KM CDR Process™ - From Notion to “World’s Largest”

2018 CCUS Student Week
Golden, Colorado

October 16th, 2018
January 2017 Owner’s PR:
“NRG Energy, JX Nippon complete world’s largest post-combustion carbon capture facility on-budget and on-schedule”¹

¹NRG press release
January 2017 Owner’s PR:

“NRG Energy, JX Nippon complete world’s largest post-combustion carbon capture facility on-budget and on-schedule”¹

¹NRG press release

How did we get here?
KM CDR Process™ Overview

- **KM CDR Process™** = Kansai Mitsubishi Carbon Dioxide Removal Process
- Amine-based technology
- Proprietary features developed over 28 years of experience
- KS-1™ solvent boasts high CO₂ capacity, low degradation, and low regeneration energy
- Capable of capturing ~90+% CO₂ from combustion gas sources
KM CDR Process™ Technology Development Timeline

- Began R&D with Kansai Electric Power Co. - 1990
- 2 tpd pilot plant at KEPCO’s Nanko Power Station - 1991
- Developed KS-1™ and KM CDR Process™ - 1994

1999 - 200 tpd plant in Malaysia

- 1 tpd coal pilot test at Hiroshima R&D Center - 2002
- Developed proprietary energy efficient process - 2003
- 10 tpd coal pilot test at Matsushima - 2006
- Large absorber flow test at Mihara works - 2008

2005 - 330 tpd plant in Japan
- 2006 - two 450 tpd plants in India

Plant Barry 500 tpd demonstration project – 2011-2014

- 2009 - 450 tpd plant in India; 450 tpd plant in Bahrain
- 2010 - 400 tpd plant in UAE; 240 tpd plant in Vietnam
- 2011 - 340 tpd plant in Pakistan
- 2012 - 450 tpd plant in India
- 2014 - 500 tpd plant in Qatar

2016 - Petra Nova Project – 4,776 tpd plant in Texas
MHI believed that CO₂ regulations would be implemented and began investigating CO₂ capture technologies for combustion gases.

- 1990 – MHI screened more than 200 solvent formations.
- Flue gas composition can be varied with CO₂ recycle and air.
- Max CO₂ capture capacity: 2 tpd
- Over 14,000 hours of direct testing to date.

✓ 1994 – MHI settled on KS-1™ and KM CDR Process™
MHI understood that the impact of flue gas impurities on the solvent and process must be well-characterized before scale-up.

- **2002** – Tested on coal-fired flue gas at Hiroshima R&D.
  - Max CO$_2$ capture capacity: 2 tpd
  - Over 1,700 hours of direct testing to date.
  - Evaluated effects of PM, SOx, NOx, metals, and aerosols.
- **2006** – Tested at Matsushima coal fired power plant.
  - Max CO$_2$ capture capacity: 10 tpd
  - Completed more than 6,000 hours of solvent and process testing.
  - Demonstrated and verified long-term performance of solvent on coal exhaust.
High performance packing is very sensitive to liquid distribution. Without proper distribution, performance cannot be predicted.

- 2008 – tested liquid distributors
- Absorber measures ~36’L x ~18’W x 105’H
- Scaling technique is similar to that used on more than 200 commercial FGD systems.
Large-Scale Coal Demonstration Project at Plant Barry (25MWeq)

Large-scale demonstration was necessary to combine the lessons learned from the smaller pilot projects before scaling up for commercial power projects.

- Majority of funding by Southern Company and MHI.
- CO₂ capture capacity: 500 tpd
- From 2011-14: over 12,000 hours, over 250,000 tons captured, over 125,000 tons injected
  - Tested various technologies developed from pilots.
  - Confirmed design expectations and performance.
  - Confirmed long-term stable system operation.
  - Verified long-term performance under various flue gas conditions and coal characteristics.
25MW$_{eq}$ CCS Demonstration Project at Plant Barry

**Verified Process Improvements**

**Energy Saving System**
Deployed and verified an optimized system for reduced steam consumption

**Automatic Load Adjustment System**
Deployed and verified dynamic response simulator and automatic control system for load following

**Amine Emission Reduction System**
Deployed and verified countermeasures including multi-stage wash and demisters at elevated inlet SO$_3$ conditions.

**Amine Purification System**
Verified performance of batch reclaiming operation to remove coal combustion impurities from solvent

**Automatic Load Adjustment System**

- [Diagram: Automatic system control including solvent circulation and steam use depending on plant load, flue gas condition, and CO$_2$ demand](#)
- Allows rapid response to changing system conditions and turndown to 50%

**Amine Emissions Reduction System**

- MHI Plant without Amine Reduction System
- MHI Plant with Amine Reduction System
The Petra Nova project is MHI’s first commercial power project and has ~10x the capacity of the Plant Barry demonstration.

- The Petra Nova project captures CO₂ from NRG’s WA Parish Plant Unit 8 and transports the CO₂ to the West Ranch Oil field for EOR.
- Plant is owned by NRG and JX Oil & Gas.
- Captures 4,776 mtons/day (240 MWeq, 90% capture) from a ~37% flue gas slip stream.
- MHI - TIC consortium for full turnkey EPC delivery of the CO₂ capture and compression system and BOP.
- Successfully completed Performance Test in December 2016.
Petra Nova Project – Lessons Learned

Operating the plant has provided valuable insights that can be implemented into the next projects.

- Operating parameters exceeded expectations:
  - Steam consumption, absorber performance, and CO$_2$ capacity exceeded expectations -> Reduce size of absorber tower.
  - Quencher and SO$_2$ removal system exceeded expectations -> Reduce size of quencher tower.

- Initial flue gas impurities assumptions were conservative. Actual flue gas conditions should be thoroughly considered.
  - Filtration system loading is lower than expected.
  - Reclaiming operation less frequent than expected.
  - VOC emissions lower than expected.
## What’s Next?

Plant Barry 500 tpd demonstration project – **2011-2014**

- 2011 - 340 tpd plant in Pakistan
- 2012 - 450 tpd plant in India
- 2014 - 500 tpd plant in Qatar

2016 - **Petra Nova Project** – 4,776 tpd plant in Texas

### New Solvent Testing

- Multiple new solvent formulations have been evaluated.
- KS-21 appears to have advantages over KS-1™ that may help reduce overall capital and operating costs.
- Pilot testing currently underway.

### Parameters

<table>
<thead>
<tr>
<th>Parameters</th>
<th>KS-1™</th>
<th>KS-21</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volatility</td>
<td>100</td>
<td>50-60</td>
</tr>
<tr>
<td>Thermal degradation rate</td>
<td>100</td>
<td>30-50</td>
</tr>
<tr>
<td>Oxidation rate</td>
<td>100</td>
<td>70</td>
</tr>
<tr>
<td>Heat of absorption</td>
<td>100</td>
<td>85</td>
</tr>
</tbody>
</table>

### Design Standardization

- How will we deliver the next 10,000+ tpd systems on a timeline compliant with 45Q credits?
- MHI currently evaluating how to standardize portions of the design to reduce overall project costs and schedule.
Without large scale demonstration of the KM CDR Process™, the performance of the Petra Nova Project could not have been guaranteed.

Thoughtful technology development, extensive testing, and large scale demonstrations are essential for successful commercial projects.
MOVE THE WORLD FORWARD