Global Technology Roadmap for CCS in Industry

Sectoral Workshops Report - Annexes

30 June – 1 July 2010
Abu Dhabi, United Arab Emirates
Annexes

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Global Technology Roadmap for CCS in Industry

Sectoral Workshops – Annotated Agenda

30 June – 1 July 2010
Abu Dhabi, United Arab Emirates
Hotel Fairmont Bab Al Bahr
08:30  Welcome Coffee and registration

09:00  Opening
Chaired by Dolf Gielen, UNIDO
- Dale Seymour, Global CCS Institute
- Sam Nader, MASDAR

09:30  Scene setting
Chaired by Dale Seymour, Global CCS Institute
Project overview: objectives and rationale
- Dolf Gielen, UNIDO
CCS in Industry: Data and projections
- Nathalie Trudeau, IEA
Initial insights and framing of the sectoral assessments and workshops
- Heleen de Coninck, ECN

10:30  Coffee Break

11:00  Sectoral workshops - Session 1
Background of sector, current status and trends, emission sources, sector baseline and future developments;
Abatement options and technologies, potential of CCS, current activities
- High-purity CO2 sources (Moderator: Dolf Gielen)  Al Reem
- Cement (Moderator: Mohammad Abuzahra)  Yas
- Iron & Steel (Moderator: Heleen de Coninck)  Saadiyat
- Refineries (Moderator: Keristofer Seryani)  Sir Baniyas A
- Biomass-based CO2 sources (Moderator: Patrick Nussbaumer)  Sir Baniyas B

12:30  Buffet Lunch  Al Saker Ballroom, Section C
13:30  Sectoral workshops - Session 2

Major gaps and barriers to implementation

- High-purity CO2 sources (Moderator: Heleen de Coninck)  Al Reem
- Cement (Moderator: Nathalie Trudeau)  Yas
- Iron & Steel (Moderator: Dolf Gielen)  Saadiyat
- Refineries (Moderator: Alice Gibson)  Sir Baniyas A
- Biomass-based CO2 sources (Moderator: Wolfgang Heidug)  Sir Baniyas B

15:00  Coffee Break

15:30  Working groups on cross-cutting issues

- Long-term vision, data and uncertainties (Moderator: Dolf Gielen)  Al Reem
- Costs, financing and business models (Moderator: Dale Seymour)  Yas
- Incentives, policy and legislation (Moderator: Alice Gibson)  Saadiyat
- Technical issues for CO2 compression, transport and storage (Moderator: Heleen de Coninck)  Sir Baniyas A
- Early opportunities in the Middle East (Moderator: Keristofer Seryani)  Sir Baniyas B

17:00  End

Evening Reception

19:00  Departure of transportation from hotel Fairmont

19:30  Evening Reception at Yas Hotel

21:30  Departure of transportation from Yas Hotel back to hotel Fairmont
1 July 2010 - Day 2

9:00  Sectoral workshops - Session 3

Actions and milestones
- High-purity CO2 sources (Moderator: Dale Seymour)  Al Reem
- Cement (Moderator: Nathalie Trudeau)  Yas
- Iron & Steel (Moderator: Paul Crooks)  Saadiyat
- Refineries (Moderator: Dolf Gielen)  Sir Baniyas A
- Biomass-based CO2 sources (Moderator: Alice Gibson)  Sir Baniyas B

10:30  Coffee Break

11:00  Wrap-up and synthesis

Feedback from sectoral and cross-cutting workshops

Actions and milestones
Chaired by Heleen de Coninck, ECN

12:30  Closing and way forward

Chaired by Dolf Gielen, UNIDO
- Dale Seymour, Global CCS Institute
- Keristofer Seryani, MASDAR

13:00  Buffet Lunch

Elements Restaurant
Annex 2: Participants list
Global Technology Roadmap for CCS in Industry

Sectoral Workshops - List of Participants

30 June – 1 July 2010
Abu Dhabi, United Arab Emirates
Hotel Fairmont Bab Al Bahr
## List of Participants

<table>
<thead>
<tr>
<th>Name</th>
<th>Title/Position</th>
<th>Organisation/Region</th>
<th>Sector</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bruce Adderley</td>
<td>Research Programme Manager, Corus (UK)</td>
<td></td>
<td>Iron &amp; Steel</td>
</tr>
<tr>
<td>Klaus Angerer</td>
<td>General Manager Abu Dhabi Office, OMV Exploration &amp; Production (Austria)</td>
<td></td>
<td>Refineries</td>
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<tr>
<td>Duncan Barker</td>
<td>Senior Principal Engineer, Mott MacDonald Ltd (UK)</td>
<td></td>
<td>Cement</td>
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<tr>
<td>Kamel Bennaceur</td>
<td>Chief Economist, Schlumberger (USA)</td>
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<tr>
<td>Rakesh Bhargava</td>
<td>Chief Climate Officer, Shree Cement Ltd (India)</td>
<td></td>
<td>Cement</td>
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<tr>
<td>Jean-Pierre Birat</td>
<td>Expert, European Coordinator of the ULCOS program; ArcelorMittal (France)</td>
<td></td>
<td>Iron &amp; Steel</td>
</tr>
<tr>
<td>Jock Brown</td>
<td>Engineer, Det Norske Veritas (Norway)</td>
<td></td>
<td>Refineries</td>
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<tr>
<td>Michiel Carbo,</td>
<td>Energy research Centre of the Netherlands</td>
<td></td>
<td>Biomass-based CO2 sources</td>
</tr>
<tr>
<td>Paul Crooks</td>
<td>Project Manager, Pipelines, Masdar - Abu Dhabi Future Energy Company (UAE)</td>
<td></td>
<td>Iron &amp; Steel</td>
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<tr>
<td>Heleen de Coninck</td>
<td>Manager, Energy research Centre of the Netherlands</td>
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<tr>
<td>Åsa Ekdahl</td>
<td>Manager, World Steel</td>
<td></td>
<td>Iron &amp; Steel</td>
</tr>
<tr>
<td>Mahmoud S. El-Hassan</td>
<td>Senior Business Manager, Mitsubishi Corporation-Abu Dhabi Liaison Office</td>
<td></td>
<td>Cement</td>
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<tr>
<td>Michel Folliet</td>
<td>GMS Industry Specialist, International Finance Corporation</td>
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<tr>
<td>Brian Freeman</td>
<td>Business Development Manager, Integrated Environmental Solutions Company (Kuwait)</td>
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<tr>
<td>Michel Gimenez</td>
<td>Directeur Projets CO2, Lafarge (France)</td>
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<td>Cement</td>
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<tr>
<td>Henrik Karlsson</td>
<td>CEO, Biorecro (Sweden)</td>
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<tr>
<td>Satish Kumar</td>
<td>Masdar - Abu Dhabi Future Energy Company (UAE)</td>
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<tr>
<td>Marco Lotz</td>
<td>CSIR/ Promethium Carbon (South Africa)</td>
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<td>Iron &amp; Steel</td>
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<tr>
<td>Thomas Mikunda</td>
<td>Energy research Centre of the Netherlands</td>
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<tr>
<td>Kenneth Möllersten</td>
<td>Programme manager, Swedish Energy Agency</td>
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<tr>
<td>Sam Nader</td>
<td>Director, Masdar Carbon (UAE)</td>
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<tr>
<td>Sachchida Nand</td>
<td>Director (Technical), The Fertiliser Association of India</td>
<td></td>
<td>High-purity CO2 sources</td>
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<tr>
<td>Reza P. Oskui</td>
<td>Research Scientist, Kuwait Institute for Scientific Research</td>
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<tr>
<td>Lawan Pornsakulsakdi</td>
<td>Manager, PTT Exploration and Production Public Company Limited (Thailand)</td>
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<td>High-purity CO2 sources</td>
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<tr>
<td>Michael C.N.C.G. Putra</td>
<td>, Indonesia CCS Working Group</td>
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<tr>
<td>Suvaluck Ratanavanich</td>
<td>Acting Manager, PTT Exploration and Production Public Company Limited (Thailand)</td>
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<td>Refineries</td>
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<tr>
<td>Alexander Roeder</td>
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<td>Cement</td>
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<tr>
<td>Massoud Rostamabadi Sofia</td>
<td>Professor, University of Illinois at Urbana-Champaign (USA)</td>
<td></td>
<td>Refineries</td>
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<tr>
<td>Keristofer Seryani</td>
<td>Department Manager, Commercial Development, Masdar - Abu Dhabi Future Energy Company (UAE)</td>
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<tr>
<td>Jose R. Simões-Moreira</td>
<td>Associate Professor, University of Sao Paulo (Brazil)</td>
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<td>Biomass-based CO2 sources</td>
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<tr>
<td>Mohammad Soltanieh</td>
<td>Environmental Research Centre, Department of Environment (Iran)</td>
<td></td>
<td>High-purity CO2 sources</td>
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<tr>
<td>Matthias Stein</td>
<td>Managing Director, Linde Engineering Middle East LLC (UAE)</td>
<td></td>
<td>High-purity CO2 sources</td>
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<tr>
<td>Prasetyadi Utomo</td>
<td>Ministry of Environment, Indonesia</td>
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<tr>
<td>Marek Wejtko, Advisor to the Deputy Prime Minister, Poland</td>
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<td></td>
<td>High-purity CO2 sources</td>
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<tr>
<td>Paul Zakkour</td>
<td>Director, Carbon Counts (UK)</td>
<td></td>
<td>High-purity CO2 sources</td>
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<tr>
<td>Othman Zarzrou</td>
<td>Project Manager, CCS, Masdar - Abu Dhabi Future Energy Company (UAE)</td>
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<td>High-purity CO2 sources</td>
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<tr>
<td>Jianping Zhao</td>
<td>Senior Energy Specialist, The World Bank</td>
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## Project team

