# Toward Net Zero Carbon Concrete

## Logistics and Manufacturing under Attack: A Workshop

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# Concrete

Most widely used construction material in the world

- Versatile
- Resilient
- Low cost
- Durable
- Relatively easy to produce
- Resistant to environmental extremes

Sydney Opera House

Rocky Creek Bridge

Hoover Dam

Wastewater treatment plant

# Concrete Manufacturing

## Cast in place

Bridge decks

Retaining walls

Buildings

Wastewater treatment plant

## Precast

Drainage pipes

Tunnels

Bridges

Buildings

Annual global production of ~10 billion tonnes of concrete

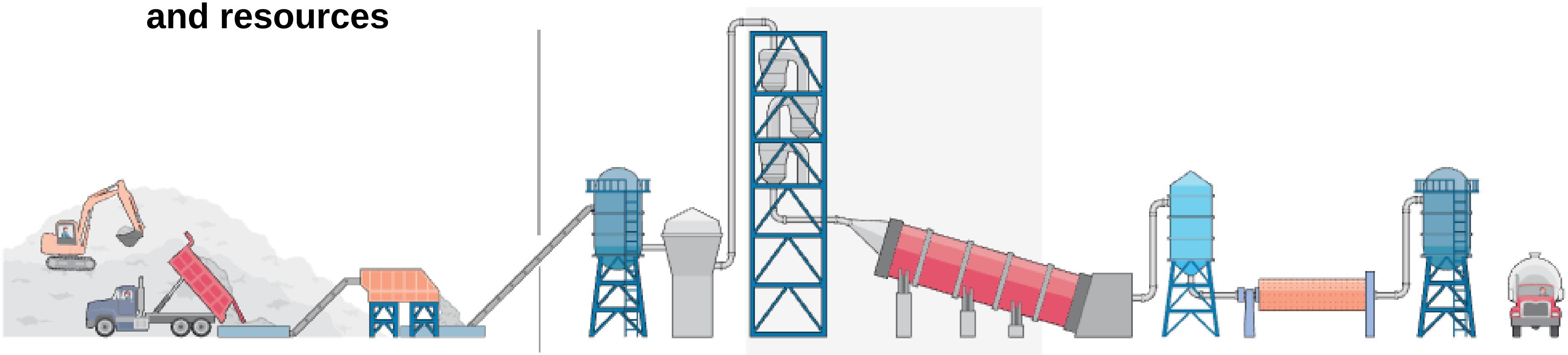
# Ordinary Portland Cement (OPC)

- OPC responsible for ~90% of $CO_2$ emissions from avg concrete mix
- OPC used in ≥98% of concrete produced globally
  - ~200-year track record
  - Cheap
  - Produces high-quality concrete
  - Abundant and collocated raw materials (limestone, chalk, marl)
- ~4+ billion tonnes of OPC per year
- 1 kg OPC $\cong$ 1 kg $CO_2$

~8% of global $CO_2$ emissions

# Ordinary Portland Cement Manufacturing

| | Raw materials, energy, and resources | | | | Clinker and cement manufacturing | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|



| | Quarry | Crusher | Transport[1] | Raw mill | Kiln and preheater/ precalcinator[2] | | Cooler[3] | Cement mill | Logis-tics[4] | **Total** |
|---|---|---|---|---|---|---|---|---|---|---|
| **Energy**, mega-joule/ton | 40<br>1% | 5<br>0.1% | 40<br>1% | 100<br>3% | 3,150<br>**81%** | | 160<br>4% | 285<br>7% | 115<br>3% | 3,895<br>100% |
| **$CO_2$**, kg/ton | 3<br>0.3% | 1<br>0.1% | 7<br>0.8% | 17<br>1.8% | 319<br>**34%**<br>Fossil fuels | 479<br>**52%**<br>Calcination process | 28<br>3% | 49<br>5% | 22<br>2% | 925<br>100% |

