More Sustainable Concrete Pavements

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Setting the Stage

What do humans need:

- Sustenance
- Shelter
- Help
- Hope

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Setting the Stage

Imagine a world without infrastructure:

- Transportation
- Energy
- Expertise

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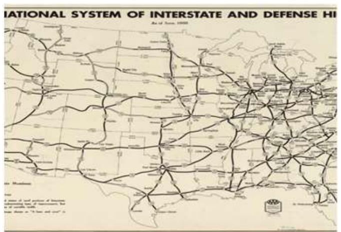
Setting the Stage

- Transportation effects are non-trivial



4 Python Maps Library of Congress

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Setting the Stage

- Imagine a world without concrete
  - Buildings
  - Services
  - Transportation

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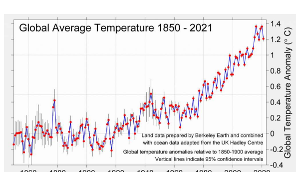
Setting the Stage

So lets keep building!

- But…



6 Berkeley Earth

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Setting the Stage

We use a lot of concrete
- Concrete impacts the environment
- Changes in environment affect infrastructure needs

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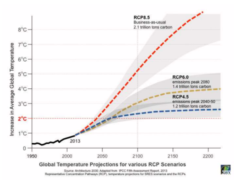
Setting the Stage

The conundrum then is: how do we deliver/maintain the infrastructure without hurting the planet?



 https://architecture2030.org/ipcc_analysis/

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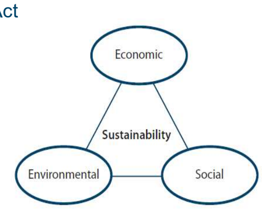
Setting the Stage

A Balancing Act



 BBC

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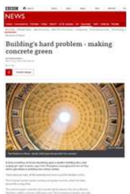
Setting the Stage

- Measurement
- Economics still rule
- It's more than carbon
- but…


NEWS

Building's hard problem - making concrete green

Impact category and inventory indicators
Global warming potential, GWP 100, IPCC 2013
Ozone depletion potential, ODP
Acidification potential, AP
Eutrophication potential, EP
Smog formation potential, SFP
Abiotic depletion potential for non-fossil mineral resources, ADP elements*
Abiotic depletion potential for fossil resources, ADP fossil*
Renewable primary resources used as an energy carrier (fuel), RPR_E*
Renewable primary resources with energy content used as material, RPR_M*
Non-renewable primary resources used as an energy carrier (fuel), $NRPR_E$*
Non-renewable primary resources with energy content used as material, $NRPR_M$*
Secondary materials, SM*
Renewable secondary fuels, RSF*
Non-renewable secondary fuels, NRSF*
Net use of freshwater, NFW*
Hazardous waste disposed, HWD*
Non-hazardous waste disposed, NHWD*
High-level radioactive waste, conditioned, to final repository, HLRW*
Intermediate- and low-level radioactive waste, conditioned, to final repository, ILLRW*
Components for re-use, CRU*
Materials for recycling, MFR*
Materials for energy recovery, MER*
Recovered energy exported from the product system, EE*
Additional Inventory Parameters for Transparency
Global warming potential - biogenic, GWP_{bio}*

10 BBC PCA

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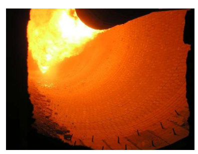
Where Does the Carbon Come From

- Heat! (about 40%)
  - Cement ingredients heated to ~1400ºC
  - Heat exchangers improve efficiency
  - Alternative fuels



- Chemistry (the rest)
  - $CaCO_3 \rightarrow CaO + CO_2$
  - CaO + other stuff → portland cement
  - Can we use alternative calcium sources?
- Most of the CO_2 footprint is tied to the cementitious system

11 The Cement Institute

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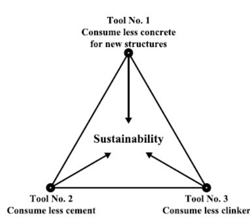
Materials

What can we do?

