Latest on CO₂ Capture Technology

2018 CO₂ & ROZ Conference
Carbon Management Workshop
Midland, Texas

December 3, 2018
Outline

- Introduction to MHI Group, MHI Engineering Ltd., and MHIA/ESD
- Introduction to KM CDR Process™
- KM CDR Process™ Development History
- Applying the KM CDR Process™ to Coal
- Commercial Projects Including Petra Nova
- Future Applications
  - Natural Gas Combined Cycle
  - Advanced KM CDR Process™ and KS-21 Solvent
- MHI’s View of the Market
MHI GROUP AT A GLANCE

As a global leader in engineering and manufacturing, Mitsubishi Heavy Industries (MHI) Group delivers innovative and integrated solutions across a wide range of industries from commercial aviation and transportation to power plants and gas turbines, and from machinery and infrastructure to integrated defense and space systems. Here is a snapshot of our financial and company highlights, along with select details about the three industry segments we operate in.

FINANCIAL & COMPANY HIGHLIGHTS

$38.7 BN ANNUAL REVENUE

$1.2 BN OPERATING INCOME

81,000 EMPLOYEES WORLDWIDE

24,500 PATENTS GLOBALLY

54% OVERALL SALES

GLOBAL FOOTPRINT 300 DOMESTIC & OVERSEAS COMPANIES

MHI Group offers a wide range of services and products including:

- Ammonia & Urea plants
- Methanol Plants
- Acrylic Acid Plants
- Polyethylene Plants
- LNG Receiving Terminals & Tanks
- Flue Gas CO₂ Capture Plants

MHI Engineering, Ltd., an MHI Group company based in Yokohama, provides technology, engineering, and execution for global infrastructure projects including:

- Ammonia & Urea plants
- Methanol Plants
- Acrylic Acid Plants
- Polyethylene Plants
- LNG Receiving Terminals & Tanks
- Flue Gas CO₂ Capture Plants

MHI America, Inc.’s Engineered Systems Division, based in Houston, provides sales, administration, engineering, and project management support for MHI CO₂ capture projects in the US.

Other MHI Group companies provide related equipment and services in the US (e.g., power generation, FGD, compression, etc).

Total MHI Group footprint in the US is significant:

- MHI United States:
  - 7,000 employees
  - 100 offices & factories in 30 states
  - 3,753 patents
  - 345 suppliers
  - $6.3 BN in revenue

*All figures from MHI as of March 2018, approximately

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Introduction to MHI’s “KM CDR Process™”

- Developed with Kansai Electric Power, provided exclusively by MHI
- Based on proprietary KS-1™ solvent with low degradation and negligible corrosion
- Refined continuously since early 1990s
1991 – Present
2 TPD KEPCO Nanko Pilot
Natural Gas Exhaust
Solvent and Process Testing

2002 - 2017
1 TPD MHI Hiroshima Pilot
Coal Exhaust
Impurities Testing

2006
10 TPD J-Power Matsushima Pilot
Coal Exhaust
Impurities Testing

2008
Flow Tests at MHI Mihara
Liquid Distribution Testing

Engineering HQ
(Yokohama)
MHI performed extensive testing to understand and minimize the impact of **coal flue gas impurities** such as:

- solvent foaming and flooding due to dust
- equipment scaling and plugging due to dust
- solvent loss due to SO₂ and NO₂ and HSS

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.)
Testing and Scale-Up for Coal-Fired Flue Gas: Plant Barry Demo

25MWeq system helped prove commercial viability of carbon capture on for coal

- Funding for capture system from Southern Company, MHI, and others such as EPRI.
- CO₂ storage was part of Phase III: Anthropogenic CO₂ Injection Field Test by SECARB.
- Designed to capture 500 metric tons per day of CO₂ at 90% capture efficiency.
- From 2011-14: over 12,000 hours, over 250,000 tons captured, over 125,000 tons injected

**Key Outcomes**

- Confirmed long-term stable system operation on coal
- Verified performance at various inlet flue gas conditions
- Tested **Energy Saving System** for reduced steam use
- Tested **Automatic Load Adjustment System** and simulator
- Tested **Amine Emission Reduction System** for elevated inlet SO₃
- Tested **Amine Purification System** for solvent filtration and reclaiming
Commercial Projects
MHI is the world’s leading provider of large scale post-combustion CO₂ capture systems.
Petra Nova incorporates significant innovations in business model as well as technology, and uses oil revenues to cover project costs.