McKinsey and Company

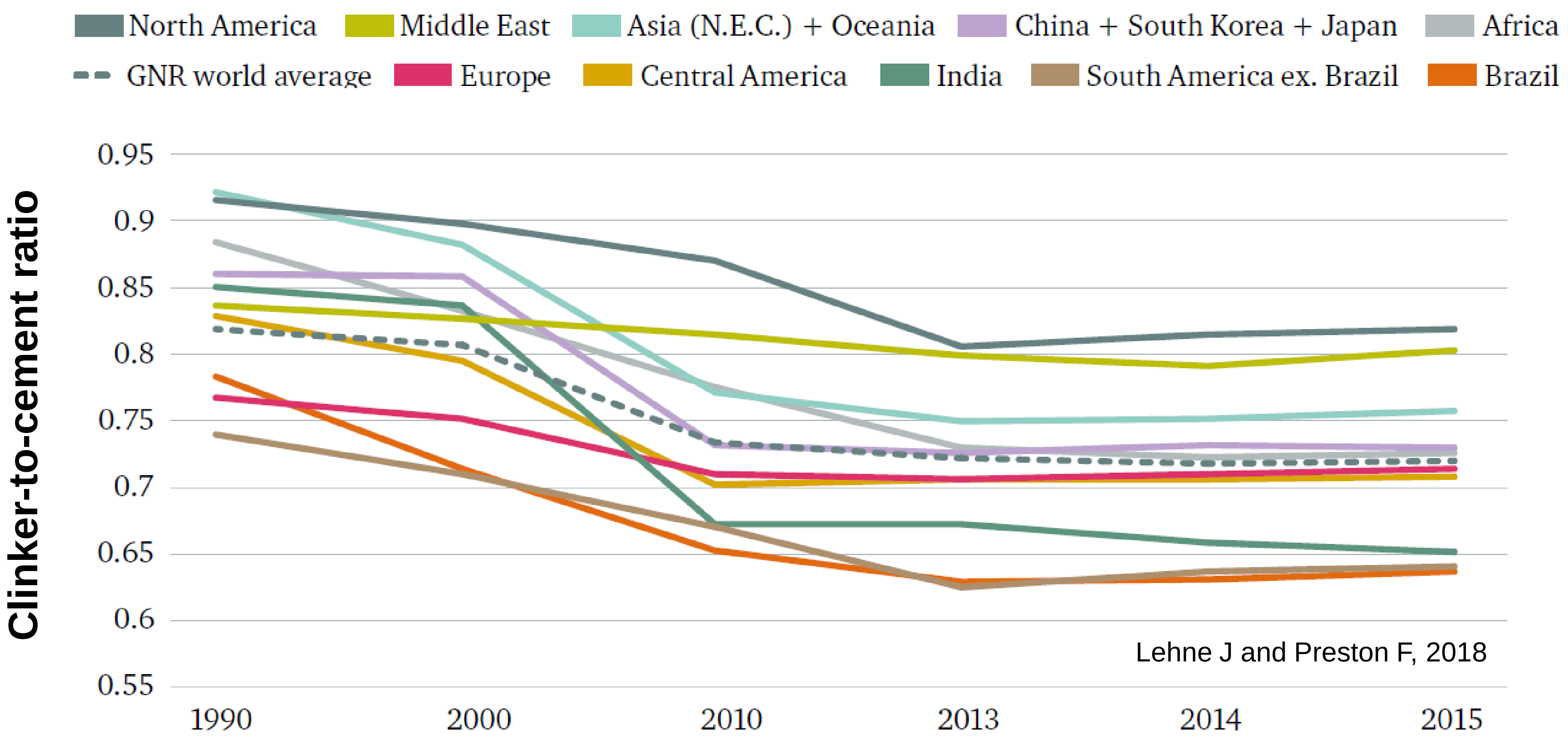
[1] Assumed with 1kWh/t/100m.

[2] Assumed global average, data from the Global Cement and Concrete Association, Getting the Numbers Right 2017.

[3] Assumed reciprocating grate cooler with 5kWh/t clinker.

[4] Assumed lorry transportation for average 200km.