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<thead>
<tr>
<th>Name</th>
<th>Title/Position</th>
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<tbody>
<tr>
<td>Mohammad Abuzahra</td>
<td>, IEA Greenhouse Gas R&amp;D Programme</td>
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<tr>
<td>Marko Emersic</td>
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<tr>
<td>Alice Gibson</td>
<td>Projects Manager, Global CCS Institute</td>
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<tr>
<td>Dolf Gielen</td>
<td>Unit Chief, United Nations Industrial Development Organization</td>
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<tr>
<td>Wolfgang Heidug</td>
<td>, International Energy Agency</td>
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<tr>
<td>Patrick Nussbaumer</td>
<td>, United Nations Industrial Development Organization</td>
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<tr>
<td>Dale Seymour</td>
<td>Senior Vice President – Strategy, Global CCS Institute</td>
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<tr>
<td>Nathalie Trudeau</td>
<td>Energy Analyst, International Energy Agency</td>
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Annex 3: Scene setting presentations
Global Technology Roadmap for CCS in Industry

Project Overview

Sectoral Workshop
30 June – 1 July 2010, Abu Dhabi, UAE

Dolf Gielen
Chief, Industrial Energy Efficiency Unit
United Nations Industrial Development Organization (UNIDO)
Funders

- Global CCS Institute
- Ministry of Petroleum and Energy

Implementing Agency

- United Nations Industrial Development Organization

Partners

- International Energy Agency
- IEA Greenhouse Gas R&D Programme
- Energy Research Centre of the Netherlands

Host of the sectoral workshop

- MASDAR - Abu Dhabi National Energy
Objective

To advance the global uptake of low-carbon technologies in industry, whilst involving developing countries and transition economies, by developing a **Global Technology Roadmap for CCS in Industry** and to build the analytical foundation allowing to identify early opportunities for pilot/demonstration projects.

Expected outcomes

- To provide relevant stakeholders with a **vision** of industrial CCS up to 2050
- To **strengthen the capacities** of various stakeholders with regard to industrial CCS, particularly in selected developing countries
- To **inform** policymakers and investors about the potential of CCS technology
- To identify a number of potential **early opportunities**
Rationale

- **Industry** accounts for approx. 40% of total energy-related \( \text{CO}_2 \) emissions
- The majority of industrial energy use and \( \text{CO}_2 \) emissions takes place in **developing countries**; therefore developing countries stakeholders should be **informed** and **participate** in technology development and deployment
- CCS is **one of the few low-carbon options** for energy-intensive industries
  - Cement clinker making: no alternative!
  - Biomass + CCS = net negative emissions (backstopping option)
- Not considering CCS is expected to **increase mitigation costs** significantly (by about 70%) – if significant emissions reduction is aimed for
- **Half** of the \( \text{CO}_2 \) emission reduction **potential** from CCS is in **industry**
- Lots of attention for CCS in the power sector, but **limited for industry** thus far
- Interesting opportunities for \( \text{CO}_2 \) Enhanced Oil Recovery (EOR)
Context

- The **need to stabilize greenhouse gas concentrations** in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system
- Request from the international community to **develop and deploy advanced technologies** for moving towards a low-carbon economy, and explicit request for the preparation of **Energy Technology Roadmaps**

Approach

- Desktop review and analysis informed by **sectoral assessments**
- Series of **workshops** with selected stakeholders
- Will **build on past and on-going work**, e.g. IEA CCS Roadmap, Cement Technology Roadmap, etc.

Timeframe

Roadmap expected to be completed by the **end of 2010**
CCS: Status today

- About 50 million tons/yr transported and used for Enhanced Oil Recovery since 40 years – not a single accident

- CO\textsubscript{2} capture technologies have long been used in gas streams treatment (ammonia and hydrogen production, natural gas processing) – 15-30 Mt/yr – all chemical absorption based

- Three main methods: post-combustion (chemical absorption), pre-combustion and oxy-fuel

- For industry, process re-design can reduce cost substantially (eg FINEX, black liquor gasification)

- Transport and storage >600 m underground “supercritical stage” – depleted oil & gas fields or aquifers

- About 10 demonstration projects for CCS are operational worldwide – technical feasibility is proven

- Tens of plants are in planning/construction phase
Sectoral focus

- High-purity CO₂ sources
  - Natural gas processing
  - Coal-to-liquids
  - Hydrogen from refineries
  - Ammonia production
- Cement
- Iron and steel
- Refineries
- Biomass-based industrial CO₂ sources
CO$_2$-EOR

- Suited for certain types of oil reservoirs
- Can generate revenues that can offset (part of) capture cost
- Interesting opportunities in the Middle East and elsewhere in the developing world
- CO$_2$-EOR targeting storage requires special care
- Successful Weyburn demonstration project in Canada
- A niche for early deployment
- Try to identify and characterize some projects for industrial CCS + EOR
THANK YOU!

D.Gielen@unido.org

http://www.unido.org/
GLOBAL STATUS OF CCS DEVELOPMENT

Dale Seymour, Senior Vice President - Strategy
Global CCS Institute
UNIDO Global Technology Roadmap for CCS in Industry, 29June 2010
A CRUCIAL ROLE AND DEFINITIVE PURPOSE

The Global CCS Institute has an integral role to play in reducing the effects of climate change and enhancing energy security.

Removing CCS barriers
Create an environment conducive to CCS deployment

Knowledge Broker
Provision of fact-based, evidence-based information & advice

Key Global Influencer
Influence Governments, industry and CCS stakeholders

“Global CCS Institute approach - long-term outcomes supported by near-term targeted action”
FORGING AHEAD - STRATEGIC FRAMEWORK

- Establishes overarching strategic framework that embraces early actions and longer term needs for successful commercial deployment of CCS at scale

**Purpose**

“To contribute to CO₂ emissions reduction and energy security by accelerating the commercial deployment of CCS projects”

**Regional Profiles and Global Services**

**Enabling Strategies**
- Policy/Regulatory
- Financial/Commercial
- Public Awareness
- Technical
- Capacity Building

**Members**
- Services Model
- Member Charter

**Project Strategy**
- Project Support Program
ANALYSIS OF THE GLOBAL STATUS OF CCS

- Four foundation reports:
  - Status of CCS projects
  - Costs of CCS (power and other industrial sectors)
  - Policy and regulation
  - Research and development

- One synthesis report:
  - Overall challenges, barriers, gaps
  - Recommendations

- Two databases:
  - CCS projects
  - Research networks

Undertaken over June-September 2009
275 PROJECTS IDENTIFIED WORLDWIDE IN 2009

Total - 275

Completed - 34
Cancelled or delayed - 26
Input withheld - 2

Active or planned - 213
Commercial scale - 101
Integrated - 62

Prepared for the Global CCS Institute by WorleyParsons, 2009

62 large scale integrated projects
2010 - PROJECT UPDATE

- WorleyParsons commissioned to build upon first stock-take of CCS projects:
  - Status of CCS projects ever changing
  - Taking into account the G8 criteria
  - Taking into account industry feedback received
  - As of February/March 2010 (G8 timetable)

- Fundamental objective is to ascertain the status of projects and “real” progress to achieve G8 goal
STATUS OF CCS PROJECTS WORLDWIDE 2010 – INITIAL FINDINGS

Total - 328

Active or planned - 238

Integrated - 151

Large scale, integrated projects (LSIPs) - 80

Completed - 31

Cancelled / delayed - 59

80 commercial scale integrated projects
RESULTS - Large scale, integrated CCS projects by asset lifecycle and region/country
G8 CRITERIA USED TO MEASURE PROGRESS

1. Scale is large enough to demonstrate the technical and operational viability of future commercial CCS systems

2. Projects include full integration of CO₂ capture, transport (where required) and storage

3. Projects are scheduled to begin full-scale operation before 2020, with a goal of beginning operation by 2015 when possible

4. Location of the storage site is clearly identified

5. A monitoring, measurement and verification (MMV) plan is provided

6. Appropriate strategies are in place to engage the public and to incorporate their input into the project

7. Project implementation and funding plans demonstrate established public and/or private sector support
TRAFFIC LIGHTING SUMMARY - BY CRITERIA

IEA criteria to track progress against the G8 large-scale projects goal
SUMMARY OF PROGRESS

- Majority of projects are classified green against scale and operation by 2020 criteria
- However, detailed project schedules may not have been developed
- Majority of projects classified amber against storage criterion due to lack of identified transport routes
- Most projects classified grey against MMV criterion as they currently lack a MMV plan
- A number of projects classified grey against public engagement criterion
- Most projects classified amber on funding criterion
CONCLUSIONS

- Global CCS Institute can and will play a crucial role in CCS
- Institute strategic framework to establish acceleration actions and fact based products to address urgency
- Sharing of knowledge gained, especially from early projects a critical element
- Total 328 CCS projects identified: 238 active or planned; 80 active or planned, large scale, integrated CCS projects
- In terms of a “balanced portfolio”- significant under-representation in developing countries and industrial sector
- Key challenges remain: policy uncertainty, public acceptance, particularly financing

Unprecedented need for effective collaboration worldwide
Developing a roadmap and insights so far

Heleen de Coninck - deconinck@ecn.nl
Abu Dhabi, June 30 2010
Outline

• What is a roadmap?
• Steps in a roadmap process
• Current status and insights
• Aim and process of this meeting
A roadmap is a first step

- A document that provides an exhaustive overview of opportunities, gaps, barriers and measures to achieve a specific technological aim
- The technological aim can be RD&D or commercialisation of a technology, but can also comprise the full innovation chain
- A roadmap is actionable and should provide an agenda to act for government, industry and financial sector stakeholders
- A roadmap could be made measurable by defining milestones associated with actions
- The process of making and agreeing is important
This roadmap...

