Oxyfuel Technology for CCUS Applied to Coal Fired Power Plants

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1. What is Oxyfuel Technology for CCUS?
**Concept of Oxyfuel Combustion**

**<Conventional air combustion>**
As air contains N\textsubscript{2} and Ar by 79%, CO\textsubscript{2} concentration in flue gas is about 15% in combustion with air.

Flue gas (dry base)

**<Oxyfuel combustion>**
In oxy-fuel combustion, since N\textsubscript{2} is removed before combustion, CO\textsubscript{2} concentration in flue gas is theoretically more than 90%.

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Oxyfuel Technology will convert coal power plants into clean power plants enabling longer operation by way of coping with the climate change issue, and will contribute to the environment and the economy of the community.

**Features**
- Applicable to both existing and new power plants
- Achievable of CO$_2$ capture rate up to 98% and nearly zero emissions
- Lower CO$_2$ capture cost for full capture
- Byproduct reuse such as N$_2$ resulting from air separation for O$_2$
IHI is one of pioneers in the development of oxyfuel technology, applying for patent in 1973 and starting R&D in 1989. Basic research and FS were carried out in the 1990’s with Japanese partners.

- FS for demonstration was conducted in collaboration with Australian partners from 2004 and demonstration project commenced in 2008 (“Callide Oxyfuel Project”).
- The demonstration ended in 2015 with the completion of CO\(_2\) underground injection.

**Development Schedule of Oxyfuel Technology**

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<th>Stage 1</th>
<th>Stage 2</th>
<th>Stage 3</th>
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<td>R&amp;D</td>
<td>Demonstration</td>
<td>Commercialization</td>
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<td>Basic research and FS (NEDO)</td>
<td>Collaboration with J-POWER</td>
<td>Application to Callide A Commissioning</td>
</tr>
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<td>Callide FS (NEDO)</td>
<td>Research (METI)</td>
<td>Demonstration operation</td>
</tr>
<tr>
<td>Upgrading and R&amp;D</td>
<td>FS of commercial plant (Oxyfuel CCS &amp; CCUS) (NEDO)</td>
<td>Commercial Demonstration</td>
</tr>
</tbody>
</table>

NEDO: New Energy and Industrial Technology Development Organization
METI: Ministry of Economy, Trade and Industry

Now (Sep. 2017)
2. Callide Oxyfuel Project
Callide Oxyfuel Project Overview

Features
The world’s first and only oxyfuel power plant;
✓ having all processes required for commercial use
✓ selling electricity with capturing CO₂
✓ using existing old, not CCS-Ready, coal fired power plant
Injection of captured CO₂ into the underground;
✓ the world’s first injection from oxyfuel power plant

Callide A Power Station
Owned by CS Energy
4 x 30 MWe
Steam: 136 t/h at 4.1MPa, 465°C
Commissioned: 1965 – 69
Refurbished: 1997/98
Placed in storage in 2002

Scope:
• No.4 Boiler refurbishment
• 2 x 330 TPD ASU
• Oxyfuel combustion Retrofit
• 75 TPD liquid CO₂ recovery
• Trucking to CO₂ reservoir
• Injection and monitoring

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Callide A P/S
QLD
Brisbane
Melbourne
VIC
Otway CO₂ Injection Site

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Callide Oxyfuel Project - History

Boiler (Before modification)

Air Separation Unit (ASU)

CO₂ Processing Unit (CPU)

History of commissioning and operation

23 March, 2011  - First fire on fuel oil after retrofit
12 March, 2012  - First oxygen injection to boiler
19 March, 2012  - Successful 100% RFG and oxyfiring
14 Sept., 2012  - First oxyfuel flue gas to CPU
Oct. – Dec., 2014 - CO₂ captured was transported overland and injected underground
March, 2015      - Final oxyfuel operation

It achieved:
- over 10,000 hours of accumulated oxyfuel operation
- over 5,500 hours of CPU operation

Boiler (After modification)
Air-firing mode

Oxyfiring mode

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Mode conversion was smoothly operated between air-firing and oxyfiring.
Heat balance of the boiler

Heat absorbed in Oxy is 3 - 4 % smaller due to higher boiler efficiency and heat balance is almost same as in Air.

Air : 30MW, Oxy : 30MW (inlet-O₂ = 27%)

NOx emission

NOx from Oxy is about 1/3 of Air due to decomposition of recycled NOx in flame.

