Costs for CO₂ Capture in Cement Manufacture

Duncan Barker
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CCS Cost Workshop, Paris
Duncan Barker

• Chartered chemical engineer with +10 years experience in engineering consultancy
• Has undertaken technical due diligence, feasibility studies, conceptual design and design review of numerous thermal and renewable energy projects globally
• Experience covers UK, Continental Europe, Asia, Middle East, North and Latin America
• Manager of Mott MacDonald’s power team in Bangkok
• Project manager of IEA GHG study on ‘CO₂ capture in cement study’ in 2008
• Cement Sector leader for UNIDO Global Technology Roadmap for CCS in Industry in 2010
• Project manager for feasibility study stage of Longannet UK CCS competition entry in 2008-2009

duncan.barker@mottmac.com
Tel. +66 (0)2643 8648
Outline

• Introduction to Mott MacDonald
• CO₂ capture at cement plants
  – Post-combustion capture
  – Oxy-combustion capture
  – Status update
• Published cost data
• Costing approach & challenges in IEA GHG study
• Concluding remarks
• Q&A
Who is Mott MacDonald?

One of the world’s largest management, engineering and development consultancies
What we do…

Construction economics
Project finance
Programme management
Design
Management consultancy
Capacity building
Planning
Technical advisory
... and the sectors we do it in

- OIL AND GAS
- COMMUNICATIONS
- HEALTH
- EDUCATION
- URBAN DEVELOPMENT
- TRANSPORT
- BUILDINGS
- WATER
- ENERGY
- ENVIRONMENT
- INTERNATIONAL DEVELOPMENT
- INDUSTRY
Comprehensive Suite of CCS Services

• Worldwide experience for both power and non-power CCS applications e.g. cement industry, oil and gas sector, etc.
• Understanding of the whole CCS chain from source to sink
• Plus development and delivery of End to End CCS solutions
• Technical, commercial and environmental advisory capability across the entire sectors involved: power, oil and gas, chemical, process and general major projects
• Broad range of services offered:
  – Technical (advisory, concept/studies, reviews, FEED/detailed design, overall project management, project integration, OE/EPCM, etc.)
  – Non-technical (legislation, policies, financial and economic modelling, carbon management strategies, etc.)
Mott MacDonald Track Record

- **UK CCS Commercialisation Programme, DECC** - Technical Advisory Services
- **NER300 Technical Advisory Services, DECC**
- **Gassnova Framework Agreement** - Technical Advisory Services including Contract administration, Procurement support – including industrial CCS
- **EUTREN monitoring project, European Commission** – monitored the implementation of CCS projects financed under EEPR
- **CCS cost analysis for cement industry, Confidential client**
- **UK Electricity Generation Costs Update, DECC, UK**
- **Projected generation costs in the UK to 2050, Committee of Climate Change**
- **Levelised cost of power generation, DECC, UK**
- **CO₂ Capture as a Factor in Power Station Investment Decisions, IEA GHG**
- **Potential cost reductions in CCS in the power sector, DECC, UK**
- **Long run power and carbon prices, various clients**
- **CO₂ capture in the cement industry** – Comparative study of providing oxy- and post-combustion capture at a new-build cement plant. Conceptual designs, process modelling, analysis of costs and financial modelling
- **Global technology roadmap for CCS Industry, UNIDO**
Mott MacDonald Track Record

- **Norway CCS Strategy, Gassnova**
- **Longannet CCS Project, Scottish Power** – Concept design work for the power station site, consolidation and assessment of the initial End-to-End CCS chain solutions. Overall system integrator and delivery management during FEED
- **Longannet CCS Project, Aker Clean Carbon** – Detailed design for the interconnections between the power plant and capture plant during FEED
- **Carbon Capture Ready UMPP, India** – Feasibility study of developing UMPPs (9 x 4,000 MWe) as carbon capture ready. Conceptual design, techno-economic modelling, investment appraisal and evaluation of risks and sensitivities.
- **Conceptual CCS retrofit design for two UMPPs, India** – Development of plant-specific carbon ‘capture-ready’ design measures and associated guidance for their implementation for the plant owner’s design team.
- **Feasibility Study for CDM Projects in Dubai, UAE** – Conceptual design for post-combustion CO₂ capture at two DEWA CCGT facilities, environmental impact with respect to local legislation, assessment of potential CO₂ off-takers for EOR use
- **Various Confidential Clients, UK** – Feasibility study of providing post-combustion CO₂ capture at new CCGT plants – compliance with EU CCS Directive
Carbon capture at cement plants

- Cement industry accounts for 2 billion tonnes of CO$_2$ emissions per year (~5% of all emissions)
- 0.6 – 1.0 tCO$_2$/tonne of cement
- CO$_2$ emitted:
  - 50% from calcination of calcium carbonate to calcium oxide
    \[ \text{CaCO}_3 \rightarrow \text{CaO} + \text{CO}_2 \]
  - 40% from fuel (Coal/Pet coke/Tyres/Waste Oil/Solvents/Sewage Sludge etc.)
  - 10% from electricity and transportation
- Pre-combustion capture not viable
- Exhaust gases contain ~25% CO$_2$ compared to ~12% CO$_2$ for coal-fired power plants and ~4% CO$_2$ for gas-fired power plants
- 95% of calcination occurs in precalciner and 60% of fuel used in precalciner i.e. majority of CO$_2$ emitted from precalciner
Cement Plant (No CCS)

