CALCIUM LOOPING CAPTURE IN THE CEMENT INDUSTRY – CEMCAP CONCLUSIONS

G. Cinti\textsuperscript{1}, R. Mathai\textsuperscript{2}, S. Becker\textsuperscript{2}, M. Alonso\textsuperscript{3}, C. Abanades\textsuperscript{3}, E. De Lena\textsuperscript{4}, M. Spinelli\textsuperscript{4}, M. Gatti\textsuperscript{4}, S. Campanari\textsuperscript{4}, S. Consonni\textsuperscript{4}, M. Romano\textsuperscript{4}, M. Hornberger\textsuperscript{5}, R. Spörl\textsuperscript{5}

\textsuperscript{1} Italcementi, Bergamo, Italy
\textsuperscript{2} IKN GmbH, Neustadt, Germany
\textsuperscript{3} Agencia Estatal Consejo Superior de Investigaciones Científicas (CSIC), Madrid, Spain
\textsuperscript{4} Politecnico di Milano, Milan, Italy
\textsuperscript{5} Institute of Combustion and Power Plant Technology (IFK), University of Stuttgart, Stuttgart, Germany

2nd ECRA/CEMPCAP/CLEANER workshop: Carbon Capture Technologies in the Cement Industry
Brussels, 17 October 2018
Calcium Looping process fundamentals

**Carbonation**

\[
\text{CaO} + \text{CO}_2 \rightarrow \text{CaCO}_3 \\
\sim 650 \degree C
\]

- Heat
- \(\text{CO}_2\)-lean flue gas
- CaCO₃

**Calcination**

\[
\text{CaCO}_3 \rightarrow \text{CaO} + \text{CO}_2 \\
\sim 900 \degree C
\]

- Heat
- \(\text{CO}_2\)-rich gas to sequestration
- CaO purge
- CaCO₃ make-up
- CaO (\(F_R\))
- Flue gas (\(F_{CO2}\))
Calcium Looping for CO$_2$ capture: history

- Continuously developed since 1998, mainly for application in power plants
- Several fluidized bed pilot facilities - demonstrated up to 1.7 MW
Calcium Looping for cement plants

1. **Cement plant-power plant coupling**: CaO-rich spent sorbent from a CaL power plant as feed for the cement plant, as substitute of CaCO$_3$

2. **Post-combustion “tail end” configuration**: CaL process is integrated in the cement plant with a conventional post-combustion capture configuration

3. **Integrated CaL configuration**: the CaL process is integrated within the cement production process by sharing the same oxyfuel calciner
Calcium Looping CO$_2$ capture: Tail-end CaL configuration

General features of the process:

• Carbonator removes CO$_2$ from cement plant flue gas  
  → Easy integration in existing cement

• Limestone partly calcined in Calcium Looping calciner  
  → CaO-rich purge from CaL calciner used as feed for the cement kiln

• High fuel consumption (double calcination for the mineral CO$_2$ captured)

• Heat from fuel consumption recovered in efficient (~35% efficiency) steam cycle for power generation

• CFB CaL reactors: d$_{50}$=100-250 μm, vs. particle size for clinker production d$_{50}$=10-20 μm  
  → CaL purge milled in the raw mill at low temperature
Calcium Looping CO$_2$ capture: Tail-end CaL configuration

Conducted Work:

- Parameter screening at 30 kW scale at CSIC (TRL5)
- Demonstration at semi-industrial scale (200 kW$_{th}$) at IFK (TRL6)
- Process integration study and techno-economic analysis


Calcium Looping $\text{CO}_2$ capture: Tail-end CaL configuration

Demonstration at semi-industrial scale:

- High $\text{CO}_2$ capture up to 98% demonstrated in TRL6 facility
- The CaL design parameters for cement plant applications are in good agreement with the design parameters for power plant operation.
- Tail-end CaL ready for demonstration at TRL7-8.
Calcium Looping CO$_2$ capture: integrated configuration

**General information:**
- CaL calciner coincides with the cement kiln pre-calciner
- Calcined raw meal as CO$_2$ sorbent in the carbonator
- Sorbent has small particle size ($d_{50}=10$-20 $\mu$m) $\rightarrow$ entrained flow reactors


Calcium Looping CO$_2$ capture: integrated configuration

Development of integrated CaL concept using entrained flow calciner/carbonator:

• 1D carbonator modelling showed possibility of achieving high capture efficiency with solids/gas ratio of $\sim$10 kg/Nm$^3$.
• Belite formation in calciner may cause a decrease of the sorbent CO$_2$ carrying capacity.
• Demonstration of chemistry and fluid-dynamics of the reactors in industrially relevant conditions needed.

