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IEAGHG International Interdisciplinary CCS Summer School 2016
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Reserves: Our use of the term “reserves” in this presentation means SEC proved oil and gas reserves.

Resources: Our use of the term “resources” in this presentation includes quantities of oil and gas not yet classified as SEC proved oil and gas reserves. Resources are consistent with the Society of Petroleum Engineers 2P and 2C definitions.

Organic: Our use of the term “Organic” includes SEC proved oil and gas reserves excluding changes resulting from acquisitions, divestments and year-average pricing impact.

Shales: Our use of the term ‘shales’ refers to tight, shale and coal bed methane oil and gas acreage.

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- Founded in 1997
- Extensive experience with regenerable amine processes
- Track record of delivering commercial scale flue gas treating amine plants worldwide
- 20+ licenses, 15 plants in operation worldwide
- Part of Shell since 2008
- Based in Montreal, Canada and Beijing, China
First commercial-scale post-combustion carbon capture system at a coal-fired power plant

Demonstrates the viability of large-scale post-combustion CO₂ capture

Uses Shell Cansolv CO₂ technology.
Captures up to 90% CO₂, high or low SO₂ content

Enables EOR with CO₂ from power plant flue gas

Meets stringent CO₂ regulations

CO₂ is permanently stored
WHY IS INDUSTRIAL CO2 CAPTURE ESSENTIAL?

- The 2DS suggests a steep deployment path for CCS technologies applied to power generation and a number of industries.

\[ \text{Industry/ total} = \sim 45\% \]
EMISSION OF CO₂ FROM INDUSTRIAL PROCESSES

- On-site production of heat or electricity
- Chemical reactions that produce CO₂
INDUSTRIAL CO₂ SOURCES
WHAT ARE THE MAJOR CONTRIBUTORS?

- Steel
- Cement
- Chemicals
- Refineries
- Gas processing
- Pulp and Paper
- Bio-fuels
- Gasification
CO2 CAPTURE FROM INDUSTRIAL SOURCES
IRON AND STEEL PLANT
GLOBAL STEEL PRODUCTION

Global Crude Steel Production: 1980-2025

- By 2030 Production of steel will increase to 2.5 Gt/year,
- 65% of it will be in BRIC countries,

WHAT ARE THE SOURCES OF CO2 IN IRON AND STEEL PROCESS?

1.8 ton CO2/ton crude steel
Steel plant: 1.8 ton CO$_2$/ton crude steel

Estimate of cumulative steel production from now to 2030 = 30.5 Gt

Estimate of cumulative CO$_2$ emission from steel plant by 2030 = 55 Gt

Applying CCS on 15% of Steel production

8.3 Gt CO$_2$ Captured
This map is without prejudice to the status of any territory, to the delimitation of international boundaries and to the name of any territory, city or area.
CO2 CAPTURE FROM INDUSTRIAL SOURCES
CEMENT PLANT
By 2030 Production of cement will increase to 5.5 Gt/year,

India and China are the major producers.
WHAT ARE THE SOURCES OF CO₂ IN CEMENT PROCESS?

0.5 ton CO₂/ton clinker

Diagram showing the cement process with CO₂ emissions, calcining zone, clinkering zone, and fuel combustion. The calcining zone has the reaction CaCO₃ → CaO + CO₂ at 600-900°C.
CO2 CAPTURE FROM INDUSTRIAL SOURCES

CHEMICALS
numerous large-scale ammonia production plants worldwide, producing equivalent to 159 million tonnes of ammonia in 2010

China produced 32.1% of the worldwide production, followed by India with 8.9%,

80% or more of the ammonia produced is used for fertilizing agricultural crops.

Source: www.indexmundi.com/en/commodities/minerals/nitrogen/nitrogen_t12.html
WHAT ARE THE SOURCES OF CO2 IN AMMONIA PROCESS?