Corrective value:

\[ \text{NOcorr} = \text{NO} \times \frac{12}{\text{CO}_2} \]

Unburnt carbon in ash

Reduced to a half mainly due to gasification.
# CPU – Process gas quality (actual)

<table>
<thead>
<tr>
<th>Gas Composition</th>
<th>Unit of Measure</th>
<th>CPU - LP Inlet</th>
<th>CPU - LP Outlet</th>
<th>Product CO₂</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>From Boiler</td>
<td>To compressor</td>
<td></td>
</tr>
<tr>
<td>Boiler Load Factor</td>
<td>%</td>
<td></td>
<td>80 - 100</td>
<td></td>
</tr>
<tr>
<td>H₂O</td>
<td>mol. %</td>
<td>19 - 22</td>
<td>5 - 7</td>
<td>&lt; 20 ppm</td>
</tr>
<tr>
<td>O₂</td>
<td>mol. %</td>
<td>3 - 5</td>
<td>3.5 - 6</td>
<td>&lt; 30 ppm</td>
</tr>
<tr>
<td>CO₂</td>
<td>mol. %</td>
<td>50 - 57</td>
<td>58 - 67</td>
<td>&gt; 99.95</td>
</tr>
<tr>
<td>CO</td>
<td>ppmv</td>
<td>20 - &gt; 200</td>
<td>25 - &gt; 200</td>
<td>&lt; 10</td>
</tr>
<tr>
<td>NO</td>
<td>ppmv</td>
<td>500 - 700</td>
<td>580 - 820</td>
<td>&lt; 2.5</td>
</tr>
<tr>
<td>NO₂</td>
<td>ppmv</td>
<td>20 - 40</td>
<td>Nil</td>
<td>&lt; 20</td>
</tr>
<tr>
<td>SO₂</td>
<td>ppmv</td>
<td>800 - 1000</td>
<td>&lt; 10</td>
<td>&lt; 0.1 ppm</td>
</tr>
<tr>
<td>SO₃</td>
<td>ppmv</td>
<td>10 - 15</td>
<td>&lt; 0.1</td>
<td>&lt; 0.1 ppm</td>
</tr>
<tr>
<td>N₂ (+ Ar)</td>
<td>mol. %</td>
<td>Balance</td>
<td>Balance</td>
<td>trace</td>
</tr>
<tr>
<td>Hg</td>
<td>ppbv</td>
<td>0.3 - 0.5</td>
<td>0.04 - 0.1</td>
<td>&lt; 0.00002</td>
</tr>
<tr>
<td></td>
<td>μg/Nm³</td>
<td>2.7 - 4.9</td>
<td>0.4 - 0.9</td>
<td>&lt; 0.002</td>
</tr>
<tr>
<td>Particulates</td>
<td>mg/Nm³</td>
<td>150 - 250</td>
<td>&lt; 0.02</td>
<td>nil</td>
</tr>
<tr>
<td>(at 60 - 70% CO₂)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>mg/Nm³</td>
<td>20 - 50</td>
<td>&lt; 0.01</td>
<td>nil</td>
</tr>
<tr>
<td>(at 12% CO₂)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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Behavior of Mercury

A part of CO\(_2\) captured and liquefied at Callide power station was transported overland to the state of Victoria from October to December 2014 and was injected underground in the Otway Project Site of the CO2CRC (Cooperative Research Centre for Greenhouse Gas Technologies). The injected CO\(_2\) was used to assess its geochemical and geophysical behavior in the storage layer. This was the first time in the world that CO\(_2\) captured from an oxyfuel boiler in a coal-fired power plant was injected into underground. This was also the first time in Australia that CO\(_2\) captured from a thermal power plant was injected into underground.

The objective of the project, a complete demonstration of total process from CO\(_2\) capture to injection, was accomplished.
3. Business Model

World largest nitrogen plant for EOR (40,000t/day)

Linde:「Enhanced Oil Recovery」
There are up to 4 revenue sources in the business model resulting from ① power generation, ② CO2 recovery, ③ N2 separation, and ④ CO2 emission reduction.
4. Conclusions
Conclusions

• With the successful completion of its demonstration project, Oxyfuel is a proven technology ready for commercialization and will convert coal power plant(s) to clean power plant(s) with “zero emission”.

• With the optimization of up to 4 revenue sources and government support, Oxyfuel can be economically feasible and will contribute to improving the cost effectiveness of the power plant(s) whilst providing the pathway for future CO₂ emission reduction mandate and a countermeasure for carbon tax.
These studies have been greatly supported by the Australian and Japanese governments, the Queensland state Government, New Energy and Industrial Technology Development Organization (NEDO), as well as by ACALET, GLENCORE, Schlumberger, J-Power, Mitsui & CO., LTD., JCOAL and many others in Australia and Japan, to which the authors would like to express gratitude for their help and support.

Thank you for your attention.