PRECOMBUSTION TECHNOLOGY for Coal Fired Power Plant

IEA Greenhouse Gas R&D Programme
2011 Summer School

Monica Lupion
CO₂ Capture Programme
CIUDEN
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Fundación Ciudad de la Energía

An initiative of the Spanish Administration

CIUDEÑE was created in 2006 as a R&D institution fully conceived for collaborative research in CCS and CCTs in order to strengthen the social, industrial and technological base in El Bierzo and by extension in Spain and Europe.
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To create a world-wide reference centre for CCS technology development

Plants for CO\textsubscript{2} Capture, Transport and Storage

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Technology Development Centre for CO₂ Capture
Presentation Outline

• Introduction
• Gasification
  – Technology Overview
  – Types of Gasifiers
  – Combustion versus Gasification
• IGCC
  – IGCC Overview
  – IGCC Comparison
  – Large Scale IGCC Projects
• IGCC with CO₂ Capture
  – General Overview
  – Economics of IGCC with CO₂ capture
  – Experiences
Introduction

Precombustion Technology
Combating Climate Change...
Introduction: Precombustion Technology

Clean Coal Technologies CCTs
Clean Coal Technologies CCTs

CCS alone will provide up to 20% of the GLOBAL cuts in emissions we need by mid-century.

Introduction: Precombustion Technology
Introduction: Precombustion Technology

- **Postcombustion (PC)**
  - Coal → Power & Heat
  - Air → CO₂ Separation
  - CO₂: 3-15%

- **Precombustion (IGCC)**
  - Coal → Gasification
  - Air/O₂ → Shift, Gas Cleanup + CO₂ Separation
  - Steam → Power & Heat
  - CO₂: 40%

- **Oxyfuel Combustion**
  - Air → Air Separation
  - Coal → O₂
  - CO₂: >95%
  - N₂

Adapted from EPRI 2007
Introduction: Precombustion Technology

Precombustion (IGCC)
- Coal
- Air/O₂
- Gasification
- Shift, Gas Cleanup + CO₂ Separation
- Power & Heat
- CO₂ > 95%
- CO₂ Compression and Dehydration

Postcombustion (PC)
- Coal
- Air
- Power & Heat
- CO₂ Separation
- CO₂: 3-15%

Oxyfuel Combustion
- Coal
- Air
- Air Separation
- Power & Heat
- CO₂: >95%

NO SILVER BULLETS!!

Adapted from EPRI 2007
Introduction: Precombustion Technology

- CO₂ Capture and H₂ Production

Source: CO2CRC
Introduction: Precombustion Technology

- CO$_2$ Capture and H$_2$ Production
Gasification
Technology Overview
A partial oxidation process that can convert any hydrocarbon into hydrogen and carbon monoxide (synthesis gas or SYNGAS)

\[(\text{CH})_n + \text{O}_2 \rightarrow \text{H}_2 + \text{CO}\]

For example:

\[2 \text{ CH}_4 + \text{O}_2 \rightarrow 4\text{H}_2 + 2\text{CO}\]

[ Methane] [Oxygen] [Hydrogen] [Carbon Monoxide]

Process Conditions: • 950-1550 ºC, 25-70 bar
A bit of technology: GASIFICATION

So what can you do with CO and H2?

Building Blocks for Chemical Industry

Transportation Fuels (Hydrogen)

Clean Electricity
A bit of technology: COAL GASIFICATION

PC Boiler

Gasifier

CFB Boiler

Bed material
Absorbent

AIR

O₂

H₂O

DeNOₓ

DeSOₓ

Dedusting

Dedusting

Dedusting

CYCLE
(GT+ST)

Fisher-Trops
Metanol

Chemicals
Transport fuels

Steam Turbine

ST

Ash + Absorbent

Ash

Ash

IEAGHG Summer School.
18th - 22nd July 2011. Champaign, Illinois (USA)
A bit of technology: COAL GASIFICATION

