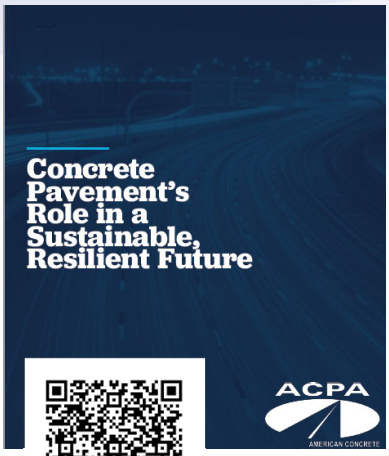
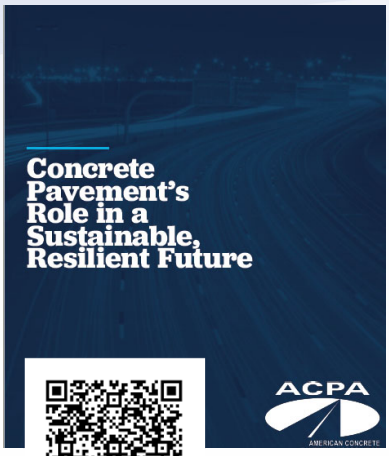
ACPA's White Paper on Sustainability and Resilience



2023 Spring NCC
Savannah, GA
April 10, 2023

Eric Ferrebee, P.E.
Senior Director of Technical Services
AMERICAN CONCRETE PAVEMENT ASSOCIATION

20 Questions About Concrete Pavement Sustainability



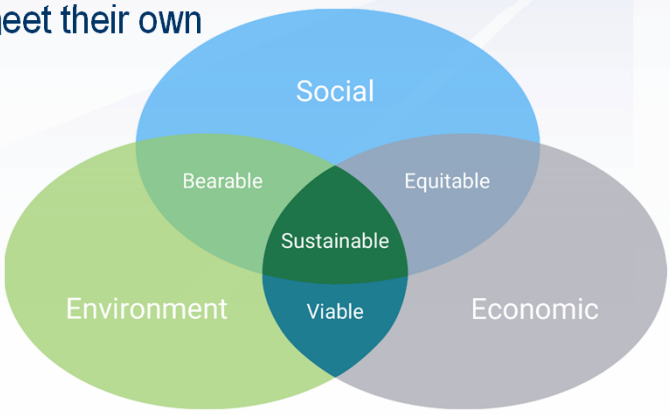
2023 Spring NCC
Savannah, GA
April 10, 2023

Eric Ferrebee, P.E.
Senior Director of Technical Services
AMERICAN CONCRETE PAVEMENT ASSOCIATION

1. Sustainability… Never heard of it… what is it?

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

Sustainable practices are simply good engineering!



2. Environmental Impacts? Is that what Environmental Product Declarations (EPDs) are all about?

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

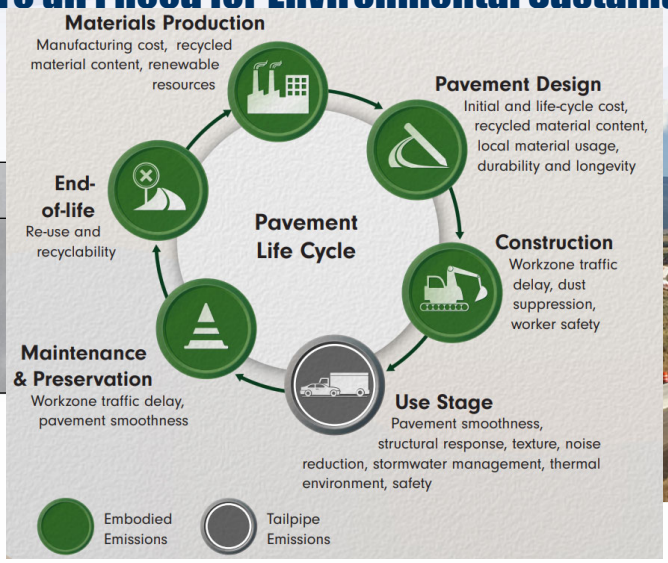
Global Warming Potential (kg CO_2-eq)	392
Ozone Depletion Potential (kg CFC-11-eq)	1.1E-5
Acidification Potential (kg SO_2-eq)	2.06
Eutrophication Potential (kg N-eq)	0.46
Photochemical Ozone Creation Potential (kg O_3-eq)	45.5
Abiotic Depletion, non-fossil (kg Sb-eq)	1.4E-6
Abiotic Depletion, fossil (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. Summary Results (A1-A3

