SUSTAINABILITY IN CONCRETE:

REDUCING ENVIRONMENTAL IMPACT THROUGH BENCHMARKING AND ALTERNATIVES

ANDREW MERCKER – IRVING MATERIALS INC
JASON JIMENEZ – EUCLID CHEMICAL
MASON BOOTH – MASTER BUILDERS SOLUTIONS
Global Sustainability Initiatives – The Why...

**Structural Engineers 2050 Challenge:**

“All structural engineers shall understand, reduce and ultimately eliminate embodied carbon in their projects by 2050”

**Cement/Concrete Industry & International Energy Agency:**

-50% reduction in CO2 emissions from 2006 levels by 2030 (CarbonCure)

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-50% reduction in CO2 emissions from 2006 levels by 2030 (CarbonCure)
Cement accounts for ~8% of global CO2 emissions (Chatham House)

Cement accounts for 79% of CO2 emissions related to concrete (Jeremy Gregory)

**Embodied carbon figures**

*Embodied carbon (kg/CO2e) - Quantity produced (metric tonnes)*

Source: The Inventory of Carbon and Energy

- Aluminium: 9.16 Gt CO2 (2012)
- Copper: 2.71 Gt CO2 (2012)
- Iron: 1.85 Gt CO2 (2014)
- Lead: 2.03 Gt CO2 (2014)
- Steel: 1.67 Gt CO2 (2014)
- Concrete: 1.46 Gt CO2 (2014)
- Total: 12.58 Gt CO2 (2014)

NB: CO2e = carbon dioxide equivalent: a single unit that expresses the global warming potential of various greenhouse gases in terms of the amount of carbon dioxide required to produce the same effect.
Avenues for Reducing Environmental Impact

1 lb cement = 1.04 lb in CO2 (EPD - US Portland Cement)

- Water
- Supplemental Cementitious Materials (SCM)
- Blended Cements
- Admixtures
## Impact of Water on Cement Content

<table>
<thead>
<tr>
<th>Excess Water Impacts:</th>
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**Excess Water Impacts:**
- Strength Development
- Durability

**Common Water Addition:**
- Material Water Demand
- On site

**Response:**
- Overdesign
- Liability
Admixtures

- **Strength Enhancing Admixtures**: Optimization & Strength Equivalency
- **Water Reducers & Workability Retainers**: Control w/cm and total water
- **Synthetic Fibers**: Reducing secondary reinforcing steel & freight
Portland Limestone Cement

- Reduce GWP of mixes by 10%
- Equivalent Performance to Portland Cement
- 1:1 replacement of Portland Cement
- Contains 5%-15% Limestone
- Retain same amount of SCM usage
- Minor to no change on admixture dosages
- Permitted by Building Codes
- Conforms to ASTM C595, Type IL

Potential CO2 Savings in a 100,000 Sq Ft Building Project
- 82 Tons
- 164,835 lbs
- 75 Metric Tons
- 74,768 kg

BY VOLUME
(Buildings, Ready Mix Producers, Geotechnical)

<table>
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<tr>
<th>Total volume of concrete (cu. yd.)</th>
<th>CO2 Savings with PLC</th>
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<tbody>
<tr>
<td>100</td>
<td>2 Tons</td>
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<tr>
<td>564</td>
<td>4,591 lbs</td>
</tr>
<tr>
<td></td>
<td>2 Metric Tons</td>
</tr>
<tr>
<td></td>
<td>2,082 kg</td>
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Basic calculator assumptions:
- 180 cu. yd. of concrete are used per sq. ft. of building floor space
- 1 cu. yd. of concrete contains 620 lbs of cement
For advanced calculation, input your total concrete volume and cement factor.
Athena Impact Estimator

- Free tool that evaluates whole building and assemblies based on Life Cycle Assessment methodology
- Assess & Compare environmental implications of designs
- The Impact Estimator instantly provides cradle-to-grave implications in terms of:
  - Global Warming Potential
  - Acidification Potential
  - Ozone Depletion Potential
  - Fossil Fuel Consumption
  - Eutrophication Potential
  - Photochemical Smog Potential
  - Human Health Respiratory Effects Potential
- The Estimator takes into account the environmental impacts of:
  - Material manufacturing
  - Related transportation
  - On-site construction
  - Operational phase
  - Building type and assumed lifespan
  - Demolition and disposal
  - Maintenance and replacement effects
Replacement Solutions:

- **CO2**
  - Carbon mineralization
  - Reduction of cementitious material

- **Slag**
  - 50% or higher replacement
  - 0.1466 kgCO2/kg (Slag Cement Ass.)

- **Fly Ash**
  - 30% or higher replacement
  - 0.074 kgCO2/kg (Climate Earth)

**Cement**
- 1.04 kgCO2/kg (Portland Cement Ass.)
1. Class 3000 – Concrete fill
   a. Compressive strength at 28 days: 3000 psi.
   b. Minimum cement content: 423 lb/cu yd.
   c. Maximum water-cementitious ratio: 0.58
   d. Air content: Optional.
   e. Water-reducing admixture required.
   f. Synthetic fibers required in unreinforced concrete

2. Class 4000: Building interior slabs on grade, not subjected to fluid or freezing
   a. Compressive strength at 28 days: 4000 psi.
   b. Minimum cement content: 517 lb/ cu yd.
   c. Maximum water-cementitious ratio: 0.48
   d. Air content: 0 to 3 percent
   e. Mid-range water-reducing admixture required.
   f. Synthetic fibers required.