Severe thermo-chemical operating conditions

**Reactants**
- O2
- Chlorine
- Nitrogen
- Mineral matter
- Sulphur
- Carbon
- Hydrogen

**Products**
- Water
- Carbon monoxide
- Carbon dioxide
- Ash
- Ammonia
- Hydrochloric Acid, HCl
- Hydrosulfuric Acid, H2S

**Reactants** and **products** are illustrated in a diagram.
A bit of technology: COAL GASIFICATION

COAL → HEAT (673 K) → PYROLYSIS → PRIMARY REACTIONS → AIR/OXYGEN + STEAM (973 K) → GASES VOLATILES + MINERAL MATTER → GASIFICATION → COKE + COMBUSTION

CO2, CH4, H2
CONCEPT

- Partial oxidation process to produce syngas

GASIFICATION AGENTS

- Elemental Oxygen (Air): POOR SYNGAS (CO + H₂ + N₂)
- Elemental Oxygen (O₂)
- Combined Oxygen (H₂O): WATER SYNGAS (CO + H₂)
- Mixtures Oxygen/Water

IDEAL GASIFICATION

- Carbon: - CO
- Inefficiencies:
  - Partial Formation CO₂
  - Incomplete Carbon Oxidation
- Collateral Reactions
  - Pyrolysis
  - Hydrogenation (C + 2 H₂ = CH₄)
Gasification

Types of Gasifiers
Technology Overview: Gasifiers

### First Generation Gasifiers

<table>
<thead>
<tr>
<th>Technology</th>
<th>C %</th>
<th>Resident time</th>
<th>Pressure (bar)</th>
<th>Temperature (°C)</th>
<th>Particle Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moving Bed (LURGI)</td>
<td>99</td>
<td>1-1/2 h</td>
<td>30</td>
<td>1100</td>
<td>&gt;10 mm</td>
</tr>
<tr>
<td>Fluidized Bed (WINKLER)</td>
<td>70</td>
<td>3/4 h</td>
<td>1</td>
<td>900</td>
<td>0-10 mm</td>
</tr>
<tr>
<td>Entrained Flow (KOPPERS-TOTZEK)</td>
<td>88-98</td>
<td>Few seconds</td>
<td>1</td>
<td>1500</td>
<td>70% 200 mesh x down (dry)</td>
</tr>
</tbody>
</table>
Dry carbon fuel is fed through the top of the gasifier. As it slowly drops through the vessel, it reacts with steam and oxygen as they flow in opposite directions over the bed. The fuel goes through the process until it is completely spent leaving behind low temperature syngas and dry ash. Trace contaminants are later scrubbed from the syngas.
Steam and oxygen flow upwards through the reactor tower while fuel is injected into, and remains suspended in this stream while gasification takes place. Moderate temperature syngas exits the while dry (unmelted) ash is evacuated at the bottom.
Fuel can be fed dry or wet (mixed with water) into the gasifier. The reactants (steam and oxygen) flow unidirectionally through the gasifier, as the stages of gasification take place, until high temperature syngas exits the reactor. Molten slag drops out at the bottom.
Gasification

Combustion vs Gasification
## Combustion

- **SO₂ & SO₃** is scrubbed out of stack gas – reacted with limestone to form gypsum
- **NOₓ** controlled with low NOₓ burners and catalytic conversion (SCR)
- Flyash removed via ESP or bag filters
- Hg can be removed by contacting flue gas with activated carbon

## Gasification

- **H₂S & COS** easily removed from syngas and converted to solid sulfur or sulfuric acid
- **NH₃** washes out of gas with water, thermal NOₓ controlled by diluent injection, optional SCR for deeper NOₓ removal
- Ash converted to glassy slag which is inert and usable
- >90% of Hg removed by passing high pressure syngas thru activated carbon bed
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IGCC

