Large Pilot Testing of the MTR Membrane Post-Combustion CO$_2$ Capture Process
(DE-FE0031587; FOA 1788)

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Membrane Technology and Research, Inc.
NETL Project Manager: Sai Gollakota

Project Kickoff Meeting
May 22, 2018
Project Overview

- **Award name:** Large Pilot Testing of the MTR Membrane Post-Combustion CO\textsubscript{2} Capture Process (DE-FE0031587; FOA 1788)
- **Project period:** 4/1/18 to 7/31/19
- **Funding:** $957k DOE + $239k cost share = $1.196M total
- **DOE-NETL Project Manager:** Sai Gollakota
- **Participants:** MTR (prime), Trimeric, WorleyParsons, EPRI, NRG (host)
- **Overall goal:** Design, build, and operate a 200 TPD large pilot capture system using partial capture to achieve the lowest cost-of-capture possible ($/tonne CO\textsubscript{2}).
- **Project plan:** (Phase I)
  - selection of the host power plant
  - conduct environmental information volume
  - secure of financial commitments
  - update pilot design and budget, and finalizing team commitments and organization for Phase II / III
Topics

- Background
- Technical Approach
- Project Objectives
- Project Structure
- Project Schedule
- Project Budget
- Project Management Plan and Risk Management
MTR CO$_2$ Capture Development Timeline

**Feasibility study (DE-NT43085)**
- Sweep concept proposed
- Polaris membrane conceived

**APS Red Hawk NGCC Demo**
- First Polaris flue gas test
- 250 lb/d CO$_2$ used for algae farm

**APS Cholla Demo (DE-FE5312)**
- First Polaris coal flue gas test
- 1 TPD CO$_2$ captured (50 kW$_e$)

**NCCC 1 MW$_e$ Demo (DE-FE5795)**
- 11,000 hours of 1 TPD system operation
- 1 MW$_e$ (20 TPD) system operation

**Low Pressure Mega Module (DE-FE7553)**
- Design and build a 500 m$^2$ optimized module

**Hybrid Capture (DE-FE13118)**
- Membrane-solvent hybrids with UT, Austin

**B&W Integrated Test**

**10+ MW$_e$ Large Pilot**

2006 - 2020

TRL3 - TRL8
Membrane Separation Basics
Power Consumption is Key

Permeate vacuum to 0.1 bar, 70% CO₂ capture

<table>
<thead>
<tr>
<th>Feed / Permeate Pressure (bara)</th>
<th>Power</th>
<th>Membrane Area</th>
<th>Permeate Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.5 / 1.0</td>
<td>330 kWₑ/tonne CO₂</td>
<td>X</td>
<td>43.5% CO₂</td>
</tr>
<tr>
<td>1.1 / 0.2</td>
<td>91 kWₑ/tonne CO₂</td>
<td>5X</td>
<td>43.5% CO₂</td>
</tr>
<tr>
<td>1.1 / 0.1</td>
<td>99 kWₑ/tonne CO₂</td>
<td>2.5X</td>
<td>59% CO₂</td>
</tr>
</tbody>
</table>

Vacuum at 0.1 to 0.2 bar is the way to go.
Partial CO$_2$ Capture with a Two-Stage Membrane Process

307 kW$_{e}$h/tonne CO$_2$
50% CO$_2$ capture

197 kW$_{e}$h/tonne CO$_2$

110 kW$_{e}$h/tonne CO$_2$
Using a Contactor Helps a Lot

Using a contactor reduces power by 10% and increase CO₂ capture from 50 to 80%.

277 kWₑ/tonne CO₂
80% CO₂ capture

172 kWₑh/tonne CO₂

105 kWₑh/tonne CO₂
MTR system

- MTR pilot system completed successful six months of operation.

Membranes are simple and compact compared to competing technologies, such as amines (see columns in photo).

