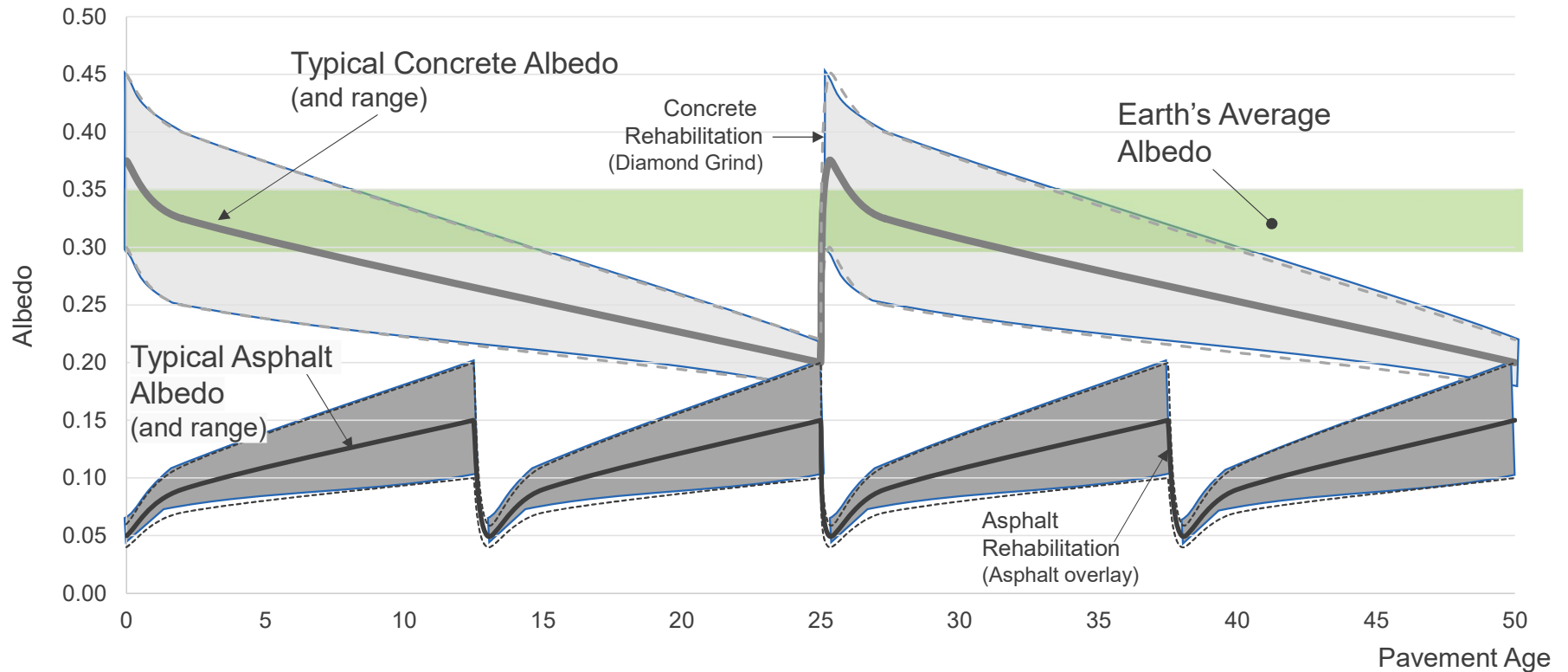
4) Change Pavement Type



Changing Pavement Type can have other Co-Benefits for addressing Climate Change

Pavement Albedo Changes Throughout the Pavement's Life

Illustrative Albedo Profile for Pavements

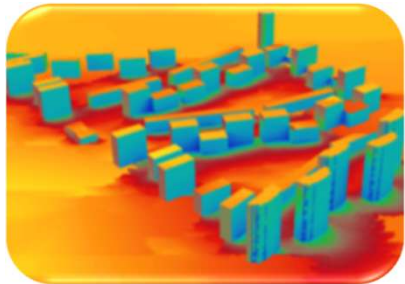


Concrete Pavements have a consistently higher Albedo
Range \approx 0.10 to 0.26

Sources:
Earth Albedo – NASA, <https://earthobservatory.nasa.gov/images/84499/measuring-earths-albedo>
Pavements - FHWA, Towards Sustainable Pavement Systems: A Reference Document. FHWA-HIF-15-002 and Quantifying Pavement Albedo, national Center for Asphalt Technology (NCAT) Report 19-09

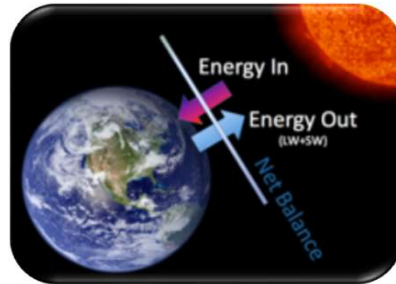
Pavement Albedo Impacts Climate Change by 4 Mechanisms

Urban Heat Island (UHI)