- Has a focus on CO₂ capture in five industries:
  - High-purity CO₂ sources, including gas processing, chemical industry
  - Cement
  - Iron and steel
  - Refineries
  - Biomass-based industrial sources of CO₂
- Has a global scope, but a focus on developing countries where relevant
- Builds on earlier roadmaps (e.g. CCS roadmap from IEA)
Steps in a roadmap process

1) Assessment of current situation
2) Data, methods and assumptions
3) Vision of the future
4) Gaps and barriers
5) Actors and stakeholders
6) Identification concrete options
7) Actions and milestones
Hypothetical examples of actions and milestones

• In order to overcome awareness barriers for CO\textsubscript{2} capture in gas processing in developing countries, a demand-driven capacity building programme is initiated for local industry and government stakeholders

• Reduce energy penalty of CO\textsubscript{2} capture through process design and heat optimisation

• Optimise integration, particularly for retrofit applications, to achieve plant availabilities and capture rates above 85% by 2020
The (draft!) sectoral assessments:

1) Assessment of current situation

2) Data, methods and assumptions

3) Vision of the future
Current status and insights so far

• Data, methods and assumptions being discussed between sectoral specialists, UNIDO and IEA
• Overlap handled as much as possible
• Sectoral assessments good progress but not complete
• Need for industry-specific future vision
• (Probably most actions and milestones will also be industry-specific)
• Data are a problem, in particular in developing countries
This meeting:

1) Assessment of current situation
2) Data, methods and assumptions
3) Vision of the future
4) Gaps and barriers
5) Actors and stakeholders
6) Identification concrete options
7) Actions and milestones
Structure of this meeting

Plenary
- Opening & set-up
- Background, data, baseline, future vision
- Gaps and barriers

Sectoral workshops
- Discussion and alignment between sectors
- Feedback crosscutting groups
- Actions and milestones

Crosscutting groups

June 30

July 1

Wrap-up and closing
Structure of this meeting

• Sectoral workshops
  - Please remain in your group!
  - Moderates chair
  - Sectoral consultants provide substance
  - Rapporteur reports back to plenary tomorrow

• Crosscutting groups for consistency and interaction
  - Do not report back to plenary but to sectoral workshops
  - Except for special crosscutting group on Middle East
Thank you!
Annex 4: Introduction to each industrial sector
UNIDO CCS Roadmap for Industry: *High Purity Sources*

Sectoral Workshop, Fairmont Hotel, Abu Dhabi

Paul Zakkour, Director, Carbon Counts
30 June – 1 July 2010
Abu Dhabi
Overview

• The CCS Roadmap for high purity CO$_2$ sources aims to provide a clearer picture on the scope for applying CCS to these installations.

• The workshop will cover the following topics:
  – Why high purity sources? Why are they of interest?
  – What are the sources? How big are emissions? Where
  – What other options exist to reduce emissions?
  – How much will it cost?
  – How does that compare with other abatement measures?
  – What has industry done with CCS to date?
  – What is the way forward?
Why High Purity sources?

- Capture of CO$_2$ from dilute gas streams is the most expensive component of the CCS chain:
  - Combustion plants (4-14% CO$_2$) – must be concentrated to make transport & storage economic
  - High temperature – must be cooled to avoid solvent degradation (post-combustion)
  - Low pressure & partial pressure – must use chemical solvents
  - High-levels of impurities (SO$_2$, particulates) – contaminate solvents
  - High energy demand for flue gas treatments (increases costs)

- High purity sources avoid many of these issues
## Characteristics

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<th>Source</th>
<th>CO(_2) conc (%)</th>
<th>Pressure (Mpa)</th>
<th>Partial pressure (CO(_2))</th>
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<tr>
<td>Gas processing</td>
<td>Process (amine/memb)</td>
<td>100</td>
<td>0.9-8</td>
<td>0.05-4.4</td>
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<td>Ammonia/Fert</td>
<td>Process (gasifier/reform)</td>
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<td>2.8</td>
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<tr>
<td>H(_2) production</td>
<td>Process (gasifier/reform)</td>
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<td>2.2-2.7</td>
<td>0.3-0.5</td>
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<tr>
<td>CtL</td>
<td>Process (gasifier)</td>
<td>100</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Ethylene oxide</td>
<td>Process (desorption)</td>
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<td>2.5</td>
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- All highly amenable to low cost capture (and compression, transport & storage)
- Several pathways to high purity CO\(_2\) process streams.
Gas processing pathway

**GAS PROCESSING PLANT**

- **CO₂ vented to atmosphere**

  Composition:
  - 1-4% CHₓ
  - 96-99% CO₂

- **Raw natural gas feed from field**
  Composition:
  - 30-98% CHₓ
  - 2–70% CO₂

- **Amine or membrane separation to remove CO₂**

  *(Gas sweetening)*

- **Treated gas**
  - Pipeline
    - 98%+ CHₓ
    - <2% CO₂
  - **LNG** \(^{(1)}\)
    - 99.8%+ CHₓ
    - <0.2% CO₂

- **Typical plant with high CO₂ field:**
  0.5 – 1+ million tCO₂ p.a.

- **New natural gas resources:** valoration challenges include increasing CO₂ content

Notes:

\(^{(1)}\) Very low CO₂ content required to avoid dry ice formation
Gasification/reformer pathway

Feedstock in

- Coal/Biomass
- Natural gas

O2 and/or Air

GASIFIER

Coal/Biomass

Natural gas

O2 and/or Air

Steam

CO2:
- Vented
- To urea production
- Enhanced oil recovery

H2 and to ammonia and F-T processes

SHIFT REACTOR

Syngas (H2, CO, CO2, H2O)

H2O, H2, CO, CO2 shift to H2 & CO2

GAS CLEAN UP

(H2 & CO2 separation)
PSA, physical absorption e.g. Selexol

Notes:
SMR = Steam methane reforming; ATR = Auto thermal reforming; POX = Partial oxidation
Ethylene oxide pathway

Feedstock in

$O_2$ and/or Air

Ethylene

REACTOR CATALYST (silver-based)

EO ABSORPTION

EO DESORPTION

CO$_2$ vented

Typical plant: ~0.2 million tCO$_2$ p.a.

To ethylene glycol and other products
• 350-400 MtCO₂ globally generated from high purity sources
• Not all available for CCS – c.100-130 Mt to urea, only 3 Mt from CtL

Note: Data patchy and incomplete. Mostly from IEA GHG emissions database (2006)
Future emissions – other sources

• Need to work on data for all high purity sectors:
  – **Gas processing** – gas demand + quality
  – **Ammonia** – need to understand projections for future NH$_3$ and fertiliser demand
  – **CtL** – currently only 1 operational plant (Secunda, Sasolburg, RSA). Number of proposed projects (c. 30 worldwide in discussion)
  – **H$_2$** – potential emergence for use in fuel cells and transportation
  – **Ethylene glycol** – need to understand demand
CCS potential - technical

• High purity means little if any CO₂ treatment required. Main requirements:
  – **Compression** – large compressors suitable for CO₂ not standardised product. Cost c. M$25-30 for 75,000 m³/day compression train
  – **Transport & Storage** – gas processing likely to have *in situ* storage resource. Other sources likely require transportation.
  – **Storage** – need access to secure storage capacity
CCS potential – IEA Roadmap (2009)

- Chemicals includes EO, ammonia and fertilizer + others

- MtCO2 captured

- No. of CCS projects

Chemicals – includes EO, ammonia and fertilizer + others
## CCS potential – costs

<table>
<thead>
<tr>
<th></th>
<th>2010</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Abatement potential (MtCO$_2$)</td>
<td>Average cost ($/tCO$_2$)</td>
</tr>
<tr>
<td>Gas Process</td>
<td>219</td>
<td>$18</td>
</tr>
<tr>
<td>Ammonia</td>
<td>97</td>
<td>$62</td>
</tr>
<tr>
<td>Fertilizer</td>
<td>97</td>
<td>$92</td>
</tr>
<tr>
<td>Ethanol</td>
<td>14</td>
<td>$104</td>
</tr>
<tr>
<td>Refineries</td>
<td>292</td>
<td>$115</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>6</td>
<td>$115</td>
</tr>
<tr>
<td>Cement</td>
<td>600</td>
<td>$138</td>
</tr>
<tr>
<td>Coal power</td>
<td>0</td>
<td>n/a</td>
</tr>
<tr>
<td>Gas power</td>
<td>0</td>
<td>n/a</td>
</tr>
<tr>
<td>TOTAL</td>
<td>1,240</td>
<td>-</td>
</tr>
</tbody>
</table>

Notes: Based on IEA GHG CDM potential study (2008). Analysis considered the potential for CCS deployment through the clean development mechanism (CDM), so focus on developing countries.
CCS potential – investment needs

**Industry & Upstream:** $78 Bn investment required 2010-2020

Data covers all Industry and Upstream sectors

**Source:** IEA CCS Roadmap (2009)

<table>
<thead>
<tr>
<th>Region</th>
<th>Total CCS projects (2020)</th>
<th>Captured 2020 (MtCO₂/yr)</th>
<th>Incremental CCS cost 2010-2020 ($billion)</th>
</tr>
</thead>
<tbody>
<tr>
<td>OECD NA</td>
<td>12</td>
<td>44</td>
<td>10.3</td>
</tr>
<tr>
<td>OECD Europe</td>
<td>5</td>
<td>11</td>
<td>2.0</td>
</tr>
<tr>
<td>OECD Pacific</td>
<td>5</td>
<td>17</td>
<td>3.5</td>
</tr>
<tr>
<td>China &amp; India</td>
<td>15</td>
<td>29</td>
<td>4.1</td>
</tr>
<tr>
<td>Other Non-OECD</td>
<td>25</td>
<td>68</td>
<td>7.6</td>
</tr>
<tr>
<td>World</td>
<td>62</td>
<td>168</td>
<td>27.5</td>
</tr>
</tbody>
</table>
Actions and milestones

• Need to consider what actions and milestones can be highlighted for the sector:
  – Awareness raising
  – Research & development needs (ongoing activities?)
  – Further demonstration projects (potential)
  – Other emission reduction measures
  – Regulatory requirements
  – Financing
  – Incentives

• Consider these needs for near, medium, and longer-term
Issues for workshop to consider

• Focus on the following aspects:
  – **Key metrics** – what information should be presented? What are the key data sources?
  – **Opportunities** – where are the main opportunities located? What is the outlook for each sector going forward (i.e. growth)?
  – **Barriers** – what potential barriers will CCS face?
  – **Alternatives** – what alternatives are there for reducing emissions (e.g. process shift, stock turnover, product substitution)?
  – **Stakeholders** – who is the information aimed at? Who should we raise awareness with?
Thank-you

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Duncan Barker

+10 years experience in engineering consulting

Business Sector Leader for Bioenergy and Low Carbon Processes in Mott MacDonald’s Power business

Experience covers a wide range of projects and technologies

Experience in UK, Continental Europe, Asia, North and Latin America

CO₂ Capture in the Cement Industry (UK) – Project manager and responsible for process engineering inputs to an IEA GHG study assessing technologies that could be used to capture CO₂ in new cement plants and retrofits of existing plants.

