# Why Incorporating Sustainability and Resiliency into Your Design is the Right Decision

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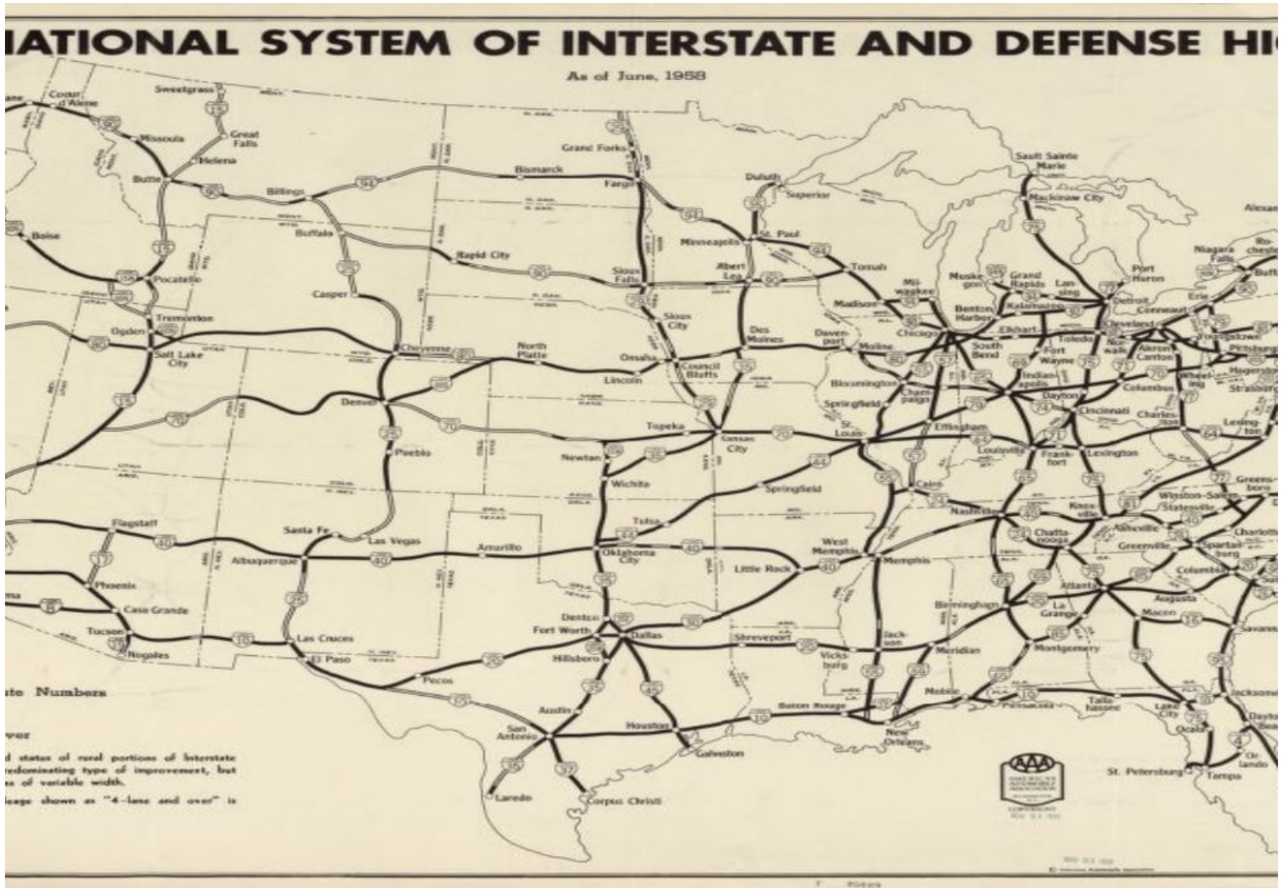
# Setting the Stage

Imagine a world without infrastructure:

- Transportation
  - Sustenance
  - Shelter
  - Expertise
- Energy

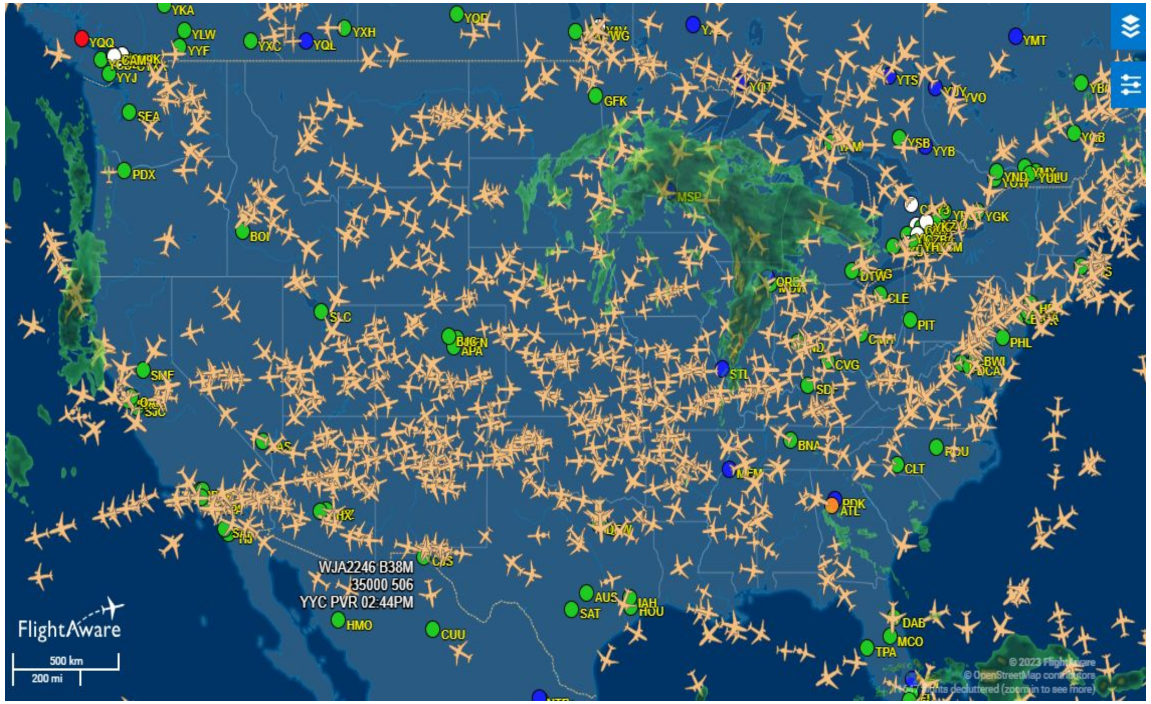
# Setting the Stage

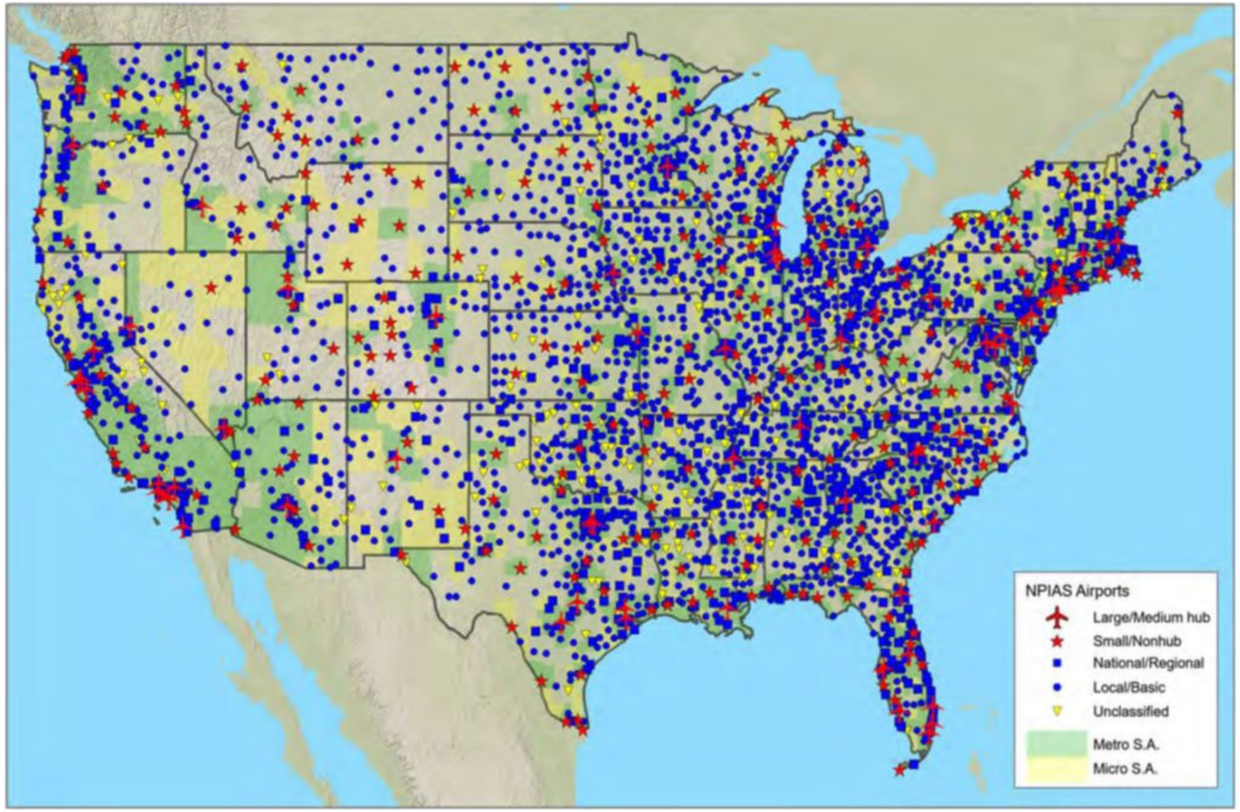
- Transportation effects are non-trivial