		Minimum	Maximum	4000-00-FA/SL	4000-20-FA	4000-30-FA	4000-40-FA	300 400 SL
Core Mandatory Impact Indicators								
GWP	kg CO_2e	261.19	426.75	426.75	365.48	332.37	297.41	3
ODP	kg CFC11e	7.84E-06	1.11E-05	1.11E-05	9.56E-06	8.73E-06	7.84E-06	1.0
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	
ADPf	MJ, NCV	1,522.19	2,229.70	2,229.70	1,921.20	1,754.51	1,578.49	1,8
ADPe	kg Sbe	2.44E-04	3.69E-04	3.69E-04	3.25E-04	3.02E-04	2.77E-04	2.9
FFD	MJ Surplus	143.16	180.58	180.58	162.85	153.28	143.16	1

3. So EPDs are all I need for Environmental Sustainability?



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

4. I've seen doom and gloom articles, should we just not use concrete?

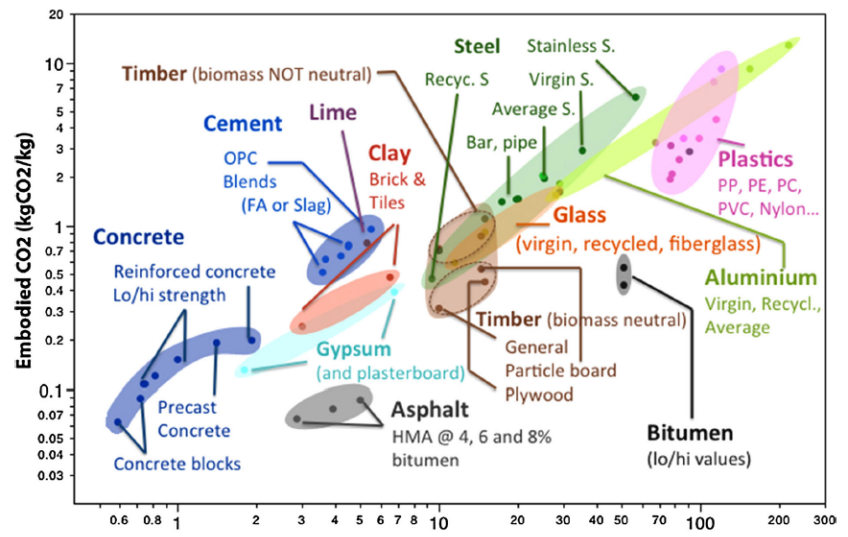
Limestone quarries and cement factories are often sources of air pollution. Photograph: Zoonar

Best of 2019

Concrete: the most destructive material on Earth

Source: Guardian.com

4. I've seen doom and gloom articles, should we just not use concrete?



Source: Barcelo et al. 2019. Cement and carbon emissions. DOI: 10.1617/s11527-013-0114-5

5. What can I do to DESIGN a more sustainable pavement?

- Use the best available design tools
  - Pavement ME Design
  - *PavementDesigner.org*
- Concrete overlays
  - Capitalize on equity already in pavement
  - Long-life and low-carbon design solution
- OPTIMIZE!!!
  - Long-life Pavements

6. Optimize my design for what? Thickness?

Design Proposal & Context
Layers
Traffic
Climate

Analyze Using ME Design Principles

N — Adequate Performance — Y

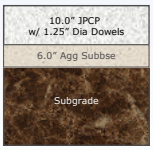
Final Design

Apply Lifecycle Bill of Activities

Evaluate LCCA / LCA

6. Optimize my design for what? Thickness?

Design Proposal & Context
Layers
Traffic
Climate



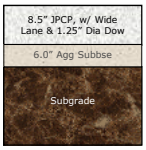
Analyze Using ME Design Principles

Develop Lifecycle Bill of Activities

Evaluate LCCA / LCA

N — Adequate Performance — Y

Final Design



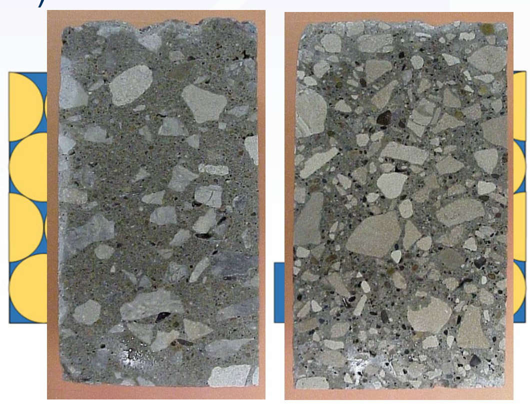
Designing pavements in an iterative procedure provides a Feedback Loop