Owner’s Engineer for Post-Combustion CCS Project (UK) – Project manager for feasibility stage for ScottishPower CCS Project at Longannet for UK post-combustion CCS demonstration competition

CCS pre-feasibility study for CCGT generation plant (Khazakstan) – Process engineer

UMPP CO₂ Capture (India) – Process engineer

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Tel. +44 (0)1273 365185
• Current and projected emissions
• Technical overview of capture options
• Energy requirements and emission reductions for CO\textsubscript{2} capture
• Current activities and projections on role of CCS
• Estimated investment and costs
• Characterisation of the industry
• Current environmental legislation and pressures
• Major gaps and barriers to implementation
Current and projected emissions

Current
- Total emissions = 0.8 (fuel) + 1.1 (process) = 1.9 GtCO$_2$/y in 2006 (IEA, 2009)

Projections
- Dependent on demand, adoption of BAT and technology changes
Technical overview of capture options

Post combustion
- Coal Gas Biomass
- Air
- Power & Heat
- CO₂ Separation
- N₂ O₂
- CO₂

Pre combustion
- Gasification
- Gas, Oil
- Air/O₂ Steam
- Reform + CO₂ Sep.
- H₂
- Power & Heat
- N₂ O₂
- CO₂
- CO₂ Compression & Dehydration

Oxyfuel
- Coal Gas Biomass
- Air
- Power & Heat
- CO₂
- O₂
- Air Separation
- N₂
Carbon capture at cement plants

• 0.6 – 1.0 tCO₂/tonne of cement
• CO₂ 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 approx. 25% CO₂ compared to approx. 12% CO₂ for coal-fired power plants and approx. 4% CO₂ for gas-fired power plants
• 95% of calcination occurs in precalciner and 60% of fuel used in precalciner i.e. majority of CO₂ emitted from precalciner
Post-combustion capture

- ‘End of pipe’ solution
- CO₂ separation technologies already widely applied in industrial manufacturing processes, refining and gas processing although not typically at low pressures
- Leading CO₂ separation technologies for post-combustion:
  Chemical solvent scrubbing (absorption) e.g. amines, ammonia
- Developing CO₂ separation technologies:
  Novel absorbents (e.g. carbonate looping)
  Adsorption e.g. Temperature swing adsorption (TSA)
  Membrane separation
  Cryogenic separation
- Number of technology suppliers already in market (e.g. MHI, Fluor, Aker Clean Carbon, Alstom, Cansolv, HTC)
- Challenges:
  Scale
  Flue gas cooling required
  Flue gas clean-up required to reduce solvent degradation (low SOₓ, dust and NO₂ required in feed gas)
  Energy consumption during stripping
### Fundamental issues for post-combustion for cement

<table>
<thead>
<tr>
<th>Component</th>
<th>Typical exhaust gases from cement process</th>
<th>Requirement for CO₂ absorption using MEA</th>
<th>Treatment method</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>14-33% (w/w)</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>NOₓ</td>
<td>&lt;200-3000 mg/Nm³</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>NO₂</td>
<td>5-10% of NOₓ</td>
<td>20 ppmv</td>
<td>SNCR/SCR</td>
</tr>
<tr>
<td>Dust</td>
<td>5-200 mg/Nm³</td>
<td>15 mg/Nm³</td>
<td>Bag filter/ESP</td>
</tr>
<tr>
<td>SO₂</td>
<td>&lt;10-3500 mg/Nm³</td>
<td>10 ppmv</td>
<td>Absorbent addition (Dry scrubber) Wet scrubber + Spray scrubbing</td>
</tr>
<tr>
<td>O₂</td>
<td>8-14 % (v/v)</td>
<td>&gt;1.5 % (v/v)</td>
<td>None required</td>
</tr>
<tr>
<td>Temp</td>
<td>110-130°C</td>
<td>~50°C</td>
<td>Heat recovery and SO₂ scrubbing</td>
</tr>
</tbody>
</table>
Fundamental issues for post-combustion for cement

- Heat availability for regeneration of CO₂ absorbent
  - 1.5 tonnes of low pressure steam/tCO₂ captured
- Air dilution
  - Occurs in raw mill, preheater and kiln
- Waste disposal
  - Degraded amines (1.6 kg MEA/tCO₂ captured)
- Power requirements
  - Power input needed for CO₂ compression (0.146 kWh/kgCO₂)
- Suitability for retrofit
  - Layout of plant
  - Available land
Post-combustion cement plant

Fuel → Cement plant → SCR, ESP, FGD → Solvent scrubbing → CO₂-reduced flue gas

Air

Raw meal → Cement plant → Flue gas → CHP plant

Clinker

Fuel → CHP plant → Steam → Solvent stripping → CO₂ compression

Power

Steam

CO₂ to storage
Post-combustion cement plant

- Advantages for cement plants
  - The cement plant itself is unaffected
    - Except more stringent flue gas cleaning may be needed
    - Retrofit to existing plants is possible
      - Provided space is available and CO\textsubscript{2} can be transported away from the site for storage
  - Disadvantages
    - A substantial quantity of low pressure steam is needed for solvent stripping, requiring an on-site CHP plant
Oxyfuel capture

- Combustion in O₂ instead of air
- Flue gas recycle required to control combustion temperature
- Generates high concentration CO₂ stream
- Flue gas from process contains other products associated with combustion e.g. SOₓ, NOₓ and H₂O
  - Minor clean-up required
- Number of demonstration projects underway in power industry
- Some technology providers e.g. Doosan-Babcock and Air Products
- Challenges
  - Scale
  - Power consumption of generating O₂ (200-240 kWh/tO₂)
  - Air in-leakage reduction
  - Gas purity for transport
Fundamental issues for oxyfuel capture for cement

- Kiln design
  - Flame temperatures and ballast ratio
  - Improved heat transfer
  - Feed lifting in preheater
  - Wear and tear
- Process chemistry
  - Will product have same properties?
  - Kinetics in CO₂ rich atmosphere
- Air dilution
  - Occurs in raw mill, preheater and kiln
- Waste disposal
  - Water vapour/NOₓ/SOₓ to be removed prior to storage?
- Power requirements
  - Power input needed for CO₂ compression (0.146 kWh/kgCO₂)
- Air separation unit
  - 200-240 kWh/tO₂
- Suitability for retrofit
  - Layout of plant
Oxyfuel cement plant design (full capture)

CO₂ rich stream for CCS

Exhaust Gas Cleaning
Exhaust Gas Condition
Exhaust Gas Cleaning
Fuel Preparation
Fuel (solid)

Raw Mill
Preheater
Precalculator
Rotary Kiln
Cooler

Air intake

Air Separation Unit
N₂

Fuel (solid)
Raw meal/clinker
Inert air
Non-inert air
Oxygen
Oxyfuel cement plant design (partial capture)

- Maximum capture is approx. 75% of $\text{CO}_2$ generated
Advantages for cement plants

- Low oxygen consumption
  - Compared to a coal fired boiler, 1/3 of the amount of O₂ is needed per tonne of CO₂ captured

Disadvantages

- Retrofit would be more difficult than for post combustion capture
- Oxy-firing the precalciner only limits the amount of CO₂ that can be captured
- For full oxy-firing, air in-leakage in mills and the kiln would have to be greatly reduced
- The impacts of full oxy-firing on kiln chemistry etc are uncertain
- More R&D is needed
### Energy requirements and emission reductions for CO₂ capture

#### Impact on energy consumption for different CCS technologies in the cement sector

<table>
<thead>
<tr>
<th>Technology</th>
<th>Thermal [MJ/tonne clinker]</th>
<th>Electric [kWh/tonne clinker]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxyfuel technology as part of CCS</td>
<td>Increase of 90-100</td>
<td>Increase of 110-115</td>
</tr>
<tr>
<td>Post combustion technology using absorption</td>
<td>Increase 1000-3500</td>
<td>Increase of 50-90</td>
</tr>
<tr>
<td>technologies</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Post combustion technology using membrane</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>processes</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: ECRA (2009)

- **Specific thermal energy consumption in 2006 = 3,382 MJ/tonne clinker (ECRA, 2009)**
- **Specific electrical energy consumption in 2006 = 111 kWh/tonne clinker (ECRA, 2009)**
Energy requirements and emission reductions for CO₂ capture

Potential CO₂ reduction for different CCS technologies in the cement sector

<table>
<thead>
<tr>
<th>Technology</th>
<th>Direct CO₂ reduction potential (kg CO₂/tonne clinker)</th>
<th>Indirect CO₂ reduction potential (kg CO₂/tonne clinker)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxyfuel technology as part of CCS</td>
<td>Decrease of 550-870</td>
<td>Increase of 60-80</td>
</tr>
<tr>
<td>Post combustion technology using absorption technologies</td>
<td>to 740</td>
<td>Increase 25-6</td>
</tr>
<tr>
<td>Post combustion technology using membrane processes</td>
<td>&gt; 700</td>
<td>n/a</td>
</tr>
</tbody>
</table>

Source: ECRA (2009)

- Average = 870 kgCO₂/t (Mahasenan et al., 2005)
Current activities and projections on role of CCS