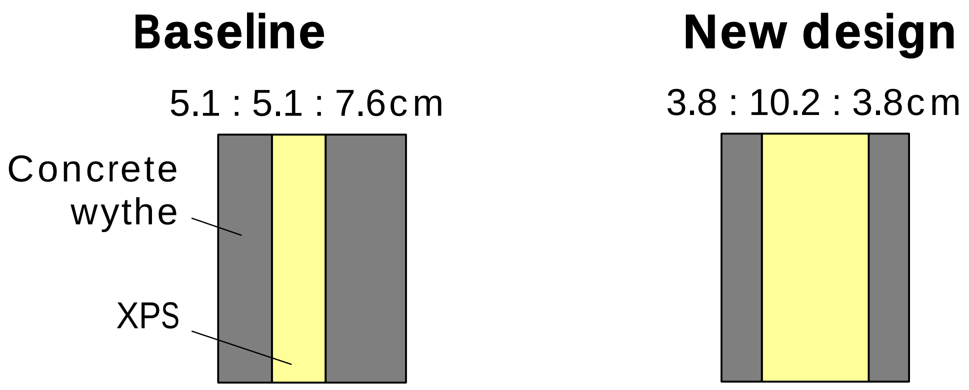
# Portland Clinker Substitutes




Common substitutes: fly ash, granulated blast furnace slag (GBFS), limestone

# Cement Blends and High-Performance Concrete Mix

- ~58% lighter precast insulated panels
  - Savings in transportation, erection, structure
  - 3.8cm-thick wythes → 40% less concrete
  - 30% lower concrete density
- Concrete mix specs (US Patent #10836678)
  - 1,600 kg/m$^3$ (100 pcf) density
  - 4.1 MPa (600 psi) flexural strength at 12 hours
  - Self-consolidating
  - Cost neutral approach ~$392/m$^3$ (~$300/yd$^3$)
- Research funded by DOE's Building Technologies Office



