MHI’s Carbon Capture Technology

2017 CO₂ & ROZ Conference
Carbon Management Workshop
Midland, Texas

December 4
- Similar to other amine-based technologies
- KS-1™ solvent with low degradation and negligible corrosion
- Proprietary features

KM CDR Process is a registered trademark of Mitsubishi Heavy Industries, Ltd., in Japan, the United States of America, European Union (CTM), Norway, Australia, and China.
KM CDR Process® Development History

From 1991 –
2 TPD Nanko Pilot Plant on Natural Gas Exhaust (Kansai Electric Power Co.)

From 2002 -
1 TPD Hiroshima Pilot Plant on Coal Exhaust (MHI R&D Center)

From 2006 –
10 TPD Matsushima Pilot Plant on Coal Exhaust (J-Power)

From 2008 -
400MWeq Absorber Flow Tests (MHI Mihara)

Engineering HQ (Yokohama)
MHI is the world’s leading large scale post-combustion CO\textsubscript{2} capture technology licensor.
Testing and Scale-up for Coal-fired Flue Gas

MHI performed extensive testing to understand the impact of **flue gas impurities** and develop countermeasure technologies.

MHI performed liquid distribution tests for rectangular towers which **simplify scale-up and modularization efforts.**

(Scaling technique is similar to that used on more than 200 commercial FGD systems.)

2002 – Hiroshima R&D Facility (1 tpd)
2006 – Matsushima Pilot Plant (10 tpd)
2008 – Mihara Works (~35 ft x ~15 ft)
Plant Barry CO\textsubscript{2} Demo Plant – helped prove commercial viability of carbon capture on coal fired flue gas

- Funding for capture facility from Southern Company, MHI, and others.
- Designed to capture 500 metric tons per day of CO\textsubscript{2} at 90% capture efficiency.
- From 2011-14: over 12,000 hours, over 250,000 tons captured, over 125,000 tons injected as part of SECARB sequestration demonstration.
- Tested multiple technology improvements.
Petra Nova Project
Oil revenues from CO₂ enhanced oil recovery can recover costs for the entire project without significant impact to the existing power plant.

Four Key Components:

- CO₂ Capture System (MHI technology)
- Cogeneration Plant
- CO₂ Transport / Pipeline
- Oil Field & Processing Facilities

NRG Energy and JX Oil and Gas formed the Joint Venture, Petra Nova Parish Holdings. They own the CCS facility and 50% of the CO\textsubscript{2} pipeline and oil field.
NRG Energy, JX Nippon complete world’s largest post-combustion carbon capture facility on-budget and on-schedule

- Takes a partial “slip” stream from host unit - NRG’s Parish Plant Unit 8
- Captures 5,200 tons of CO₂/day
- Achieved COD on Dec 29, 2016
- 2017 – Power Magazine “Plant of the Year”
- October 2017 – 1M tons of CO₂ captured

Petra Nova Project CCS Facility Layout

- CO\textsubscript{2} Compressor
- Absorber
- Flue Gas Quencher
- Regenerator
- Cooling Tower
- Flue Gas Duct
- Cogeneration
Captured CO₂ is compressed by Mitsubishi’s compressor and transported 81 miles by pipeline to the West Ranch Oil field for EOR.

- 81 Miles (Parish to West Ranch)
- 12” diameter
- .1,900 psi at inlet

Reference: Petra Nova Parish Holdings
CO$_2$ captured from Parish Unit 8 is expected to boost oil production from 300 bbls/day to up to 15,000 bbls/day.

Reference: Petra Nova Parish Holdings
MHI’s proprietary control system (ALAC) successfully maintained stable operation.

**CO₂ Production Flow Rate Trend (72hrs)**

![CO₂ Production Flow Rate Trend Graph]

**Design: 219 ston/hr**

**CO₂ Recovery Rate Trend (72hrs)**

![CO₂ Recovery Rate Trend Graph]

**Design: 90%**
Steam consumption exceeded expectations and has been consistently below design.

Steam Consumption Trend (Actual / Design) (72hrs)

Average Ratio: 0.98

Steam Consumption Trend (steam-ton/CO₂-ton) (72hrs)

Average Ratio: 1.09
World’s largest integrally geared CO₂ compressor delivered by Mitsubishi Compressor.