# Setting the Stage

- Transportation effects are non-trivial



# Setting the Stage

- Imagine infrastructure without concrete

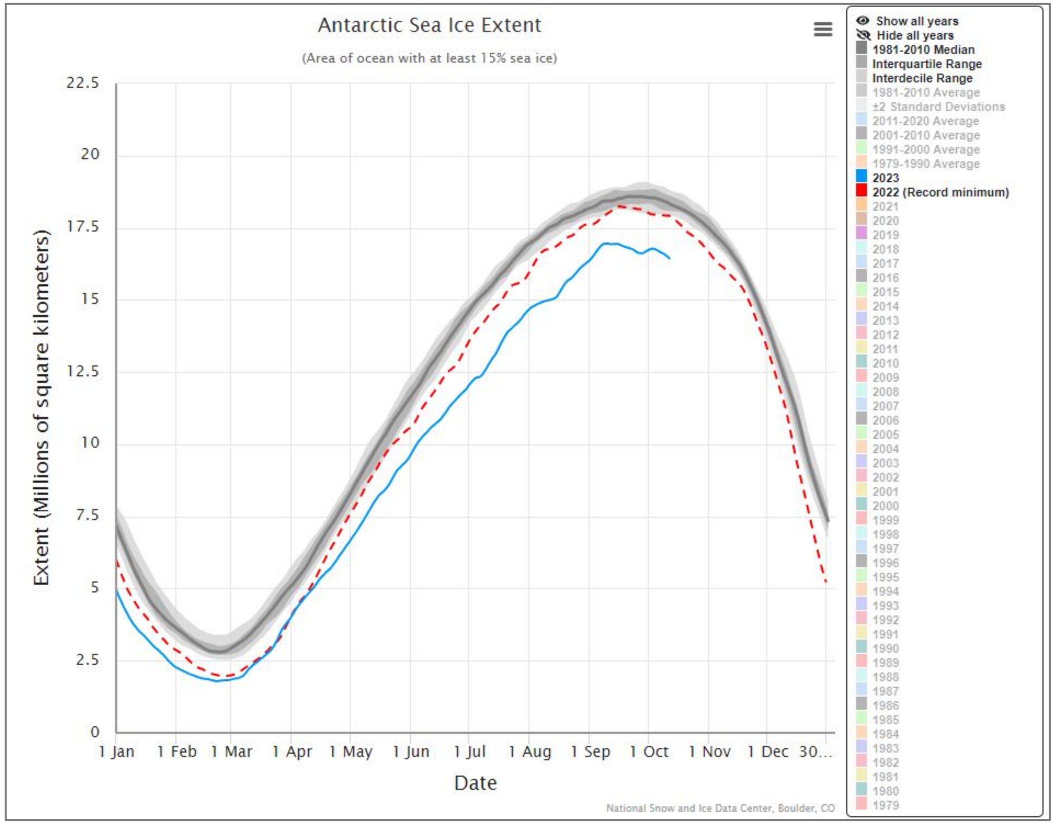


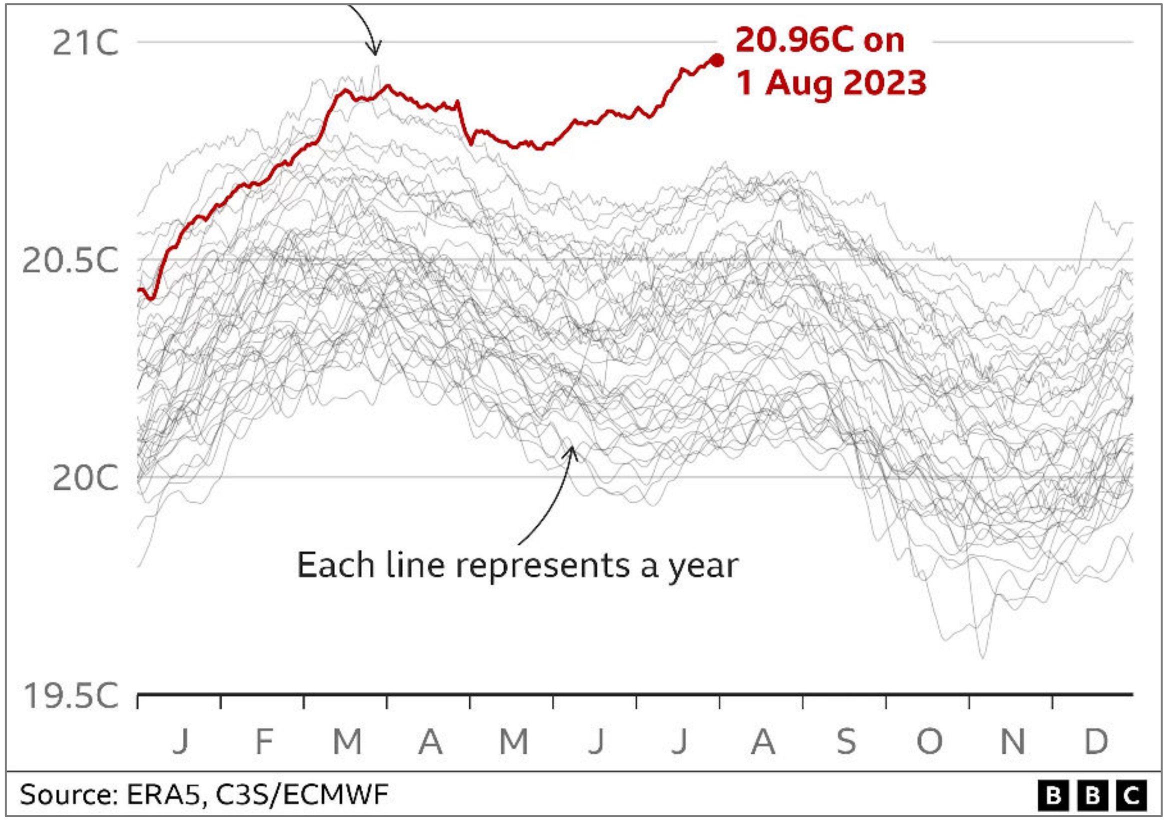
Source unknown

# Setting the Stage

## So lets keep building!

- But…





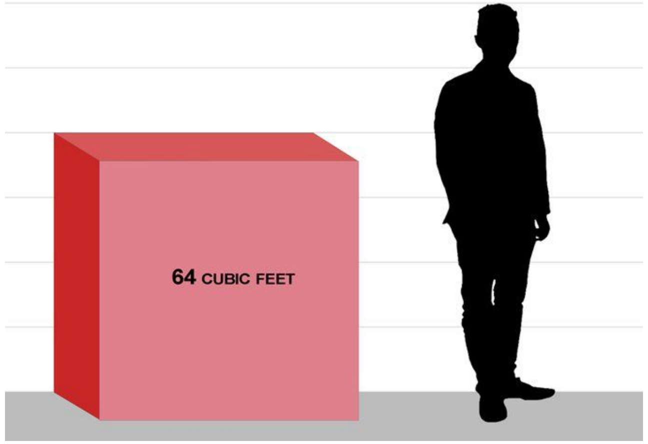

National Snow and Ice Data Center

BBC 2023

# Why Sustainability?

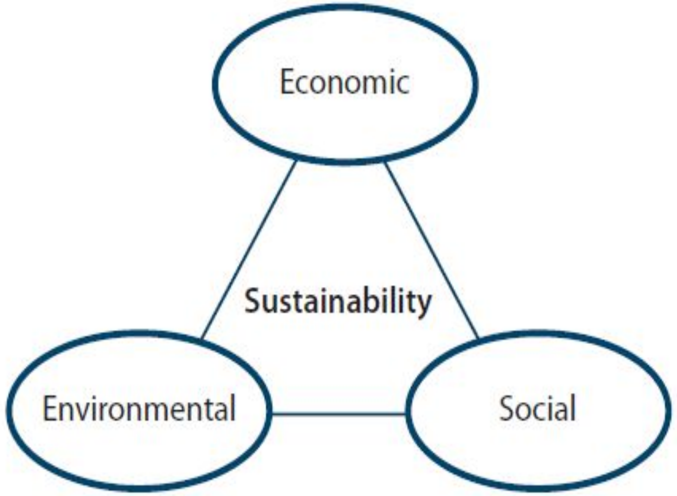
- 30 billion tons of concrete is used each year worldwide
- ~¼ ton $CO_2$ per person per year