3. Class 5000WP: Concrete for below grade structures. Concrete for structures that contain or convey water or wastewater (Contains crystalline waterproofing additive).
   a. Compressive strength at 28 days: 5000 psi.
   b. Minimum cement content: 620 lb/ cu yd.
   c. Maximum water-cementitious ratio: 0.40
   d. Air content: 6 +/- percent at point of delivery
   e. High-range water-reducing admixture required.
   f. Permeability reducing admixture required.

1. INTERPRET & INVESTIGATE

2. PROPOSE REVISIONS:
   - ULTIMATE STRENGTHS
   - W/CM
   - MINIMUM CEMENTITIOUS
Athena Impact Tool

- Tool was developed in partnership with the Slag Cement Association
- Calculator allows for custom mixes and comparison of different designs
- We utilized it for comparison of 3 mix classes with 7 mixes in each class
Class 3000 – Options & Analysis

Benchmark Mix Design (per CY)
- Cement 450 lbs
- Water 31 gal
- CA 1850 lbs
- FA 1540 lbs
- Low Range Water Reducer

Comparison of Entered Mixes to Strength Class Benchmarks

<table>
<thead>
<tr>
<th>Option</th>
<th>Cement</th>
<th>Slag</th>
<th>Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Option 2</td>
<td>225 lbs</td>
<td>225 lbs</td>
<td>38%</td>
</tr>
<tr>
<td>Option 3</td>
<td>360 lbs</td>
<td>90 lbs</td>
<td>22%</td>
</tr>
<tr>
<td>Option 4</td>
<td>414 lbs</td>
<td>CO2 3.5 lbs/CY</td>
<td>7%</td>
</tr>
<tr>
<td>Option 5</td>
<td>PL Cement 450 lbs</td>
<td>1 to 1 replacement</td>
<td>9%</td>
</tr>
<tr>
<td>Option 6</td>
<td>405 lbs</td>
<td>Strength Enhancing Admix 8 oz/cwt</td>
<td>12%</td>
</tr>
<tr>
<td>Option 7</td>
<td>218 lbs</td>
<td>Slag 218 lbs</td>
<td>39% reduction</td>
</tr>
</tbody>
</table>

Life Cycle Assessment Results

<table>
<thead>
<tr>
<th>Mix ID</th>
<th>Class 3000 - Be</th>
<th>Class 3000 - 50%</th>
<th>Class 3000 - 20%</th>
<th>Class 3000 - CO</th>
<th>Class 3000 - PL</th>
<th>Class 3000 - Ad</th>
<th>Class 3000 - Co</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate Change (kg CO2-en)</td>
<td>245.63</td>
<td>153.24</td>
<td>190.95</td>
<td>228.35</td>
<td>224.03</td>
<td>217.06</td>
<td>149.39</td>
</tr>
</tbody>
</table>

- Mix 1
  - Cement 450 lbs
  - Water 31 gal
  - CA 1850 lbs
  - FA 1540 lbs
  - Low Range Water Reducer

- Mix 2
  - Cement 225 lbs
  - Slag 225 lbs

- Mix 3
  - Cement 360 lbs
  - Fly Ash 90 lbs

- Mix 4
  - Cement 414 lbs
  - CO2 3.5 lbs/CY

- Mix 5
  - PL Cement 450 lbs
  - 1 to 1 replacement

- Mix 6
  - Cement 405 lbs
  - Strength Enhancing Admix 8 oz/cwt

- Mix 7
  - Cement 218 lbs
  - Slag 218 lbs
  - CO2 3.5 lbs/CY
  - 39% replacement
Class 4000 – Options & Analysis

Mix Options

1. Benchmark
2. 50% Slag
3. 20% Fly Ash
4. CO2
5. Portland Limestone Cement
6. Strength Enhancing Admixture
7. 50% Slag & CO2
Class 5000 – Options & Analysis

Mix Options
1. Benchmark
2. 50% Slag
3. 20% Fly Ash
4. CO2
5. Portland Limestone Cement
6. Strength Enhancing Admixture
7. 50% Slag & CO2
Several options to mitigate environmental impact while still designing mix that achieves project goals
○ Design can reduce concrete volume

Sustainability push is coming from one direction and/or another... Legislation & Project Owners

Special consideration should be given to what is ACTUALLY being specified when considering CO2 emission project allowances... ex. 4000 psi post-tension mix at 24 hours is NOT a standard 4000 psi mix

Specifications impact GWP through w/cm, min cement content, SCM limits
○ Performance specifications will have a lower impact
○ Designers and producers need to work together to utilize options available TODAY to make an impact


Climate Earth EPD Generator: [https://www.climateearth.com/instant-on-demand-epds/](https://www.climateearth.com/instant-on-demand-epds/)


Slag Cement Association: [https://www.slagcement.org/resources/faqs.aspx](https://www.slagcement.org/resources/faqs.aspx)