CCS in the Process Industries

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UKCCSRC Biannual Meeting
Cranfield, UK
22nd to 23rd April 2015
2013 CCS Roadmap: Key findings

- CCS is a **critical component** in a portfolio of low-carbon energy technologies, contributing 14% of the cumulative emissions reductions between 2015 and 2050 compared with business as usual.

- The individual component technologies are generally well understood. **The largest challenge is the integration** of component technologies into large-scale demonstration projects.

- Incentive frameworks are urgently needed to deliver upwards of **30 operating CCS projects by 2020**.

- CCS is not only about electricity generation: 45% of captured CO₂ comes from **industrial applications** between 2015 and 2050.

- The largest deployment of CCS will need to occur in **non-OECD countries, 70% by 2050**. China alone accounts for 1/3 of the global total of captured CO₂ between 2015 and 2050.

- The urgency of CCS deployment is only increasing. **This decade is critical** in developing favourable conditions for long-term CCS deployment.
Rationale for CCS:
Only large-scale option for many industries.

CCS is the only large-scale mitigation option for many industrial sectors.
EU Zero Emission Platform Report 2013

- EU 2011 Roadmap for a competitive low carbon economy in 2050,
- Emission reductions will be required to take place in all sectors,
- CO₂ emissions from the industrial sectors reduced by 34% to 40% by 2030, and by between 83% to 87% by 2050.
- Only CCS can provide the required large-scale emission reductions in EU industry.
Early Commercial Application of CCS (Monitored)

- Sleipner: 1Mt/y CO₂ (1998)
- Weyburn: 2.5 Mt/y CO₂ (2000)
- In-Salah: 1.2 Mt/y CO₂ (2004)
- Snohvit: 0.7 Mt/y CO₂ (2002)
- Gorgon: 4 Mt/y CO₂ (2010)

- 350km overland pipeline
- 160km sub sea pipeline

Timeline:
- 1996
- 1998
- 2000
- 2002
- 2004
- 2006
- 2008
- 2010
- 2012
- 2014
- 2016
- 2018
Industry Sector drivers

- CO₂ removed to meet pipeline standards
  - High purity CO₂ stream
- Additional costs of injection low relative to power plant
  - Norway = offshore emission tax $35/t
- CO₂ capture plants in close proximity to storage resources
- Industry has gas injection/storage reservoir expertise
Outcomes and Developments

- Sleipner nearly 20 years continuous operation
  - Follow monitoring developments
    - IEAGHG Monitoring Network meetings
    - International Journal of Greenhouse Gas Control
- Sleipner, Snohvit, In-Salah, Gorgon all use Amine scrubbing technology
  - Land or platform based
- Lula project – uses membrane technology for CO₂ separation
  - Modular lighter design for use on the floating platform
- IEAGHG study currently underway that is looking at new capture technology options for gas processing
  - Cost, size etc.
  - Published - 3rd Quarter 2015
- Potential new developments in South East Asia
EU Industry considerations

- Core business is making globally competitive products e.g. steel, cement, chemicals......
- Is there a business case for CCS in industry?
  - Probably not – price on CO2 currently too low
- Industry has no experience of transport and storage
  - same as power sector initially
- Ideally would like a storage company to handle out of gate storage
  - No market outside North America such as EOR
  - In EU therefore no such companies currently exist
Infrastructure considerations

- Each industrial site will be site specific
  - No generalities possible like CCS Ready Guidelines for Power sector
- Need a gas gathering system?
  - More than one stack
  - Central capture plant or multiple?
  - Or do you target most competitive single source – 45% capture enough?
- Development of transport infrastructure
  - Strategic planning?
  - Who pays?
    - NER400 in Europe?
    - CO2-EOR operators/companies in North America
- Project Clusters have significant potential going forward
  - Waste heat utilisation and process cost savings
  - Pipeline accessibility
IEAGHG CCS Cluster Project

Capacities of CCS clusters present, planned and projected

- Projected Ultimate
- Tranche 2
- Tranche 1
- Initial "anchor" capture projects
- Separation from NG progressing
- Separation from NG operational
- Natural CO2
Study Outcomes

Most successful Cluster projects are based on CO$_2$ EOR application.

Cost reduction can be achieved by combining infrastructure e.g. CO$_2$ pipeline and pooling services (maintenance and operation of capture facility).

Long term funding is required, in order to maintain momentum in the project and keep the key staff members.

Good CCS cluster locations should be in the position to attract international funding.

It is required to develop a mechanism and structure of international investment to widen the support for cluster projects.
Heavy Industry CCS activities

- **Steel sector**
  - 1st Steel industry CCS workshop with VDEH in Germany in November 2011
  - Techno-economic assessment of CCS in steel sector – completed 2013
    - Included a case evaluating Oxy-Blast Furnace with TGR & MDEA CO2 Capture
  - Overview of the current state and future development of CO2 capture technologies in the Iron Making Process, TR3, April 2013
  - 2nd Steel industry CCS workshop in Japan November 2013 – collaboration with WSA and IETS

- **Cement Industry**
  - Techno-economic assessment completed in 2008
  - Studies on barriers to implementation completed in 2013 (with GCCSI)

- **Oil Refining Sector**
  - Techno-economic assessment to underway
    - Report due mid 2016

- **Industrial sources of Hydrogen**
  - State of the art review completed
  - Techno-economic assessment now underway – due mid 2015
Costs of CO2 Capture

- Costs estimated for a 1Mt/y cement plant in N-W Europe
- Post combustion capture (PCC)
  - €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
  - €60/t CO2 emissions avoided
- Capture costs for PCC could be reduced by up to 50% if waste heat could be integrated from other sources
- At a larger Asian type plant 3 Mt/y costs could be 30-40% lower than EU case
  - Oxy fuel case - €23/t CO2 emissions avoided
CO₂ Capture at Cement Plants
Oxy-combustion Pilot Plant Project