Graphic taken from ECRA website (http://www.ecra-online.org/226/)
Cement Plant (Post Combustion Capture)

Graphic taken from ECRA website (http://www.ecra-online.org/226/)
Cement Plant (Full Oxy-combustion Capture)

Graphic taken from ECRA website (http://www.ecra-online.org/226/)
Cement Plant (Full Oxy-combustion Capture)

- **CO₂ rich stream**
- **Exhaust Gas Cleaning**
- **Exhaust Gas Condition**
- **Exhaust Gas Cleaning**
- **Fuel Preparation**
- **Raw Mill**
- **Preheater**
- **Precalciner**
- **Rotary Kiln**
- **Cooler**
- **Air Separation Unit**

- **Air intake**
- **Fuel (solid)**
- **Raw meal/clinker**
- **Inert air**
- **Non-inert air**
- **Oxygen**
- **N₂**
Cement Plant (Partial Oxy-combustion Capture)

- Maximum capture is approx. 75% of CO$_2$ generated
Status update - highlights

- IEA GHG sponsored study in 2008
- UNIDO / IEA roadmap for CCS in industrial applications in 2011
- Ongoing ECRA CCS Project
  - Phases I to III complete
  - Phase IV due to complete mid-2015
  - Phase V is for implementation of a demonstration plant
- Norcem is progressing pilot scale post-combustion projects at Brevik cement works, Norway
  - Aker Solutions (Amine scrubbing)
  - DNV KEMA (Gas separation membranes)
  - RTI International (Solid sorbent)
  - Alstom (Hot carbonate looping)*
  - Trails to continue until 2016

*At University of Darmstadt, Germany
## Post-Combustion Retrofit Cost Data

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Norwegian Kroner (NOK)</th>
<th>Euro (€)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total equipment cost</td>
<td>255M</td>
<td>32M</td>
</tr>
<tr>
<td>Total investment cost</td>
<td>877M</td>
<td>111M</td>
</tr>
<tr>
<td>Total variable operating costs</td>
<td>212M</td>
<td>27M</td>
</tr>
<tr>
<td>Fixed operating costs</td>
<td>40M/y</td>
<td>5M/y</td>
</tr>
<tr>
<td>Total cost per capture</td>
<td>360/t of CO(_2)</td>
<td>46/t of CO(_2)</td>
</tr>
</tbody>
</table>

- Hegerland *et al.* (2006)
- Retrofit at a 1.4 Mt/y cement plant in Norway
- Reported accuracy was ±35%
# Post-combustion New Build Cost Data

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Without CCS (European scenario)</th>
<th>With post-combustion capture (European scenario)</th>
<th>With post-combustion capture (Asian Developing Country scenario)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total investment cost</td>
<td>€M</td>
<td>263</td>
<td>558</td>
<td>n/a</td>
</tr>
<tr>
<td>Net variable operating costs</td>
<td>€M/y</td>
<td>17</td>
<td>31</td>
<td>n/a</td>
</tr>
<tr>
<td>Fixed operating costs</td>
<td>€M/y</td>
<td>19</td>
<td>35</td>
<td>n/a</td>
</tr>
<tr>
<td>Cost per tonne of CO(_2) emissions avoided</td>
<td>€/t</td>
<td>n/a</td>
<td>107.4</td>
<td>58.8</td>
</tr>
<tr>
<td>Costs per tonne of cement product</td>
<td>€/t</td>
<td>65.6</td>
<td>129.4</td>
<td>72.2</td>
</tr>
<tr>
<td>Cost per tonne of CO(_2) captured</td>
<td>€/t</td>
<td>n/a</td>
<td>59.6</td>
<td>n/a</td>
</tr>
</tbody>
</table>

- IEA GHG (2008)
- Post-combustion plant using MEA
- European scenario based on 1 Mt/y cement plant in UK
- Asian Developing Country scenario based on 3 Mt/y cement plant
- Reported accuracy was ±25%
## Further Post-Combustion Cost Data

<table>
<thead>
<tr>
<th>Year</th>
<th>New installation</th>
<th>Retrofit</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>2030</td>
<td>100 to 300</td>
<td>10 to 50</td>
</tr>
<tr>
<td>2050</td>
<td>80 to 250</td>
<td>10 to 40</td>
</tr>
</tbody>
</table>

- ECRA (2009)
- Post-combustion capture using absorption technologies
- A learning rate of 1% per year is considered for the period between 2030 and 2050
- “Rough estimations” based on IEA and McKinsey studies
## Oxyfuel Cost Data

<table>
<thead>
<tr>
<th>Year</th>
<th>New installation</th>
<th>Retrofit</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>2030</td>
<td>330 to 360</td>
<td>Plus 8 to 10 compared to conventional kiln</td>
</tr>
<tr>
<td>2050</td>
<td>270 to 295</td>
<td>Plus 8 to 10 compared to conventional kiln</td>
</tr>
</tbody>
</table>