Spinelli et al., 2018. One-dimensional model of entrained-flow carbonator for CO$_2$ capture in cement kilns by calcium looping process. Chemical Engineering Science, 191, 100-114.
# Mass and energy balance

## Mass and Energy Balance Table

<table>
<thead>
<tr>
<th></th>
<th>Cement plant w/o capture</th>
<th>Tail-end CaL (20% integration)</th>
<th>Tail-end CaL (50% integration)</th>
<th>Integrated CaL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbonator CO₂ capture efficiency [%]</td>
<td>--</td>
<td>88.8</td>
<td>90.0</td>
<td>82.0</td>
</tr>
<tr>
<td>Total fuel consumption [MJ LHV/t clk]</td>
<td>3240</td>
<td>8720</td>
<td>7100</td>
<td>5440</td>
</tr>
<tr>
<td>Rotary kiln fuel consumption [MJ LHV/t clk]</td>
<td>1230</td>
<td>1220</td>
<td>1220</td>
<td>1150</td>
</tr>
<tr>
<td>Pre-calciner fuel consumpt. [MJ LHV/t clk]</td>
<td>2010</td>
<td>1550</td>
<td>850</td>
<td>4290</td>
</tr>
<tr>
<td>CaL calciner fuel consumpt. [MJ LHV/t clk]</td>
<td>--</td>
<td>5950</td>
<td>5040</td>
<td></td>
</tr>
<tr>
<td>Net electricity consumpt. [kWh el/t cem]</td>
<td>97</td>
<td>-81</td>
<td>42</td>
<td>117</td>
</tr>
<tr>
<td>Direct CO₂ emissions [kg CO₂/t clk]</td>
<td>865</td>
<td>119</td>
<td>79</td>
<td>55</td>
</tr>
<tr>
<td>Indirect CO₂ emissions [kg CO₂/t clk] *</td>
<td>35</td>
<td>-29</td>
<td>15</td>
<td>46</td>
</tr>
<tr>
<td>Equivalent CO₂ emissions [kg CO₂/t clk]</td>
<td>900</td>
<td>90</td>
<td>94</td>
<td>101</td>
</tr>
<tr>
<td>Equivalent CO₂ avoided [%]</td>
<td>--</td>
<td>90.0</td>
<td>89.5</td>
<td>88.8</td>
</tr>
<tr>
<td>SPECCA [MJ LHV/kg CO₂] **</td>
<td>--</td>
<td>4.42</td>
<td>4.07</td>
<td>3.16</td>
</tr>
</tbody>
</table>

* Evaluated with the average EU-28 electricity mix: η_e = 45.9%, E_CO₂,e = 262 kg/MWh

** Specific primary energy consumption for CO₂ avoided

---

Cost of CO$_2$ avoided = 50-55 €/t$_{CO2}$, mainly due to Capex.
Conclusions and outlook

Ca-LOOPING PROCESS INTEGRATION OPTIONS:

1. Post-combustion capture configuration:
   - Low uncertainty in the technical feasibility ✓
   - Very high CO\(_2\) capture expected ✓
   - Two calciners are present in the system, leading to high fuel consumptions ✗

2. Integrated CaL configuration:
   - High CO\(_2\) capture efficiency without modifying rotary kiln operation (no need of kiln oxyfiring). ✓
   - Higher thermal efficiency and lower fuel consumptions ✓
   - New carbonator design and fluid-dynamic regime: fluid-dynamics, heat management and sorbent performance need validation ✗

- Competitive cost of CO\(_2\) avoided. ✓
CEMCAP Partners

Cement Producers

Italcementi HEIDELBERGCEMENT Group
NORCEM HEIDELBERGCEMENT Group
HEIDELBERGCEMENT

Technology providers

GE
IKN
thyssenkrupp

R&D providers

SINTEF
ecra
TNO innovation for life
ETH zürich
University of Stuttgart
POLITECNICO MILANO 1863
CSIC
vdz.

Coordinated by SINTEF
Acknowledgements

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement no 641185

This work was supported by the Swiss State Secretariat for Education, Research and Innovation (SERI) under contract number 15.0160

www.sintef.no/cemcap

Twitter: @CEMCAP_CO2