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

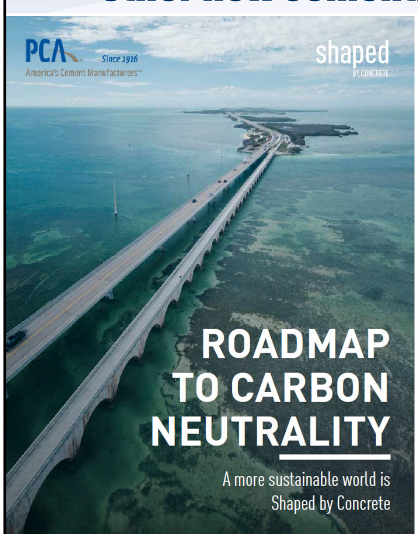
Optimize for Sustainability!

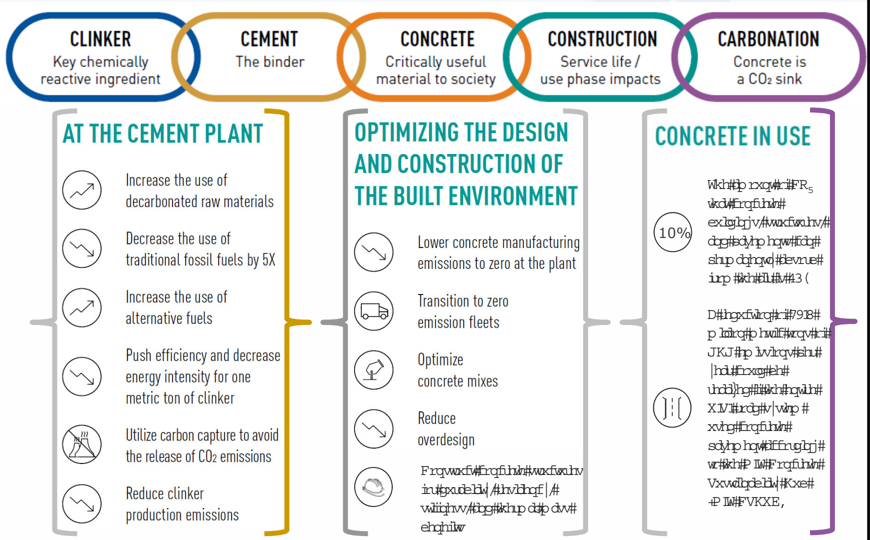
7. Let's get back to Materials! … My focus has been on implementing PEM, will this conflict with working towards sustainable concrete pavements?

- Performance Engineered Mixtures (PEM)
  - Ensuring durable, long-lasting concrete
  - Optimized aggregate gradations lead to optimized cementitious contents