20 TPD System at NCCC

- MTR pilot system completed successful six months of operation.
The NCCC 1 MW$_e$ System Used Nested Module Tubes in a Single Large Vessel
We Also Tested Large Area Plate-and-Frame Modules at NCCC
Topics

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The Current State of Development
The “2017 Base Case”

- **Membrane**
  - $P/\ell$, 1,500 gpu, $\alpha$ 25, 3-year lifetime

- **Module**
  - Plate-and-frame
  - 0.1 bar feed-side pressure-drop
  - 0.05 bar permeate-side pressure-drop
  - Module and skid: $100/m^2$ each

- **Rotating equipment**
  - 0.2 bar, efficiency 80%, $1,000/kW

- **Installation factor:** 100% of equipment cost

- **Capital expenditure depreciation/amortization change:** 12%/annual
How do we Estimate Cost and Performance

- A CHEMCAD computer simulation package with MTR Membrane Unit Ops calculate system performance.
- A linked Excel program uses cost assumptions to calculate $/tonne CO$_2$ captured.
- The membrane simulation package is reliable.
- The Excel costing program depends on harder-to-know assumptions.
Ongoing Programs will Change the “2020 Base Case”

- Mongstad test program – ongoing.
- Advanced Polaris™ research program – ongoing.
- The 200 tonne CO$_2$/day pilot system will be 10x bigger than the NCCC system – economies of scale.
## Base Case Changes 2017 – 2020

### The Membrane

<table>
<thead>
<tr>
<th></th>
<th>2017</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P/\ell$</td>
<td>1,500</td>
<td>$P/\ell$ 2,000</td>
</tr>
<tr>
<td>$\alpha$</td>
<td>25</td>
<td>$\alpha$ 30</td>
</tr>
<tr>
<td>Lifetime tested for</td>
<td>11,000 hrs</td>
<td>No change</td>
</tr>
<tr>
<td>3-year lifetime assumed</td>
<td></td>
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</tr>
</tbody>
</table>
Base Case Changes 2017 – 2020
Plate-and-Frame Skid Costs

Skid 2017

$40,000/400 m²
$100/m²

Skid 2020

~ $15,000/600 m²
$25/m²
The Future: Low-Pressure Containerized Plate-and-Frame Modules
The Current State of Development
The 2017 Base Case

• Membrane
  – $P/\ell$, 1,500 gpu, $\alpha$ 25, 3-year lifetime

• Module
  – Plate-and-frame
  – 0.1 bar feed-side pressure-drop
  – 0.05 bar permeate-side pressure-drop
  – Module and skid: $100/m^2$ each

• Rotating equipment
  – 0.2 bar, efficiency 80%, $1,000/kW

• Installation factor: 100% of equipment cost

• Capital expenditure depreciation/amortization change: 12% per annual
The System We Propose to Build
Site #1 NRG’s WA Parish (Houston)

Connect to Unit #7 or Unit #8 (Petra Nova)
Site #2 NRG’s Limestone Generating Station
Topics

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Project Objectives

• Bring MTR’s membrane-based, post-combustion CO$_2$ capture process to the final pre-commercial/demonstration stage of development.

• Design, build, and operate a 200 TPD large pilot capture system using partial capture to achieve the lowest cost-of-capture possible ($/tonne CO$_2$).

• Phase I:
  – selection of the host power plant
  – conduct environmental information volume
  – secure of financial commitments
  – update pilot design and budget, and finalizing team commitments and organization for Phase II / III
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Roles and Responsibilities

Large Pilot Testing of the MTR Membrane Post-Combustion CO$_2$ Capture Process (DE-FE0031587)

- Phase I award: $1,000,000 / April 1, 2018 to July 31, 2019.
  - MTR (prime): Design process design for partial capture system sized at 200 tonnes/day using partial capture.
  - Trimeric: Update design for carbon purification unit.
  - EPRI: Evaluate opportunities for CO$_2$ utilization and Phases II and III cost-sharing.
  - WorleyParsons: Perform Environmental Information Volume.
  - NRG: Provide site information for candidate host site.
Topics