- 8 stages
- 28,700 hp

**CO₂ Production Pressure Trend (72hrs)**

Design: 1900 psig
MHI’s proprietary control system (ALAC) smoothly ramps CO₂ production from 50% to 100% in less than 1 hour.

**Automatic CO₂ Production Ramp up (50% -> 100%)**

Design: 219 ston/hr

**Automatic CO₂ Production Ramp down (100% -> 50%)**

Design: 219 ston/hr
Future
MHI has been investigating new solvents to further reduce the cost of CO$_2$ capture.

### New Solvent Testing – Lab Results

<table>
<thead>
<tr>
<th></th>
<th>KS-1™</th>
<th>New Solvent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steam Consumption</td>
<td>1</td>
<td>0.92</td>
</tr>
<tr>
<td>Solvent Degradation</td>
<td>1</td>
<td>0.53</td>
</tr>
<tr>
<td>Solvent Emission</td>
<td>1</td>
<td>0.40</td>
</tr>
</tbody>
</table>

- MHI conducted solvent screening in the laboratory and the Nanko pilot plant.
- New solvent has achieved lower steam consumption, solvent degradation, and solvent emissions than KS-1™.
- New solvent may require a higher solvent circulation flow rate which increases electricity consumption.
- Benefits appear to outweigh the higher flow rate.
Table 12.1 Carbon Dioxide Emissions From Energy Consumption by Source

Million Metric Tons of Carbon Dioxide

- Coal, Including Coal Coke Net Imports, CO2 Emissions
- Natural Gas, Excluding Supplemental Gaseous Fuels, CO2 Emissions
- Petroleum, Excluding Biofuels, CO2 Emissions

Source: U.S. Energy Information Administration
MHI’s KM CDR Process® can be successfully applied to NGCC power plants.

### Typical Flue Gas Conditions

<table>
<thead>
<tr>
<th></th>
<th>Unit</th>
<th>Coal fired Boiler</th>
<th>NG fired GT</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>Vol.%</td>
<td>10 - 14</td>
<td>3 - 4</td>
</tr>
<tr>
<td>O₂</td>
<td>Vol.%</td>
<td>4 - 6</td>
<td>10 - 15</td>
</tr>
<tr>
<td>SOx</td>
<td>ppm(dry)</td>
<td>1 - 50</td>
<td>&lt;0.3</td>
</tr>
<tr>
<td>PM (Dust)</td>
<td>mg/Nm³</td>
<td>3 - 10</td>
<td>NA</td>
</tr>
</tbody>
</table>

- KS-1™ has proved resistant to O₂ degradation despite higher concentration.
- MHI can provide large absorbers to account for lower CO₂ concentration.
- KM CDR Process® requires fewer treatment systems as a result of the minimal SOx and dust in flue gas.
MHI has the capability to investigate advanced NGCC-CO$_2$ capture configurations to consider existing and new assets.

Fully optimized integration between NGCC and CO$_2$ capture can:

- Take advantage of high efficiency gas turbines
- Reduce parasitic load of CO$_2$ capture
- Reduce capital cost of CO$_2$ capture
# MHI’s Past, Present, and Future

## Past
- **Tested**  
  MHI proved viability at multiple R&D facilities.
- **Delivered**  
  MHI delivered *eleven (11) operating commercial CO₂ capture plants* prior to the Petra Nova Project.
- **Scaled-up**  
  MHI successfully scaled-up and demonstrated long-term operation at Alabama Power’s Plant Barry.

## Present
- **Petra Nova**  
  *December 2016* – the world’s largest post-combustion CO₂ capture project on coal-fired flue gas (4,776 mtpd) – completes performance testing.

## Future
- **New Solvents**  
  MHI is developing new solvents to reduce utility consumption and emissions.
- **NGCC**  
  MHI is ready to optimize CO₂ capture for *NGCC applications*. 
MOVE THE WORLD FORWARD