- Feasibility of oxy-combustion at cement plants investigated by Lafarge, FLSmidth and Air Liquide
- Pre-calciner pilot plant at Dania, Denmark successfully modified and operated with oxy-combustion
  - 2-3t/h raw meal (~1t/h CO₂)
  - Pre-calciner accounts for 90% of CO₂ from carbonate decomposition and 60% of fuel-derived CO₂ from a cement plant
- Feasibility and costs of retrofitting oxy-combustion calciner to Lafarge commercial cement plant at Le Havre was assessed
  - €62/t CO₂ captured (consistent with IEAGHG studies)
- Technology now ready to move into the demonstration phase
  - Next stage would be a 1-2 year FEED study
  - Currently no viable business case for CCS at European cement plants
ThyssenKrupp Steel Europe – Main CO₂-Emitters (schematically) up to 20 mio t CO₂ p.a.
### The 4 process routes

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<th>Natural gas</th>
<th>Electricity</th>
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<td>Pilot tests (1.5 t/h)</td>
<td>Pilot plant (8 t/h) start-up 2010</td>
<td>Pilot plant (1 t/h) to be erected in 2013?</td>
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- **CO2 Capture & Storage (CCS):**
  - **Revamped BF: ULCOS-BF**
  - **Greenfield: HIsarna**
  - **Revamped DR: ULCORED**
  - **Greenfield: ULCOWIN ULCOLYSIS**

- **Demonstration under way:**
  - Pilot tests (1.5 t/h)
  - Pilot plant (8 t/h) start-up 2010
  - Pilot plant (1 t/h) to be erected in 2013?
Oxy-Blast Furnace Operation

(Picture of OBF courtesy of Tata Steel)

**CO₂ avoided $56/t**

**Raw Materials**
- Coke 253 kg
- Sinter 1096 kg (70%)
- Pellets 353 kg (22%)
- Lump 125 kg (8%)
- Limestone 6 kg
- Quartzite 3 kg

**OBF Screen Undersize**
- 21 kg

**Oxygen**
- 253 Nm³

**Nitrogen**
- 5 Nm³

**PCI Coal**
- 152 kg

**Oxygen**
- 253 Nm³

**Nitrogen**
- 5 Nm³

**Flue Gas**
- 352 Nm³

**BF Slag**
- 235 kg

**BF Sludge**
- 4 kg

**Top Gas Cleaning**
- BF Dust 15 kg
- BF Sludge 4 kg

**Steam**
- 2.0 GJ

**OBF Process Gas**
- 938 Nm³

**Carbon Dioxide**
- 867 kg

**OBF Process Gas Fired Heaters**
- 563 Nm³
- 900ºC

**Coke 253 kg**

**Sinter 1096 kg (70%)**

**Pellets 353 kg (22%)**

**Lump 125 kg (8%)**

**Limestone 6 kg**

**Quartzite 3 kg**

**Air**
- 332 Nm³
- 1700ºC

**Natural Gas**
- 18 Nm³
- 152 kg

**Flue Gas**
- 205 Nm³
- 41ºC

**Hot Metal**
- 1000 kg
- 1470ºC

**OBF-PG to Steel Works**
- 171 Nm³
SMR with CO\textsubscript{2} Capture
(Picture Courtesy of AmecFW)

By firing H\textsubscript{2} fuel instead of NG/light HC, CO\textsubscript{2} Capture of ~90% could be achievable for options #1 and #2.
Review of Large Scale Demo and Pilot CCUS Projects from SMR Based H₂ Production

- **Large scale demo projects**
  - AP Port Arthur Project (USA)
    - Operational - ~1 million tpy CO₂ captured for EOR
  - Shell Quest Project (Canada)
    - Under construction - ~1 million tpy CO₂ captured and stored (on-shore) in saline acquifer

- **Large scale pilot projects**
  - AL Port Jerome Project (France)
    - Under commissioning - ~100k tpy CO₂ captured for sale as food grade CO₂.
  - Japan CCS Tohokamai Project (Japan)
    - Under construction - ~200k tpy CO₂ captured and stored (off-shore) in saline acquifer
Observations to date

- Capture of CO₂ from SMR is not new.
  - Low hanging fruit but **not cheap**
- Large scale demonstration of the integration of CO₂ capture, transport and storage is important; and this has been achieved.
- Development of new novel technologies are on-going to reduce cost

**Figure 4.** Repsol, Spain, H₂ plant with partial CO₂ capture.

- Repsol SMR Plant (67,000 Nm³/h H₂)
- Operational since 2002
- ~60,000 TPD of CO₂ captured via MDEA from syngas for food market
Distribution of CO$_2$ Emissions for Refineries with CO$_2$ Capture

Data from CONCAWE 2011
Challenges

- Variation of Refinery Capacity and level of Complexity should also lead to variation of overall CO$_2$ emissions from oil refineries
  - In Europe capacity varies from 0.4 Mtpy to 5.5 Mtpy CO$_2$. (CONCAWE)
- Diverse point sources of CO$_2$
  - Oxy fire furnaces – CCP project
  - Central CHP plant – Statoil Mongstad
- Wide ranging percentage/concentration of CO$_2$ from different sources
Summary

- Provided an overview of IEAGHG completed and ongoing work in this area
  - Reference material on our web site
- First to publish “transparent” costs in cement and steel sectors
- Industry under a range of commercial pressures
  - Cutting CO2 emissions just another problem
- Complex systems: is no one fits all engineering solution
- Likely only a partial reduction of emissions is financially viable
- Capture ready guidelines for industry?
Thank you, any Questions?

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