- ECRA (2009)
- Clinker capacity of 2 Mt/y
- A learning rate of 1% per year is considered for the period between 2030 and 2050
- Operational costs expressed as additional costs compared to a conventional kiln
- Retrofit refers to oxyfuel operation of calciner only i.e. only 60% reduction of total CO₂ emissions
- “Huge uncertainty of the cost estimation from the incomplete developed technology”
## Partial Oxyfuel New Build Cost Data

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Without CCS (European scenario)</th>
<th>With oxyfuel capture (European scenario)</th>
<th>With oxyfuel capture (Asian Developing Country scenario)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total investment cost</td>
<td>€M</td>
<td>263</td>
<td>327</td>
<td>n/a</td>
</tr>
<tr>
<td>Net variable operating costs</td>
<td>€M/ y</td>
<td>17</td>
<td>23</td>
<td>n/a</td>
</tr>
<tr>
<td>Fixed operating costs</td>
<td>€M/ y</td>
<td>19</td>
<td>23</td>
<td>n/a</td>
</tr>
<tr>
<td>Cost per tonne of CO$_2$ emissions avoided</td>
<td>€/t</td>
<td>n/a</td>
<td>42.4</td>
<td>22.9</td>
</tr>
<tr>
<td>Costs per tonne of cement product</td>
<td>€/t</td>
<td>65.6</td>
<td>82.5</td>
<td>46.4</td>
</tr>
<tr>
<td>Cost per tonne of CO$_2$ captured</td>
<td>€/t</td>
<td>n/a</td>
<td>36.1</td>
<td>n/a</td>
</tr>
</tbody>
</table>

- IEA GHG (2008)
- European scenario based on 1 Mt/y cement plant in UK
- Asian Developing Country scenario based on 3 Mt/y cement plant
- Reported accuracy was ±25%
Costing Approach used in IEA GHG study

Overall
• Assumptions validated by British Cement Association (BCA) [now Mineral Products Association, MPA] which included cement plant owners
• Mott MacDonald partnered with a specialist cement industry consultant to get valuable input on latest cost data for new build cement plant

Capital Costs
• Budgetary inputs supplied by a cement plant equipment supplier
• Other costs scaled from published information and Mott MacDonald in-house database
• Typical methods included
  – Power law (exponential) estimating
  – Cost indices
  – Standard factors e.g. insurance, contingencies
Costing Approach used in IEA GHG study

Operating Costs

• Variable operating costs
  – Unit prices (e.g. limestone, fuel, power) obtained from suppliers or from benchmarking against existing cement plants and other IEA GHG studies
  – Consumption/performance based on process modelling

• Fixed operating costs
  – Benchmarked against existing cement plants and other IEA GHG studies
Challenges faced in IEA GHG study

- Very limited published data
  - Danger of ‘group think’
- Potential bias of supplier/cement plant operator inputs given different agendas
- Developing an accurate cost estimation requires significant time and money

<table>
<thead>
<tr>
<th>Nomenclature</th>
<th>Probable range of accuracy</th>
<th>Cost as % of project expenditure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detailed estimate</td>
<td>±2 to ±5%</td>
<td>5 to 10%</td>
</tr>
<tr>
<td>Definitive estimate</td>
<td>±5 to ±15%</td>
<td>1 to 3%</td>
</tr>
<tr>
<td>Preliminary estimate</td>
<td>±10 to ±25%</td>
<td>0.4 to 0.8%</td>
</tr>
<tr>
<td>Study estimate</td>
<td>±20 to ±30%</td>
<td>0.1 to 0.2%</td>
</tr>
<tr>
<td>Order of magnitude estimate</td>
<td>±30 to ±50%</td>
<td>0 to 0.1%</td>
</tr>
</tbody>
</table>

- Site specific issues critical
  - E.g. land costs, type of raw limestone, access to utilities
- Engineering judgment (subjective) used where limited data available
Important future developments relating to costs

• ECRA Phase IV has the following components:
  – Pre-engineering study that will derive the first cost figures for a retrofitted full oxyfuel plant
  – Capital and operational costs will be derived

• Brevik project
  – Performance data (if published) will help to determine performance parameters and operating costs

• JRC - Techno-economic assessment of European Carbon Capture Utilisation (CCU) pathways: operational, environmental and cost performance - market opportunities (ongoing)

• BIS/DECC – Techno-Economic Study of Industrial Carbon Capture for Storage and Capture for Utilisation (tender stage)
Concluding Remarks

- Platform of studies already undertaken on CO₂ capture in cement industry
- Post-combustion and oxy-combustion both offer options for industry as new-build and retrofit
- Several important projects underway which will improve estimates of performance and cost
- Accuracy of cost estimation requires time and costs money
- Site specific issues can significantly influence costs
- Important to gain input from independent experts to reduce potential bias
- Ultimately the price will be what a contractor is willing to bid the job for!
Questions & Discussion

For further information please contact:

duncan.barker@mottmac.com

A copy of the IEA GHG report on ‘CO$_2$ capture in the cement industry’
can be obtained from:

sian@ieaggh.org