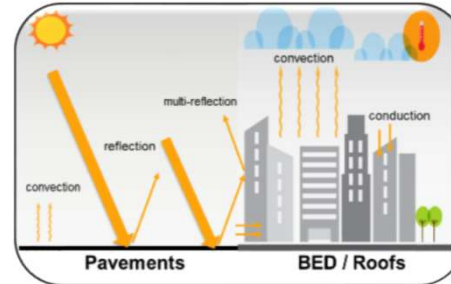
Ambient Temperature

Radiative Forcing



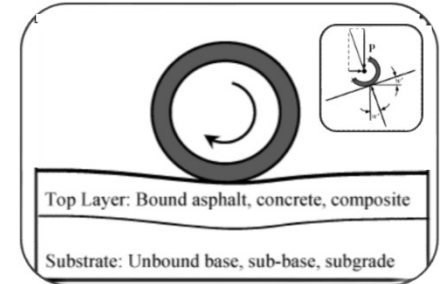
Earth's Energy Balance

Building Energy Demand



Incident radiation

Pavement Vehicle Interaction



Excess Fuel Use

Increasing pavement albedo

- Reduced Temperature
- Cooling Benefits

- **Negative RF**
- **Cooling benefits**

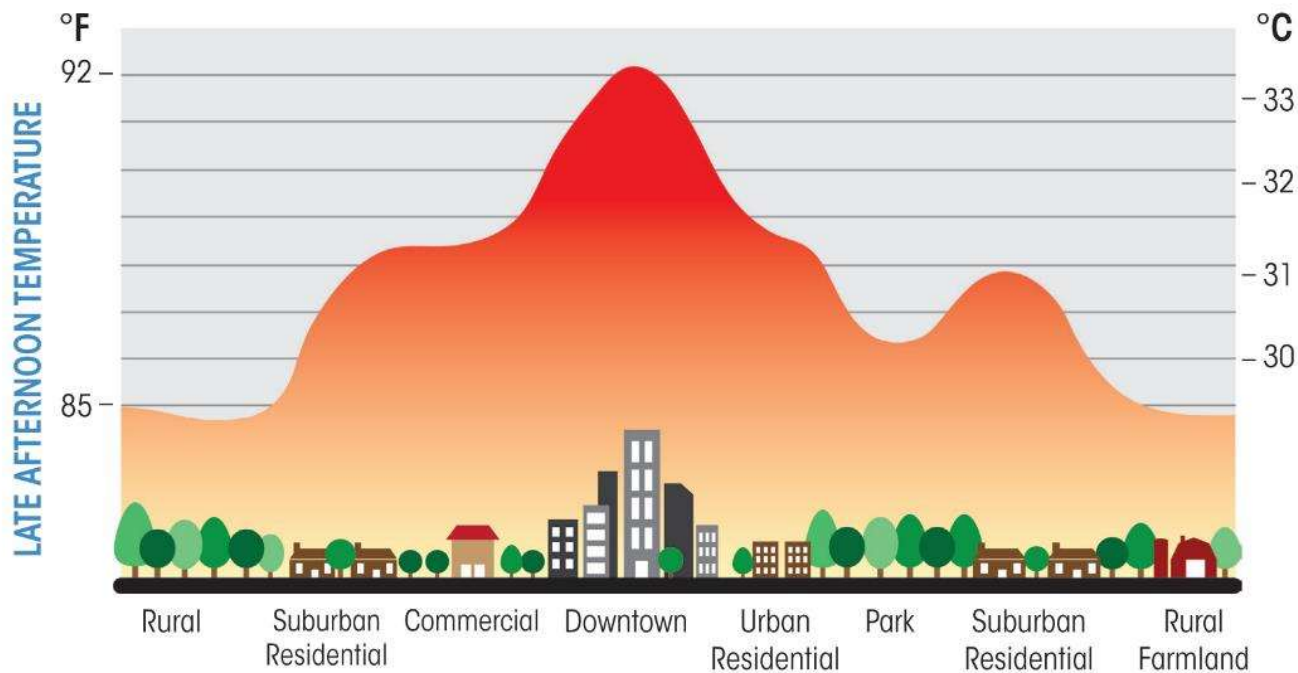
- Increased Radiation
- Mixed Benefits

- Co-Benefit of switching pavement types
- Decreased Deflection
- Reduced CO2
- Cooling Benefits

These phenomenon do not occur in rural areas.

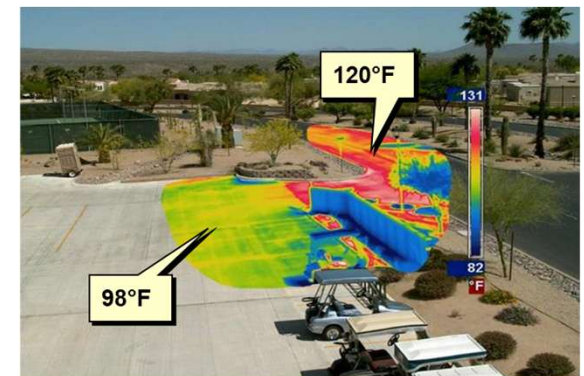
Concrete's High Albedo Reduces Urban Heat Island Impacts

Example of Heat Island effect



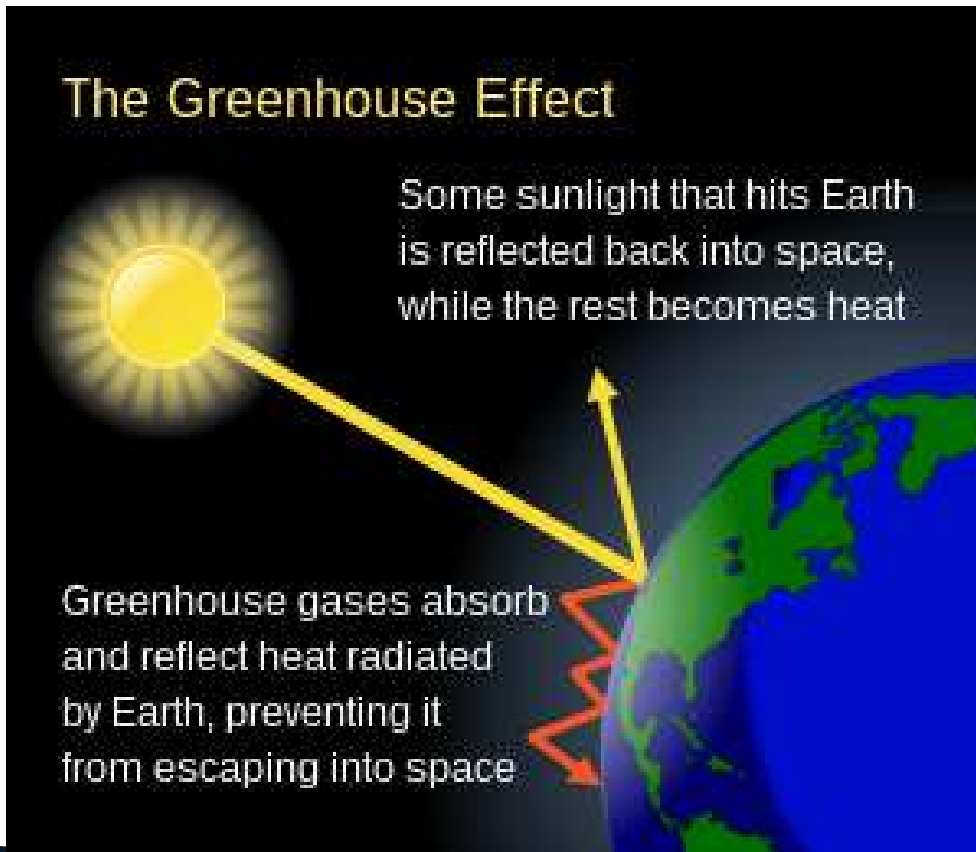
Increasing pavement albedo by 0.20 (asphalt to concrete) can reduce city temperatures by :