8. Where do PEM and Sustainability intersect with PLC and other new cementitious technologies?

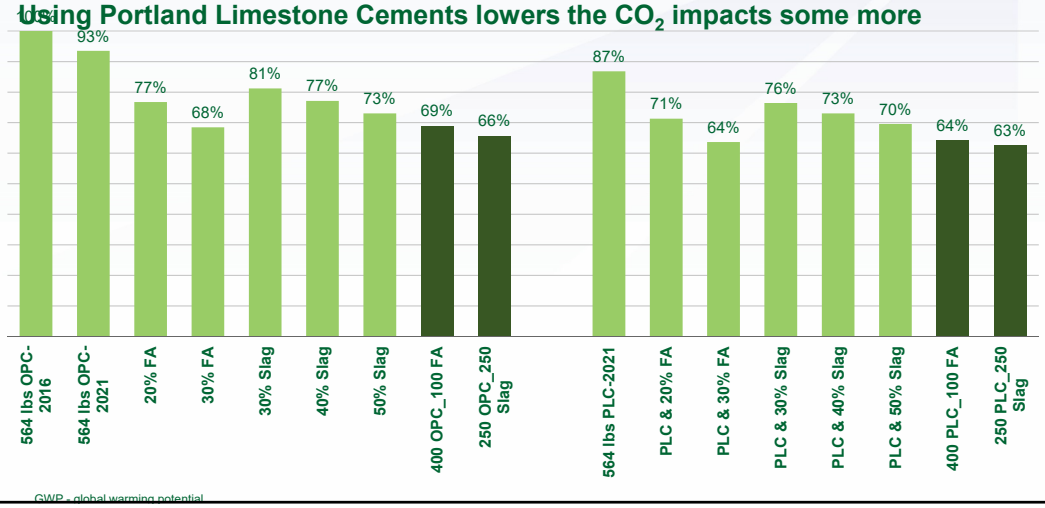



CLINKER
Key chemically reactive ingredient
CEMENT
The binder
CONCRETE
Critically useful material to society
CONSTRUCTION
Service life / use phase impacts
CARBONATION
Concrete is a CO2 sink
AT THE CEMENT PLANT
Increase the use of decarbonated raw materials
Decrease the use of traditional fossil fuels by 5X
Increase the use of alternative fuels
Push efficiency and decrease energy intensity for one metric ton of clinker
Utilize carbon capture to avoid the release of CO2 emissions
Reduce clinker production emissions
OPTIMIZING THE DESIGN AND CONSTRUCTION OF THE BUILT ENVIRONMENT
Lower concrete manufacturing emissions to zero at the plant
Transition to zero emission fleets
Optimize concrete mixes
Reduce overdesign
CONCRETE IN USE
10%

9. Ok… but how big an impact does PEM, mix optimization, PLC, and all this really make? Is it worth the effort?

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

10. Is there anything I can do in Construction to improve sustainability?

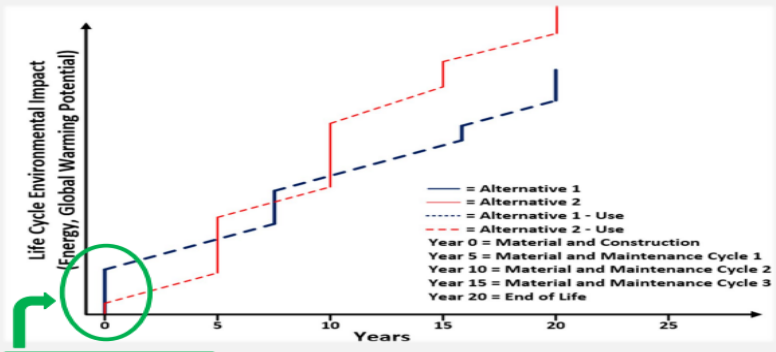
- Construction Phase
  - Optimized construction planning
  - Reduced transportation
  - Recycling!
  - Smoothness… within reason…
  - Construction equipment improvements

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

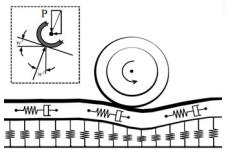
[Source: Jacquelyn Wong (CalTrans)]

12. But how can I possibly impact the use phase?

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

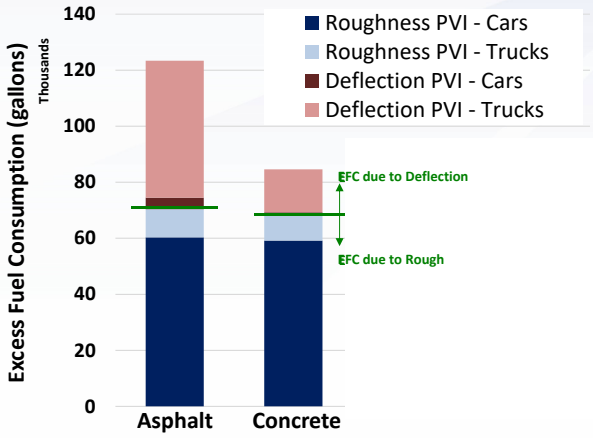


- Deflection/dissipation induced PVI**:
  - Vehicle deflects the pavement and vehicle drives up a hill
  - Pavement Design Parameters (materials, stiffness & thickness) matter
  - Speed and temperature dependent, especially for inter-city pavement systems

*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.

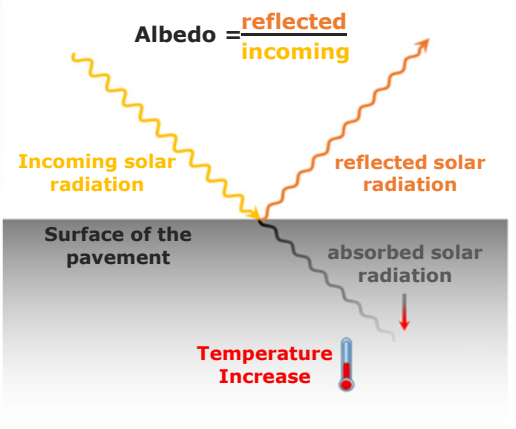
13. So it's not just about smoothness?

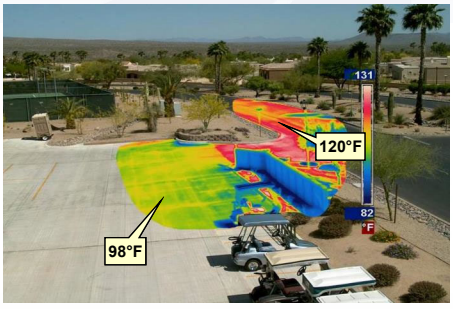
- Excess fuel consumption matters!



