

## Increasing Concrete Sustainability while Improving Durability




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Did you know?

## Concrete is the world's most consumed resource after water.

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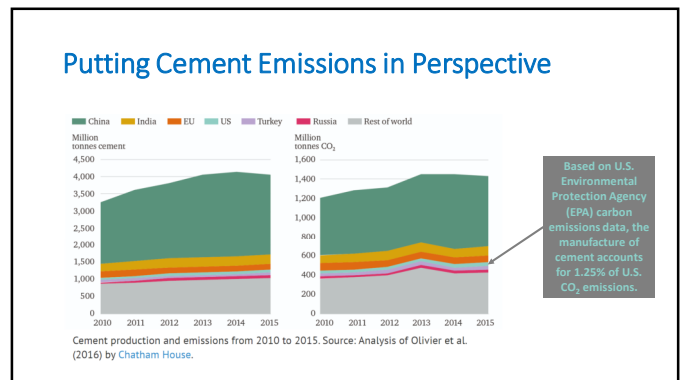
### Attention-Grabbing Headlines

The massive CO2 emitter you may not know about

## Concrete: the most destructive material on Earth

If the cement industry were a country, it would be the third largest emitter in the world - behind China and the US.

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### Stages of Opportunities for Reducing GHG Emissions & Increasing Sustainability

- Before Construction
- During Construction
- After Construction

**CLINKER**  
Key chemically reactive ingredient

**CEMENT**  
The binder

**CONCRETE**  
Critically useful material to society

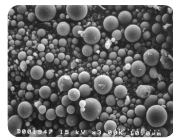
**CONSTRUCTION**  
Service life / use phase impacts

**CARBONATION**  
Concrete is a CO<sub>2</sub> sink


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### Opportunities Before Construction

- Pavement Design
- Materials Selection and Mixture Design Specifications
- Aggregates
  - Multiple gradations
  - Recycled concrete
- Cementitious Materials
  - Portland Limestone Cement (PLC), or Type II
  - Supplementary cementitious materials



*Most common target of discussion based on cement's reputation as a large producer of greenhouse gas emissions*





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## Design for Longevity

ACPA Special Report on Green Roadways...  
Emphasizes **longevity** as the primary opportunity


**Longevity means...**  
Less frequent reconstruction

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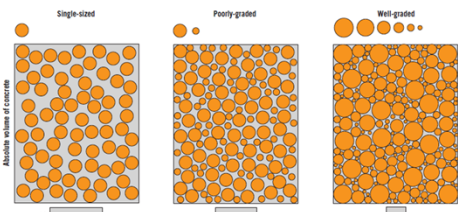

## Concrete Mix Specifications: Use Performance Engineered Mixtures (PEM)

- Optimized gradations – reduces paste content (and cement)
- Recycled concrete
  - Aggregate in new concrete
  - Base material
- Allow for Portland Limestone Cement (PLC) – aka Type II
- Require use of supplementary cementitious materials
  - Fly ash – byproduct of coal fired power production
  - Slag cement – byproduct of steel production



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## Optimized Gradations

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## Recycled Concrete Aggregate (RCA)




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## Recycled Aggregate Base



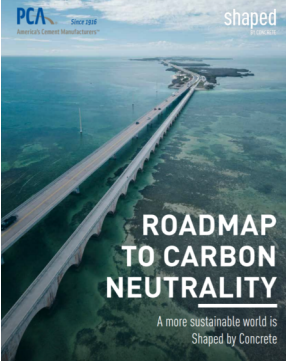

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## Cement Industry Efforts

**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 CO<sub>2</sub> emissions
- Reduce clinker production emissions

Source: ShapedByConcrete.com




ROADMAP TO CARBON NEUTRALITY  
A more sustainable world is Shaped by Concrete

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### Why Portland Limestone Cement (PLC)?