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# Project Schedule

<table>
<thead>
<tr>
<th>Project Tasks</th>
<th>Start Date</th>
<th>End Date</th>
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</thead>
<tbody>
<tr>
<td>Task 2. Select Project Host Site</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Task 2.1. Visit Host Site for Evaluation</td>
<td>4/1/2018</td>
<td>9/31/2018</td>
</tr>
<tr>
<td>Task 2.2. Obtain Host Site Commitment</td>
<td>4/1/2018</td>
<td>9/31/2018</td>
</tr>
<tr>
<td>Task 3. Prepare an Environmental Information Volume (EIV)</td>
<td>10/1/2018</td>
<td>12/31/2018</td>
</tr>
<tr>
<td>Task 4.1 Update Process Design</td>
<td>7/1/2018</td>
<td>12/31/2018</td>
</tr>
<tr>
<td>Task 4.2. Update Budget and Schedule</td>
<td>7/1/2018</td>
<td>3/31/2019</td>
</tr>
<tr>
<td>Task 5. Obtain Commitments for the Phase II/Phase III Program</td>
<td>10/1/2018</td>
<td>3/31/2019</td>
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</tbody>
</table>

### 2018

<table>
<thead>
<tr>
<th>2018</th>
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<tbody>
<tr>
<td>Apr</td>
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### 2019

<table>
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<th>2019</th>
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<tr>
<td>Jan</td>
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</table>

**NOTES:**

See Milestone Log for description of milestone sets for each budget period.

▲ = Milestone
Topics

• Background
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# Project Budget

## Phase I - Budget Period I

<table>
<thead>
<tr>
<th>Date Range</th>
<th>Q1 Total</th>
<th>Q2 Total</th>
<th>Q3 Total</th>
<th>Q4 Total</th>
<th>Q5 Total</th>
<th>Total BPI</th>
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<tbody>
<tr>
<td>02/01/2018-04/30/2018</td>
<td>Federal Share</td>
<td>$182,187</td>
<td>$246,746</td>
<td>$301,864</td>
<td>$226,314</td>
<td>$0</td>
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<tr>
<td></td>
<td>Non-Fed Share</td>
<td>45,547</td>
<td>61,686</td>
<td>75,466</td>
<td>56,579</td>
<td>$0</td>
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<tr>
<td></td>
<td>Total Planned</td>
<td>$227,734</td>
<td>$308,432</td>
<td>$377,330</td>
<td>$282,892</td>
<td>$0</td>
</tr>
<tr>
<td>05/01/2018-07/31/2018</td>
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<tr>
<td>08/01/2018-10/31/2018</td>
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<tr>
<td>11/01/2018-03/31/2019</td>
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<tr>
<td>04/01/2019-06/30/19</td>
<td></td>
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</tr>
</tbody>
</table>
Topics

• Background
• Technical Approach
• Project Objectives
• Project Structure
• Project Schedule
• Project Budget

• Project Management Plan and Risk Management
Phase I – Project Tasks

- Task 1. Project Management and Planning
- Task 2. Select Project Host Site
  - Subtask 2.1. Visit Host Sites for Evaluation
  - Subtask 2.2. Obtain Host Site Commitment
- Task 3. Prepare an Environmental Information Volume (EIV)
- Task 4. Updated System Design, Budget and Schedule
  - Subtask 4.1. Update Process Design
  - Subtask 4.2. Update Budget and Schedule
- Task 5. Obtain Commitments for the Phase II/Phase III Project
# Project Milestones

<table>
<thead>
<tr>
<th>Milestone Number</th>
<th>Task/Subtask No.</th>
<th>Milestone Description</th>
<th>Planned Completion Date (*)</th>
<th>Verification Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.2</td>
<td>Host site selected and commitment received.</td>
<td>9/31/18</td>
<td>Letter of intent written</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>Completion of EIV.</td>
<td>12/31/18</td>
<td>EIV report</td>
</tr>
<tr>
<td>3</td>
<td>4.1</td>
<td>Updated system design based on host site completed</td>
<td>12/31/18</td>
<td>Quarterly report</td>
</tr>
<tr>
<td>4</td>
<td>4.2</td>
<td>Revised Phase II/III budget and schedule completed.</td>
<td>3/31/19</td>
<td>Final report</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>Team commitments with cost share contributions signed.</td>
<td>3/31/19</td>
<td>Agreement signed</td>
</tr>
</tbody>
</table>
Phase I – Success Criteria

