BCSAF clinkers

A credible low carbon alternative to Portland Cement

Laurent Barcelo, John Kline, Gunther Walenta, Bruce Blair and Ellis Gartner
Cement and Concrete are not the “bad guys” we hear too often…
Conservative estimation of the amount of concrete produced every year on the planet:

15,000,000,000,000 t

...over 2t/inhabitants
... and there are good reasons for this ...

Orders of magnitude

100g  10kg  1t

Source: INTRODUCTION à LA SCIENCE DES MATÉRIAUX, Kurz, Mercier, Zumbell, PPUR, 3rd ed 2002
... and there are good reasons for this ...

Cost
Local availability in large quantities
Ease of use
Relative robustness to misuse
Versatility
Durability
...
data extracted from Hammond and Jones (2011), University of Bath, UK
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Of course, we need to develop “greener” cement and concrete…
IEA Blue Map Scenarios

- Mandated by G20 to work on long-term scenarios of carbon reduction (2050);

- 2012 update provides BAU scenario (eq. +6°C) as well as +4°C and +2°C scenarios by 2050

- Promote a sectorial approach as the least cost way to reduce carbon emissions

- Lead the development of technology roadmaps in key areas. One developed for the cement industry!
The Cement Industry Technology Roadmap to Reduce Carbon Emissions

In terms of specific emissions (kg of CO2 per ton of cement):

- 2006: 680 kg
- Low Demand: 406 kg (-40%)
- High Demand: 338 kg (-50%)

Blue Map
We need to go beyond the traditional levers that the industry has been using.
The IEA & WBCSD cement technology Roadmap for carbon reduction
We need to be creative for the use of cementitious additives
Estimation of WW cementitious reserves made by IEA

Table 3.5  Availability of clinker substitutes in the BLUE scenario, 2005 and 2050

<table>
<thead>
<tr>
<th></th>
<th>2005 (Mt)</th>
<th>2050 (Mt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fly ash</td>
<td>590</td>
<td>368</td>
</tr>
<tr>
<td>Blast-furnace slag</td>
<td>308</td>
<td>364</td>
</tr>
<tr>
<td>Other clinker substitutes</td>
<td>50</td>
<td>100</td>
</tr>
<tr>
<td>Other additions, e.g. ground limestone</td>
<td>267</td>
<td>500</td>
</tr>
<tr>
<td>Total</td>
<td>1,215</td>
<td>1,332</td>
</tr>
</tbody>
</table>

=> Fly-ash based geopolymers cannot be a global solution!
=> Fly-ash and slag may not be carbon neutral in the future
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We may need to develop alternative clinkers…
# 3 main levers to reduce CO2 emissions

## Direct CO₂ emissions in Cement Manufacture

<table>
<thead>
<tr>
<th>Category</th>
<th>Formula/Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂ from Limestone calcination</td>
<td>~535 kg/t clinker</td>
</tr>
<tr>
<td>(fairly constant from plant to plant)</td>
<td></td>
</tr>
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<td>CO₂ from fuels combustion</td>
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<td>(larger variations from plant to plant)</td>
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</tr>
<tr>
<td>Direct CO₂ emissions for clinker</td>
<td>~865 kg/t clinker</td>
</tr>
<tr>
<td>Average clinker content in cement</td>
<td>~680 kg/t cement</td>
</tr>
<tr>
<td>(2006 value from CSI)</td>
<td></td>
</tr>
<tr>
<td>Direct CO₂ emissions for cement</td>
<td></td>
</tr>
</tbody>
</table>

Note: Excludes CO₂ from electricity (about 10% in the case of cement)

To what extent we can reduce this through clinker formulation?
Energy Required for $C_3S$ formation

1. Limestone Decarbonation
   \[ CaCO_3 \rightarrow CaO + CO_2 \]

2. Formation of $C_2S$
   \[ 2 \cdot CaO + SiO_2 \rightarrow Ca_2SiO_4 \]

3. Formation of $C_3S$
   \[ Ca_2SiO_4 + CaO \rightarrow Ca_3SiO_5 \]

The “double penalty” of high CaO clinkers
Clinker formulation: Traditional PCC

Assumes all CaO from CaCO3; Assumes bituminous Coal as fuel; Assumes fuel consumption at BAT