- Producing PLC reduces amount of cement clinker needed per ton
  - Reduces carbon footprint of cement/concrete
  - Every 10 tons of PLC produced reduces CO<sub>2</sub> emissions by approximately 1 ton compared to OPC
  - Reduces the amount of energy required per ton of cement
- Producing PLC increases cement plant capacity
  - Varies from plant to plant depending on clinker capacity vs. mill capacity
- Designed to perform the same as Ordinary Portland Cement (OPC)
  - Water demand may be slightly higher due to fineness
  - Early strengths may be higher
  - Set time should be equal
  - Color is slightly lighter




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### Opportunities During Construction



- Locally available materials (including recycled concrete)
- Mobile batch plants





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### Opportunities During Construction

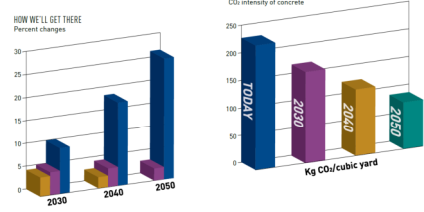
Accelerated construction to reduce **congestion**

- Concrete mixtures for particular situations
- Nondestructive testing
- Optimize phasing

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### Optimizing Concrete: Pushing Performance



**HOW WE'LL GET THERE**  
Percent changes


Year	Reduced mfr. CO <sub>2</sub>	Reduced transport. CO <sub>2</sub>	Improvements in mix design
2030	~5%	~10%	~15%
2040	~10%	~15%	~20%
2050	~15%	~20%	~25%

**THE RESULTS**  
CO<sub>2</sub> intensity of concrete

Year	Kg CO <sub>2</sub> /cubic yard
TODAY	~230
2030	~180
2040	~130
2050	~80

Optimized concrete: Efficient manufacturing and transportation, zero waste, optimized mixtures engineered for peak performance

Source: PCA's Roadmap to Carbon Neutrality




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### Opportunities After Construction

Everyone knows that making cement produces CO<sub>2</sub>. But did you know that **concrete reabsorbs a significant amount of that CO<sub>2</sub> over its lifetime** in a process known as **carbon uptake** or **recarbonation**?

- Recarbonation is a natural process: concrete reacts with CO<sub>2</sub> in the air
- Maximum amount of CO<sub>2</sub> that concrete can reabsorb = amount emitted during calcination of limestone in cement manufacturing process
- Practical estimate of global carbon sink provided by all concrete = 25% of process CO<sub>2</sub> emissions released during cement production

Source: gccassociation.org/carbon-uptake/





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### Opportunities After Construction

Pavement preservation/restoration

- Objective: extend the life of the pavement
- Minimize disruption and maximize resource efficiency
- Negligible resource extraction
- Often utilize numerous techniques





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### Opportunities After Construction

Diamond grinding

- Often combined with other CPR procedures
- Expected life of 14-17 years (Caltrans Study)
- Option for multiple grinding cycles
- Improved smoothness
- Improved texture
- Reduced noise



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### Opportunities After Construction

Concrete overlays as preservation

- Resource efficient
- Eliminate disposal
- Cost effective
- Quick to construct
- Long life



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### Sustainability and Concrete Roadways...


Are we missing significant opportunities?

**YES!**

Opportunities are missed by ignoring the operational or use-phase of the pavement!

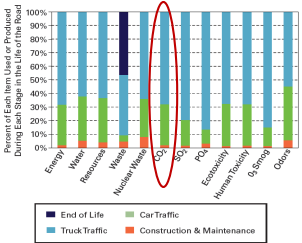
**All the commonly adopted sustainability strategies are important and should be embraced!**

...though, it is useful to know where we can be most impactful.




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### Where can we be most impactful?

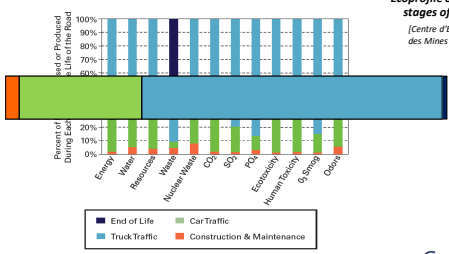


- For high volume applications, the Use Phase can dominate ALL other phases of the roadway life cycle.
- From energy perspective... construction and maintenance accounts for less than 2% of the entire energy footprint. (EAPA 2004)
- A 2-3% improvement in the truck/car portion of the ecoprofile could offset the entire construction and maintenance ecoprofile.




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### What should we be doing?

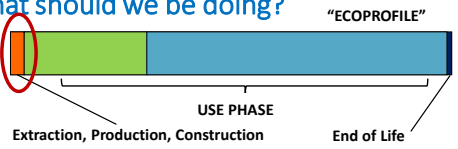


**Ecoprofile of different life cycle stages of a typical road.**  
(Centre d'Energetique de l'Ecole des Mines de Paris)




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### What should we be doing?