• CCS research programmes in the cement sector
  
  ECRA CCS Project – Phase II complete
  IEA GHG / BCA (now MPA) - complete
  CO2CRC
  WBCSD / CSI – Cement Technology Roadmap 2009
  Cansolv
  DVV / VDZ
  The Earth Institute at Columbia University (Zeman/Lackner)
  Institute of Energy Systems

• Demonstration projects
  
  CEMEX USA DOE project
  ECRA Phase III, IV and V
  Lafarge?
  Cansolv trial in California
Current activities and projections on role of CCS

- IEA (2009): Shift to BAT, increased use of clinker substitutes and alternative fuels, and application of CCS reduces direct CO₂ emissions by around 18% below 2006 levels.
- CCS expected to contribute 0.45 Gt CO₂ (BLUE low-demand scenario) and 0.88 Gt CO₂ (BLUE high-demand scenario).
Estimated investment and costs

- **Post-combustion**
  
  Mahesanen *et al.* (2005): $50/tCO\textsubscript{2} (capture) + $9/tCO\textsubscript{2} (compression)
  
  Hegerland *et al.* (2006): €46/tCO\textsubscript{2}
  
  IEA GHG (2008): €129/t cement (cf. € 66/t cement for no capture) (European scenario)
  
  
  ECRA (2009): Additional costs to cement plant investment -

<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>
Estimated investment and costs

- **Oxyfuel**
  
  Zeman and Lackner (2008): $15-18/t\text{CO}_2$ captured
  
  IEA GHG (2008): €83/t cement (cf. € 66/t cement for no capture) (European scenario)
  
  
  ECRA (2009): Full plant costs -

<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>
Characterisation of the industry

• What industries are involved in the sector?
• What are the dominant companies?
• Does the sector consist of many smaller companies or is the global picture dominated by a limited number of players?
• Is the industry risk-averse or risk-seeking; innovative or conservative; globally active or primarily supplying a domestic market; heavily regulated or fully free?
Current environmental legislation and pressures

• High level review of relevant environmental legislation and differences between continents to be provided
• Key aspects:
  Kyoto protocol / CDM
  Emissions Trading Schemes (e.g. EUTS)
  IPPC / BAT
  LCPD (if relevant)
What are the major gaps and barriers to deployment of CO\textsubscript{2} capture in the sector?

IEA and WBSCD Cement Industry Roadmap (2009):

- From a technical point of view, carbon capture technologies in the cement industry are not likely to be available before 2020.
- Due to higher specific costs, it is expected that kilns with a capacity of less than 4,000 – 5,000 tonnes per day will not be equipped with CCS technology and that retrofits will be uncommon.
- As CCS requires CO\textsubscript{2} transport infrastructure and access to storage sites, cement kilns in industrialised regions could be connected more easily to grids, compared to plants in non-industrialised areas.
- Cement kilns are usually located near large limestone quarries, which may or may not be near suitable CO\textsubscript{2} storage sites. It is also likely that CCS clusters will be influenced by proximity to much larger CO\textsubscript{2} sources such as major coal-fired power plants.
Major gaps and barriers

- The economic framework will be decisive for future applications of CCS in the cement industry. Although it is expected that the cost of CCS will decrease in the future the current estimated costs for CO$_2$ capture are high.
- CCS could be applied in the cement industry only if the political framework effectively limits the risk of carbon leakage (relocation of cement production into countries or regions with fewer constraints). As the cost of CCS implementation will be lower for new installations than for retrofitting existing facilities, and as the majority of future demand will be in regions with no current carbon constraints, incentives must be in place to encourage the early deployment of CCS in all regions.
Questions for attendees

• What is your view regarding the summary provided?
• Are you aware of any further developments which were not covered in the summary?
• What other sources of information on the subject do you recommend?
• Are you aware of any work that has been done on CCS in the cement industry outside of Europe?
• Are there any other stakeholders that should be consulted as part of the preparation of the roadmap?
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Contact:
Duncan Barker
Tel: +44 1273 365 185, Email: duncan.barker@mottmac.com
Steel and CCS

Abu Dhabi, 30 June-1 July 2010
Global Technology Roadmap for CCS in Industry
Context

- there are already 30+ roadmaps on CCS out there…
- also quite a few active projects on technology of capture and storage, mainly uncoupled
- most focus on non-industry applications
- this meta-activity is outpacing the practical, physical one and this shows in roadmaps, which are prescriptive-normative and sometimes quite far away from what can be done and when it can be done!
- "real" data are scarce and re-used over and over
- we should aim at something more realistic, more practical and closer to the truth in this new roadmap!
Steel…

- Steel is the second major material produced in the world in terms of volume (1.3 Gt/yr)
- Steel is ubiquitous and lies at the core of our technological episteme; at rend that will continue indefinitely (production should double by 2050)
- Steel is recycled at the level of 85% but a recycling-closed loop society will not replace the present production scheme (30% secondary, 70% primary) any time soon
- Therefore, carbon-lean production of steel from ore will be needed indefinitely
  - This means in the short term, CCS in association with smelting & direct reduction
**Present CO₂ emissions of the sector**

<table>
<thead>
<tr>
<th></th>
<th>scaling factor</th>
<th>t&lt;sub&gt;CO₂&lt;/sub&gt;/ t crude steel</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Integreated Mill</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>model mill</td>
<td>1,0</td>
<td>1,7</td>
</tr>
<tr>
<td>best</td>
<td>1,0</td>
<td>1,6</td>
</tr>
<tr>
<td>worst</td>
<td>3,0</td>
<td>5,0</td>
</tr>
<tr>
<td>average</td>
<td>1,4</td>
<td>2,3</td>
</tr>
<tr>
<td><strong>EAF C-Steels</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>model mill</td>
<td>1,0</td>
<td>0,3</td>
</tr>
<tr>
<td>best</td>
<td>0,8</td>
<td>0,2</td>
</tr>
<tr>
<td>worst</td>
<td>5,0</td>
<td>1,5</td>
</tr>
<tr>
<td>average</td>
<td>1,9</td>
<td>0,6</td>
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<tr>
<td><strong>sectoral, world</strong></td>
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<td></td>
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<tr>
<td>model mill</td>
<td>1,0</td>
<td>1,3</td>
</tr>
<tr>
<td>best</td>
<td>0,9</td>
<td>1,2</td>
</tr>
<tr>
<td>worst</td>
<td>3,6</td>
<td>3,9</td>
</tr>
<tr>
<td>average</td>
<td>1,6</td>
<td>1,8</td>
</tr>
</tbody>
</table>

- major issues on boundaries (what plants are included in the steel mill), scopes (I, II and III) and level of technology excellence (best performers, worst performers and sectoral average + model steel mill)
Present energy consumption of the sector

![Graph showing present energy consumption of the sector in GJ/t for different routes and performers.]

- **Best performer**
- **Worst performer**
- **Sectoral average**

- **IM**
- **EAF route**
- **Sector**

---

Confidential

JP. Birat, 30 June-1 July 2010, UNIDO CCS meeting
Prospective – foresight (1)

Reference
(tax : 600 €/tCO2 for European Steel Industry)

F2 World
(tax : 300 €/tCO2 for European Steel Industry)
Prospective – foresight (2)

- Crude steel production [Mt-CS/yr]
  - EAF (High-eff.)
  - EAF (Middle-eff.)
  - EAF (Low-eff.)
  - Advanced Hydrogen Use (BF-BOF, DRI)
  - DRI (High-eff.)
  - DRI (Middle-eff.)
  - BF-BOF (High-eff. With Next-generation coke oven)
  - BF-BOF (High-eff.)
  - BF-BOF (Middle-eff.)
  - BF-BOF (Low-eff.)

- CO2 emission reduction from Baseline [GtCO2/yr]
  - CCS
  - DRI contribution (fuel switching and energy saving)
  - EAF contribution (fuel switching and energy saving)
  - Energy efficiency improvement of BF-BOF
Processes for low-carbon steelmaking

Carbon

H₂ by electrolysis of H₂O

Hydrogen

Natural gas prereduction

Blast Furnace

Electric Arc Furnace

Natural Gas

Coal

Syngas

Coke

Electricity

Electrons

CO₂ capture & storage
Decarbonatation
Biomass
# ulcos processes...

## Coal & sustainable biomass
- Revamping BF
- Brownfield
- TGR-BF
- HIsarna
- Pilot tests (1.5 t/h)
  - Demo phase launched

## Natural gas
- Revamping DR
- ULCORED
- Pilot plant (8 t/h)
  - start-up 2010

## Electricity
- Greenfield
- ULCOWIN
- ULCOLYSIS
- Pilot plant (1 t/h)
  - to be erected in 2011?
- Laboratory pilot

**Electricity Sources:**
- Greenfield
- Revamping DR
- Brownfield
- Revamping BF
- Coal & sustainable biomass
  - Electricity: Natural gas, Coal & sustainable biomass
Main features of "CCS" for the steel sector

- there is no such technology as CCS for the steel industry! It is just a concept or an injunction, like "you should wash your hands before a meal"!
- the only existing program where the construction of the technology has been attempted is the ULCOS program
- CCS is thus part of 3 process concepts, ULCOS-BF, HIsarna and ULCORED, which have reached various stages of development (demonstrator, pilot, modeling and lab).
- because of the particular features of the physics-thermodynamics of steelmaking, where carbon is used as a reducing agent & not a fuel, they shift the operating windows of the processes they are derived from to a region where energy is saved (10%), coke and coal as well (20%) and thus also CO2 emissions prior to storage. Also expectations of higher productivity of equipment (like t/m2/day).
Main features of "CCS" for the steel sector

- this is not enough to make them a no-regret solution, though!
- in the "short" term (until 2020), the ULCOS-BF ought to be validated at demonstrator scale; then ULCORED, then Hlsarna. Then, in the long-term (post-carbon world), possibly electrolysis, hydrogen steelmaking…
- these processes will not simply replace each other, but coexist.