- 0.3° C (Boston)
- 2.1° C (Phx)



Global Warming is Caused by Excessive Radiative Forcing

As of April 2025, the Earth's energy imbalance was 1.04 W/m²



https://en.wikipedia.org/wiki/Greenhouse_effect

Global warming is due to more solar energy arriving than leaving the planet (Earth's energy balance)

- Called Radiative Forcing

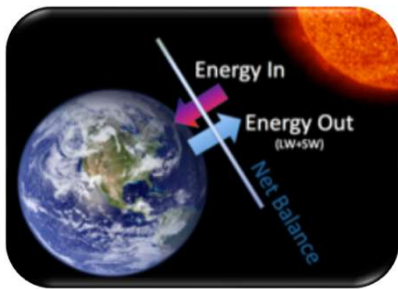
Radiative forcing can be changed by influencing two different mechanisms:

1. Minimizing Greenhouse gases (GHGs) - traps less heat
2. Increase surface reflectivity (albedo) – changes the amount of solar radiation leaving

Current Policies and actions have only focused on Reducing GHG

Increasing Pavement Albedo is Meaningful and Low-cost / Low Risk Endeavor to Address Climate Change

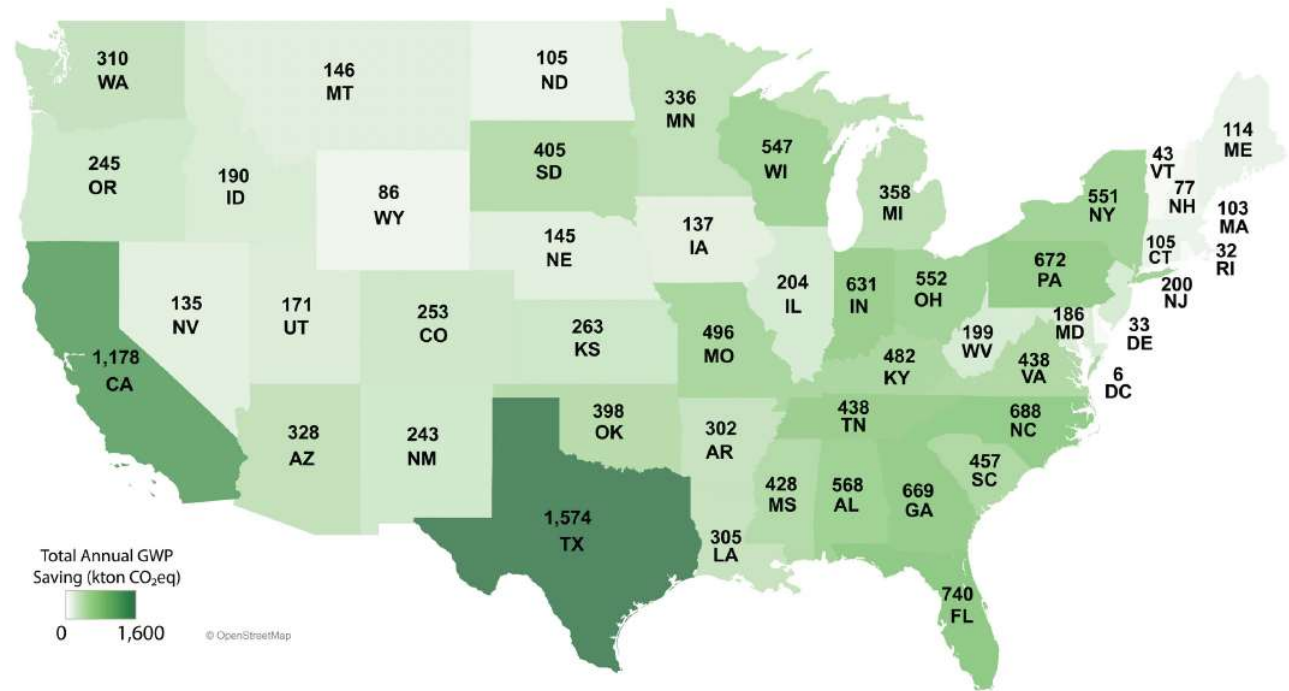
Earth's Energy Balance



Radiative Forcing

Switching Pavement types saves approximately 0.5 kgCO₂ / yd² / yr
 Range = 0.34 – 0.77 kgCO₂ / yd² / yr

