Current Status of MHI CO₂ Capture Plant Technology & Commercial Experiences

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Chemical Plant & Infrastructure Division
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1. MHI’s CO$_2$ Capture Technologies & Experience

2. 500 Metric TPD CO$_2$ Capture Demonstration Plant in USA

3. Project Status of World’s Largest CO$_2$ Capture Plant from Coal-fired Flue Gas

4. Summary
As a global leader in industrial and infrastructure manufacturing, Mitsubishi Heavy Industries is creating commercially viable technology for capturing carbon emissions from coal-fired plants, while enhancing domestic oil production.

1. MHI’s CO₂ Capture Technologies & Experience
### 1.1 History of Development of MHI’s CO₂ Capture Technology

<table>
<thead>
<tr>
<th>Year</th>
<th>Event Description</th>
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<tbody>
<tr>
<td>1990</td>
<td>Started R&amp;D activities with Kansai Electric Power Company (KEPCO)</td>
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<tr>
<td>1991</td>
<td>Started a 2 ton per day pilot plant at KEPCO’s Nanko Power station</td>
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<td>1994</td>
<td>Development of proprietary hindered amine solvent “KS-1®” and “KM CDR Process®” with KEPCO</td>
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<td>1999</td>
<td>First commercial plant in Malaysia (200 ton per day, to enhance urea synthesis from the CO₂ recovered from a reformer flue gas)</td>
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<tr>
<td>2002</td>
<td>Started a pilot test for coal-fired power plant at MHI’s Hiroshima R&amp;D center</td>
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<td>2003</td>
<td><strong>High energy efficiency</strong> - Development of proprietary energy efficient process “Improved KM CDR Process”</td>
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<tr>
<td>2008</td>
<td>First commercial plant in Middle east (400 ton per day) which “Improved KM CDR Process” applied</td>
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<tr>
<td>2011</td>
<td><strong>World’s First</strong> - Started 500 ton per day fully integrated CCS demonstration plant with Southern Company for a coal-fired power plant at Alabama Power's James M. Barry Electric Generating Plant</td>
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<tr>
<td>2014</td>
<td><strong>World’s Largest</strong> - Received an order for a PCC plant of 4,776 ton per day for EOR mainly promoted by NRG Energy Inc. and JX Nippon Oil &amp; Gas Exploration Corporation</td>
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</table>
1.2 MHI - R&D Strength & Experience

Deployment of R&D Facilities for specific CO$_2$ capture testing. More than 25 years R&D Experience

(A) 2.0 TPD Nanko Osaka pilot plant from 1991
(B) 1.0 TPD Hiroshima pilot plant
(C) 10 TPD Matsushima pilot for testing coal fired flue gas
(D) 500 TPD Barry CCS demonstration plant in Alabama, (25MW equivalent)
1.3 KM CDR Process®

1. The flue gas is cooled to a process desired temperature.

2. CO2 is recovered from the flue gas by contacting with KS-1™ solvent.

3. The “CO2-rich solution” is pumped into the upper section of the stripper.

4. CO2 is stripped from KS-1™ solvent in the Regenerator.

5. The flue gas is fed into the bottom section of the absorber and passed upward through the packing material inside the tower.
1.4 MHI CO₂ Capture Plants Commercial Experience

- World leading large scale post combustion CO₂ capture technology licensor, with 11 commercial plants in operation from a variety of natural gas or heavy oil flue gas sources
- World’s largest CCS plant is under construction in Texas.

![Images of CO₂ capture plants from various countries and years]

- 1999: 210 t/d Malaysia
- 2005: 330 t/d Japan
- 2006: 450 t/d India
- 2009: 450 t/d Bahrain
- 2010: 400 t/d UAE
- 2010: 240 t/d Vietnam
- 2011: 340 t/d Pakistan
- 2012: 450 t/d India
- 2014: 500 t/d Qatar
2. 500 Metric TPD CO₂ Capture Demonstration Plant in USA
2.1 Specification of Demonstration Plant