- there is life outside of ULCOS, but similar breakthrough technologies, and, otherwise, there is really not much else under the radar!
Processes for low-carbon steelmaking

- vision… so long term that no other word can be used.
- peaks may not be peaks but plateaus, they may occur within ± 50 years
- e.g. the GDP peak might be called the time when prosperity & CO₂ are uncoupled
Barriers to implementation

- these breakthrough processes are costly to develop, costly to build, costly to run, much more so than the margin of operation today! Exact figures are NOT know, which is why we need demonstrators – that are built as much to test the technology as to evaluate how much it costs.
- strong support is needed for development of breakthrough processes, like 100% government funding
- for implementation, a clear cost of CO₂ (differentiated carbon value?), a level playing field across the world (carbon leakage, mill vagrancy, carbon havens) and legal framework for carbon-lean technologies, including CCS ARE NEEDED
- temporalities of climate change and of project implementation not yet in phase
Barriers to implementation

- capture may not be the major deadlock
- but storage can be it!
  - storage capacity is very much unknown… especially regarding deep saline aquifers, which ought to be the major solutions if CCS is to become a significant way to curb emissions
  - permitting is time consuming and its length is not clear
  - storage need stakeholders' approval, an area where there not much experience, especially of the proper experts (sociologists, not engineers!!)
- time is also a barrier!
Last caveats…

- CCS is only one the solutions towards a post-carbon society
- CCS only deals with CO$_2$, not with "CO$_2$ equivalent"
- CO$_2$ is almost always thought in terms of smokestack emissions, smokestack responsibility and smokestack remediation, especially as far as CCS is concerned: a little bit of creative thinking around the analysis of cause of Aristotle or of Life Cycle Thinking might point out innovative concepts and more ways to deal with the Climate Change issue than simply charging the final user as consumer or tax payer.
Thanks!
Global Technology Roadmap for CCS in Industry

Refineries

Jock Brown
24 June 2010
Refining Industry

- Oil and Gas Journal Worldwide Refining Survey 2009 defines 661 refineries worldwide, with total capacity of 87,223,000 bbl/d
- Range 1,500 bbl/d (Russia) to 940,000 bbl/d (Venezuela)
- World Average: 132,000 bbl/d
- OECD Average: 140,000 bbl/d (49% of world capacity)
- OPEC Average: 167,000 bbl/d (10% of world capacity)
- 1993 to 2007, reduced number of refineries, but 30% increase in individual capacity
- Bio-fuels are expected to have impact on refining,
  - expect 100 million t/y by 2020 mainly in Europe
  - also North and Latin America to lesser extent
Refining Industry

- Refining Capacity and Throughput in relation to world oil consumption. Source: BP statistical Review of World Energy 2010
Refining Industry

# Refining Industry


<table>
<thead>
<tr>
<th>Rank</th>
<th>Company</th>
<th>Capacity [bbl/d]</th>
<th>Proportion of World Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>ExxonMobil</td>
<td>5,357,850</td>
<td>0.061</td>
</tr>
<tr>
<td>2</td>
<td>Sinopec</td>
<td>4,210,917</td>
<td>0.048</td>
</tr>
<tr>
<td>3</td>
<td>Royal Dutch Shell</td>
<td>3,985,129</td>
<td>0.046</td>
</tr>
<tr>
<td>4</td>
<td>BP</td>
<td>3,231,887</td>
<td>0.037</td>
</tr>
<tr>
<td>5</td>
<td>ConocoPhillips</td>
<td>2,799,200</td>
<td>0.032</td>
</tr>
<tr>
<td>6</td>
<td>Petroleos de Venezuela (PDVSA)</td>
<td>2,642,600</td>
<td>0.030</td>
</tr>
<tr>
<td>7</td>
<td>PetroChina</td>
<td>2,607,407</td>
<td>0.030</td>
</tr>
<tr>
<td>8</td>
<td>Valero Energy Corp</td>
<td>2,422,590</td>
<td>0.028</td>
</tr>
<tr>
<td>9</td>
<td>Saudi Aramco</td>
<td>2,005,000</td>
<td>0.023</td>
</tr>
<tr>
<td>10</td>
<td>Total</td>
<td>1,934,733</td>
<td>0.022</td>
</tr>
</tbody>
</table>
Historic and Projected $\text{CO}_2$ Emissions

- IEAGHG $\text{CO}_2$ Emissions database 2008 – 818 Mt/y
  - Uncertainty in specific emissions value of 0.219 kg $\text{CO}_2$ / kg product
  - Uncertainty in full load operating hour of 8,300 hours/y
- McKinsey – Downstream oil and gas accounted for 1.1 Gt/y in 2005
  - Expect 1.5 Gt/y in 2020

- Lack information for projections
Refinery Emissions and Assessment Scope

- A simplified overview of CO\(_2\) emissions sources at a typical refinery complex. Source: van Straelen (2009)

<table>
<thead>
<tr>
<th>CO(_2) emitter</th>
<th>Description</th>
<th>% of total refinery emissions</th>
<th>Concentration of CO(_2) stream</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heaters and boilers</td>
<td>Heat required for the separation of liquid feed and to provide heat of reaction to refinery processes such as reforming and cracking</td>
<td>30-60 %</td>
<td>8-10%</td>
</tr>
<tr>
<td>Utilities</td>
<td>CO(_2) from the production of electricity and steam at a refinery.</td>
<td>20-50%</td>
<td>4% (CHP Gas turbine)</td>
</tr>
<tr>
<td>Fluid catalytic cracker</td>
<td>Process used to upgrade a low hydrogen feed to more valuable products</td>
<td>20-35%</td>
<td>10-20%</td>
</tr>
<tr>
<td>Hydrogen manufacturing</td>
<td>For numerous processes, refineries require hydrogen. Most refineries produce this hydrogen on site. The requirements for Hydrogen increase with demands of stricter fuel quality regulation.</td>
<td>5-20%</td>
<td>90-99%</td>
</tr>
</tbody>
</table>
Capture Technology

- **Heaters and Boilers**
  - Post Combustion Capture – Centralised CO₂ separation and compression
  - Oxy fuel combustion & capture – Central ASU, with local partial compression and central compression to HP
  - Pre-combustion – Centralised generation of H₂ fuel by gasification or SMR and CO₂ capture, combustion of H₂ at modified furnaces

- **Utilities**
  - Co-generation reduce heater and boiler requirements
  - Post combustion capture on power plant
  - Pre-combustion power plant
  - Oxy-fuel power plant

- **Fluidised Catalytic Cracker (FCC)**
  - Post combustion capture of flue gas
  - Oxy-firing regeneration process with flue gas recycle

- **Hydrogen Production**
  - High purity CO₂ stream requiring compression
Role of CCS in Refining Sector

- Most probable installation of CCS is on high purity CO$_2$ streams such as Steam Methane Reforming (SMR) or Gasification for Hydrogen production.

- Generally tight margins in refining sector, make uneconomic to install CCS without incentives or legislation

- McKinsey (2010) predicts little role outside of Europe and North America before 2030

- Maybe local need, where there is a use for CO$_2$

- Many other options for carbon abatement within refining sector
  - Process integration, waste heat recovery
  - Optimising excess air
  - Process control and improved maintenance
  - Fuel switching (may not give global CO$_2$ savings)
  - Other energy saving measures
Refining Industry Research

- Trend for large oil and gas companies to reduce research budgets and draw on third party technology when required.

- Areas of focus for research in refining sector
  - Higher Yields
  - Shorter Downtimes
  - Energy Efficiency

- Other uses for CO₂
  - Enhanced agriculture and biomass production
  - Methanol production
  - Urea production

- European CO₂ Technology Centre Mongstad (TCM)
  - Start up 2010, 100,000 tonne/y capture rate (Full scale uncertain)
  - 2 post combustion technologies in parallel
  - Capture either gas turbine flue gas (4% CO₂) or refinery process flue gas (13% CO₂)
  - Shareholders – Gassnova (Norwegian Govt.), Norske Shell, Statoil ASA, SASOL
Legislative and other Pressures

- EU Emissions Trading Schemes
  - Carbon Leakage Mechanisms
  - Free allocations until 2012, then propose 80% of current

- Transport Fuel Quality Legislation
  - \( \text{SO}_x < 10 \text{ ppm} \)
  - Cause increase refinery in \( \text{CO}_2 \) emissions by 5,400 kt/y in Europe in 2020
  - However, it will reduce European tailpipe \( \text{CO}_2 \) emissions by 15,000 kt/y in 2020

- IMO Specification Changes
  - sulphur < 0.1% in \( \text{SO}_x \) emissions control area’s
  - Suphur < 0.5% in all other area’s
  - 5% increase in refinery \( \text{CO}_2 \) emissions in 2015 when implemented

- Combustion plant legislation
  - \( \text{NO}_x, \text{SO}_x, \) particulates, VOCs,
  - Mitigation measures increase energy demand and hence \( \text{CO}_2 \) emissions
Investments and Costs

- McKinsey and Company (2008) study for coal fired power plant capture
  - €30-50/tonne for commercial scale plants
  - €60-90/tonne for initial demonstration projects

- INTEK (2009) based on US refining cases
  - $US 34-61 capture costs
  - $US 43-115 total costs (€35-93)

- Tel Tek (2009) Norwegian study look at industrial capture costs, more specifically for distillation in refining sector
  - €77/tonne CO$_2$ for atmospheric distillation heater

- Other publications with costs for CCS specific to refining industry to be considered:
  - Concawe Well to Wheel report for EC DG Energy (2007)
  - CO$_2$ Capture Project studies of Grangemouth refinery (2005)
  - IEAGHG Study of CCS for fired heaters in refining (2000)
  - Rotterdam Climate Initiative study on CCS for Rotterdam industrial complex (2009)
  - Shell capture study for refineries (2009)
Investments and Costs

- Carbon abatement potential and cost for the oil and gas industry. Source: McKinsey and Company Quarterly Survey 2010