14. Are there any other Use phase concepts I need to know?

- Albedo – The measure of solar energy reflected by surface





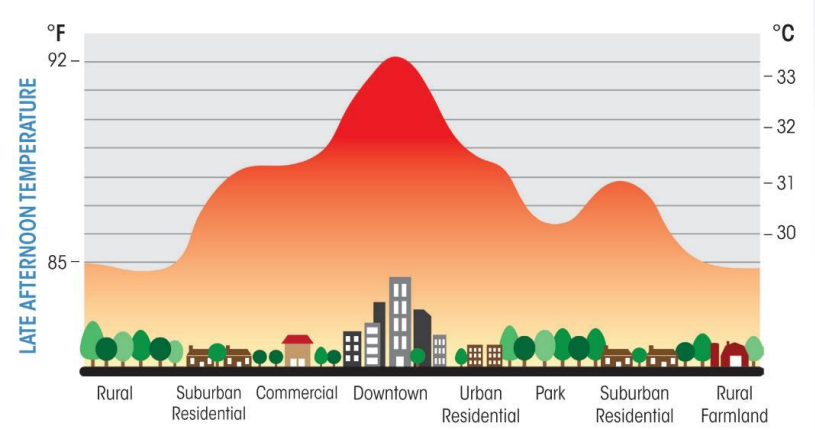
Albedo Values

- 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

14. Are there any other Use phase concepts I need to know?

- 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 :

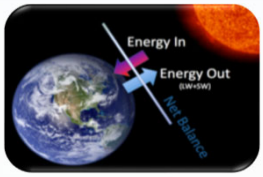
- **0.3° C (Boston)**
- **2.1° C (Phx)**

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

14. Are there any other Use phase concepts I need to know?

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

Earth's Energy Balance

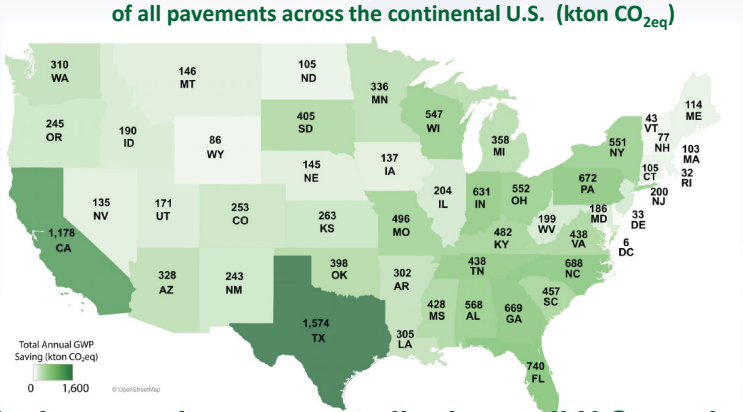


Radiative forcing

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

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

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



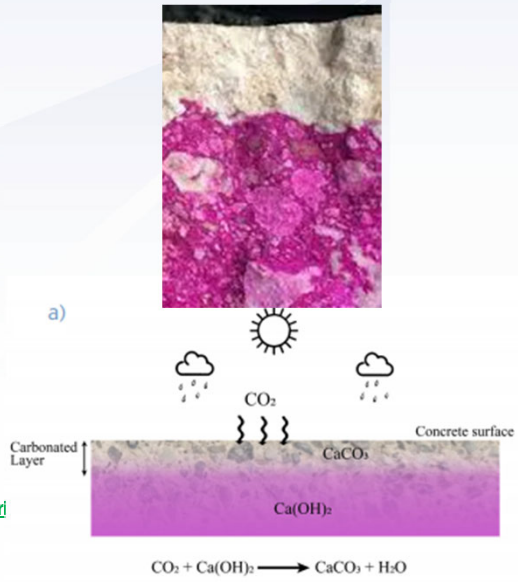
An increase in pavement albedo on all U.S. roads would reduce CO2-eq by 17.45 Mton per year due to radiative forcing—equivalent to ~ 4 million cars

