Determining the Technologies & System Components for Commercially Viable CCS

IEA GHG – What Have We Learned From Large-Scale CCS Projects?

KM-CDR Post-Combustion CO₂ Capture with KS-1™ Advanced Solvent
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Development History

LABORATORY

MHI Hiroshima R&D Center
Kansai Environmental Research Center
1983-present

Kansai Environmental Research Center
1991-present

BENCH SCALE

MHI Hiroshima R&D Center
KANSAI (Nanko) Pilot Plant - 2 MTPD
1991-present

PILOT PLANTS

MHI Hiroshima R&D Center
1 MTPD
Validation of the process on Natural Gas and Coal flue gas
2002-present

Kansai Environmental Research Center
KANSAI (Nanko) Pilot Plant - 2 MTPD
1991-present
Nanko Pilot Plant

Solvent & Process Development

Location: Nanko Power Plant, Osaka, Japan
Capacity: 2 TPD
Start Up: 1991
Feed Gas: Natural gas fired boiler

- Over 200 solvents tested – lots of data
- New Solvent KS-1™ was developed.
- KS-1™ alone can reduce steam consumption by about 20% compared to standard MEA.
- Energy efficient steam systems developed.
- Ongoing process testing and solvent development
Basic Process Flow Diagram

Flue Gas

Flue Gas Cooler

C.W.

ABSORBER

Flue Gas Outlet

CO₂ Purity 99.9 %

Reboiler

Steam

C.W.

STRIPPER (Regenerator)

C.W.
Process Improvements

- 15% reduction in steam consumption over MHI’s conventional process
- Advanced process demonstrated at MHI’s Nanko Pilot Plant and other commercial plants
- Process Features
  - Utilize lean solvent and steam condensate heat for regeneration inside the stripper
- Performance
  - Steam Consumption: <1.30 Ton Steam/ Ton CO2 (660 Kcal/ Kg CO2)
  - Note: Steam = 3 BarG Saturated

Patent Application submitted in various countries
KEY ADVANTAGES
compared to MEA

KS-1™ solvent
- Higher CO₂ Loading
- More Efficient Regeneration
- Lower Circulation Rate
- Lower Solvent Degradation
- Low Corrosion – no solvent inhibitor

KM-CDR Process
- Lower Utility & Solvent Consumption
- Atmospheric process – safe and easy operation & Maintenance
MHI’s Commercial Achievements

Five Large Commercial PCC plants in operation
(from Natural Gas flue gas)

- 200 tpd Malaysia 1999
- 330 tpd Japan 2005
- 450 tpd India 2006
- 450 tpd India 2006
- 450 tpd India 2009

Construction on 4 additional commercial plants continues;

- UAE 400 tpd (2009)
- Bahrain 450 tpd (2009)
- Pakistan 340 tpd (2010)
- Vietnam 280 tpd (2010)

Several other contracts under negotiation
More than 17 years of cumulative operational experience of these large scale plants has allowed us to:

- Refine certain aspects of the process
- Confirm material selection for key components
- Confirm utility & solvent consumption
- Develop and incorporate countermeasures against impacts of impurities
- Develop a commercial contracting structure for delivery of CO2 capture equipment together with our partners
- Prove operation of the KM-CDR process at a sufficient scale for us to be confident to move ahead with scale-up of a single train design
CO$_2$ Recovery from Natural Gas Flue Gas – MHI is ready to go!!

- MHI has learned from these large commercial plant experiences
- Design of a 3,000 tpd single train PCC Plant is complete
- Being offered on a commercial basis

Gas Boiler

Gas Turbine
MHI’s Global Natural Gas Fired CO$_2$-EOR/CCS Project Work under Negotiation

- Canada CO$_2$-EOR / CCS Project, Natural Gas Flue Gas
- Norway CO$_2$-EOR / CCS Project, Natural Gas Flue Gas
- US CO$_2$-EOR Project, Natural Gas Flue Gas
- a) Middle East CO$_2$-EOR Project, Natural Gas Flue Gas
- b) Middle East CO$_2$-EOR Project, Natural Gas Flue Gas
Coal Fired Long Term Demonstration Plant

**Plant Outline**

- Solvent: KS-1
- Capacity: 10 tpd
- Feed Gas: Coal Fired Boiler
- Start-up: July, 2006
- Location: J-POWER Matsushima Power Station, Nagasaki, Japan

**Objective**

Demonstrate long term CO$_2$ recovery from coal fired boiler flue gas.