**Four Key Components:**

- **CO₂ Capture System (by PNPH)**
  - MHI Technology
  - Partial “slip” stream from NRG’s Parish Plant Unit 8
  - Produces 5,265 tons of CO₂/day

- **Cogeneration Plant and Cooling (by PNPH)**
  - Meets utility needs for CO₂ capture, with excess electric power to grid

- **CO₂ Transport / Pipeline (by TCV)**
  - 12” diameter, 81 miles

- **Oil Field & Processing Facilities (by TCV)**
  - West Ranch oil field

Notes on Execution:

For the core CO₂ capture system MHI licensed and provided the KM CDR Process™ and KS-1™ solvent and delivered overall system design services, engineering, procurement for major equipment, operator training, and commissioning support.

MHI formed a consortium with TIC (The Industrial Company) for execution of a full turnkey contract for the capture system.
Petra Nova Carbon Capture Facility: Initial Experience

“NRG Energy, JX Nippon complete world’s largest post-combustion carbon capture facility on-budget and on-schedule”

• EPC consortium award\(^2\) July 2014
• Construction start\(^2\) September 2014
• Performance tests completed\(^2\) December 2016
• Commercial operation\(^3\) January 2017
• 2017 – Power Magazine “Plant of the Year”
• October 2017 – 1M tons of CO\(_2\) captured\(^4\)
• Capture system continues to meet performance targets

Notes/Refs:
3) [https://www.netl.doe.gov/research/coal/project-information/fe0003311](https://www.netl.doe.gov/research/coal/project-information/fe0003311)
4) [https://www.energy.gov/fe/articles/doe-supported-petra-nova-captures-more-1-million-tons-co2](https://www.energy.gov/fe/articles/doe-supported-petra-nova-captures-more-1-million-tons-co2)
5) For further information see project final report to DOE: [https://www.osti.gov/biblio/1344080](https://www.osti.gov/biblio/1344080)
Future Applications
Natural gas power generation will likely see increasing pressure for CO₂ reductions in the coming years.
MHI’s KM CDR Process™ can be successfully applied to NGCC power plants.

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<tr>
<th>Typical Flue Gas Conditions</th>
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<td></td>
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<tr>
<td>CO₂</td>
</tr>
<tr>
<td>O₂</td>
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<tr>
<td>SOx</td>
</tr>
<tr>
<td>PM (Dust)</td>
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- MHI tested KS-1™ extensively on this gas composition at the Nanko facility
  - KS-1™ proved resistant to O₂ degradation
  - Solvent stability and stable process operation confirmed
- 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 can provide CO₂ capture and integration with NGCC at commercial scale today
Introducing MHI’s “Advanced KM CDR Process™”

Phase I: Design refinements based on recent construction and operating experience

- Integrated SO₂ polisher and direct contact cooler
- Reduced size of DCC and absorber
- Modularization of towers and process racks
- Reduced size of filtration and HX systems
- Optimized layout and compact footprint
- Reduced design margins

Note: Application and level of benefit depends on site location and other factors.
Introducing MHI’s “Advanced KM CDR Process™”

Phase II: Application of new “KS-21” solvent
- Reduced thermal degradation allows increased regeneration temperature and pressure, reducing CO₂ compressor work
- Reduced volatility reduces absorber wash section size, reduces emissions & solvent loss
- Improved oxidative stability reduces solvent loss by HSS
- Reduced heat of absorption reduces steam demand

Development work is proceeding in the US and Japan
- FEED studies initiated from late 2019 will be based on KS-21 at owner’s request
- Not a “drop in” replacement for KS-1™, but retrofits possible

<table>
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<tr>
<th>Parameters Relative to KS-1™</th>
<th>KS-1™</th>
<th>KS-21</th>
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<tbody>
<tr>
<td>Volatility</td>
<td>100</td>
<td>50-60</td>
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<tr>
<td>Thermal degradation rate</td>
<td>100</td>
<td>30-50</td>
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<tr>
<td>Oxidation rate</td>
<td>100</td>
<td>70</td>
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<tr>
<td>Heat of absorption</td>
<td>100</td>
<td>85</td>
</tr>
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There is Lots of Opportunity in this Market

Analysts suggest that impact of 45Q on CCUS deployment could be significant in the next decade…

Deployment of CCS based on 45Q incentive and various construction cost and commodity price assumptions. Retrofit represents “partial capture” capacity. CO₂ sold for EOR. Most projects located in Texas and nearby states.

Cost of Capturing CO2 Drops 67% for Next Carbon Capture Plant

NOV 28, 2018


...and in Canada...

Thank You!

Questions/Contact:

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