We need a lot of concrete
So the impact is high



# Sustainability?

- Economics still rule
- Learning about social impacts
- Carbon
  - Concrete production creates a lot of carbon
  - Federal Government is pressing to reduce the impact
    - At construction
    - Over its life



# Industry Response



9

# Who Me?

- Change is hard – but possible

# Where Does the Carbon Come From

- Heating the kiln
  - Can and has been reduced
- Decomposing limestone rock
  - Must be balanced

- Traffic
  - Good design
  - Good construction
  - Cut carbon by ½

# How?

- What can we do to reduce impact?
  - Use less concrete
  - Use less binder in the concrete
  - Use less clinker in the binder
  - Reduce construction impacts
  - Reduce user impacts

# Use Less Concrete in the Structure

- Avoid replacing it
  - Longer lasting
  - Use existing equity of older pavements (overlays)

- More efficient designs
  - Beware of rules of thumb, and cut-and-paste

# Use Less Binder in the Concrete

- Many specifications call for more than needed

| | Conventional | Optimized |
|---|---|---|
| Cement | 400 | 351 |
| SCM 1 | 170 | 150 |
| SCM 2 | 0 | 0 |
| Coarse Agg | 457 | 662 |
| Fine Agg | 1171 | 1303 |
| Intermediate 1 | 1167 | 954 |
| Intermediate 2 | 244 | 254 |
| Water | 228 | 200 |
| Air | 7.0 | 7.0 |
| Total | 3837 | 3874 |
| Cementitious | 570 | 501 |
| vp/vv | 208 | 180 |
| w/cm | 0.40 | 0.40 |
| % SCM 1 | 30 | 30 |

| | Conventional | Optimized |
|---|---|---|
| Slump | 2.0 | 2.0 |
| HRWRA | 2.0 | 2.3 |
| Air content | 6.8 | 7.0 |
| Box | 1 - 0 | 1 - 0 |
| Initial set | 6:27 | 6:12 |
| Strength at 7 | 3,340 | 3,650 |

# Use Less Cement in the Binder

- Supplementary cementitious materials
  - Enhance performance
  - Increase longevity
  - Reduce disposal headaches

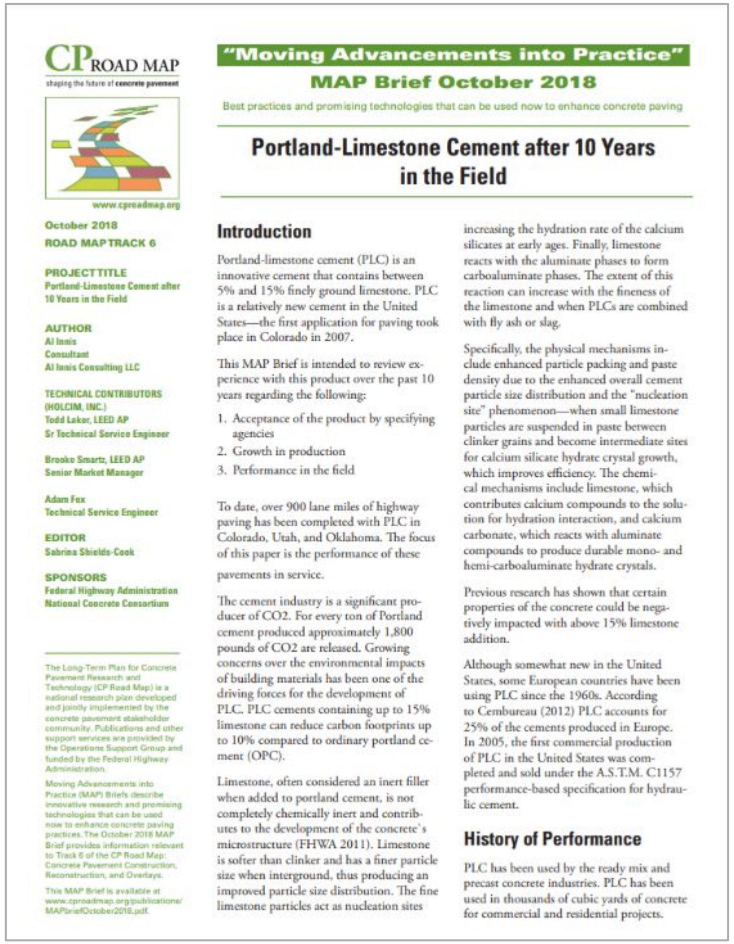
- Ternary combinations
- Harvested fly ash

# Use Less Cement in the Binder

- Other SCMs
  - Recycled Ground Glass, ASTM C1866
  - Locally processed waste products ASTM C 1709

# Use Less Cement in the Binder

- Portland Limestone Cements
  - Up to 15% ground limestone
  - Similar performance
  - Becoming the norm
- Non-portland cements
  - Geopolymer cements / Activated fly ashes
  - Calcium sulfo-alumina-cements



CP ROAD MAP
shaping the future of concrete pavement

www.cproadmap.org

October 2018
ROAD MAP TRACK 6

PROJECT TITLE
Portland-Limestone Cement after 10 Years in the Field

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The Long-Term Plan for Concrete Pavement Research and Technology (CP Road Map) is a national research plan developed and jointly implemented by the concrete pavement stakeholder community. Publications and other support services are provided by the Operations Support Group and funded by the Federal Highway Administration.