1.3 ton CO2/ton NH3

\[ \text{CH}_4 + \text{H}_2\text{O} \rightarrow \text{CO} + 3\text{H}_2 \]

\[ \text{CO} + \text{H}_2\text{O} \rightarrow \text{CO}_2 + \text{H}_2 \]
CO2 CAPTURE FROM INDUSTRIAL SOURCES
REFINING
GLOBAL OIL REFINERY PRODUCTION

Products Made from a Barrel of Crude Oil

Typical Products Made from a 42-Gallon Barrel of Refined Crude Oil

- 3% Asphalt
- 4% Liquefied Petroleum
- 10% Jet Fuel
- 18% Other Products
- 23% Diesel Fuel & Heating Oil
- 47% Gasoline


## WHAT ARE THE SOURCES OF CO$_2$ IN TYPICAL COMPLEX REFINERY?

<table>
<thead>
<tr>
<th>CO$_2$ emitter</th>
<th>Description</th>
<th>% of total refinery emissions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Furnaces and boilers</td>
<td>Producing heat and steam</td>
<td>30–60%</td>
</tr>
<tr>
<td>Utilities</td>
<td>Electricity and steam</td>
<td>20–50%</td>
</tr>
<tr>
<td>Fluid catalytic cracker</td>
<td>CO$_2$ as by-product</td>
<td>20–35%</td>
</tr>
<tr>
<td>Hydrogen manufacturing</td>
<td>CO$_2$ as by-product</td>
<td>5–20%</td>
</tr>
</tbody>
</table>

CO\textsubscript{2} Capture from Industrial Sources

Challenges of Deploying CO\textsubscript{2} Capture Process
## CHALLENGES ➔ HIGHER COST FOR CCS

### Characterization of inlet gas to capture process

<table>
<thead>
<tr>
<th></th>
<th>Steel and Iron</th>
<th>Cement</th>
<th>Chemicals (Ammonia plant)</th>
<th>Refinery</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CO₂ Concentration (% vol.)</strong></td>
<td>20-30</td>
<td>20-40</td>
<td>~8</td>
<td>5-15</td>
</tr>
<tr>
<td><strong>Temperature (°C)</strong></td>
<td>~150</td>
<td>100-150</td>
<td>200-250</td>
<td>200-300</td>
</tr>
<tr>
<td><strong>Pressure (Mpa)</strong></td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td><strong>Contaminations</strong></td>
<td>dust</td>
<td>dust</td>
<td>---</td>
<td>SO₃, NO₂, dust</td>
</tr>
</tbody>
</table>

### Size and location

<table>
<thead>
<tr>
<th></th>
<th>Steel and Iron</th>
<th>Cement</th>
<th>Chemicals (Ammonia plant)</th>
<th>Refinery</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Distributed or concentrated</strong></td>
<td>Distributed</td>
<td>Distributed</td>
<td>Distributed</td>
<td>Concentrated</td>
</tr>
<tr>
<td><strong>Plant capacity</strong></td>
<td>&lt; 1Mton CO₂/year</td>
<td>&lt; 1Mton CO₂/year</td>
<td>&lt; 1Mton CO₂/year</td>
<td>&gt; 1Mton CO₂/year</td>
</tr>
</tbody>
</table>

### Other items

<table>
<thead>
<tr>
<th></th>
<th>Steel and Iron</th>
<th>Cement</th>
<th>Chemicals (Ammonia plant)</th>
<th>Refinery</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Low grade heat available on site</strong></td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td><strong>Availability of the water</strong></td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

IS CCS THE ONLY OPTION?

- Alternative materials with lower carbon foot options,
  - Material of construction,
  - Chemicals,
- Process improvement:
  - Efficient energy consumption
  - Different chemistry and reaction pathway to eliminate CO₂ as a byproduct
- Onsite CO₂ utilization
  - Example: Cement curing at cement plant
- Alternative solutions will reduce CO₂ emission but cannot replace CCS,
SUMMARY
Capture

- Capture-related technology has been utilised in industry for decades

- Most mature technology uses amine solvents for CO₂ Capture

- Emerging capture technologies build on industrial processes e.g. gas/solid fluidised beds & membranes.

- CCS will play major role for CO₂ emission reduction from industrial sources
CCS PROJECTS ARE OPERATIONAL BUT MORE ARE NEEDED

15 large scale projects in operation globally, a further 7 under construction

Most projects are associated with O&G industry and using CO₂ for EOR

Capacity to prevent 40 million tons of CO₂ per annum from reaching the atmosphere

Source: Global CCS Institute, 2016
SHELL CCS APP.

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