CO₂ Utilization in Ready Mixed Concrete Production

Sean Monkman PhD PEng
CarbonCure Technologies Inc
The Importance of Concrete

- Approximately 0.4 tonnes concrete/person
- Approximately 4.3 tonnes concrete/person
- Estimated output of plastic is less than 0.1% of the output of concrete
5.6% of annual global carbon dioxide emissions attributable to fossil fuels and industry are associated with cement production.

Market segmentation

- Total US market for concrete about $49B per year
- Ready mix = cast in place
- Precast = factory produced
- Masonry = pipe and block
- Estimated 5,550 ready mix plants in US
CarbonCure History

- CO₂ utilization for concrete production
- Research 2004-08
- Masonry technology
  - Development start 2009
  - Commercialization 2013
- Ready mix technology
  - Development start 2014
  - Commercialization 2016
Beneficial CO$_2$ Utilization In Concrete Production

a) Water is mixed with cement, dissolution occurs.
b) Carbon dioxide is introduced and enters the solution.
c) CO$_2$ is mineralized and thermodynamically stable CaCO$_3$ forms in-situ.
d) Normal cement hydration pathways proceed with nanoscale CaCO$_3$ acting as a seeding/nucleation element.
The carbonation reaction results in the in-situ development of carbonate particles that act within the hydration process.
Pilot trials (June 2013 to June 2015)

- Technology trials at 12 locations
- Limited scale
- Optimal dosing not assured
Conservative industry and innovation

- No appetite for large-scale change
  - Retrofit technology preserves traditional production methods and materials
- Integration cannot change output rate, cycle times, overall method
- Economic benefit is motivation
- Environmental value proposition is not interesting
Compressive strength benefit

<table>
<thead>
<tr>
<th></th>
<th>7 day</th>
<th>28 day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control Mix</td>
<td>4,772</td>
<td>6,459</td>
</tr>
<tr>
<td>Control Mix with 5% cement reduction</td>
<td>4,206</td>
<td>5,717</td>
</tr>
<tr>
<td>Mix with 5% cement reduction + CO2</td>
<td>109%</td>
<td></td>
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</table>
Commercial Viability

- Often a market and product where lowest price wins
- Generic values
  - $100 yd$^3$ concrete
  - $7$ margin for producer
  - Saving $0.50 is meaningful
Permanent System Install
Environmental impact

- Even if a CO₂ utilization technology is not sold on an environmental basis it should offer a net environmental benefit
- Analysis considers
  - mix design changes
  - capture and compression of the CO₂
  - transportation of the CO₂
  - production of the gas injection equipment
  - transportation of the gas equipment
  - Direct CO₂ mineralization
  - Avoided CO₂ emissions via reduced cement loading
LCA - Overall Emissions Balance

- CO₂ dose 0.15%
- Cement reduction 5%
- Gas processing at 200 kWh/tonne CO₂
- Gas transport 100 miles
- Electrical grid emissions according to EPA US Avg
- Carbon intensity of cement from PCA EPD

<table>
<thead>
<tr>
<th>Factor</th>
<th>g CO₂/m³ concrete</th>
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<tbody>
<tr>
<td>Emissions – CO₂ from gas processing</td>
<td>49.4</td>
</tr>
<tr>
<td>Emissions – CO₂ from gas transport</td>
<td>6.1</td>
</tr>
<tr>
<td>Emissions – CO₂ from equipment production</td>
<td>0.1</td>
</tr>
<tr>
<td>Emissions – CO₂ from equipment transport</td>
<td>0.0</td>
</tr>
<tr>
<td>Emissions – CO₂ from equipment operation</td>
<td>9.2</td>
</tr>
<tr>
<td>Emissions – Avoided CO₂ from materials transport</td>
<td>-123.6</td>
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<tr>
<td>CO₂AB: CO₂ absorbed</td>
<td>-289.1</td>
</tr>
<tr>
<td>CO₂AV: Avoided CO₂ emissions from cement</td>
<td>-17584.8</td>
</tr>
<tr>
<td>Total CO₂ avoided and absorbed</td>
<td>-17997.4</td>
</tr>
<tr>
<td>CO₂EM: Total CO₂ produced</td>
<td>64.7</td>
</tr>
<tr>
<td>Net CO₂ reduction</td>
<td>-17932.7</td>
</tr>
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</table>
LCA – Process emissions

- There are four main aspects affecting the carbon emissions of the approach
- Grid – carbon intensity of the electrical grid (re: capture and operations)
- Gas – energy required to capture and liquefy the CO₂
- Transport – how far the CO₂ is transported
- Hardware – energy demand of the injection hardware

Specific emissions
- 49 g CO₂/m³ concrete for CO₂
- 167 g CO₂/m³ concrete for admixtures (EFCA and NRMCA data)
LCA - CO\textsubscript{2} Footprint Reduction

- Carbon footprint is reduced by 4.6%
- Cement reduction is responsible for 97.7% of the reduction
- CO\textsubscript{2} utilization served as a platform to make the reduction.

On Carbon Dioxide Utilization as a Means to Improve the Sustainability of Ready-Mixed Concrete, S. Monkman and M. MacDonald, Journal of Cleaner Production. doi:10.1016/j.jclepro.2017.08.194
Marketing & Sales – opportunities for growth

US Commercial Green Building Market Size ($ billions)

- $3 billion, 2% of market in 2005
- $25 billion, 12% of market in 2008
- $48 billion, 31% of market in 2010
- $67 billion, 45% of market in 2013
- $115 billion, 50% of market in 2016

The commercial green building market is growing rapidly.
2017 production of CO$_2$-treated concrete
Cumulative Net CO$_2$ benefit

CO$_2$ benefit realized (tonnes CO$_2$)

Jan  Feb  Mar  Apr  May  Jun  Jul  Aug  Sep  Oct  Nov  Dec

0  1,000  2,000  3,000  4,000  5,000  6,000
Challenges

• Performance benefit relationship with cement chemistry?
  o Cement chemistry varies, performance outcome varies (akin to admixtures)

• Carbon dioxide sourcing
  o Merchant sources are $300 - $400 per ton,
  o Typically from ethanol, ammonia or hydrogen production
  o No relationship with concrete production

• Time value of carbon
  o Action to reduce emissions today will have a greater impact than action delayed

• Code and standards
  o How to innovations fit within existing standards?
Future and needs

• Future: Further CO\textsubscript{2} utilization technologies under development
• Future: Slipstream retrofit cement kiln CO\textsubscript{2} capture for integrated downstream utilization
• Needs: Process emissions were most sensitive to the carbon intensity of the electrical grid and the CO\textsubscript{2} capture energy – most important levers to reduce impact
• Needs: Deeper physiochemical mechanistic understanding
Thank You

Sean Monkman, PhD PEng
VP Technology Development
smonkman@carboncure.com

@carboncure