Moving Advancements into Practice (MAP) Briefs describe innovative research and promising technologies that can be used now to enhance concrete paving practices. The October 2018 MAP Brief provides information relevant to Track 6 of the CP Road Map: Concrete Pavement Construction, Reconstruction, and Overlays.

This MAP Brief is available at www.cproadmap.org/publications/MAPbriefOctober2018.pdf.

"Moving Advancements into Practice"

MAP Brief October 2018

Best practices and promising technologies that can be used now to enhance concrete paving

## Portland-Limestone Cement after 10 Years in the Field

### Introduction

Portland-limestone cement (PLC) is an innovative cement that contains between 5% and 15% finely ground limestone. PLC is a relatively new cement in the United States—the first application for paving took place in Colorado in 2007.

This MAP Brief is intended to review experience with this product over the past 10 years regarding the following:

1. Acceptance of the product by specifying agencies
2. Growth in production
3. Performance in the field

To date, over 900 lane miles of highway paving has been completed with PLC in Colorado, Utah, and Oklahoma. The focus of this paper is the performance of these pavements in service.

The cement industry is a significant producer of CO2. For every ton of Portland cement produced approximately 1,800 pounds of CO2 are released. Growing concerns over the environmental impacts of building materials has been one of the driving forces for the development of PLC. PLC cements containing up to 15% limestone can reduce carbon footprints up to 10% compared to ordinary portland cement (OPC).

Limestone, often considered an inert filler when added to portland cement, is not completely chemically inert and contributes to the development of the concrete's microstructure (FHWA 2011). Limestone is softer than clinker and has a finer particle size when interground, thus producing an improved particle size distribution. The fine limestone particles act as nucleation sites increasing the hydration rate of the calcium silicates at early ages. Finally, limestone reacts with the aluminate phases to form carboaluminate phases. The extent of this reaction can increase with the fineness of the limestone and when PLCs are combined with fly ash or slag.

Specifically, the physical mechanisms include enhanced particle packing and paste density due to the enhanced overall cement particle size distribution and the "nucleation site" phenomenon—when small limestone particles are suspended in paste between clinker grains and become intermediate sites for calcium silicate hydrate crystal growth, which improves efficiency. The chemical mechanisms include limestone, which contributes calcium compounds to the solution for hydration interaction, and calcium carbonate, which reacts with aluminate compounds to produce durable mono- and hemi-carboaluminate hydrate crystals.

Previous research has shown that certain properties of the concrete could be negatively impacted with above 15% limestone addition.

Although somewhat new in the United States, some European countries have been using PLC since the 1960s. According to Cembureau (2012) PLC accounts for 25% of the cements produced in Europe. In 2005, the first commercial production of PLC in the United States was completed and sold under the A.S.T.M. C1157 performance-based specification for hydraulic cement.

### History of Performance

PLC has been used by the ready mix and precast concrete industries. PLC has been used in thousands of cubic yards of concrete for commercial and residential projects.