**Note:**
Project funding support from RITE (50%) and cooperation from J-Power
Coal Fired Long Term 10 tpd Demonstration

What have we learned?

~6,000 hours of operation

1) Increased understanding of the effects of impurities on the system and solvent (SOx, NOx, Dust, etc.).
   - SO₂ and NO₂ in the flue gas were absorbed by the solvent and generated heat stable salts. If maintained at low levels do not cause operational problems
   - By maintaining the dust levels at or below 10mg/kg concentration in the solvent, no flooding occurs
   - Solvent loss as predicted
   - Incorporated countermeasures for the impurities where necessary.

2) The operational experience and lessons learned are helping us to facilitate scale-up of KM-CDR process for CO₂ capture from coal fired boilers.
MHI’s Global Coal Fired CCS Project Work in Various Study & Test Phases

- Canada CCS Project, Coal Fired Flue Gas
- UK CCS Project, Coal Fired Flue Gas
- Denmark CCS Project, Coal Fired Flue Gas
- Japan CO2 Capture Project, Coal Fired Flue Gas, ~6,000 hrs testing complete
- Germany CO2 Capture Project, Coal Fired Flue Gas
- Australia CCS Project, Coal Fired Flue Gas
- a) US CCS Project, Coal Fired Flue Gas
- b) US CCS Project, Coal Fired Flue Gas

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Coal Fired CO$_2$ Capture Plant Scale-up

From Pilot to Full Scale

From what have we learned, how do we get there?

Phased approach

Next Step: Large Scale Demonstration backed by commercial experience and lessons learned in other industries

1,000’s TPD Large Scale

Small Scale Demonstration 10’s TPD Scale

Pilot 1’s TPD Scale
Flue gas CO2 recovery scale-up — MHI’s experiences.

<table>
<thead>
<tr>
<th>Country</th>
<th>Plant Type</th>
<th>CO2 Recovery Capacity</th>
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<tbody>
<tr>
<td>Japan Nanko</td>
<td>Pilot plant</td>
<td>2 TPD</td>
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<tr>
<td>Japan</td>
<td>Coal-Fired demo plant</td>
<td>10 TPD</td>
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<td>Malaysia</td>
<td>Commercial plant</td>
<td>200 TPD</td>
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<tr>
<td>Japan</td>
<td>Commercial plant</td>
<td>330 TPD</td>
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<td>India</td>
<td>Commercial plant</td>
<td>450 TPD</td>
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<tr>
<td>TBA</td>
<td>Coal Fired Demo plant</td>
<td>500 TPD</td>
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<td>TBA</td>
<td>Coal Fired project</td>
<td>3,000 TPD</td>
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MHI do not believe it feasible to move from Pilot to Commercial in one step!
Coal Fired CO$_2$ Capture Plant Scale-up

With scale-up there are some issues to consider.
Current Commercial Plant - Cylindrical Absorber Tower
Large Scale CO₂ Capture Plant - Rectangular Absorber Tower
Large Scale CO$_2$ Capture Plant - Rectangular Absorber Tower

- Limitation on size of shop fabricated cylindrical vessels for delivery to site. Large cylindrical vessels need to be fabricated on site.

- As the diameter becomes large, cylindrical vessels need heavy structural members to support trays or packing.

- Rectangular Absorber - panel design. Fabricated in the shop and assembled on site.