14. Are there any other Use phase concepts I need to know?

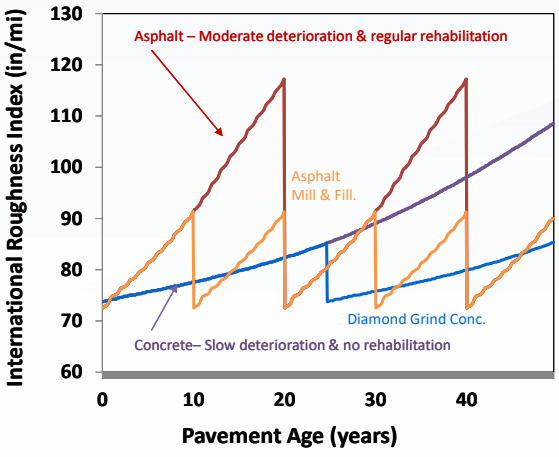
- Concrete – CO_2 Absorption
- Carbonation CO_2 reacts with calcium carbonate in concrete
- In US, concrete pavements could absorb about 2.8 million tons of CO2 30 years use
  - More in states w/ concrete pavements

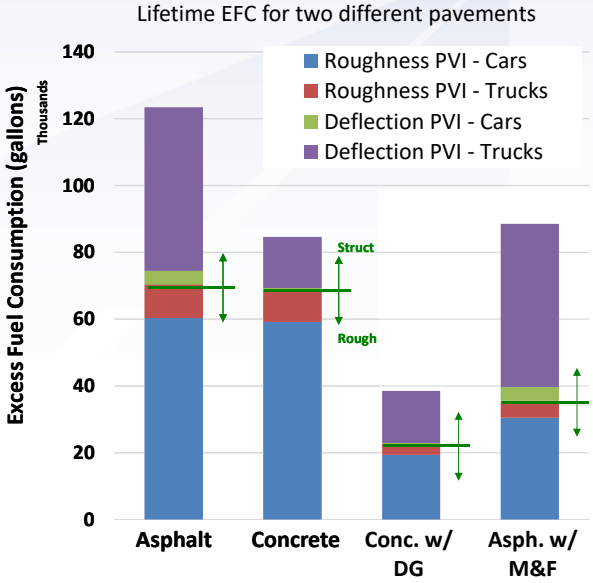
https://news.mit.edu/2021/unravelling-carbon-uptake-concrete-pavements-0126

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



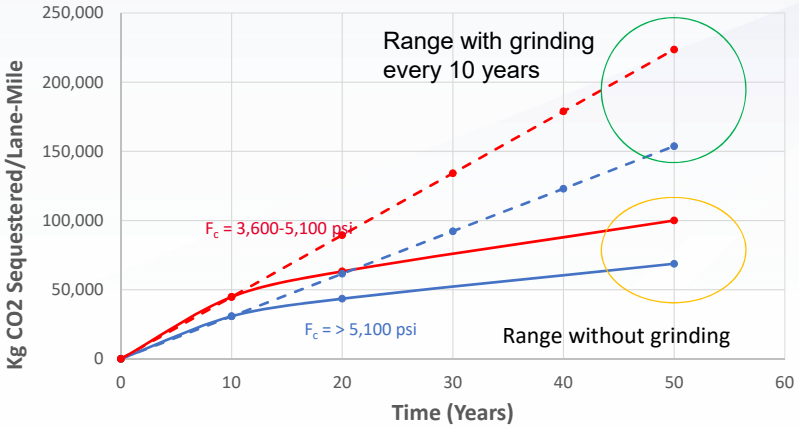
15. Ok… I've considered use phase impacts, can I please just leave my concrete pavement alone now for 20+ years like I have in the past?!





Pavement design developed by Applied Research Associates (ARA), Inc,:

15. Ok… I've considered use phase impacts, can I please just leave my concrete pavement alone now for 20+ years like I have in the past?!