# Use Low-Carbon Cements

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

# Put the Carbon Back!

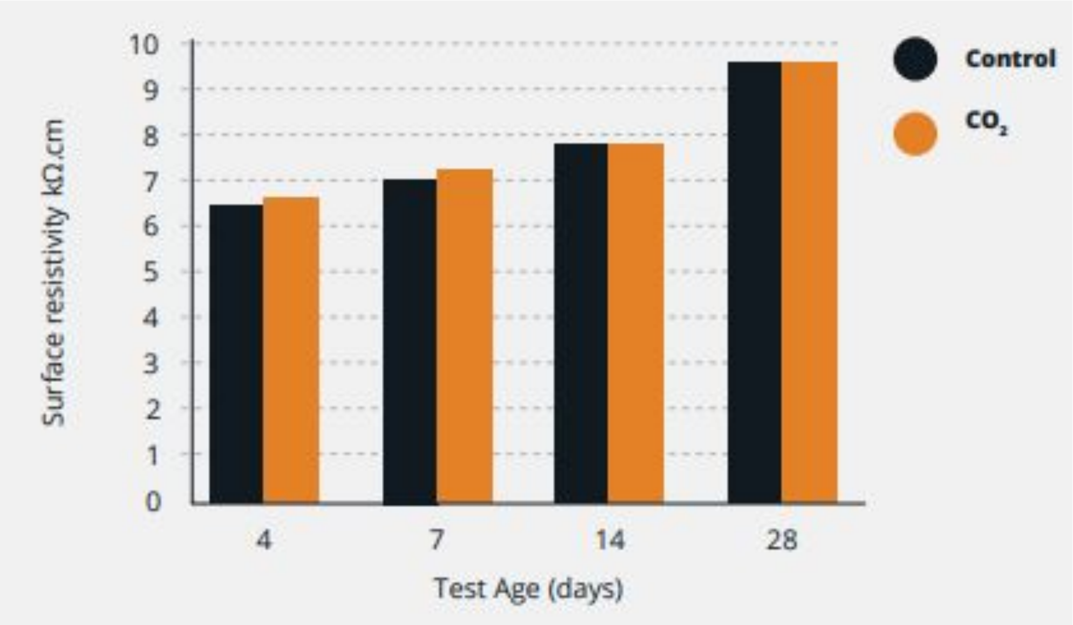
Natural carbonation

- Slow
- Dependent on environment
- Can compromise steel protection

- Can be accelerated with grinding

# Put the Carbon Back!

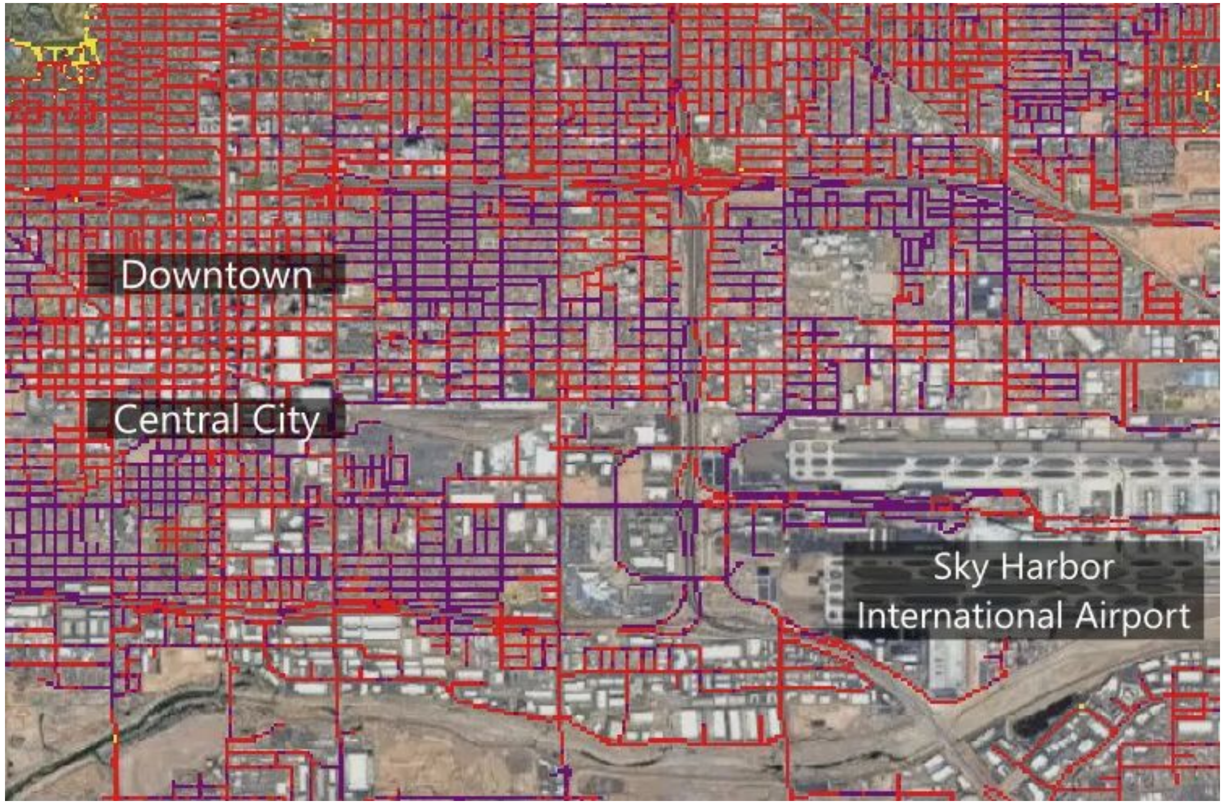
- Inject carbon dioxide into concrete in the mixer
- $CO_2$ is mineralized then converts to solid $CaCO_3$
- Reported to improve permeability



# Other Factors

- Recycled Concrete Aggregate
- Albedo (heat island)

“Surprisingly, the hottest land surface temperature within Phoenix was recorded not on a street or sidewalk but at Sky Harbor International Airport, where it reached a scorching 140°F (60°C)”.