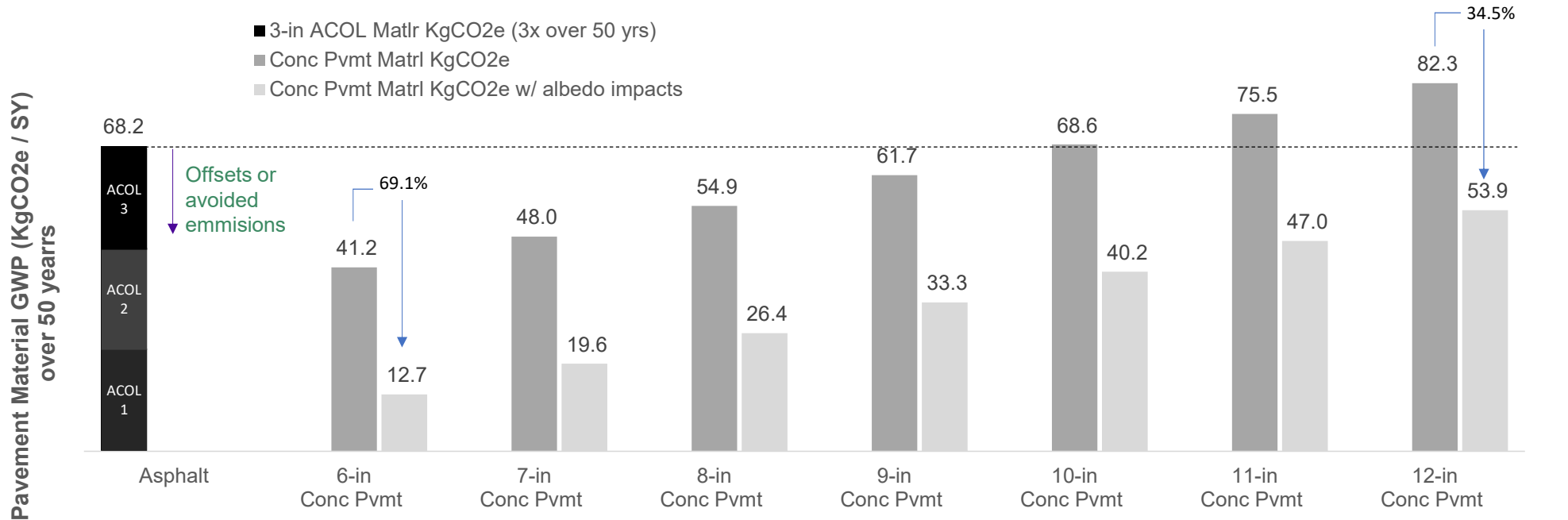
Increasing pavement albedo on all U.S. roads by 0.2 would reduce CO₂-eq by 17.45 Mton / year due to radiative forcing—equivalent to ~ 4 million cars



Pavement Albedo Offset's Concrete's High Initial Embodied CO2

Phoenix AZ - Urban

KgCO2 / SY of Pavement with & without RF Impacts



Assumes 247 kgCO2 / 1 CY of concrete – NRMCA industry Average for Pacific SW Region
 Albedo Increase = 0.20 with GWP Saving from 0.01 increase in Albedo = 1.7 kgCO2e/m2

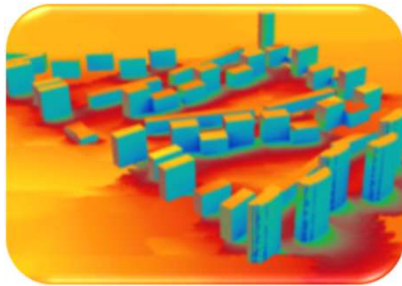
Over a 50-year period, albedo offsets 34% to 70% of the embodied CO2 for the concrete used in pavements (depends on thickness)

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

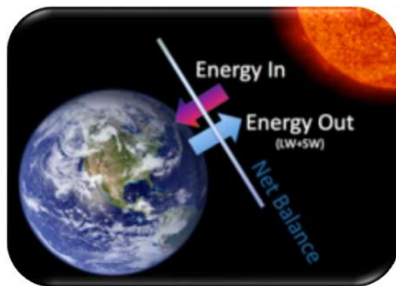
Increasing Pavement Albedo can Increase Incident Radiation on Buildings

Increased Incident Radiation MAY increase Energy Demand and act in opposite ways as Radiative Forcing & Ambient Temperature (UHI)

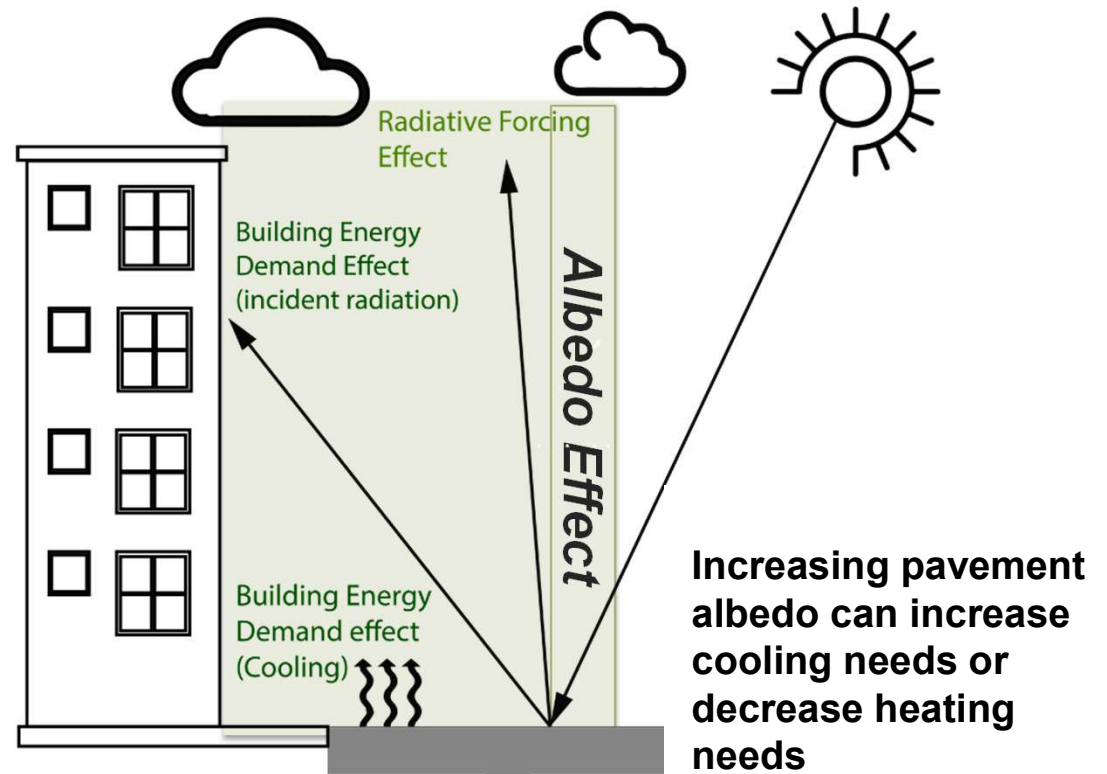
Urban Heat Island (UHI) & Radiative Forcing (RF)