![Abatement cost graph]

Abatement cost, € per metric ton CO₂e equivalent (tCO₂e)

- Improved planning
- Energy efficiency from behavioral changes
- Energy efficiency from improved maintenance and process control
- More new energy-efficient buildings
- Replacement of compressor seals
- Directed inspection and maintenance on compressors
- Directed inspection and maintenance on distribution network
- Reduction of continuous, remote flaring
- Carbon capture and storage (CCS)
- Energy efficiency requiring capital expenditures (CAPEX) at process unit level on retrofits
- Energy efficiency from improved behavior, maintenance, and process control on retrofits

Abatement potential, million metric tons CO₂ equivalent (mmtCO₂e) per year
Gaps and Barriers

- At this meeting as a minimum we would like to discuss the following issues:
  - Is the scope of the assessment suitable for the roadmap?
  - Do the references accurately represent the current status of refining industry and CCS technology?
  - Refineries are unique in the number of different processes, with different specifications of CO2 to be captured, how can the roadmap be flexible to deal with this?
  - For the refining sector carbon abatement options, other than CCS, exist that offer “quick wins” for reducing CO2 emissions, how should the roadmap consider these?
  - Emissions taxation and trading mechanisms can lead to carbon leakage, how can the roadmap address this?
  - Fuel quality regulations aimed at reducing CO$_2$ emissions in the transport sector have implications for the emissions of the refining sector, how can carbon taxes and emissions trading schemes be sympathetic to these implications?
  - Large scale CCS could be implemented in other sectors before refining, what methods for knowledge transfer from these sectors could enhance opportunities for deployment in refining sector?
  - Financing CCS (in refineries and otherwise) remains a major barrier to its implementation, how can perceived risk be reduced for investors?
Safeguarding life, property and the environment

www.dnv.com
Sectoral workshop: Biomass-based CO$_2$ sources
Session 1: Developments and CO$_2$ abatement options

Michiel Carbo
CO₂ capture and storage (CCS)

Source: IPCC Spec. Report, 2005
What is the objective of this assessment?

- Roadmap: “to provide relevant information on actions and milestones to government and industry decision-makers, that can facilitate the deployment of CCS in industry”
- Biomass-based non-power CO$_2$ sources
- Starting point is the IEA global technology roadmap for CCS (2009)
Why biomass-based CO$_2$ sources?

- CCS at biomass-based CO$_2$ sources potentially leads to negative CO$_2$ emissions, i.e. CO$_2$ uptake from atmosphere by natural CO$_2$ sequestration in biomass
- Indispensable for low GHG stabilisation levels in the longer term (after 2050)
- A relatively pure CO$_2$ stream is always produced during biomass-to-biofuel conversion processes (capture-ready)
- Low incremental cost for CO$_2$ capture → drying, compression, transport and storage
- Large potential for developing nations
- Possibly more positive public perception than fossil CCS
Future biomass use

Source: IEA: Energy technology transitions for industry (2009)
Future CO$_2$ capture potential

Captured in 2020 (168 Mt CO2/yr)

- Biomass (synfuels + H2): 21%
- Gas (synfuels + H2): 3%
- Gas processing: 41%
- Chemicals: 11%
- Iron and steel: 18%
- Cement: 6%

Captured in 2050 (4 570 Mt CO2/yr)

- Biomass (synfuels + H2): 47%
- Chemicals: 7%
- Pulp and paper: 1%
- Iron and steel: 18%
- Gas processing: 8%
- Gas (synfuels + H2): 9%
- Cement: 11%

Caution: these figures are based on different assumptions than the figure in the previous slide

Source: IEA: global technology roadmap for CCS (2009)
Which biomass-based CO$_2$ sources?

Scope sectoral assessment

Source: Rhodes & Keith (2005)
Which biomass-based CO$_2$ sources?

- Bio-chemical biomass conversion:
  - Ethanol
- Thermo-chemical biomass conversion:
  - Substitute Natural Gas (SNG)
  - Fischer-Tropsch Diesel
  - Alcohols
  - Gasoline
  - Hydrogen
Which biomass-based CO$_2$ sources?
Fact finding: what do we know?

1st generation ethanol (IEA, 2008):
• Brazilian ethanol production (2007): $18.0 \times 10^9$ liter
• USA ethanol production (2007): $24.4 \times 10^9$ liter
• Roughly translates to 32 Mt CO$_2$, being vented from fermentation operations in Brazil and the USA alone
• Average plant size USA: 200 Mliter/a $\rightarrow$ ~140 kt CO$_2$/a
• Estimated GHG emission reduction w/o CCS in Brazil: 2.6-2.7 kg CO$_2$ eq./liter $\rightarrow$ 47 Mt CO$_2$ (Macedo, 2004)
• Including CCS $\rightarrow$ 61 Mt CO$_2$
Fact finding: work in progress

- Publications with technical and economic details about combination of biomass-based industrial processes and CCS are scarce, especially for application in developing nations.
- 2nd generation ethanol & thermo-chemical conversion processes, both w/o CCS, are in early stage of development; a selection:
  - 2nd gen. ethanol: Abengoa in Spain (2007): 4 MW_{th, output}
  - SNG: CoBiGas project in Sweden (2012): 20 MW_{th, output}
  - Fischer-Tropsch: Choren in Germany (2010): 45 MW_{th, input}
  - Gasoline: GTI in USA (201?): 1 MW_{th, output}
Ethanol from lignocellulose

- Straw (100% C)
  - Pre-treatment & pre-hydrolysis
  - Hydrolysis & fermentation
  - Distillation & dehydration
  - CO₂ capture & storage
  - CHP
  - Lignin & residues
  - Vented

- Bio-ethanol (25% C)
- CO₂ (13% C)
- CO₂ (62% C)
Substitute Natural Gas (SNG)

- Woody biomass (100% C)
- Indirect gasification
- Gas cleaning & treating
- Methanation
- CO₂ capture & storage
- SNG (40% C)
- CO₂ (40% C)
- CO₂ (20% C)
Questions to be addressed

- Is the scope of the assessment ok? Which sources should be added or removed?
- Which sources have the largest potential for application in developing countries?
- What is the anticipated minimum plant size at which CO₂ should be captured? What are the scale issues?
- What CO₂ capture from biomass-based industrial sources can be considered “low-hanging fruit”?
- ....
Sectoral workshop: Biomass-based CO$_2$ sources
Session 2: Major gaps and barriers

Michiel Carbo
Questions to be addressed

• What major technological breakthroughs are needed, and in which biomass-based industrial processes?
• What is the minimum required plant size to effectively capture CO$_2$?
• What are other specific gaps and barriers for CO$_2$ capture from biomass-based industrial sources?
• Which capacity building efforts are needed to ensure broad implementation in developing nations?
• Which financial incentives are needed?
Sectoral workshop: Biomass-based CO$_2$ sources
Session 3: Actions and milestones

Michiel Carbo
Questions to be addressed

• What are crosscutting issues with other sectoral assessments?
• What are possible synergies with other industrial sectors (pulp & paper, iron & steel and cement)?
• Who are the actors relevant to the industrial biomass-based CO$_2$ capture technologies? Who has an interest in it? What institutions and networks exist that fulfill functions for industrial CO$_2$ capture in biomass?
• What actions are needed to overcome the gaps and barriers? What are associated timing and milestones?
Questions

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fuel composition database: www.phyllis.nl
tar dew point calculator: www.thersites.nl
IEA bioenergy/gasification: www.ieatask33.org
Milena indirect gasifier: www.milenatechnology.com
OLGA tar removal: www.olgatechnology.com
SNG: www.bioSNG.com and www.bioCNG.com
Annex 5: Sectoral workshop results
Global Technology Roadmap for CCS in Industry

Results from sectoral workshops –

Biomass-based CO$_2$ sources – BECCS (Bio Energy with Carbon Capture and Storage)

Consultant: Michiel Carbo

Moderators: Patrick Nussbaumer, Wolfgang Heidug and Alice Gibson

Rapporteur: Henrik Karlsson, Biorecro
Session 1 – 30\textsuperscript{th} June, 11:00

Key points - abatement options and technologies, potential of CCS, current activities -

- Wide array of possible CO2 sources such as biomass conversion, pulp mills, ethanol plants. Difficulties to assess potential.
- Near term, low cost opportunities: Ethanol production in the US, Brazil and Europe.
- Very large long term contribution (IEA: “47% of industry CCS in 2050”). Potential on the gigaton scale of CO\textsubscript{2} removed, depending on a number of factors. Low cost in combination with biomass fuel conversion.
- BECCS/BiomassCCS feasibility and costs heavily dependent on type of underlaying biomass industrial system.
- Less than a handful of pilots and demonstrations planned/under construction presently, mainly in the US DOE partnerships.
Session 2 – 30th June, 13:30

Major gaps and barriers to implementation

- “BECCS - The forgotten technology”.
- Falls between chairs – overlooked by both CCS and biomass communities.
- Lack of awareness and capacity among stakeholders.
- Biogenic emissions are not the problem, but rather a solution if combined with CCS. With a focus on problems, reactive (i.e. non-pro-active) stakeholders overlook this solution.
- BECCS lacks champions to drive implementation – “classic example of policy failure”.
- Excluded from incentive and demonstration programs (eg. EU CCS funding).
Session 3 – 1st July, 9:00

Actions and milestones

- Build a BECCS stakeholder network.
  - Mobilize political, NGO, scientific and industrial champions.
  - Involve and utilise the IEA, UNIDO, GCCSI, other political forums and key nations such as Brazil, Sweden, the US and Indonesia.