IGCC overview
IGCC Overview

Gasifier

Fuel

O₂

Bottom Ash

Deducting

DeSO₂

Ash

S

GAS TURBINE

HEAT RECOVERY

STEAM TURBINE

Stack

Combined Cycle

40%

60%

ASU

Air

N₂

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IGCC

IGCC Comparison
IGCC vs Conventional Coal PS

Clean-up of fuel prior to power generation

Solid waste

- Less Volume: IGCC produce about half the solid wastes of conventional coal plants
- Better Form: IGCC solid wastes less likely to leach toxic metals than fly ash from conventional coal plants because IGCC ash melts and is vitrified (encased in a glass-like substance)

Water Use

- Less Water: IGCC units use 20%-50% less water than conventional coal plants and can utilize dry cooling to minimize water use
IGCC vs Conventional Coal PS

Environmental Technology => Greatest potential for future

- Lowest NO$_x$, SO$_x$, particulate matter and lower hazardous air pollutants
- Hg and CO$_2$ removal
- Lower water usage, lower solids production
- Sulfur and non-leachable slag by-products
- CO$_2$ under pressure takes less energy to remove than from PC flue gas (Gas volume is <1% of flue gas from same MW size PC)

Proven polygeneration flexibility

- Power, hydrogen, steam, chemicals, zero-sulfur diesel

Practical opportunity to retrofit carbon capture equipment
IGCC

Large Scale IGCC Projects
## Large Scale IGCC Projects

### Coal IGCC in Operation

<table>
<thead>
<tr>
<th>Projects Site</th>
<th>Buggenum</th>
<th>Puertollano</th>
<th>Wabash River</th>
<th>Tampa</th>
<th>Nakoso</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Netherland</td>
<td>Spain</td>
<td>USA</td>
<td>USA</td>
<td>Japan</td>
</tr>
<tr>
<td><strong>Gasifier Type</strong></td>
<td>O2-blown</td>
<td>O2-blown</td>
<td>O2-blown</td>
<td>O2-blown</td>
<td>Air-blown</td>
</tr>
<tr>
<td></td>
<td>Dry-feed</td>
<td>Dry-feed</td>
<td>Slurry-feed</td>
<td>Slurry-feed</td>
<td>Dry-feed</td>
</tr>
<tr>
<td></td>
<td>Shell</td>
<td>Plenflo</td>
<td>E-Gas</td>
<td>GE</td>
<td>MHI</td>
</tr>
<tr>
<td><strong>Coal Consumption (t/d)</strong></td>
<td>2000</td>
<td>2600</td>
<td>2500</td>
<td>2500</td>
<td>1700</td>
</tr>
<tr>
<td><strong>Gross output</strong></td>
<td>284 MW</td>
<td>335 MW</td>
<td>297 MW</td>
<td>315 MW</td>
<td>250 MW</td>
</tr>
</tbody>
</table>
Large Scale IGCC Projects

Nuon- Buggenum, Netherlands 250 MW IGCC

Wabash 260 MW IGCC Repowering
Large Scale IGCC Projects

Tampa Electric
Polk 250 MW IGCC

250MWe Air Blown IGCC
(Fukushima, Japan)
Large Scale IGCC Projects

300 MWe ELCOGAS IGCC (Puertollano, Spain)

- Coal Preparation
- Gasifier
- ASU
- Gas Depuration
- Turbines: GT&ST
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IGCC with CO$_2$ capture

General Overview
General Overview of Pre-Combustion Technology

Fuel is gasified and a synthesis gas is produced. The gas primarily consists of CO and H2O.

Source: VATTENFALL
General Overview of Pre-Combustion Technology

The synthesis gas is cleaned from residuals.

Source: VATTENFALL
General Overview of Pre-Combustion Technology

The CO and H2O are converted in a shift reactor to CO2 and H2.