- Resilience

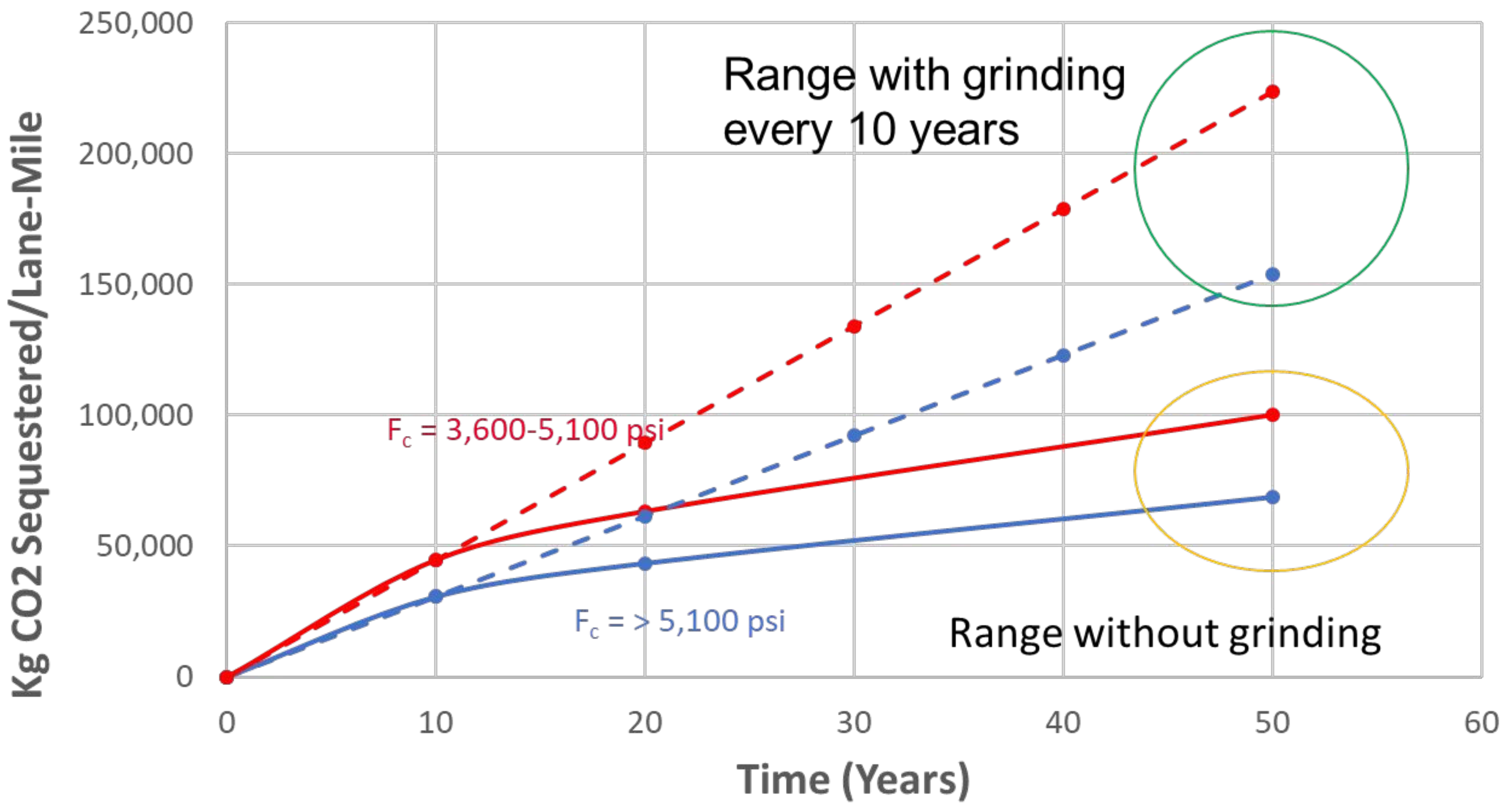
# Construction

- Haul distance
- Disturbance
  - Noise
  - Dust
  - Access

# Preservation - Concrete overlays

- Existing pavements get old and tired
  - We can toss them out and start again
  - We can patch them
  - We can overlay them

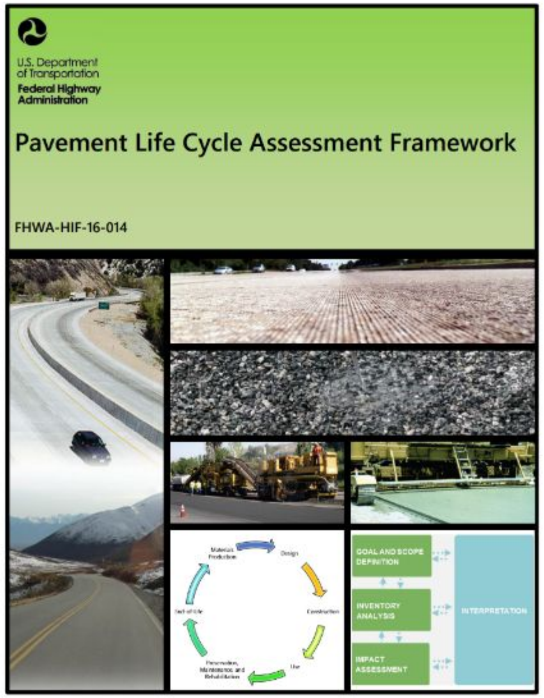
# Reducing Use Phase Impacts – With Preservation

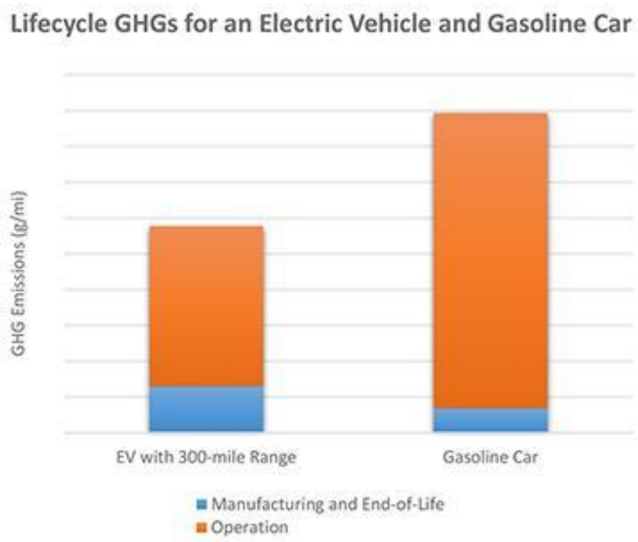



Additional Diamond Grinding also improves vehicle fuel efficiency due to improved smoothness and increases Albedo resulting in even greater GHG reductions

# Measurement

- Life-cycle assessment (LCA)







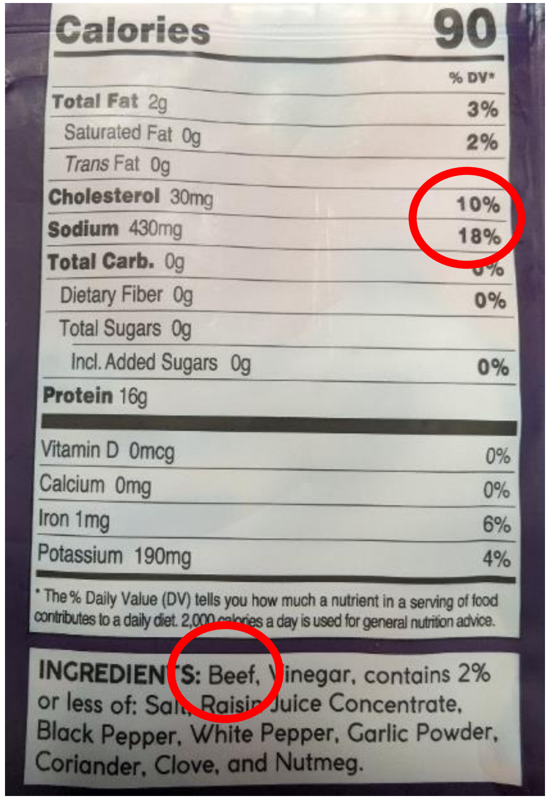
https://www.epa.gov/greenvehicles/electric-vehicle-myths#Myth5