- Use less concrete
- Use less binder in the concrete
- Use less clinker in the binder



12 Mehta, CI Feb. 2009

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Use Less Concrete in the Structure

- More efficient designs
  - Beware of rules of thumb, and cut-and-paste
  - ME-Design procedure
  - Appropriate construction systems
- Avoid replacing it
  - Longer lasting
  - Use existing equity of older pavements (overlays)

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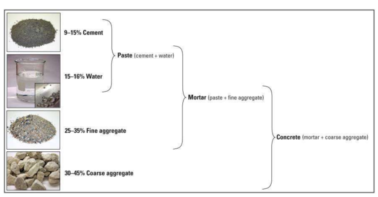
Use Less Binder in the Concrete

- Cementitious binder is about 9-15% by mass of concrete
- Many specifications call out a minimum
  - That may be more than needed



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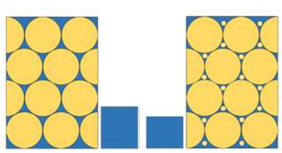
Use Less Binder in the Concrete

- Minimum required is defined by
  - Enough paste to fill the gaps between the aggregate, plus a bit
  - Aggregate gradation
  - Workability
- Excess can be deleterious
- Performance Engineered Mixtures
  - Some states are reporting cutting binder contents by 30%



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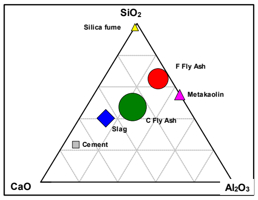
Use Less Cement in the Binder

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

  - What about their carbon footprint?



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Use Less Cement in the Binder

- Supplementary cementitious materials
  - Availability locally?
  - Harvested fly ash


TECH BRIEF

Advancing Concrete Pavement Technology Solutions

USE OF HARVESTED FLY ASH IN HIGHWAY INFRASTRUCTURE

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Use Less Cement in the Binder

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

  - Cost of testing compared with value of product

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Use Less Cement in the Binder

- Portland Limestone Cements
  - Up to 15% ground limestone
  - Similar performance
  - Becoming the norm

CP ROAD MAP

"Moving Advancements into Practice"

MAP Brief October 2018

Portland-Limestone Cement after 10 Years in the Field

Introduction

History of Performance

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Reduce Carbon Footprint of Cement

- PCA has a plan…

PRODUCTION: AT THE CEMENT PLANT	
Replace raw materials with decarbonated materials	Using decarbonated materials eliminates CO_2 emissions from processing traditional raw materials, like limestone.
Use alternative fuels	Replacing traditional fossil fuels with biomass and waste-derived fuels lowers greenhouse gas (GHG) emissions and keeps materials out of landfills.
Continue efficiency improvements	Increasing energy efficiency reduces the amount of CO_2 emitted for each ton of product.
Implement carbon capture, utilization, and storage (CCUS) technology	CCUS directly avoids a significant portion of cement manufacturing emissions.
Promote new cement mixes	Creating new cements using existing and even alternative materials reduces emissions from mining for new materials, while optimizing the amount of clinker used ensures emissions correspond to necessary production.
Increase use of portland-limestone cement (PLC)	As an existing lower-carbon blend, universal acceptance of PLC will reduce clinker consumption and decrease emissions.
CONSTRUCTION: DESIGNING AND BUILDING	
Optimize concrete mixes	Considering the specific needs of the construction project and using only the materials necessary, avoiding excess emissions.
Use renewable fuels	Switching to solar, wind and other renewable sources of energy directly reduces emissions from other energy sources.
Increase the use of recycled materials	Diverting these materials from landfills.
Avoid overdesign and leverage construction technologies	Designing for the specific needs of the construction project reduces unnecessary overproduction and emissions, incorporating just-in-time deliveries.
Educate design and construction community	Improve design and specifications to be more performance oriented which will permit innovation in cement and concrete manufacturing. Encourage the use of advanced technologies to improve structural performance, energy efficiency, resiliency, and carbon sequestration.
EVERYDAY: CONCRETE INFRASTRUCTURE IN USE	
Incentivize energy efficient buildings	Increasing buildings' energy efficiency can cut energy use and resulting emissions from heating and cooling.
Reduce vehicle emissions by improving fuel efficiency	Because of its rigidity, concrete pavements enhance the fuel efficiency of vehicles driving over them, reducing vehicle emissions.
Decreased maintenance	Due to their durability, concrete structures (buildings, pavements, bridges, dams, etc.) last longer and require less frequent maintenance.
Recycling	Concrete in place can be 100% recycled, limiting the use of raw materials and production emissions.
Carbonation	Every exposed concrete surface absorbs CO_2 and over the course of its service life, a building can reabsorb 10% of cement and concrete production emissions.