- MHI has significant scale-up experience with rectangular packed towers - FGD business.
Largest Multi-Pollutant Test Plant in the world (FGD & CO2 Capture) Absorber Test Facility (400 MW equivalent)

32 m

Commercial Scale Tests
Q1 2008 – Extensive liquid distribution tests using a commercial scale liquid distributor inside the absorber column

Critical testing to ensure highly efficient flue gas & liquid contact area to maximize CO2 absorption at large scale
MHI’s Risk Mitigation with Scale-Up

Commercial Experience to date

3,000 tpd Plant Basic Design Complete (Nat. gas)

Application of Advanced Computational Flow Dynamics (CFD) Technology

~6,000 hrs experience with CO2 capture from coal fired flue gas (10 tpd scale)

Commercial scale (400MW equiv.) liquid distribution tests at Mihara test plant

>200 Commercial FGD Plants deployed – significant experience with flue gas absorber towers using rectangular vessels (max capacity >1000 MW single tower)

Commercial Ammonia Plant Syntheses Gas 2,559 T/D CO2 recovery plant – experience with large cylindrical CO2 stripper vessels
MHI’s roadmap to commercialization for coal fired boilers

Important next step is to operate the process at a scale large enough to ensure trouble-free operation at commercial scale

MHI’s Operating Experience

- Pilot plants (1-2 tpd)
- Small scale demonstration plant (10 tpd)
- Current Commercial plants (200-450 tpd)
- Experience with natural gas and coal

E.ON Germany
SoCo USA
EU/ North America
Norway

Pilot scale experience (Natural Gas & Coal)
Commercial Experience (Natural Gas)
Demo (Coal)
Demo (Coal)
Demo/Semi Commercial (Coal)
Commercial (Gas Turbine)

1 tpd 2 10 200 330 450 450 450 100 500 3000 3000
MHI’s In-House Capability / Potential Scope in a CCS Project

MHI Fully Integrated Environmental Solutions
Power output penalty of CO2 capture and compression without heat integration

1,070MW (Gross) Supercritical Pulverized Coal Power Plant; Bituminus Coal Case

Net output improvement with heat integration

Power Output Penalty MHI CCCP (Base Case)

Power Output Penalty of CO2 Capture and Compression without heat integration decreased

CCCP: CO2 Capture, Compression Plant

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MHI’s combined know how from global CO2 Capture projects

No Other Company has this amount of Large Scale CO2 Capture Experience

- SoCo USA 500 tpd
- UK/ Nth America 3000 tpd
- E.ON Germany 100 tpd
- Vietnam 280 tpd
- Pakistan 340 tpd
- Japan 2 tpd
- Japan 10 tpd
- Norway 3000 tpd
- Bahrain 450 tpd
- Abu Dhabi 400 tpd
- India 450 tpd
- Malaysia 330 tpd
- Japan 330 tpd
- Malaysia 200 tpd
- E.ON Germany 100 tpd
- Japan 1 tpd
- UK/ Nth America 3000 tpd
- Norway 3000 tpd
- Japan 1 tpd
- Norway 3000 tpd
- Japan 2 tpd
- Japan 10 tpd
- Malaysia 200 tpd
- Japan 10 tpd
- Malaysia 200 tpd
- Japan 1 tpd
- Malaysia 200 tpd
- Japan 2 tpd
Path Forward with Lessons Learned – Large Scale Coal Fired Demonstration

- MHI has completed pilot and small scale demonstration testing and has learned from those experiences
- MHI is now taking the critical next step which will lead to the rapid commercialization of coal fired flue gas CO₂ capture technology
- Following 1 year of operation we will offer this product on a full guarantee basis – a real solution to address CO₂ emissions is here!

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<th>Year</th>
<th>03</th>
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<td>Pilot Test (1 TPD)</td>
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<td>Large Size Demo (500 TPD)</td>
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<td>Commercial Deployment (&gt;3000 TPD)</td>
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Summary

- The KM-CDR Post combustion CO2 capture process is commercially available for Natural Gas fired applications
- The KM-CDR process is close to demonstration at large scale as a solution for Coal fired applications

- Be aware…there are lessons to be learned when it comes to CO2 capture from Coal Flue gas

- You need to ‘learn to walk before you can run’
  - there are no short cuts

- MHI is one technology provider that has gone through the learning curve, that has significant large scale CO2 capture experience and is taking the next step on the path to making post combustion CO2 capture from Coal Fired applications a reality
For further information please stop by the MHI Exhibit Booth and meet the team

or contact

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