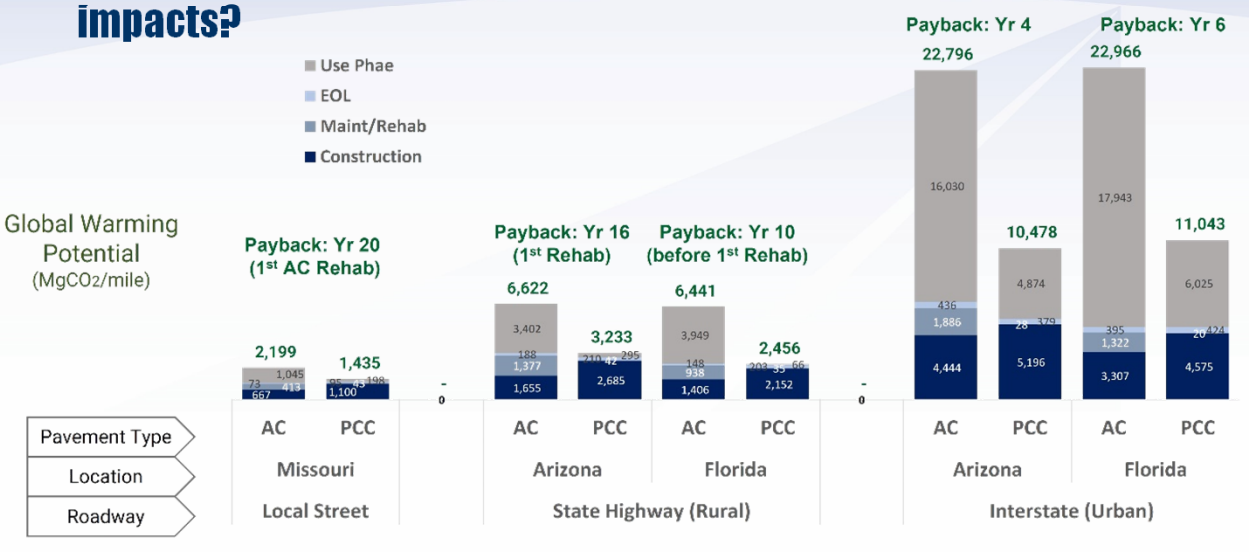


CO2 Sequestered Over Time per Lane-Mile with Diamond

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

16. What happens when I consider all these environmental impacts?



- 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

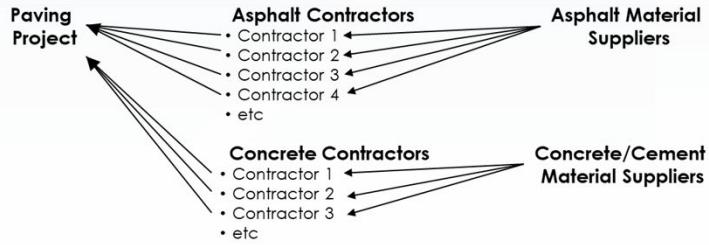
17. Back to broader sustainability… we do LCCA, so we've got the economics covered… right?

Intra-Industry (Contractor) Competition

Competition Between firms that pave with the same material

Inter-Industry (Industry) Competition

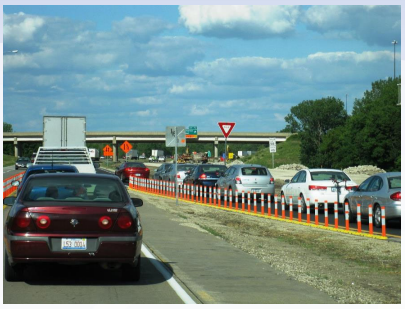
Competition between firms that pave with different material substitutes

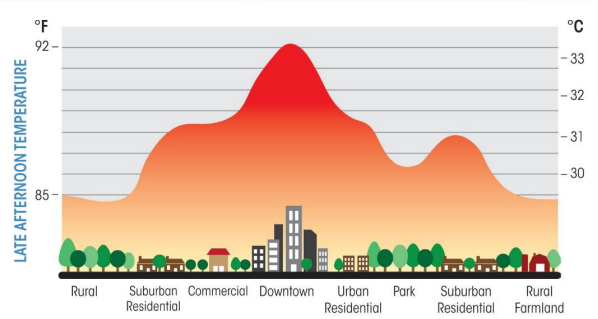


Contractor competition does not assure competition takes place at all levels of the supply chain

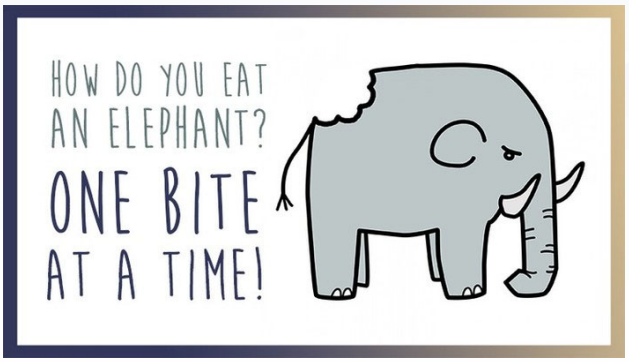
18. What about social impacts?

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





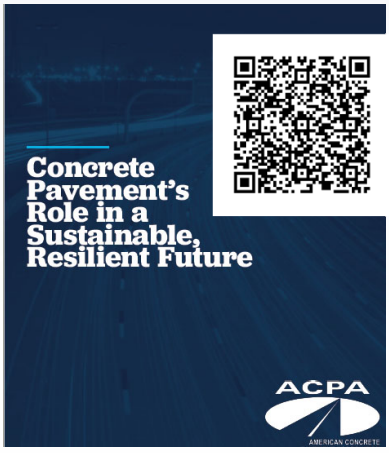
19. This… was a lot… how do you expect me to do all this?!