• Signed host-site agreement for Phase II/III activities.
• Completion of Environmental Information Volume and NEPA review.
• Completion of updated budgetary estimate (±30%) and schedule for Phases II/III.
• Letters of commitment from project team with necessary capabilities to execute Phases II and III.
• Signed cost-sharing agreement for Phase II/III effort.
## Risk Management

<table>
<thead>
<tr>
<th>Description of Risks</th>
<th>Probability (Low, moderate, high)</th>
<th>Impact (Low, moderate, high)</th>
<th>Risk Management Mitigation and Response Strategies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Management/Resource Risks</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Difficulty finding a host site</td>
<td>Low</td>
<td>High</td>
<td>We have 3 candidate host sites that meet all of MTR’s criteria. A key Phase I task will be to evaluate the pros and cons of these sites, select the preferred location, and finalize commitments to proceed with the large pilot project.</td>
</tr>
<tr>
<td>Timing uncertainty related to NEPA documentation and any other required environmental permits</td>
<td>Low</td>
<td>High</td>
<td>NRG completed environmental reviews at the possible host sites. WP has experienced environmental impact assessment personnel who will conduct an EIV study in Phase I.</td>
</tr>
<tr>
<td>Long-lead time procurement creates project delays</td>
<td>Low</td>
<td>Moderate</td>
<td>Long lead time items and equipment will be identified in Phase I Task 4. These items can be prioritized for procurement after the Phase II FEED is completed.</td>
</tr>
<tr>
<td>MTR’s financial, manufacturing and engineering capability to bring this technology to the large pilot scale</td>
<td>Low</td>
<td>High</td>
<td>MTR is a commercial producer of gas separations systems for the petrochemical, refinery and natural gas processing industries. The largest commercial systems we have installed are ~$20 million projects to treat &gt;100 MMscfd of gas. These systems are bigger than the large pilot to be built in this project. MTR has the engineering, membrane manufacturing, and management capability to execute the proposed project. We are collaborating with a large end user (NRG), engineering companies (WP and Trimeric), as well as an energy industry non-profit (EPRI) to help insure the success of this project. We have cost share commitments for Phase I secured and are actively working on Phase II/III funding.</td>
</tr>
</tbody>
</table>
## Risk Management, Cont.

<table>
<thead>
<tr>
<th>Description of Risks</th>
<th>Probability (Low, moderate, high)</th>
<th>Impact (Low, moderate, high)</th>
<th>Risk Management Mitigation and Response Strategies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical Risks</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Membrane stability is less than expected</td>
<td>Low</td>
<td>Moderate</td>
<td>Prior projects at NCCC have demonstrated a Polaris membrane lifetime of greater than one year treating coal flue gas, so we are confident the large pilot will perform well. However, each system is different, so careful performance monitoring will be conducted during operation in Phase III.</td>
</tr>
<tr>
<td>Uncertainty in vacuum pumps and compression equipment</td>
<td>Low</td>
<td>Moderate</td>
<td>In previous test systems, robust but inefficient vacuum pumps and compressors were used to ensure the system would operate consistently. This experience gives us a low risk option for the large pilot. However, we also plan to work with Trimeric and major OEM suppliers in Phase I on selection of more efficient equipment that will be more appropriate for larger scales.</td>
</tr>
<tr>
<td>Market Risks</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO₂ emissions are not regulated.</td>
<td>High</td>
<td>Low</td>
<td>Regulations on CO₂ emissions are in flux in the U.S. and worldwide. Changes in the regulations during the term of the project are likely, but their effect on the project’s execution is expected to be low. Ultimately, efficient, low-carbon technologies will find use in power and industrial settings.</td>
</tr>
</tbody>
</table>
Questions?