20 PCA

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Use Low-Carbon Cements

- Geopolymer cements / Activated fly ashes
- Calcium sulfo-alumina-cements
- Belite cements
- Other chemistries
- Balancing availability, cost, constructability and longevity…

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Use Low-Carbon Cements

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

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Other Actions

- Recycled Concrete
  - Reduces need for virgin materials
  - Eliminates disposal needs
  - Foundation or in the concrete?
    - Depends on quality needs
  - About 140 Million Tons recycled annually

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Recycled Concrete Aggregate

Technical products developed:
- How to engineer RCA applications
- Use RCA in most advantageous way

Coming soon
- Construction by-products
- RCA in pavement mixtures
- Industrial by-products

24 Cavalline

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Put the Carbon Back!

Natural carbonation
- Slow
- Dependent on environment
- Can compromise steel protection

- Can be accelerated with grinding

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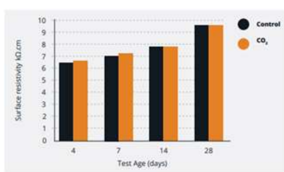
Put the Carbon Back!

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



CarbonCure

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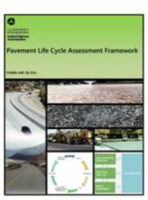
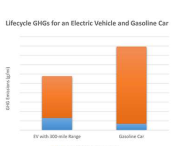
Measurement

- Life-cycle assessment (LCA)





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

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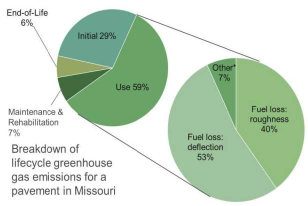
Use Phase

- Fuel consumption
- Care and keeping



Breakdown of lifecycle greenhouse gas emissions for a pavement in Missouri

*Other: carbonation & lighting

28 MIT CSHub

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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

29 NRMCA

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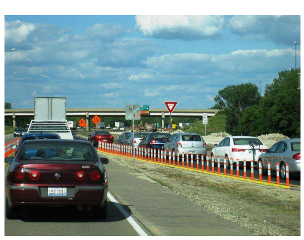
Construction

- Haul distance
- Disturbance
  - Noise
  - Dust
  - Access
- Delays
  - Traffic
  - Safety



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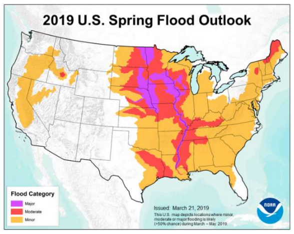
Other Factors

- Resilience
- Albedo (heat island)
- Lighting (& light pollution)
- TiO2



NOAA

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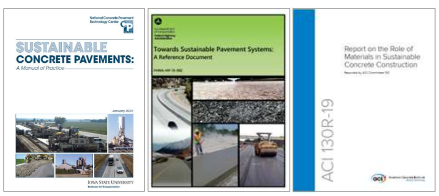
So

- This is not new



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So

- Change is inevitable
- Some change has happened
- Incremental change will help - Is that enough?
- What next?

Strijdom van der Merwe

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