Initial Engineering Design of a Post-Combustion CO$_2$ Capture System for Duke Energy’s East Bend Station Using Membrane-Based Technology:

DE-FE0031589

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Sr. Technical Leader

Presenter: Dr. Abhoyjit Bhown
Program Manager

NETL CO$_2$ Capture Technology Review Meeting
August 16th, 2018
Project Overview

- **Funding**
  - Federal Share: $1,625,244
  - Non-Federal Share: $406,485
  - TOTAL $2,031,729

- **Project Performance Dates**
  - 04/06/2018 to 3/31/2020

- **DOE Project Manager**
  - Dr. Sai Gollakota

- **Project Participants**
  - **Prime:**
    - Electric Power Research Institute
  - **Sub-contractors:**
    - Membrane Technology and Research
    - Nexant Inc.
  - **Site Host:**
    - Duke Energy

- **Project Objective**
  - Perform an initial engineering design & cost estimate for a commercial-scale, membrane-based, post-combustion CO$_2$ capture system retrofit to Duke Energy’s 600MWe coal-fired East Bend Unit.
Background - Membrane Basic Principles

- Polymeric membrane typically operate via the solution-diffusion mechanism
- Gases dissolve into an active layer and diffuse across to the other side
- Permeation is driven by differences in partial pressures

![Diagram showing gas flow through a membrane](image)

- **Feed**
- **Permeate**
- **Residue or retentate**
- **Sweep (optional)**

Gases dissolve into the membrane material, diffuse across, and enter the gas on the other side.
Background - MTR Polaris Membrane

- MTR has developed a CO$_2$ selective polymeric membrane material and module - the MTR Polaris membrane
- This provides higher CO$_2$ permeance for post combustion flue gas applications than existing polymeric membranes

Images Courtesy of MTR
Background - Membrane Module

- Compact modular system design using high permeance membranes reduces CAPEX and overall system pressure drop
- Membranes are widely used for desalination and natural gas sweetening
- The largest existing systems are similar in scale to those required for a 550MWe coal fired power plant

Images Courtesy of MTR
MTRs CO₂ Capture Development to Date

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

APS Red Hawk NGCC Demo
- First Polaris flue gas test
- 250 lb/d CO₂ used for algae farm

APS Cholla Demo (DE-FE5312)
- First Polaris coal flue gas test
- 1 TPD CO₂ captured (50 kWₑ)

NCCC 1 MWₑ Demo (DE-FE5795)
- 11,000 hours of 1 TPD system operation
- 1 MWₑ (20 TPD) system operation

Low Pressure Mega Module (DE-FE7553)
- Design and build a 500 m² optimized module

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

B&W Integrated Test

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Advantages of the Membrane Capture Process

- Simple, passive operation with no chemical handling, emissions, or disposal issues
- Not affected by oxygen, SOx or NOx; co-capture possible
- Water use is lower than most capture technologies (recovers H₂O from flue gas)
  - No steam use → no modifications to existing boiler/turbines
  - Near instantaneous response; high turndown possible
  - Very efficient at partial capture (40-60%)
Challenges of the Membrane Capture Process

- Develop a design that will **minimize the impact** on the power plant by disrupting as little of the existing facilities as possible.
  - Also shorten the amount of downtime before the plant can resume normal operations.

- Develop a design that will **minimize the cost** of each tonne of captured CO$_2$ while also maintaining the net 600 MW output of the East Bend Station.
  - This will be done by optimizing the percentage of CO$_2$ captured (~45 to 60%) and by adding a natural-gas-fired combustion turbine (CT) or possibly a combined cycle to offset the new auxiliary loads.
Partial CO$_2$ Capture with 2 Stage Membrane Process

**Preliminary Design Case for the East Bend Unit**
- 2 membrane arrangement
- Aiming for 45% - 60% CO$_2$ Capture
- No boiler recycle
Supplying the Membrane Power Requirements

- Unlike solvent PCC systems - No steam requirement, but power is required to drive the membrane systems fans, blowers, vacuum compressors pumps and CO₂ compression

- 4 ways to supply power will be considered:
  - New natural gas-fired simple cycle,
  - New simple cycle with heat recovery steam generator supplying steam to the coal power plant feedwater heaters
  - New combined cycle
  - Auxiliary power supplied from the existing station

- The technical and economic feasibility of adding a pipeline to supply the required amount of natural gas will be examined.