Source: VATTENFALL
General Overview of Pre-Combustion Technology

4 The gas is cleaned from sulphur either before or after the shift reactor.

Source: VATTENFALL
Carbon dioxide is separated from the synthesis gas in an absorption process. The carbon dioxide is transported to a storage site. The remaining gas (mainly hydrogen) is combusted.
IGCC + CCS Overview

**CO-shift:**
\[ \text{CO} + \text{H}_2\text{O} = \text{CO}_2 + \text{H}_2 \]

Combined Cycle

- **Heat Recovery:** \( \sim 40\% \)
- **Steam Turbine:** \( \sim 60\% \)

Gasifier

- Fuel
- O₂

DeSOx

- CO₂ Removal
- Gas Turbine

ASU

- Air
- N₂

Stack

- Bottom Ash
- Ash

CO-shift: \( \text{CO} + \text{H}_2\text{O} = \text{CO}_2 + \text{H}_2 \)
IGCC with CO$_2$ capture

Economics of IGCC with CO$_2$ capture
Global process efficiency must be increased in order to reduce costs and improve competitiveness.
IGCC with CO$_2$ capture

Experiences
### CO₂ Capture & H₂ Production Pilot Plant (PSE CO2 project)

#### Facts

<table>
<thead>
<tr>
<th>Company</th>
<th>ELCOGAS, S.A (Spanish utility)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td>Puertollano (Spain). Integrated in the Puertollano IGCC plant</td>
</tr>
<tr>
<td>Feed gas</td>
<td>Coal gas at 20-24 bar</td>
</tr>
<tr>
<td>Size</td>
<td>14 MWt (2% of total coal gas produced in the IGCC plant)</td>
</tr>
<tr>
<td>Technology</td>
<td>Pre-combustion Carbon Capture (90%). No Storage foreseen</td>
</tr>
<tr>
<td>Budget</td>
<td>14.3 M€ (originally 18.5 M€)</td>
</tr>
<tr>
<td>Frame</td>
<td>National Research Project, granted by Spanish Science and Innovation Ministry and Regional Government (JCCM)</td>
</tr>
<tr>
<td>Start date</td>
<td>2005</td>
</tr>
<tr>
<td>End date</td>
<td>Commissioning by September 2010</td>
</tr>
</tbody>
</table>
**Shifting Unit:**
1. Desulphurization reactor
2. Shifting reactors
3. Heat exchangers: kettles and shell&tube

**CO₂ Capture Unit (Linde):**
1. Syngas absorber - 12 m
2. CO₂ stripper - 16,5 m

**PSA Unit (Linde):**
1. Adsobers - 6,5 m
2. Tail gas drum - 12,5 m
3. Valve skid

**Electrical/control building:**
1. Control room
2. Electrical room
CO₂ Capture Pilot Plant. View and operational display

Aerial view (June 2010)

Operation display of the pilot plant
✓ Selected EEPR program (180 M€)
✓ Precombustion Technology (IGCC), 4.5 MtCO₂ / a
✓ CO₂: EOR in North Sea Area (offshore)
✓ Industrial Partners: Powerfuel, Shell and GE Energy
Summary and Concluding remarks
Summary and Concluding Remarks

• One of the main elements is the gasification of the fuel feedstock to produce SYNGAS

• Pre-combustion capture process is not a new concept
  – Primarily based on production of syngas, separating the CO$_2$ and using the decarbonised gaseous fuel for the GT

• Gasification technologies could produce a waste gas stream, which has high concentration of CO$_2$
  – This offers an opportunity to capture CO$_2$ at low cost

• CO$_2$ capture is not a process requirement,
  ➢ but could be easily implemented
Summary and Concluding Remarks

• **Advantages**
  - High CO\(_2\) concentration and high overall pressure
    * Lower energy consumption for CO\(_2\) separation as compared to post-combustion capture
    * Compact equipment
  - Proven CO\(_2\) separation technology
  - Possibility of co-production of hydrogen

• **Disadvantages**
  - IGCC is unfamiliar technology for power generators
  - Existing coal fired plants have low availability
  - IGCC without CO\(_2\) capture has generally higher costs than pulverised coal combustion
Thank you!!!

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