Ambient Temperature

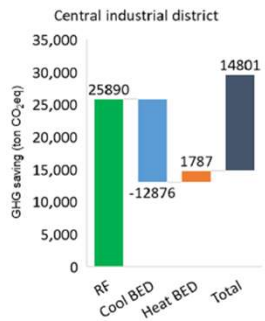


Earth's Energy Balance

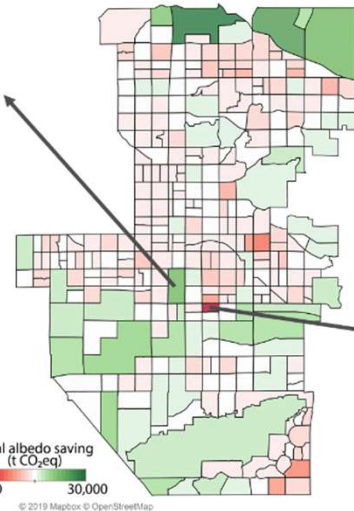


High Albedo Reduces Urban Heat Island Impacts But it can increase / impact Building Energy Demand (BED)

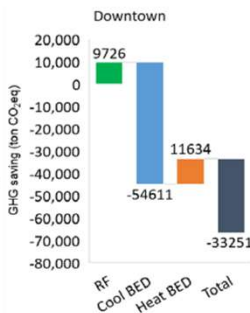
Estimated Temperature reductions due to 0.2 increase in pavement albedo



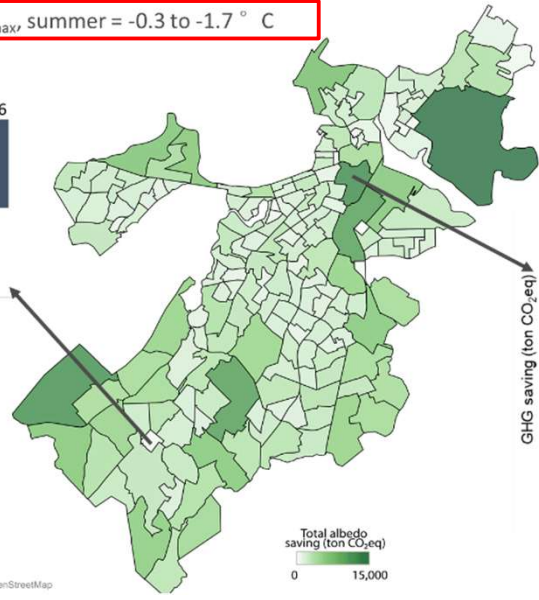
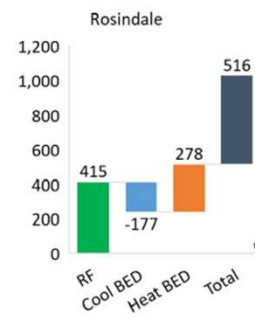
ΔT_{max} summer = -1.9 to -2.1 ° C



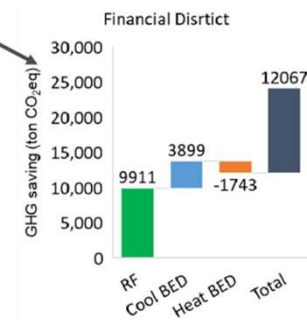
Phoenix



ΔT_{max} summer = -0.3 to -1.7 ° C



Boston



Red areas are show where albedo impacts are negative (burden)

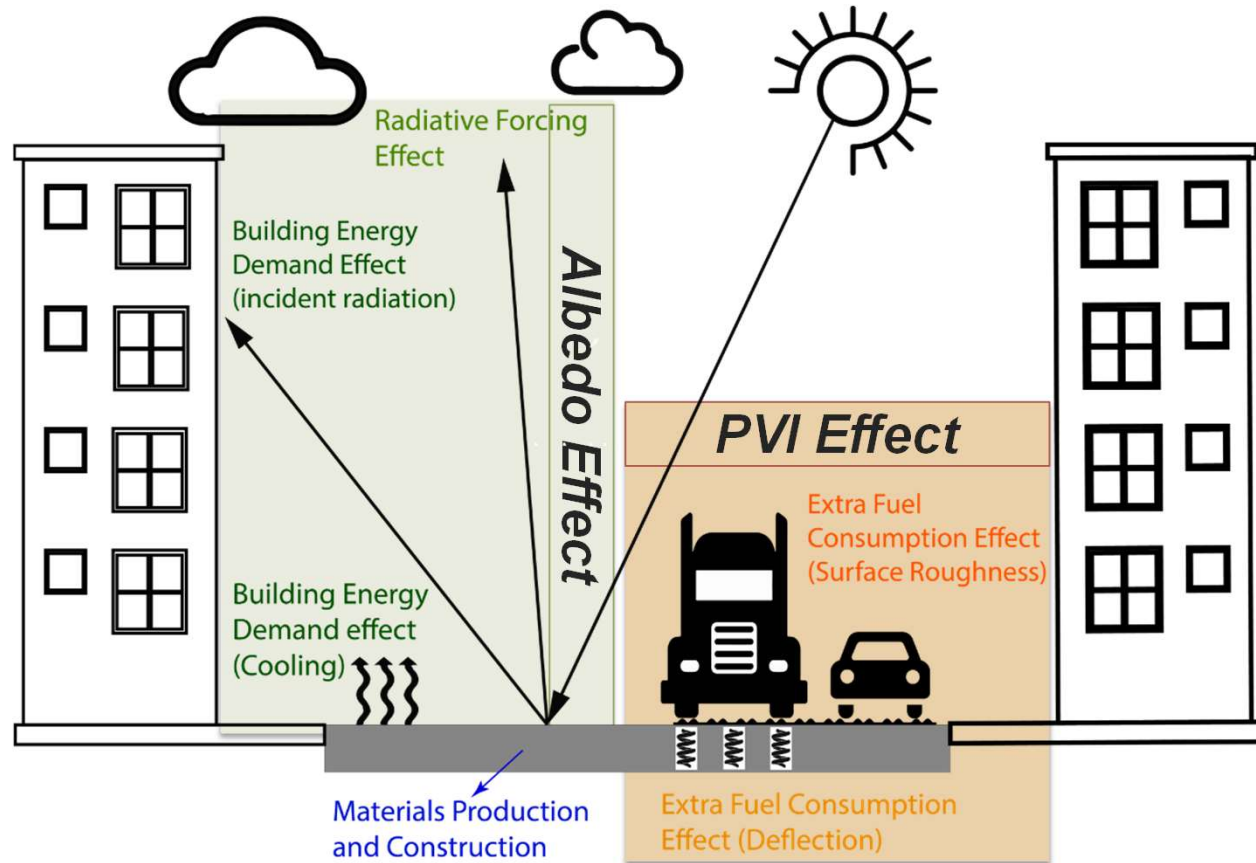
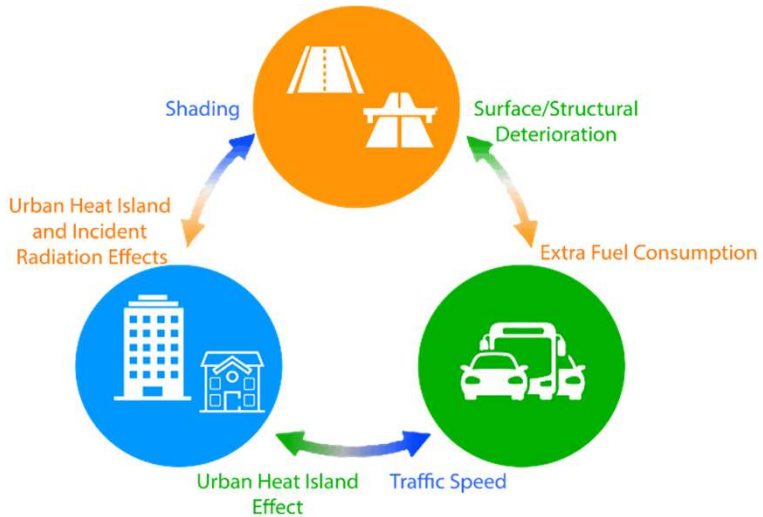
In some dense, urban downtown neighborhoods, higher albedo can leads to a net GHG burden (Reflective pavement coatings do not significantly change pavement stiffness)