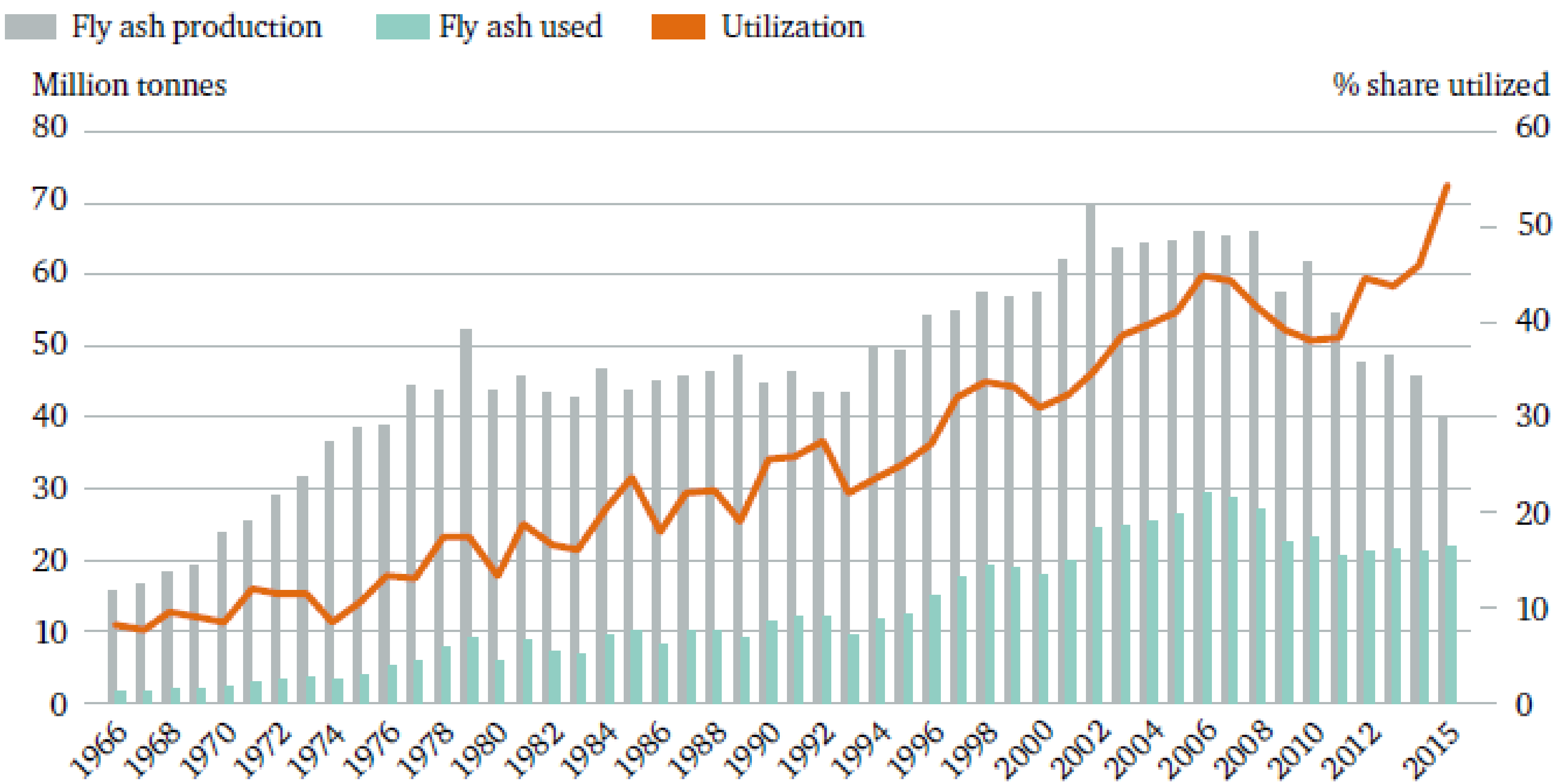

2,310 kg/m$^3$ concrete density
293 kg/m$^2$ panel weight

1,600 kg/m$^3$ concrete density
122 kg/m$^2$ panel weight

**Large-scale trial**

- ~77% clinker-to-cement ratio
- 40% less concrete
- Partnership with PCI promotes adoption

# US Fly Ash Production and Use




Kelly TD and Matos GR, 2014

- Constraints of common substitutes: availability, cost, consumer acceptance, codes/standards
- Need alternatives to common Portland clinker substitutes

# Current Approaches Toward Net Zero Carbon Concrete

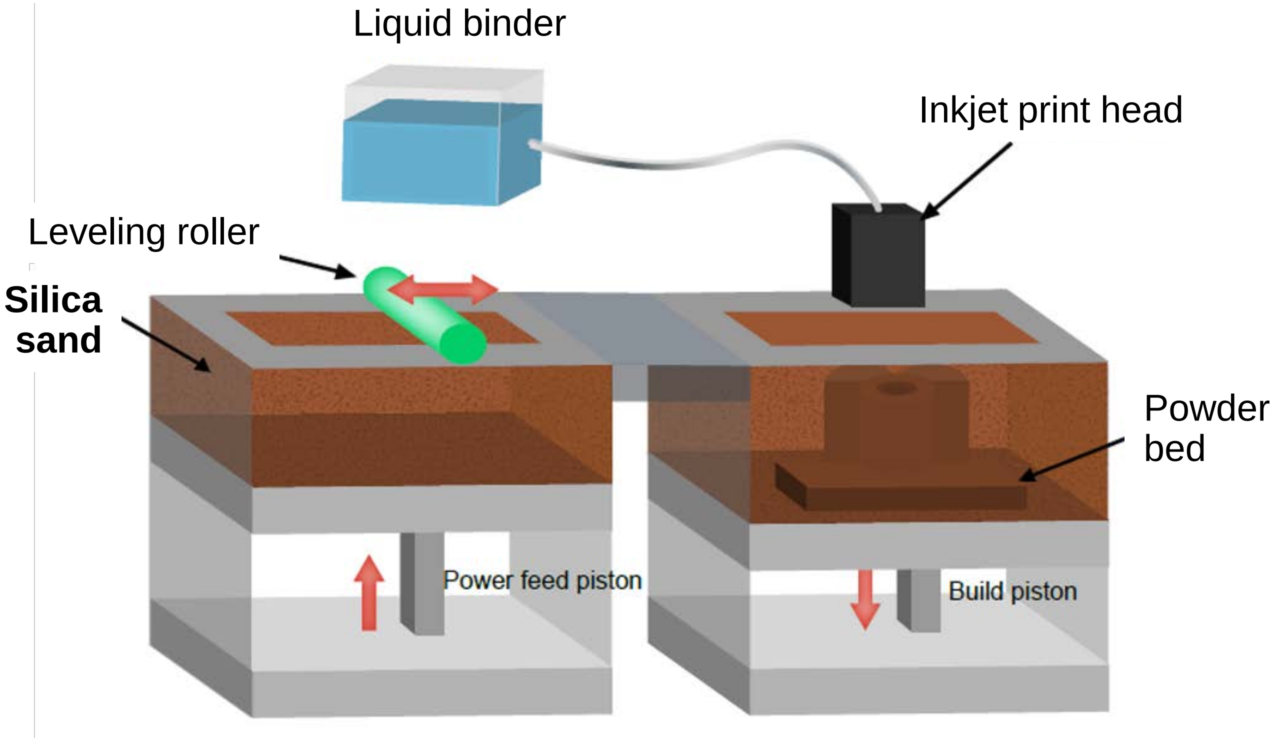
**1 Tonne of Concrete ≅ 100 to 250 kg $CO_2$**

