CCS in Industrial Processes

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IEA Greenhouse Gas R&D Programme (IEAGHG)

- A ‘Multilateral Technology Initiative’ based in the UK, established in 1991 by the International Energy Agency
- **Aim:** To provide information on the role that technology can play in reducing greenhouse gas emissions from use of fossil fuels. Objective, independent, policy relevant but not policy prescriptive
- **Focus on CCS**
- **Activities:**
  - Technical studies - over 250, freely available to our member countries
  - Organise networks of researchers, conferences and summer schools
  - Provide information to policy makers and regulators
Industrial Sources of CO$_2$

- About a quarter of global emissions
- A large proportion of emissions are in developing countries

Source: IEA/UNIDO Technology Roadmap, Carbon capture and storage in industrial applications, 2011
Cement Production

- Around 60% of the CO₂ is from decomposition of limestone
- Cannot be avoided by use of non-fossil energy sources

\[
\text{CaCO}_3 \rightarrow \text{CaO} + \text{CO}_2
\]

- Mill and drier
- Preheaters (multiple stages)
- Calciner
- Precalculer
- Rotary kiln
- Mill and drier

Cement

Additives

Fuel

1350°C

E.g. CaO + SiO₂ etc \rightarrow \text{calcium silicates etc}

Limestone etc.

Flue gas

Fuel

900°C
Post Combustion Capture
Solvent scrubbing

Air
Fuel
Raw meal
Clinker

Cement plant

24% CO₂

ESP, SCR, FGD

CO₂-reduced flue gas

Coal

CHP plant

Power

CO₂ to storage

Steam

Solvent stripping

Solvent scrubbing

CO₂ compression
Post-combustion Capture

- Advantages for cement plants
  - Flue gas CO$_2$ concentration is high (around 24%vol.)
    - Advantageous, particularly for alternative capture technologies
  - 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 CO$_2$ can be transported off site

- Disadvantages
  - A large quantity of low pressure steam is needed for solvent stripping, requiring an on-site CHP plant
    - Coal is usually available at cement plants but coal CHP plants have relatively high investment costs and high emissions
    - Natural gas CHP plants have lower investment costs
Oxy-Combustion Capture
Precalciner and kiln

- Raw meal → Raw Mill → Preheater → Precalciner → Kiln → Clinker
- Flue gas → Preheater → Precalciner
- Recycled flue gas → Purification/compression
- CO₂ → Purification/compression
- Vent gas → Purification/compression
- Fuel → Preheater → Precalciner → Kiln
- Hot gas → Kiln
- Oxygen → Air separation
- Air → Air separation
Oxy-combustion Capture
Pre-calciner only

Flue gas

Raw meal → Raw Mill → Preheater 1 → Preheater 2 → Precalciner → Kiln → Clinker

Fuel → Hot gas

Recycled flue gas

CO₂

Purification/compression → Air separation

Oxygen

Air

Vent gas
Oxy-combustion Capture

• Advantages for cement plants
  • Low oxygen consumption
    o 1/3 of the amount of O$_2$ is needed per tonne of CO$_2$ captured, compared to a coal fired boiler
  • Potentially low cost process

• Disadvantages
  • Retrofit may be more difficult
  • Involves changes to the core cement process
    o Impacts on plant design and chemistry etc.
Status of Cement Plant CCS

- **Post combustion capture**
  - Test centre for small scale and pilot trials at a cement plant, Norcem, Brevik, Norway
    - Amine scrubbing, Dry adsorption, Membranes, Ca looping
  - ITRI/Taiwan Cement Corp.
    - 1t/h CO$_2$ calcium looping unit
  - Skyonic Corp, Texas
    - 83 kt/y CO$_2$ plant at a cement plant, NaOH + CO$_2$ → NaHCO$_3$

- **Oxy-combustion**
  - Laboratory studies – ECRA, Germany
  - Pre-calciner pilot plant, Denmark,
    - Lafarge, FL Smidth, Air Products, c1t/h CO$_2$
Oil Refineries

- Many CO\(_2\) emission sources
- Complex plants - all are different
- Space can be a constraint for retrofits
- Design standards for capture plants at refineries may be different to power plants
  - Potentially higher costs
Hydroskimming/Topping Refinery

Simple, low upgrading capability refineries run sweet crude
Medium Conversion: Catalytic Cracking

Moderate upgrading capability refineries tend to run more sour crudes while achieving increased higher value product yields and volume gain.
High Conversion: Coking/Resid Destruction

Complex refineries can run heavier and more sour crudes while achieving the highest light product yields and volume gain.
Emissions from Simple and Complex Refineries

Hydroskimming refinery, 0.6 Mt/a CO₂

- Off sites, 18.0%
- Sulphur recovery, 0.4%
- Hydrotreating, 5.4%
- Alky/Isom, 3.0%
- Cat. Reformer, 20.3%

Conversion refinery, 1.4 Mt/a CO₂

- Off sites, 11.7%
- CDU, 52.9%
- Hydrogen, 20.6%
- Sulphur recovery, 0.6%
- Hydrotreating, 5.3%
- Alky/Isom, 5.5%
- Cat. Reformer, 9.8%
- FCC, 21.7%
- VDU, 6.4%

CDU: Crude distillation unit
VDU: Vacuum distillation unit
FCC: Fluid catalytic cracker

Data from CONCAWE 2011
CO$_2$ Capture at Refineries

- Post combustion capture
  - Fired heaters, fluid catalytic cracker and utility steam and power generation
  - Centralised solvent stripping may be feasible

