Challenges to the Deployment of CCS in the Energy Intensive Industries
(Part 2: Cement Industry Sector)

Stanley Santos
IEA Greenhouse Gas R&D Programme
Cheltenham, UK

IEA – MOST Joint Workshop
CCS Opportunities in Energy Intensive Industry
16th October 2012
Cement manufacture at a glance

Cement is a man-made powder that, when mixed with water and aggregates, produces concrete. The cement-making process can be divided into two basic steps:

1. Clinker is made in the kiln at temperatures of 1,450°C
2. Clinker is then ground with other minerals to produce the powder we know as cement

Source: WBCSD Cement Technology Roadmap 2009
Direct CO₂ Emissions Reduction - UK cement

MPA Cement (4) Reduction in Absolute Carbon Dioxide Emissions
1990 to 2010

[Graph showing CO₂ emissions from 1990 to 2010, indicating a decrease over time.]
Direct CO₂ emissions - clinker

Carbon Dioxide Emission from Clinker Production

<table>
<thead>
<tr>
<th>Source</th>
<th>CO₂ %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcination (Process)</td>
<td>61</td>
</tr>
<tr>
<td>Combustion (Fuel)</td>
<td>39</td>
</tr>
</tbody>
</table>

mpa cement
Cement industry research

- Cement emission ~25% CO₂
- IEA GHG - UK Cement industry Study
- CCS Cement plant will cost double a non-CCS cement plant
- Operational costs also double
- Need for transport infrastructure
- Technical barriers for Oxyfuel and post combustion
- Need for funding

Source: IEA GHG programme
CO₂ CAPTURE IN THE CEMENT INDUSTRY

Technical Study

Report Number: 2008/3

Date: July 2008
Cement Production

- **Raw meal** (limestone etc)
- **Mill and drier**
- **Preheaters** (multiple stages)
- **Precalciner**
  \[ \text{CaCO}_3 \rightarrow \text{CaO} + \text{CO}_2 \]
- **Fuel**
- **Clinker**
  \[ \text{e.g. CaO} + \text{SiO}_2 \rightarrow \text{calcium silicates} \]
- **Cement**
- **Additives**
- **Mill**
- **Cooler**
- **Rotary kiln**
  \[ 1350^\circ \text{C} \]
  \[ 900^\circ \text{C} \]
Rotary Kilns

Figure 2-7: Long Wet Rotary Kiln (Adapted from CEMBUREAU, 1999)
Pre-Calciners
Pre-combustion Capture

- *Not a good option for cement plants*
- *Almost two thirds of the CO2 emissions are from limestone calcination*
- *Pre-combustion capture would only capture the fuel-derived CO2*
- *Not evaluated in IEA GHG’s study*
Post-Combustion Capture at a Cement Plant

- Air
- Fuel
- Raw meal
- Clinker
- Coal
- Steam
- Power
- CO₂-reduced flue gas
- CO₂ compression
- CO₂ to storage

Cement plant → ESP, SCR, FGD → Solvent scrubbing → Solvent stripping → CO₂ compression → CO₂ to storage
Post Combustion Capture in Cement Kiln
(Picture Courtesy of ECRA)

Figure 1. General arrangement of post-combustion CO₂ capture in a cement plant. The full animation can be seen at www.ecra-online.org.
Post-combustion Capture

- Kilns are sited on/near quarries normally with around 50-60 years of limestone reserves

**Advantages for cement plants**

- The cement plant itself is unaffected
  - But more stringent flue gas cleaning may be needed
- Retrofit to existing plants is possible
  - Provided space is available and CO2 can be transported away from the site for storage

**Disadvantages**

- A large quantity of low pressure steam is needed for solvent stripping, requiring an on-site CHP plant
Oxy-Combustion at a Cement Plant

IEA Greenhouse Gas study was based on oxy-combustion in just the pre-calciner.
Oxyfuel Combustion Capture in Cement Kiln
(Picture Courtesy of ECRA)
Oxy-combustion Capture

• **Advantages for cement plants**
  • Low oxygen consumption
    o Compared to a coal fired boiler, 1/3 of the amount of O2 is needed per tonne of CO2 captured
  • Costs are expected to be relatively low

• **Disadvantages**
  • Retrofit would be difficult
  • Oxy-firing the pre-calciner captures only about 60% of the CO2
  • For full oxy-firing, air in-leakage in mills and the kiln would have to be greatly reduced
  • Impacts of full oxy-firing on kiln chemistry etc need investigating
  • More R&D is needed
Costs of CO2 Capture

