The current state of CO$_2$ utilization

- Overview
- EOR with CO2
- Building materials
- Outlook
How does CCU factor into emissions mitigation strategies?

Pros: Revenue for captured CO2, market entry & demonstration

Barriers: Unproven technologies, uncertain energy balances, CO2 scarcity
EOR with CO2 represented 6% of US crude oil production in 2012

- 130 CO2-EOR projects operating in US as of 2012
- 64 Mt CO2 used in EOR in 2010
- Carbon neutral oil: assuming closed loop operation where 1 metric ton of captured CO2 injected and stored for every 2.5 barrels of oil recovered
Natural CO2 sources provided 80% (49 Mt) of CO2-EOR in 2010

- How much industrial CO2 is being vented?
  - Limited CO2 transport infrastructure, Cost competitive natural source
- DOE portfolio of CCUS projected to add 14 Mt CO2 new sources by 2020
Kemper County IGCC with Precombustion CO2 Capture

Feedstock: Mississippi lignite coal
Size: 582 MW, 65% CO2 capture goal
3.5 Mt of CO2 captured annually for EOR

- $1 billion over budget, ratepayer burden looming
- $700 million in federal grant funds and tax credits averages to $10/ton captured CO2 over 20 years
- Revenue from selling CO2 for EOR is TBD
Cement manufacture makes up 5-8% of all CO$_2$ (3$^{rd}$ highest emitter) & Market to double by 2050

Annual embodied energy and CO2 emissions from common building products in US.

<table>
<thead>
<tr>
<th>Material</th>
<th>Annual U.S. Energy Consumption (MMBTU)</th>
<th>Annual U.S. CO$_2$ Emissions (MT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brick / masonry</td>
<td>86,000,000</td>
<td>6,000,000</td>
</tr>
<tr>
<td>Concrete products</td>
<td>50,000,000</td>
<td>12,000,000</td>
</tr>
<tr>
<td>Gypsum Wallboard</td>
<td>150,000,000</td>
<td>10,000,000</td>
</tr>
<tr>
<td>Cement</td>
<td>500,000,000</td>
<td>100,000,000</td>
</tr>
</tbody>
</table>

Source: NIST BEES database. Image courtesy of CalStar Products, Inc.

Portland Cement Production

Clinker: $3\text{CaO} \cdot \text{SiO}_2$

**CO$_2$ sources:**
- Chemistry $\sim$ 55%
  \[ \text{CaCO}_3 \rightarrow \text{CaO} + \text{CO}_2 \]
- Fuel $\sim$ 45%

**Total $\sim 0.8$ t / t clinker**
- $\sim$ 0.8-0.9 ton of CO$_2$ per 1 ton of cement
Alternatives to Ordinary Portland Cement

- Binding phase based on carbonation vs. Hydration
  - CCS Materials, Piscataway, NJ funded by DOE NETL

- Carbonates as Supplementary Cement Materials

- Geopolymer cement
  - Highly crosslinked gel structure (pseudo-zeolitic)
  - Waste products as precursors: Fly ash and slag
  - Growing academic research efforts
  - Commercial application: Zeobond (AUS)

Niche applications & formidable challenges to scaling

• Reduced mechanical strength with carbonate additives
• Durability of carbonation and geopolymer
  – Gel stability &
• Must meet ASTM standards (or modify prescriptive code)
Outlook

Opportunities to demonstrate ‘distributed’ direct air capture at CO2-EOR sites [and carbonated building material manufacture]

Robust MVA regulations required for CO2-EOR

Limited progress with scale-up of CCUS points to the need to pursue negative emissions mitigation strategies