Source: MIT <https://escholarship.org/uc/item/00400040#page=1113-051.pdf>

Changing Pavement Type means adding PVI to the Evaluation

Must quantify the NET effects of Radiative Balance, Ambient Temperature, Building Energy Demand & Pavement Vehicle Interaction

Need to account for the interconnection effects of built environment elements



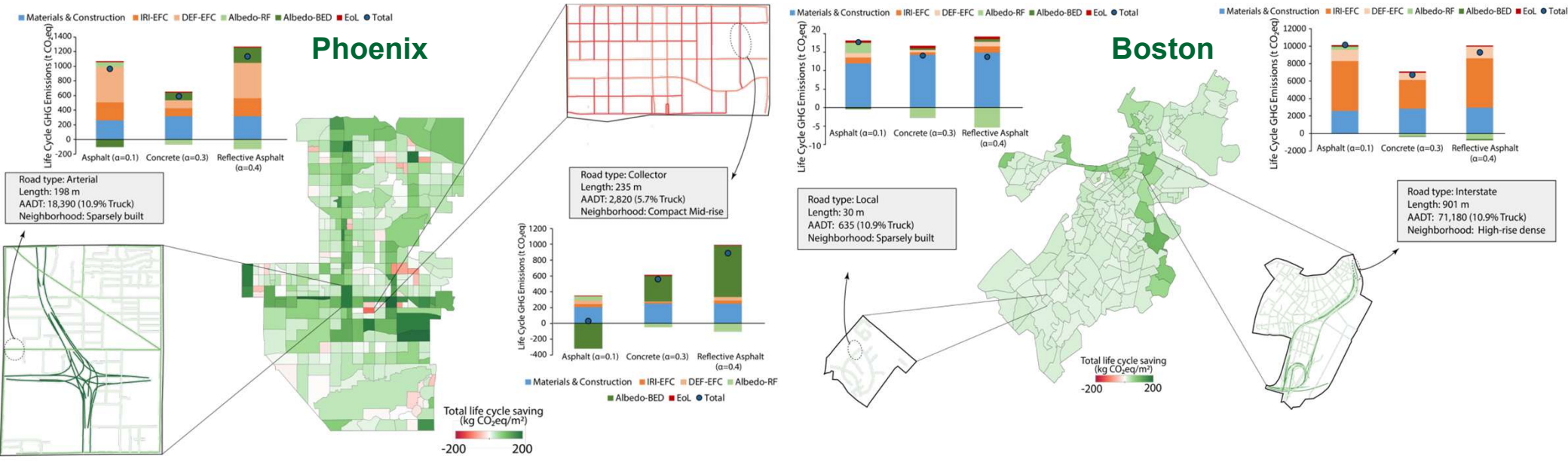
When Concrete's High Albedo & PVI are Evaluated Together

Replacing asphalt with concrete pavements results Net Life cycle GHG Savings

Net GWP Emissions after accounting for all Life Cycle Phases over a 50-year Analysis Period

ΔT_{max} summer = -1.9 to -2.1 ° C

ΔT_{max} summer = -0.3 to -1.7 ° C



Red areas are show where asphalt savings are higher

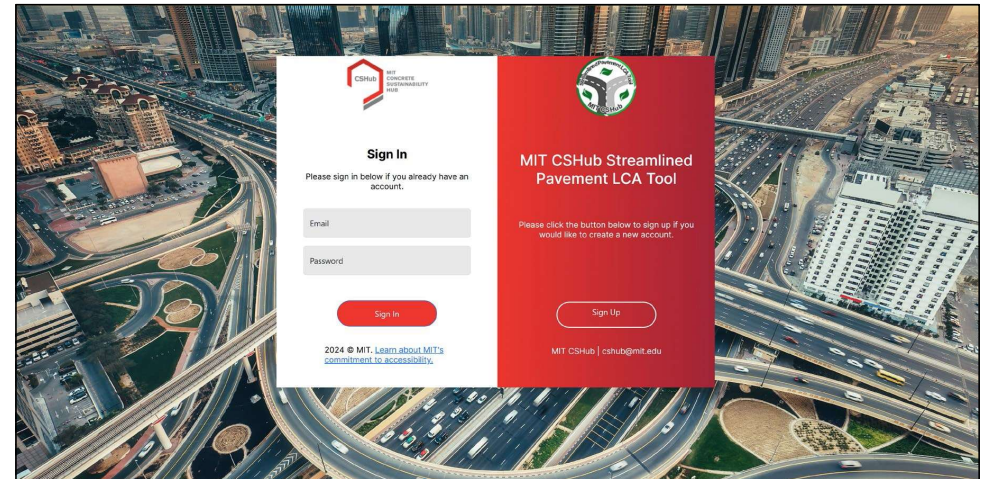
In most other urban neighborhoods, using concrete almost always results in net benefits