Southern Company Plant Barry CO₂ Demo Plant

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plant location</td>
<td>Mobile County (Alabama, U.S.A.)</td>
</tr>
<tr>
<td>Plant owner</td>
<td>Southern Company subsidiary Alabama Power</td>
</tr>
<tr>
<td>Process</td>
<td>KM CDR Process®</td>
</tr>
<tr>
<td>Absorption liquid</td>
<td>KS-1™ solvent</td>
</tr>
<tr>
<td>Plant scale</td>
<td>Corresponding to 25 megawatts (MW)</td>
</tr>
<tr>
<td>Flue gas amount</td>
<td>116,800 Nm³/h</td>
</tr>
<tr>
<td>CO₂ concentration</td>
<td>10.1 mol%-wet</td>
</tr>
<tr>
<td>CO₂ capture capacity</td>
<td>500 tonnes/day (150,000 tonnes/year)</td>
</tr>
<tr>
<td>CO₂ capture ratio</td>
<td>90 percent</td>
</tr>
</tbody>
</table>

World’s First CCS Project fully integrated with Amine-based Post Combustion Process and CO₂ Injection. Over 230,000 metric tons of CO₂ was captured and over 115,000 tons of CO₂ was injected as of August 2014.
3. Project Status of World’s Largest CO₂ Capture Plant from Coal-fired Flue Gas
The world’s largest CO₂ capture and compression plant from coal-fired power plant

- Project owner: Petra Nova, a partnership between NRG Energy, Inc. and JX Nippon Oil & Gas Exploration Corporation
- Location: NRG WA Parish Power Plant in Thompsons, TX.
- Flue gas source: Slipstream off of 650MW coal-fired boiler
- CO₂ concentration: 11.5%
- CO₂ capture capacity: 4,776 TPD (240MW equivalent)
- CO₂ capture ratio: 90%
- CO₂ Use: CO₂ EOR
- Pipeline: Approximately 81 miles
- Injection Site: West Ranch oil field in Jackson County, TX
- Operation Start: 4th Quarter, 2016

3.1 Petra Nova CO₂ Capture Plant for CO₂ EOR (2/2)

- Captured and compressed CO₂ from W.A. Parish Power Plant will be delivered by 80 mile CO₂ pipeline to the West Ranch oil field.
- 1.4 million metric tons of greenhouse gas will be annually injected into the West Ranch formation.
- It is expected that oil production will be enhanced from 500 barrels/day to approx. 15,000 barrels/day.

The West Ranch CO₂-EOR Project
3.2 MHI’s Scale-up Strategy

Road to Full Scale Commercial Plant

- **Pilot** 1 TPD Scale
- **Small Scale Demonstration** 10 TPD Scale
- **Large Scale Demonstration** 500 TPD
- **Full Scale** 5,000 TPD

**Know-how and Lesson learned from 11 commercial plants**

- **Simulators (CFD etc.)**

**Large Scale experiences for FGD**
- Large amount of flue gas
- >200 commercial plants

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Power plant refurbishment is NOT REQUIRED
Minimum tie-in work
No parasitic load on coal unit
Does not impact the price of electricity
3.4 Key Process Technologies for Petra Nova CO₂ Capture Plant

All technologies were proven in 500 Metric TPD CO₂ Capture Demonstration Plant in USA

1) Amine emission reduction system for emission control

2) Automatic load adjustment system

3) Amine purification system for dust control

4) Energy saving system
3.5 Lessons Learned from Petra Nova CO₂ Capture Plant
(1) Load Change Requirement

**Power Plant Load**
- CCS designed with load following flexibility under turndown conditions
- CCS operational profile will be optimized for various load conditions
- Wide load change is required for CO₂ Capture plant

**Automated Load Adjustment System**
→ Easy operation, maximum plant performance

: Automatic control depending on a boiler load, the flue gas condition and CO₂ demand
Construction for Quencher and Absorber

Rectangular steel towers and Modular construction → Speedy Construction / High Flexibility for transportation
3.6 Project Progress

- Construction: Ahead of Schedule (As of Dec. 2015)
- Planned Operation Start: 4th Quarter, 2016
4. Summary
4.1 Summary

- The MHI’s KM CDR process® is applied to eleven (11) commercial CO₂ capture plants.

- Southern Company and MHI carried out the 500 MTPD CO₂ capture and storage demonstration project at Alabama Power’s Plant Barry. This project became the world’s largest start to finish CCS demonstration project on coal fired flue gas.

- Based on the know-how gained from CCS demonstration project together with extensive R&D activities and commercial plant experiences, the world largest CO₂ capture plant under construction in SW Houston, Texas for NRG Energy and JX Nippon Oil & Gas Exploration Corporation.

- MHI continues extensive effort to enhance competitiveness in terms of CO₂ capture cost and to accelerates commercial viability of CCS/EOR project.