- Pre-combustion capture
  - Hydrogen plants (steam reforming, residue gasif.)
  - Hydrogen could also be used in fired heaters and utility steam and power generation

- Oxy-combustion
  - Fired heaters and steam/power generation
  - Fluid catalytic crackers
Capture from Refinery Flue gas Test Centre Mongstad, Norway

- 2 capture plants: Amine and Chilled Ammonia processes
- 100,000t/y CO₂ capture
- Flue gases from the refinery:
  - Combined cycle power plant
  - Fluid catalytic cracker
Oxy-Combustion FCC

- Retrofit at Petrobras research facility, Brazil
- 1t/d CO₂
- Operated 2011-12
- CCP consider oxy-combustion to be viable and competitive with post combustion capture for FCCs

Courtesy: CCP / Petrobras
Capture at a Hydrogen Plant
Air Products, Port Arthur, Texas

- Capture retrofit to 2 steam methane reformer units
- Vacuum swing adsorption process
- 1Mt/y CO$_2$ for EOR
- >90% CO$_2$ capture
- Started operation Dec. 2012 / March 2013
Capture at a Hydrogen Plant
Shell Quest Project, Canada

- Capture of CO₂ from 3 steam methane reformer units
- H₂ provided to the Athabasca Oil Sand Upgrader
- Shell amine technology (ADIP-X system based on MDEA/Pz)
- ~1.2 million tonne of CO₂/y
- Saline Aquifer with potential EOR application
- Operation starts 2015/16
Natural Gas Processing

- CO₂ sometimes has to be separated from natural gas to satisfy purity standards.
- Separation is usually by amine scrubbing, e.g. MDEA.
- Physical solvents and low temperature separation are also used for high CO₂ gas.
- CCS is a low cost “Low hanging fruit”
  - CO₂ just has to be compressed and dried.
- Several million tonnes/year of CO₂ separated from natural gas is used for EOR.
- CO₂ is also used for storage demonstration projects.
CO₂ Capture in Gas Production

Sleipner, Norway; 9% CO₂, Around 1 Mt/y CO₂ captured

Snøhvit, Norway; 5-8% CO₂, Around 0.7 Mt/y CO₂ captured

In Salah, Algeria; up to 10% CO₂, Around 1.2 Mt/y CO₂ captured

LaBarge, USA; 65% CO₂, Around 6 Mt/y CO₂ captured and used for EOR
Other High Purity CO$_2$ Sources

- Bio-ethanol production
  - Dacatur project, USA, 1Mt/y CO$_2$

- Synthetic natural gas from coal
  - Dakota Gasification plant, USA, ~2.5Mt/y CO$_2$

- Coal-based chemicals plants
  - Coffeyville ammonia plant, USA, ~0.7Mt/y CO$_2$
  - Many Chinese coal to chemicals plants
Capture at Iron and Steel Plants

- Some of the world’s largest sources of CO₂
- Steel plants are complex integrated plants with many sources of emissions
- Blast furnaces are the core of most large plants
  - Chemical reduction of iron oxide to iron
  - The focus of capture R&D, e.g. Europe (ULCOS project), Japan (COURSE 50 project), and Korea
- New iron and steel processes with integrated capture are being developed
Oxy-Blast Furnace
Top Gas Recycling

Coke

Top gas (CO, CO2, H2, N2)

Gas cleaning

CO2 scrubber

CO2

CO, H2, N2

Gas heater

Oxygen

PCI

Re-injection

Courtesy: Tata Steel
Technical Issues for CCS in Industries

- CO\textsubscript{2} capture technologies are well proven for some industries but not others
- Need to demonstrate CCS, particularly in cement, iron and steel and refineries
  - Different CO\textsubscript{2} concentrations and pressures
  - Impacts of different impurities
  - Operational profiles etc.
  - Develop and demonstrate new processes with integrated CO\textsubscript{2} capture
- Learn from technology demonstrations in the power sector
Costs of CCS in Industries

- Shortage of information on industrial CCS costs
  - Especially for developing countries, where most industrial emissions occur
- Estimating costs is difficult
  - Different costs for each CO$_2$ source at each site
  - Partial capture of CO$_2$ at a site may be preferred
Industrial CCS Costs

CO₂ that could be captured at a representative industrial site (and as % of total site emissions)

- Refining
- Iron and steel
- Chemicals
- Gas processing
- Pulp and paper
- Cement
- Biofuels
- Aluminium

Note: arrows represent data given by literature data. Dotted lines are ranges from selected studies.

IEA CCS Technology Roadmap 2013
Economics of Industrial CCS

• Some industrial capture is already economic
  • $\text{CO}_2$ is sold, particularly for EOR
• Economic incentives for industrial CCS without $\text{CO}_2$ utilisation in most countries are low or zero
• High potential for “leakage”
  • Industrial products are traded globally, unlike electricity
  • Transfer of production to countries with low GHG abatement requirements may be the most attractive choice for industries
• A significant challenge for policymakers
Conclusions

• Technology status
  • CO₂ is already captured in some industries but is at a relatively early stage of development in other industries
  • Further R&D and demonstration is needed, particularly for iron and steel, cement and oil refineries
  • Industries can learn from deployment of CO₂ capture technologies in the power industry

• Economics
  • Industrial CCS cost estimates have high uncertainties
  • EOR can make some industrial CCS economic but further incentives are needed in most cases
  • Agreements are needed to minimise the risk of industries re-locating to countries where CCS is not required
Thank you

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