Source: https://www.icantrustnetwork.co.uk/uploads/news-pictures/183-blackpool-blog-post-image-20200422152141.jpg

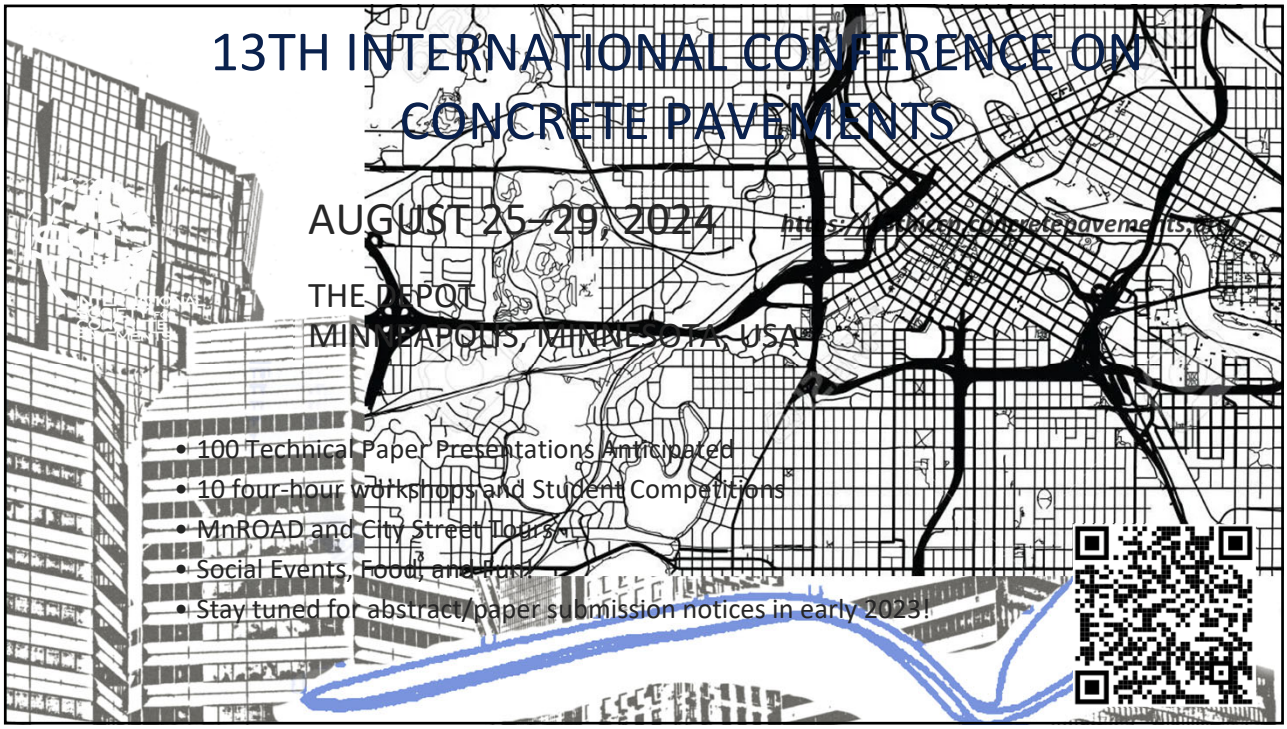
Source:https://bangkok.unesco.org/sites/default/files/styles/theme_highlights/public/assets/article/Education/images/lets-work-together-cropped-image.jpg?itok=S_44lRiu

20. Eric… you've just said a whole bunch and I'm sitting in a meeting here where I can't really do a whole lot… can you just shut up and let me know where I can look back on this and try to digest?



Acknowledgements

- Jim Mack – Cemex
- Tom Van Dam – NCE
- Leif Wathne – CP Tech
- Peter Taylor – CP Tech
- PCA
- NRMCA
- MIT's CSHub


13TH INTERNATIONAL CONFERENCE ON CONCRETE PAVEMENTS
AUGUST 25–29, 2024
THE DEPOT
MINNEAPOLIS, MINNESOTA, USA
• 100 Technical Paper Presentations Anticipated
• 10 four-hour workshops and Student Competitions
• MnROAD and City Street Tours
• Social Events, Food, and Fun!
• Stay tuned for abstract/paper submission notices in early 2023!


Concrete Pavement's Role in a Sustainable, Resilient Future
ACPA
SUSTAINABILITY
SOCIAL
ENVIRONMENTAL
ECONOMIC
P2Q:A:2C . 2
Eric Ferrebee, P.E.
Senior Director of Technical Services
eferrebee@acpa.org | 847.423.8709
Thank you!
ACPA