Direct CO2 footprint (kg/t)

- **C3S**: RM CO2 = 578 kg/t, Fuels CO2 = 282 kg/t, Total = 861 kg/t
- **C2S**: RM CO2 = 511 kg/t, Fuels CO2 = 204 kg/t, Total = 715 kg/t
- **C3A**: RM CO2 = 489 kg/t, Fuels CO2 = 298 kg/t, Total = 787 kg/t
- **C4AF**: RM CO2 = 362 kg/t, Fuels CO2 = 208 kg/t, Total = 570 kg/t
Clinker formulation: theoretical C2S clinker

- CO2 footprint (kg/t): PCC (816, -12%) vs. C2S clinker (719, -20%)
- RM CO2 and Fuels CO2 contributions

Anna Maria Workshop XIII – Nov 2012 – BARCELO, KLINE, WALENTA, BLAIR & GARTNER
What are the characteristics of the solution we’re looking for?

- A clinker that leverages all the current clinker advantages:
  - Made from raw materials locally available in large quantities
  - Cheap
  - A high level of early reactivity (similar to OPC) to work well with SCMs
  - Durable (including steel protection)

- And in addition:
  - A much lower CaO content to reduce significantly CO2 emissions;
  - Can be manufactured in existing plants
A Carbon footprint reduced by 30%

Assumes all CaO from CaCO3; Assumes bituminous Coal as fuel; Assumes fuel consumption at BAT

<table>
<thead>
<tr>
<th>Process</th>
<th>CO2 footprint (kg CO2/t clinker)</th>
<th>RM CO2</th>
<th>Fuels CO2</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCC</td>
<td>546 (8%)</td>
<td></td>
<td>271 (-12%)</td>
</tr>
<tr>
<td>C2S clinker</td>
<td>501 (-8%)</td>
<td></td>
<td>218 (-20%)</td>
</tr>
<tr>
<td>Aether</td>
<td>376 (-31%)</td>
<td></td>
<td>571 (-30%)</td>
</tr>
</tbody>
</table>

Assumes all CaO from CaCO3; Assumes bituminous Coal as fuel; Assumes fuel consumption at BAT.
BCSAF on C-A-S triangle:

- **SiO₂**
- **Silica Fume**
- **CaO**
- **Limestone**
- **Al₂O₃**
- **F-Ash**
- **MK**
- **Slag**
- **C-Ash**
- **OPC**
- **BCSAF**
Key benefits of BCSAF clinkers (Aether™)

- Reduction of up to 30% of the CO₂ footprint of clinker manufacturing
- Potential additional saving on indirect CO₂ from electricity, as clinker is easier to grind
- Gives high level of early reactivity, allowing us to maintain clinker substitution at the same level as with OPC
- Later strength development similar to OPC
- Can be manufactured in existing cement plants: No need for heavy capital expenditure. Possibility of production rate increases.
- Already demonstrated at industrial scale, in a real clinker kiln.
Thank you for your attention!!

www.lafarge.com
www.aether-cement.eu

www.facebook.com/Lafarge

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Direct CO$_2$ emissions in Cement Manufacture

CO$_2$ from Limestone calcination
(fairly constant from plant to plant)  $\Rightarrow$  $\sim$535 kg/t clinker

CO$_2$ from fuels combustion
(larger variations from plant to plant)  $\Rightarrow$  $\sim$330 kg/t clinker

Direct CO$_2$ emissions for clinker  $\Rightarrow$  $\sim$865 kg/t clinker

Average clinker content in cement
(2006 value from CSI)  $\Rightarrow$  78%

Direct CO$_2$ emissions for cement  $\Rightarrow$  $\sim$680 kg/t cement

Note: Excludes CO$_2$ from electricity (about 10% in the case of cement)
Appendix
The Cement Industry Technology Roadmap to Reduce Carbon Emissions

Cement Sustainability Initiative (CSI) and IEA partnered to establish a roadmap for the cement industry:

- **2007**: Baseline: 2 billion tons of CO2
- **2050 Baseline**: 2.34 billion tons of CO2
- **2050 Blue Map Target**: 1.55 billion tons of CO2 (a 23% reduction)

(in billion of tons of CO2)
3 main levers to reduce CO2 emissions

### Direct CO₂ emissions in Cement Manufacture

<table>
<thead>
<tr>
<th>Source of CO₂</th>
<th>Emissions per Clinker</th>
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Note: Excludes CO₂ from electricity (about 10% in the case of cement)
1. Energy Efficiency

<table>
<thead>
<tr>
<th>Process</th>
<th>Typical Fuel Consumption (GJ/t)</th>
<th>Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Theoretical consumption</em></td>
<td>1.75</td>
<td></td>
</tr>
<tr>
<td>Vertical Shaft Kilns</td>
<td>~5</td>
<td>35%</td>
</tr>
<tr>
<td>Wet Kilns</td>
<td>5.9 - 6.7</td>
<td>25-30%</td>
</tr>
<tr>
<td>Dry Kilns</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Long Dry Kilns</td>
<td>4.6</td>
<td>38%</td>
</tr>
<tr>
<td>2 Stages Pre-Heater (PH)</td>
<td>3.8</td>
<td>46%</td>
</tr>
<tr>
<td>4 Stages PH</td>
<td>3.3</td>
<td>53%</td>
</tr>
<tr>
<td>4 Stages PH + Pre-Calciner (PC)</td>
<td>3.1</td>
<td>56%</td>
</tr>
<tr>
<td><strong>5 Stages PH+PC (BAT)</strong> *</td>
<td>3</td>
<td><strong>58%</strong></td>
</tr>
</tbody>
</table>

* Industry’s Best Available Technology
2. Alternative Fuels and Biomass

Alternative Fuels used in clinker production

2006 data

3. Clinker Substitution

2006 data, CSI

- China and India: 26%
- Latin America: 26%
- Europe: 24%
- World Average: 22%
- Africa & Middle East: 21%
- CIS: 20%
- Oceania and Japan: 17%
- Other Asia: 16%
- North America: 16%
Clinker formulation: Traditional PCC

<table>
<thead>
<tr>
<th></th>
<th>CaO content (%)</th>
<th>$\Delta H$ (Gj/t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C3S</td>
<td>74%</td>
<td>1.85</td>
</tr>
<tr>
<td>C2S</td>
<td>65%</td>
<td>1.34</td>
</tr>
<tr>
<td>C3A</td>
<td>62%</td>
<td>1.95</td>
</tr>
<tr>
<td>C4AF</td>
<td>46%</td>
<td>1.36</td>
</tr>
<tr>
<td>Free lime</td>
<td>100%</td>
<td>3.18</td>
</tr>
</tbody>
</table>
Challenges

- **Cost of raw-materials can be a little bit higher.**
  - Some level of taxation of CO$_2$ needs to happen to make Aether$^\text{TM}$ commercially viable at large scale.
  - Additional cost compared to PCC is nevertheless about **one order of magnitude lower than CCS**

- Cement and Concrete science has **100+ years of R&D** and still many aspects are not fully mastered. **We have just scratched the surface!**

- Specifications, acceptance, etc..
The IEA predicts that CO₂ emissions need to be **cut in half** to maintain temperature rise to +3°C (+5°F).

**The cement industry is a large contributor** to CO₂ emissions, more because of production **volumes** than intrinsic performance.

IEA proposes a **sectorial approach** as the **least cost way** to reduce emissions.

The cement industry and IEA partnered to build a **technology roadmap** for CO₂ reduction.

The roadmap calls for **23%** reduction of **absolute** CO₂ emissions and **40 to 50%** of **specific emissions**.

Existing levers (energy eff., clinker subst.) should lead us **half-way**. **High costs** forecast for CCS.

Lafarge is proposing **one novel approach** to help reduce carbon emissions through **clinker reformulation**. **BCSAF clinkers** (Aether™) have the opportunity to **reduce by up to 30%** the CO₂ footprint of clinker manufacturing.