Source: MIT https://eprints.mit.edu/bitstream/handle/1721.1/100000/1/13_03.pdf

MIT STREAMLINED LCA PLATFORM

In “Beta” development phase

- Generalized tool to enable rapid analysis of the whole-life implications of pavement alternatives
 - Uses Neural Network of based on Pavement-ME to predict pavement performance
- Estimates the whole-life LCA using whatever level of detail is available to the user (limited or detailed)
 - Uses a process called “structured data under-specification” to provide a range of results
- Includes both Embodied Emissions and Use Phase Impacts
 - Initial construction, rehabilitation & maintenance, and End of Life activities
 - PVI, Albedo, carbonation



**MIT CSHub Streamlined Pavement
LCA Tool (Online)**

<http://pavementlca.mit.edu>

MIT STREAMLINED LCA PLATFORM

First 2 sheets define the
Pavement Context for the project

- Location
- Climate
- Functionality
- Traffic
- Basic Design Info
 - Length,
 - No. of lanes
 - Shoulders

Parameters	Min.	Mean	Max.	Distribution
AADT per Lane	722.5	1156	1589.5	Uniform
AADT All Lane	2890	4624	6358	Uniform
Truck Percentage (%)	5	7	9	Uniform
AADTT per Lane	36.125	89.6	143.055	Uniform
AADTT All Lane	144.5	358.4	572.22	Uniform
Traffic Growth (%)	1	1.5	2	Uniform
Traffic Speed (mph)	55	60	65	Uniform
Reliability (%)	90	92.5	95	Uniform

2nd sheet allows for more
detailed Traffic information
(optional)

MIT STREAMLINED LCA PLATFORM

Embodied Emission sheets provide material properties

- 3rd Sheet = Concrete
- 4th sheet = Asphalt

Both start with a “state wide” pre-populated average data, but can be adjusted with EPD data for specific mixes

- Material data covers A1-A3 Stages

State: **California** PCC Compressive Strength (psi): **4000**

Materials (A1)		
Portland Cement	294.8204	kg/m ³
Fly Ash	43.3036	kg/m ³
Slag Cement	0	kg/m ³
Mixing Water	194.5696	kg/m ³
Crushed Coarse Aggregate	444.9	kg/m ³
Natural Coarse Aggregate	422.9516	kg/m ³
Crushed Fine Aggregate	105.5896	kg/m ³
Natural Fine Aggregate	751.58	kg/m ³
Air	6	%
Air Entraining Mixture	0	kg/m ³
Water Reducer	0.03	kg/m ³
High Range Water Reducer	0.09	kg/m ³
Accelerator	0.44	kg/m ³

Energy (A3)		
Purchased Electricity	4.61	KWh
Natural Gas	0.031714816	m ³
Secondary Fuels - Liquid	3	kg
Secondary Fuels - Solid	3	tn.sh
Fuel Oil (other than diesel)	0	lit
Diesel	1.8548509	lit
Gasoline	0	lit
LPG	0	lit

Transportation (A2)		
Transportation Emission	14.522	kg CO ₂ eq / m ³

Total Emission (A1+A2+A3)			
Material (A1)	Transportation (A2)	Energy (A3)	
272.397	14.522	7.167	
Total Emissions			294.087 kg CO ₂ eq / m ³

State: **California**

Materials (A1)		
Bitumen content	0.04	
Bitumen impact	637.00	kgCO ₂ /metric ton
Gravel impact	3.81	kgCO ₂ /m ³ asphalt
Sand impact	3.81	kgCO ₂ /m ³ asphalt
RAP and WAP Modification		
RAP Content	0.16	
WAP Content	0.24	

Transportation (A2)		
Transportation GHG	14.43	kgCO ₂ /m ³ asphalt

Energy (A3)		
Asphalt heating impact	48.48	kgCO ₂ /m ³ asphalt

Total Emissions (A1+A2+A3)			
Material (A1)	Transportation (A2)	Energy (A3)	
69.72	14.43	48.48	
Total Emissions			132.63 kg CO ₂ eq / m ³

MIT STREAMLINED LCA PLATFORM

Pavement Desing sheets provide Initial & Rehab Activities

Initial designs can be input if known

- If unknown, can estimate thicknesses based on AASHTO 93 or Pavement-ME procedures
 - Only allows for 1 base type
- Uses ranges & a probabilistic distribution for material & other inputs

Has pre-populated rehabilitation activities for both pavement types.

Design Name: 9.0" JPCP / 4" Agg

Surface	JPCP	Thickness (in)	Min: 9	Max: 9
Base	Granular	Thickness (in)	Min: 4	Max: 4
Dowel Bar		Dowel diameter (in)	Min: 1.25	Max: 1.25
Subgrade		K-value (pci)	Min: 150.49	Max: 150.24

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)	650	690	730	Uniform
Coefficient of Thermal Expansion (10 ⁻⁶ in/in/F)	4	5	6	Uniform
Joint Spacing (ft)	13	13	13	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

Maintenance and Rehabilitation (M&R) Schedule

Timing (years)		Treatment Type	Material	
Min	Max		Removal	Addition
25	25	100% Diamond Grinding w/ Full Depth R	3	3
40	40	100% Diamond Grinding w/ Full Depth R	3	3
0	0	Unspecified	0	0
0	0	Unspecified	0	0
0	0	Unspecified	0	0
0	0	Unspecified	0	0