- The impacts of turning off the PCC during periods of high power demand will be evaluated (if the site has sufficient power export capacity).
Technical Approach 1/2

- Following a data gathering task that will include a site visit to the EBS, a preliminary process design will be developed for one PCC system which captures CO$_2$ from the entire flue gas stream of the power plant.
- This preliminary design will then be subjected to a series of analyses to examine various options for minimizing the cost of CO$_2$ capture on a $/tonne-captured$ basis.
- The analysis will also examine several options for providing the PCC system’s auxiliary power via a CT-based power plant.
- Once an optimized process design has been identified, that design will be documented in a complete Process Design Package (PDP).
Technical Approach 2/2

- As part of this effort a HAZOP and constructability review of the design will be conducted.
- The PDP data will be used to carry out a techno-economic analysis (TEA) that will include a +/-30% accuracy capital cost estimate as well as an estimate of the first year cost of electricity and $/tonne cost of CO$_2$ capture for the retrofitted power plant.
- The marginal operating cost of the retrofitted plant will also be calculated and used in a unit dispatch model to predict how the retrofit will impact how often the coal plant is called on to operate.
## Project Schedule

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<thead>
<tr>
<th>Task Name</th>
<th>Start Date</th>
<th>End Date</th>
<th>Budget Period 1</th>
<th>Budget Period 2</th>
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<td><strong>Task 1: Project Management and Planning (EPRI lead)</strong></td>
<td>4/1/2018</td>
<td>3/31/2020</td>
<td>M1 M2 DP M11</td>
<td>Q1 Q2 Q3 Q4 Q5 Q6 Q7</td>
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<td>1.1 Project and Risk Management (EPRI)</td>
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<td>1.2 Financial and Project Reporting (EPRI)</td>
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<td>1.3 Technology Maturation Plan (MTR)</td>
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<td><strong>Task 2: Develop Design Basis document (Nexant Lead)</strong></td>
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<td><strong>Task 3: Establish Base Case Model (Nexant Lead)</strong></td>
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<td>9/30/2018</td>
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<td><strong>Task 4: System analysis of Integration options (EPRI lead)</strong></td>
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<td>4.1 Optimize CO2 Capture Plant Design (MTR)</td>
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<td>4.2 Evaluate Options for Aux Power (EPRI, Nexant)</td>
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<td>4.3 Finalize Design Configuration (EPRI, MTR, Nexant)</td>
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<td><strong>Decision Point: Examine and Review Retrofit Options</strong></td>
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<td><strong>Task 5: Finalize Overall Retrofit PC Design (EPRI Lead)</strong></td>
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<td>5.1 Design Package of the Membrane CCS System (MTR)</td>
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<td>5.2 Design Package for BOP &amp; Aux. Power (EPRI &amp; Nexant)</td>
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<td>5.3 Preliminary HAZOP Review (Nexant, Bechtel, MTR &amp; Duke)</td>
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<td>5.4 Constructibility Review (Nexant, Bechtel &amp; Duke)</td>
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<td><strong>Task 6: Techno-Economic Analysis (EPRI Lead)</strong></td>
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<td>6.1 Capital Cost Estimation of Integrated PCC Design (Nexant)</td>
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<td>6.2 O&amp;M Cost Estimation of Integrated PCC Design (Nexant, EPRI)</td>
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<td>6.2 TEA and Dispatch Analysis (EPRI &amp; DUKE)</td>
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<td><strong>Task 7: Final Report Preparation (EPRI Lead)</strong></td>
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MTRs CO₂ Capture Development – Current Projects

Self-Assembly Isoporous Supports, CA (DE-FE31596)
- Improve gas transport through support layer
- Enables a reduction in membrane area
- Build and test new membrane at NCCC

Pilot Testing at TCM, Norway (DE-FEXXXX)
- 1 MWe - advanced Polaris™ membrane
- Partial capture for low cost-of-capture
- New modular construction

Pilot Testing at TCM, Norway (DE-FEXXXX)
- 1 MWe - Hybrid testing with TDA
- Membrane + solid sorbent for 90% capture
- Selective CO₂ recycle using sorbents

Full-Scale FEED at Duke Energy’s East Bend Station, KY (DE-FE31589)
- 460 MWe – using Advanced Polaris™
- Partial capture and modular membrane
- Rapid retrofit deployment

Large-Pilot Testing at WY ITC, WY (DE-FE31587)
- Phase I – Design ~16 MWe pilot; secure host site
- Phase II – FEED and permitting
- Phase III – Fabricate, install and operate

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