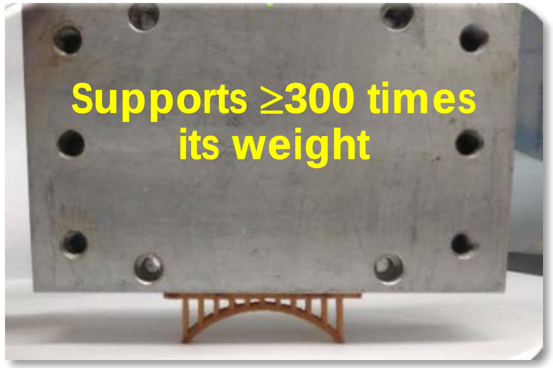
| Approach | $CO_2$ Reduction (kg/tonne of concrete) min | max |
|---|---|---|
| **Cement**<br>Alternative binders and binder systems w/ lower embodied energy. | 30 | 100 |
| **Mixing**<br>Add $CO_2$ to wet concrete mix improves strength and allows producers to use ~10% less cement.<br>**Or Curing**<br>Use $CO_2$ to cure concrete via mineralization of portlandite. | 70 | 150 |
| **Aggregate**<br>Use mineralization of limestone and portlandite to sequester $CO_2$. | 100 | 400 |

**2 steps to net zero carbon**

**3 steps to carbon negative**

# ORNL’s High-Strength Binder System for Additive Manufacturing





- 3D printed part attained flexural strength of 6.3 MPa or 1.4 times higher than OPC (~4.5 MPa)
- Flexural strength increased to 52.7 MPa after part was impregnated w/ secondary polymer

Gilmer DB, Han L, Lehmann ML, Siddel DH, Yang G, Chowdhury AU, Doughty BL, Elliott AM, Saito T. “Additive Manufacturing of Strong Silica Sand Structures enabled by Polyethyleneimine Binder ” *Nat Comm* under review

# ORNL's Ongoing Work on Polymer Cement

- Stretch goal 1: carbon neutral polymer binder
  - Petroleum-based and biobased polymers will store $CO_2$ via carbonation during synthesis
  - Biobased polymers will store $CO_2$ via photosynthesis (1 kg biomass $\cong$ 1.83 kg $CO_2$)
- Stretch goal 2: higher mechanical properties than OPC
  - Higher mechanical properties of concrete mix reduce size of concrete part and amount of concrete needed
- Adoption and commercialization
  - Aggregate agnostic so easier to integrate
  - Minimal, if any, changes to ready-mix plant procedures
  - Fewer steps to net zero carbon concrete

Preliminary prototypes

# Shorter Path to Net Zero Carbon Concrete

**1 step to net zero carbon**

| **Approach** |
| --- |
| **Polymer cement**<br>Partial OPC replacement w/ carbon neutral petroleum-based and biobased polymer binder that **sequester $CO_2$ during synthesis and photosynthesis**.<br>Higher mechanical properties than OPC **reduce** size of concrete part and **amount of concrete needed**. |
| **Aggregate**<br>Use mineralization of limestone and portlandite to sequester $CO_2$. |

**2 steps to carbon negative**

# Questions?