# Measurement

- EPDs are coming

**Table 8a. Summary Results (A1-A3): 3001-4000 psi (20.7-27.6 MPa) RMC product mix design, per cubic meter**

| | | Minimum | Maximum | 3001-4000-00-FA/SL | 3001-4000-20-FA | 3001-4000-30-FA | 3001-4000-40-FA | 3001-4000-30-SL | 3001-4000-40-SL | 3001-4000-50-SL | 6001-8000-50-FA/SL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ***Core Mandatory Impact Indicators*** | | | | | | | | | | | |
| GWP | kg $CO_2e$ | 261.19 | 426.75 | 426.75 | 365.48 | 332.37 | 297.41 | 327.67 | 294.65 | 261.62 | 261.19 |
| ODP | kg CFC11e | 7.84E-06 | 1.11E-05 | 1.11E-05 | 9.56E-06 | 8.73E-06 | 7.84E-06 | 1.01E-05 | 9.75E-06 | 9.41E-06 | 8.49E-06 |
| AP | kg $SO_2e$ | 0.99 | 1.33 | 1.33 | 1.17 | 1.08 | 0.99 | 1.28 | 1.26 | 1.25 | 1.12 |
| EP | kg Ne | 0.37 | 0.55 | 0.55 | 0.48 | 0.44 | 0.40 | 0.45 | 0.41 | 0.38 | 0.37 |
| POCP | kg $O_3e$ | 21.38 | 28.22 | 28.22 | 24.98 | 23.23 | 21.38 | 25.58 | 24.70 | 23.82 | 22.20 |
| ADPf | MJ, NCV | 1,522.19 | 2,229.70 | 2,229.70 | 1,921.20 | 1,754.51 | 1,578.49 | 1,850.63 | 1,724.28 | 1,597.92 | 1,522.19 |
| ADPe | kg Sbe | 2.44E-04 | 3.69E-04 | 3.69E-04 | 3.25E-04 | 3.02E-04 | 2.77E-04 | 2.94E-04 | 2.69E-04 | 2.44E-04 | 2.46E-04 |
| FFD | MJ Surplus | 143.16 | 180.58 | 180.58 | 162.85 | 153.28 | 143.16 | 172.58 | 169.91 | 167.24 | 154.43 |



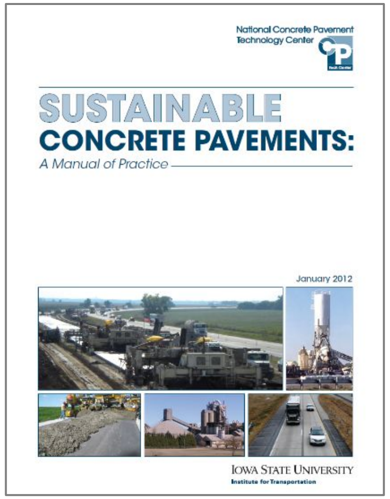
# In Summary

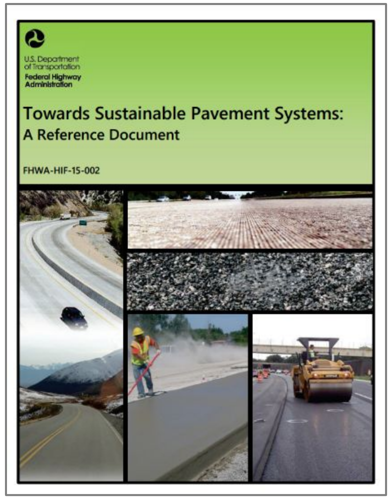
| | Measurable | Phase | Impact | Who | Side effect | Cost | When |
|---|---|---|---|---|---|---|---|
| **Efficient designs** | Yes | Construction | Point of delivery | Agencies | None | Reduced | Now |
| **Reduce cement content** | EPD | Construction | Point of delivery | All | None | Reduced | Now |
| **PLC** | EPD | Construction | Point of delivery | All | None | Reduced | Now |
| **Cement footprint** | EPD | Construction | Point of delivery | Cement | None | Reduced | Later |
| **Increased SCM** | EPD | Construction | Point of delivery | All | None | Reduced | Now |
| **Carbon injection** | ?? | Construction | Point of delivery | All | None | - | Now |
| **Non-portland** | EPD | Construction | Point of delivery | All | Cost | Increased | Later |
| **Construction practices** | Yes | Construction | Point of delivery | Contractor | None | Reduced | Now |
| **Recycling** | Yes | Construction | Point of delivery | All | Reduced disposal | Reduced | Now |
| **Smoothness** | Yes | Use phase | Reduces others' footprint | Contractor | Improved safety | Reduced | Now |
| **Albedo** | Yes | Use phase | Reduces others' footprint | Agencies | Cooler city | Reduced | Now |
| **Lighting** | Yes | Use phase | Reduces others' footprint | Agencies | Improved safety | Reduced | Now |
| **Long life** | Yes | Use phase | Later | Agencies | Improved safety | Reduced | Now |
| **Carbonation** | Yes | Use phase | Later | All | None | - | Later |
| **Sequestration** | Yes | Use phase | Later | All | None | Increased | Later |

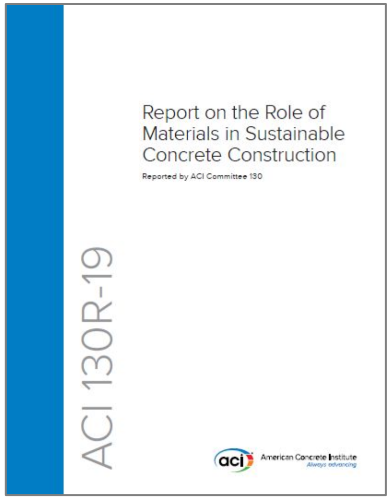
# In Summary—Why Incorporating Sustainability and Residency in into Your Design is the Right Decision

- This is not new
- Can save money
- Improve Performance
- Increase Longevity
- The RIGHT thing

Is this really a zero-emission vehicle?



# Where next?

- Keep encouraging the community to adopt change
  - Prepare for EPDs
- Keep working on:
  - Alternative materials
  - Developing the tools to quantify concrete in the field
  - Building long lasting / low impact pavements

# So…

- Some things we can change now
  - Make better concrete
  - Make better pavements
  - Reduce our carbon footprint
- Others will take time

**The Difficult We Do Immediately. The Impossible Takes a Little Longer**



Charles Alexandre de Calonne, 1794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