- Awareness program, targeting politicians, media and NGOs
- Detailed studies on costs, long term contribution and early opportunities.
- Studies on GHG negative emission accounting
  - These need to be recognised in the UNFCCC
- Targeted BECCS pilot and demonstration project
Global Technology Roadmap for CCS in Industry

Results from sectoral workshops – *Cement*

Consultant: Duncan Barker
Moderators and Rapporteur: Mohammad Abuzahra and Nathalie Trudeau

Sectoral Workshop
30 June – 1 July 2010, Abu Dhabi, UAE
Session 1 – 30th June, 11:00

Key points - abatement options and technologies, potential of CCS, current activities -

- Highlight the past improvements and the gains achievable through improvements in products.
- Need to better define the sector boundaries.
- Need to address the cooling water and land requirement issues.
- Intermittency in the CO$_2$ supply, pressure fluctuation.
- Regional distinction of the cost of new plants.
- Recommend reductions to be specified as “specific reduction” (per tonne of product).
- Better assessment of storage capacity.
- Efforts should be shared, not duplicated.
- Other options for CO$_2$ reductions are limited.
Session 2 – 30th June, 13:30

Major gaps and barriers to implementation

- Most gaps and barriers are shared by all industries.
- Steam required for amine scrubbing is not available at cement plants.
- Location of cement plants: cost of transporting cement may be higher than cost of transporting CO$_2$.
- CAPEX investments too high for small plants.
- Lack of financing for the step between lab-scale and small industrial application.
- Plant size is double, land area issue.
- Oxy-fuelling may infer with product quality, more R&D required.
- Operations for transport and storage require “pooling”.
- Gas purity specs for pipelines and final use.
Session 2 – 30th June, 13:30

Major gaps and barriers to implementation - continue

- Issue around the continuous supply of oxygen quality
- No benefit in current legal frameworks to capture CO₂ from bio sources.
- Public acceptance.
- Harmonisation of legal context.
- Higher operating costs.
- Integration of the capture plant with cement plant
- Reluctance of operators to undertake non-core business operations
- Reliance on technology providers to undertake R&D
Session 3 – 1\textsuperscript{st} July, 9:00

Actions and milestones

- Include assessment of suitability of new sites for CCS.
- Need clarity of long term carbon market.
- Regulatory certainty (clarity on liabilities).
- Technical development – demonstration plants funded.
- Collaboration and coordination between different stakeholders and industries.
- Countrywide cross-sector feasibility studies to identify best CCS opportunities.
- Knowledge transfer from transport and capture activities in other sectors.
- Oxyfuel demonstration required.
- Engagement with India and China.
Global Technology Roadmap for CCS in Industry

Results from sectoral workshops –

*High-purity CO₂ sources*

**Consultant: Paul Zakkour**

**Moderators: Dolf Gielen, Heleen de Coninck and Dale Seymour**

**Rapporteur: Kamel Bennaceur**

Sectoral Workshop
30 June – 1 July 2010, Abu Dhabi, UAE
Participants

• Klaus Angerer (OMV)
• Kamel Bennaceur (Schlumberger)
• Heleen de Coninck (ECN)
• Dolf Gielen (UNIDO)
• Wolfgang Heidug (IEA)
• Firas Kaddoura (BP)
• Sam Nader (MASDAR)
• Sachchida Nand (FAI)
• Reza Oskui (Kuwait I.S.R)
• Lawan Pornsakulsakdi (PTTEP)
• Mohammad Soltanleh (ERC-Iran)
• Dale Seymour (GCCSI)
• Mathias Stein (Linde)
• Paul Zakkour (Carbon Counts)
Session 1 – 30th June, 11:00

Key points - abatement options and technologies, potential of CCS, current activities -

- Gas Processing / Sweetening to meet pipeline/LNG specification
- XtL: CTL and GtL
- Ammonia production
- Hydrogen production for petroleum refining and other uses
- Ethylene oxide – offgas processing

Status:

- Majority of current industrial size CCS projects (circa 1 Mtpa)
- Scale expansion with Australia’s Gorgon project: 3.5 Mtpa
- Some of capture technology used for decades: amines, membranes. Skills, knowledge and experience concentrated in this sector
- Costs: Amongst the lowest for capture
Session 2 – 30th June, 13:30

Major gaps and barriers to implementation

- **Gaps**
  - Incentives/Risks: Carbon pricing
  - Regional transport infrastructure
  - Need thorough assessment of matching sinks and sources (existing/future)
  - Need updating of early opportunities
  - Further assessment of gas (sour/unconventional)
  - Legal and regulatory, liability
  - Gap analysis for fertilizers’ value chain

- **Barriers**
  - Distinction between Storage and EOR
  - NIMBY Issues Public awareness / Risk communication
  - No technological barriers, but issues with CO2-EOR as cost per barrel is significantly higher than greenfields in the Middle East
Session 3 – 1\textsuperscript{st} July, 9:00

Actions and milestones

- Gulf States are an early opportunity for CCS – greater cooperation through existing forums is an important 1\textsuperscript{st} step (e.g. GCC, OPEC)
- Raise awareness with policy makers about the potential for applying CCS for high purity sectors – source identification, scale etc.
- Develop regional reviews of CCS potential focusing on cheap CO2 sources i.e. High purity sources.
- Data sharing is a must – lack of disclosure is preventing serious dialogue on the potential.
- Development of regional CCS strategies can kick start discussions on creating CCS enabling policy frameworks
- Govts. to develop industrial strategies that support early utilization of high purity sources in CCS demonstration, especially demonstration of storage (e.g. site selection, regulation, monitoring etc).
- For high purity sources, demand side issues seem critical – EOR requirements, acceptance all need to be clarified to enhance the “market pull”
Action points

• Need to understand the long-term role of CO2-EOR in oil-rich regions
• Internal demand for gas is rising in the Gulf – need a value for gas replacement (as used in secondary oil recovery).
• Capacity building is needed in many regions

Milestones
• CCS to be recognized as a mitigation activity under CDM
• CO2-EOR to be recognized as a climate mitigation technology?
• Suitable international emission reduction mechanism developed which includes CCS (e.g. NAMAs). MRV requirements outlined
• Develop viable financing mechanism to support CCS demonstration projects, focusing on high purity sources
• Several feasible projects in the Gulf and other regions to be identified
• Complete CO2 source and storage map for the Gulf region
• Establish a regional network of CCS stakeholders
Global Technology Roadmap for CCS in Industry

Results from sectoral workshops

Iron and Steel

Consultant: Jean-Pierre Birat
Rapporteur: Heleen de Coninck, Dolf Gielen and Paul Crooks

Rapporteur: ....

Sectoral Workshop
30 June – 1 July 2010, Abu Dhabi, UAE
Session 1 – 30th June, 11:00

Key points - abatement options and technologies, potential of CCS, current activities -

- Steel is a globally diverse industry
- Varying CO2 emissions and calculation systems
- Steel production at 1 billion tonnes/yr, assumed to double by 2050
- ULCOS and the Worldsteel ‘Breakthrough Programme’ – address CO₂
- Data on China is an issue
- Programme such as ULCOS offer energy efficiency improvements as well as CO₂ Capture
- TGR-BF is the cheapest option and can be retrofitted
- Hisarna is not yet available – potentially in 10 years
- Risk of investing in sub-optimum capture technology
Session 2 – 30th June, 13:30 - Major gaps and barriers to implementation

**Iron and steel specific**
- Availability of data – particularly in developing and emerging economies
- Consistency of emissions ‘measurement’
- Steel manufacturers – not pipeline operators or geologists
- Shortage of skilled people

**CCS in general**
- Uncertainty of storage locations and transport possibilities
- The ‘lifetime’ business model(s) for steel with CCS not defined
- Developing countries short of energy, how can CCS be justified?
- Conflict between realistic deployment timelines and G20 ambitions
- Carbon leakage, competitiveness, level playing field
Session 3 – 1st July, 9:00

Actions and milestones

- Data gathering, especially outside the EU
- Training programmes for engineers and scientists
- Communication with the general public – by governments, UN, NGO
- Standards for impurities in capture streams from steel processes
- Steel sector “Source to Sink” demonstration plant by 2020
- Geological quantification to facilitate further deployment
- IP & technology transfer (inter and intra industry)

- Globally regulatory framework to level playing field
Global Technology Roadmap for CCS in Industry

Results from sectoral workshops

*Refineries*

*Consultant: Jock Brown*

*Moderators: Keristofe Seryani, Alice Gibson and Dolf Gielen*

*Rapporteur: …*

Sectoral Workshop

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Session 3 – 1st July, 9:00

Common Issues

- General lack of training in the field for technical professionals and managers
- Water & electrical supply security.
- CO2 specifications for sinks can make any specification but this has a cost associated. (Need guidelines for CO2 specification final use and this needs to reflect regional needs)
- International Legislation – to do with liability, both short and long term. Initially may be able to use local regulations, but long term needs to be international.
Specific Issues relating to Refining

- Unique issues to Refining
  - Technology needs to be tested in the sector, need to have targets for industry similar to those for power sector.
  - Capture ready design of new refineries: need incentives and design guidelines for building capture ready refineries.
- Multiple CO2 Sources
- Different Technologies depending on source
- Private vs state owned plants (IOCs, NOCs, JV and Independents)
- Low refinery margins
- Age of refineries
- Monitoring criteria needs to specific to industry, for taxation & trading schemes
Session 3 – 1st July, 9:00

Actions and milestones

- **Actions**
  - Comprehensive emissions inventory
  - Ensure all low cost emissions abatement have been addressed to reduce capture inventory.
  - Characterise capture by unit operation
  - Develop training for engineers
  - Guidelines (& specifications) for both retrofit and capture ready specific to refining
  - Comprehensive pilot demonstrations, due to complexity and differences between each refinery
  - Knowledge transfer, specifically risk management from other areas where new technology is used regularly
Session 3 – 1st July, 9:00

Actions and milestones

- Milestones
  - Follow up with IEAGHG program to discuss opportunities and above issues
  - Refining specific conference with all technology providers in next 2 years
  - Disseminate information from developed nations
  - Global agreement
  - Industry agreement
  - Demonstration of technology
  - Develop local knowledge in CCS, training
  - Find local champions for the cause in these regions
  - Regulations
  - Technology transfer and financing mechanisms