Design Name: 10" HMA/6" Agg

Surface	HMA	Thickness (in)	Min: 10	Max: 10
Base	Granular	Thickness (in)	Min: 6	Max: 6
Subgrade		K-value (pci)	Min: 150.49	Max: 150.24

Custom Design

Parameters	Min	Mean	Max	Distribution
AC Binder Type: Viscosity Grade	AC 20			Uniform
Effective Binder Content (%)	9.2	11.6	14	Uniform
AC Air Voids (%)	4	7	10	Uniform
AC Elastic Modulus (psi)	20000	35000	70000	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

Maintenance and Rehabilitation (M&R) Schedule

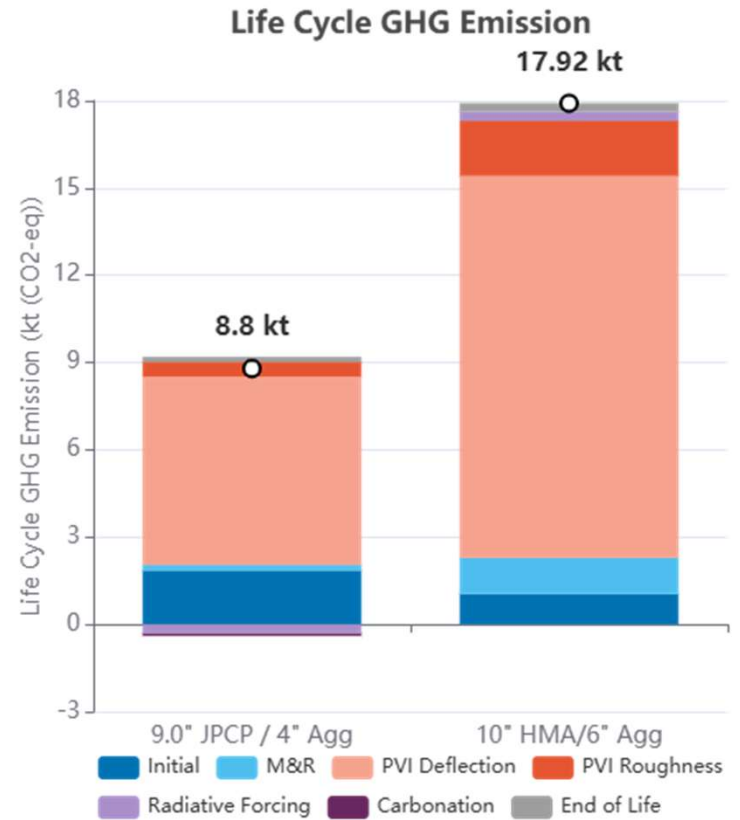
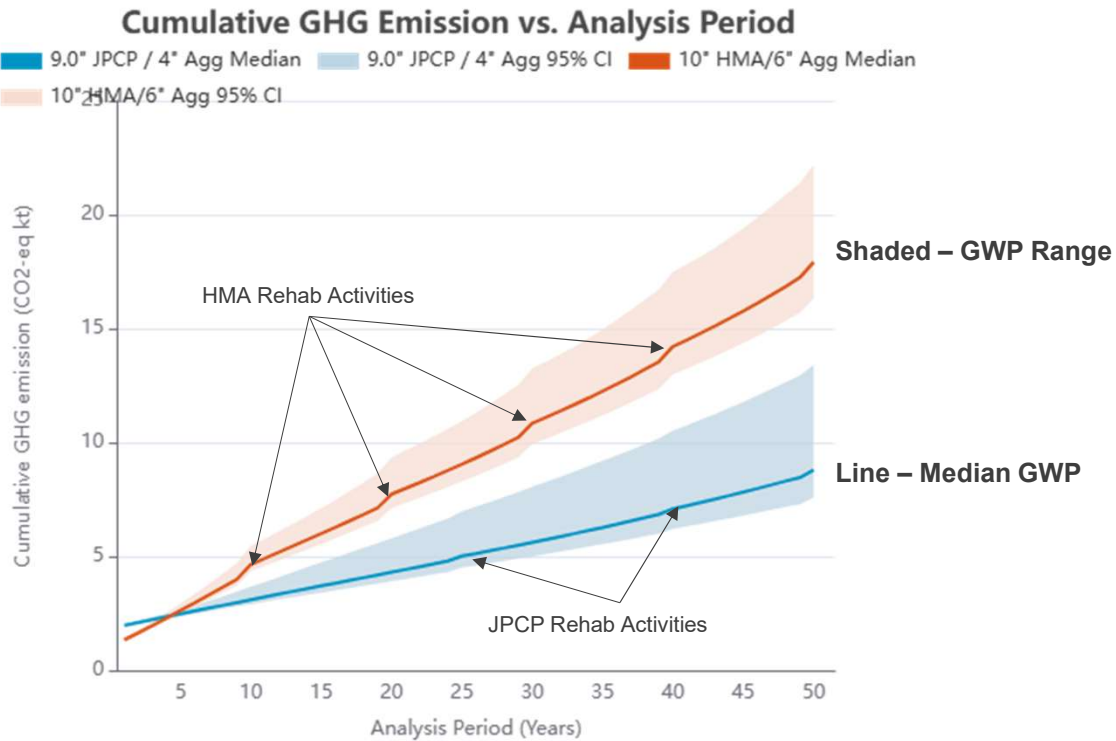
Timing (years)		Treatment Type	Material	
Min	Max		Removal	Addition
10	10	AC Mill and Fill (in)	3	3
20	20	AC Mill and Fill (in)	3	3
30	30	AC Mill and Fill (in)	3	3
40	40	AC Mill and Fill (in)	3	3
0	0	Unspecified	0	0
0	0	Unspecified	0	0

Design Specification: AASHTO1993 | Design Life (years): 20 | Number of Iteration: 100 | Analysis Period: 50

[Run Design](#) [Run Pavement Lifecycle Analysis](#)

MIT STREAMLINED LCA PLATFORM - OUTPUT

<http://pavementlca.mit.edu>



**Concrete
Pavement's
Role in a
Sustainable,
Resilient Future**



**For Additional Information, see
ACPA's Publication**

***Concrete Pavement's Role in a
Sustainable and Resilient Future***

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