- **Costs estimated for a 1Mt/y cement plant in N-W Europe**
- **Post combustion capture**
  - €107/t of CO2 emissions avoided
  - Could be reduced to €55/t by locating a cement plant next to a power plant and using a low sulphur raw meal
  - Alternative CO2 capture solvents could significantly reduce costs
- **Oxy-combustion**
  - €40/t CO2 emissions avoided
- **Cement plants would need to be close to other CO2 sources to minimise CO2 transport costs**
  - CO2 captured is 0.5-1.0 Mt/y
  - Equivalent to about 100-200 MWe coal fired power plant
Costs – Developing Countries

• **Most cement production is in developing countries**
  - Almost 50% in China alone

• **New cement plants are often larger in developing countries and construction costs are lower**

• **Sensitivity case: 3Mt/y cement plant in Asia**
  - Costs of CO₂ abatement would be lower
  - e.g. €23/t for oxy-combustion
Conclusions

• CO₂ could be captured at cement plants
• Post-combustion capture is the lowest risk option and is well suited to retrofit but costs are relatively high
• Oxy-combustion would have similar costs to CO₂ capture at large power plants
• Most cement production is in developing countries
• Abatement costs would be lower in developing countries
• Imports of cement from countries without CO₂ abatement requirements is a concern
Cement industry research - ECRA

- Initiated in 2007
  - Work package A - Oxyfuel
  - Work Package B - Post Combustion

**Oxyfuel**
- Integrated concept
- Burning process is affected
- Oxygen enrichment has been applied to cement kilns
- CO₂ from the combustion process is concentrated
- Kiln plant needs redesign, retrofitting would be difficult
- High energy consumption for oxygen production

**Post-combustion**
- End-of-the pipe technology
- Commercially available in other industry sectors
- Minimal impact on existing clinker process
- Pure CO₂ stream for compression
- Retrofitting is possible, no kiln redesign required
- Very high energy consumption for solvent regeneration
ECRA CCS Project: Research Consortium Phase III

Cement Producers: Buzzi Unicem, CRH, Cementos Molins, Cemex, Cimpor, HeidelbergCement, Holcim, Italcementi, Lafarge, Phoenix, Schwenk, Secil, Spenner, Titan, Vicat, PZW Wittekind

Cement Organizations: CEMBUREAU, Cemsuisse, CSI, VDZ

Equipment Suppliers: Polysius, FLSmidth, KHD

Gas Producers: Praxair
ECRA CCS Project: Work Packages Phase III

The research work is organised in individual work packages, in cooperation with external project partners:

**Work packages oxy-fuel technologies:**
Process simulation, burner design, investigations on clinker quality, optimization of sealings and refractories, flue gas conditioning, layout of an oxy-fuel cement plant

**Work packages chemical absorption technologies:**
Modelling of absorption processes, amine degradation studies, small-scale trials with cement flue gases, FEED study
Oxy-fuel – Impact on Clinker Burning Process

Issues arising from oxy-fuel application investigated in phase II:

- Influences of an increasing CO₂ partial pressure on material conversion
- Influences on kiln operation due to changed burning atmosphere
- Integration of chemical plant components
- Modifications of the plant technology
- Maximum capture rate
- Energy demand and costs

Areas requiring further research:

- Influences of an increasing CO₂ partial pressure on
  - Process modelling
  - Laboratory tests
  - Optimization of seals
  - Waste heat utilization
  - Burner design
  - CO₂-purification facility
  - Clinker Cooler Design
  - Refractory lining
Oxy-fuel – Process modelling

Objectives:
• Developing oxy-fuel process model by adding further aggregates
• Comprehensive simulation study by parameter variation
• Iterative data exchange with other work packages

Deliverables:
• Identification of limiting factors
• Optimization of operational mode
• Energetic implementation of additional plant aggregates
Post-combustion – Impact on the Clinker Process

Issues arising from post-combustion application investigated in phase II:

- Resulting energy and mass flows
- Influences on kiln operation due to additional equipment
- Energy efficient integration into the existing process
- Absorbent degradation
- Modifications of the plant technology
- Maximum capture rate
- Energy demand and Costs

Areas requiring further research:

- Process modelling
- Degradation experiments
- Energy integration
- Waste heat utilization
- Small-scale tests
- Alternative heat sources
Post-combustion – Small-scale trials

- Location: Brevik, Norway
- Concept: Small-scale unit for testing different absorption techniques
- Dimension: approx 1 t/h
- Application to Norwegian government on track (September 2010)
- Open to participation from others
- Vision: Operate the first small-scale post-combustion capture facility in cement industry by 2013/14