**Where do typical "sustainable practices" fit in this ecoprofile?**

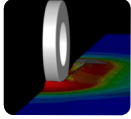

**Recycled Concrete Aggregate, SCMs, Reduced Cement, etc.**



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### What are these use/operational phase impacts?


- Pavement-Vehicle Interaction (PVI)**
  - Excess emissions by vehicles using the pavement due to excess rolling resistance between the pavement & vehicle
  - Increases fuel usage
- Pavement surface reflectivity - Albedo**
  - Urban heat island mitigation
  - Visibility
  - Nighttime lighting needs





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### Pavement Vehicle Interaction (PVI)

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**ROUGHNESS:** whether the road is bumpy or smooth. Roughness, commonly seen and felt as the presence of cracks and potholes, has a significant impact on passenger vehicles.
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**TEXTURE:** the abrasiveness of the road surface, which relates to vehicle traction when the surface is wet.
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**DEFLECTION:** the bending of a pavement under the weight of a vehicle. Deflection is present from the initial construction, and depends on pavement design. Think of the difference between walking or riding on sand versus a paved surface.

**The amount of fuel used is impacted by the quality of the roads we drive on.**


CSHub studies suggest that excess fuel consumption can be significantly reduced by building stiffer roads and maintaining smoother pavements.



Source: MIT Concrete Sustainability Hub - CSHUB.MIT.EDU/PAVEMENTS/PVI

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### Albedo



**As global temperatures increase, reducing heat on roadways and in cities can help to lower emissions that contribute to climate change, and to improve quality of life.**

Albedo is the measure of solar energy reflected by the Earth's surface. Lighter colored surfaces reflect more light, and have a higher albedo. Darker surfaces absorb light and have a lower albedo. Surfaces that absorb heat keep temperatures elevated longer, releasing heat that keeps nearby areas hot even long after the sun has set.

**Tackling "Urban Heat Islands" through higher pavement albedo**

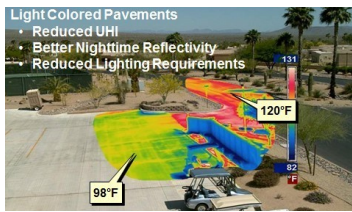
Increasing pavement albedo in urban areas helps fight urban heat island (UHI) effects that can noticeably decrease our quality of life. When pavement albedo is increased, lower urban temperatures and fewer extreme heat days and heat waves can result. UHI events have been directly tied to increased mortality in urban areas.

**How is albedo measured?**  
Albedo is a ratio expressed on a scale from 0 to 1. A surface with an albedo of 0 would be impossibly dark, taking in 100% of solar energy. A surface with an albedo of 1 would be completely reflective.

Source: MIT Concrete Sustainability Hub - CSHUB.MIT.EDU/PAVEMENTS/ALBEDO

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### Albedo of Average Surfaces




- Concrete  $\approx$  0.40 (new) to 0.2 (old)
- Asphalt  $\approx$  0.05 (new) to 0.15 (old)
- Earth Avg  $\approx$  0.3 to 0.35 (impacted by cloud cover)

Light Colored Pavements



- Reduced UHI
- Better Nighttime Reflectivity
- Reduced Lighting Requirements

120°F, 98°F, 82°F



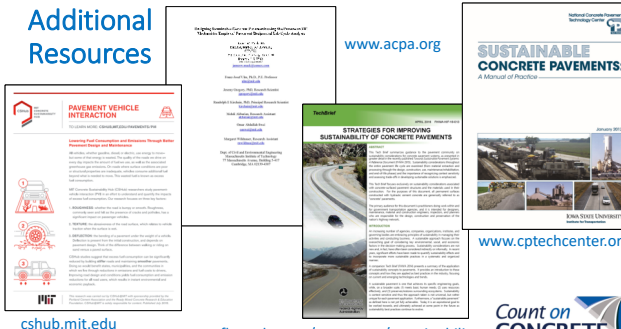
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### Albedo & Safety

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### Additional Resources




[www.acpa.org](http://www.acpa.org)

[www.cptechcenter.org](http://www.cptechcenter.org)

[www.fhwa.dot.gov/pavement/sustainability](http://www.fhwa.dot.gov/pavement/sustainability)

[cshub.mit.edu](http://cshub.mit.edu)



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