A High Efficiency, Ultra-Compact Process For Pre-Combustion CO$_2$ Capture

DE-FOA-0001235
FE0026423

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• Co-P.I.: Professor Vasilios Manousiouthakis, University of California (UCLA), Los Angeles, CA
• Co-P.I.: Dr. Rich Ciora, Media and Process Technology Inc. (M&PT), Pittsburgh, PA

U.S. Department of Energy National Energy Technology Laboratory (NETL)
2017 NETL CO$_2$ Capture Technology Project Review Meeting
August 22, 2017
Presentation Outline

• Project Overview
• Technology Background
• Technical Approach/Project Scope
• Project Progress and Current Status
• Future Plans
Project Overview

Performance Period: 10-01-2015 – 9-31-2018

Project Budget: Total/$1,909,018; DOE Share/$1,520,546; Cost-Share/$388,472

Overall Project Objectives:

1. Prove technical feasibility of membrane/adsorption-enhanced water gas shift (WGS) process.

2. Achieve overall fossil energy performance goals of 90% CO₂ capture, with 95% CO₂ purity, at a cost of electricity of 30% less than baseline capture approaches.

Key Project Tasks/Participants:

1. Design, construct and test the lab-scale experimental MR-AR system. (USC)

2. Select and characterize appropriate membranes/adsorbents/catalysts. (M&PT/USC)

3. Develop and experimentally validate mathematical model. (UCLA/USC)

4. Experimentally test the proposed novel process in the lab-scale apparatus, and complete the initial technical and economic feasibility study. (M&PT/UCLA/USC)
Technology Background

Conventional IGCC Power Plant
Technology Background Cont’d

Baseline IGCC Power Plant

Source: NETL

*Picture: DOE/NETL-2015/1727 NETL SHELL IGCC CASE B5B
Technology Background Cont’d

Proposed IGCC Power Plant

*Original Picture: DOE/NETL-2015/1727 NETL SHELL IGCC CASE B5B
Technology Background Cont’d

Ceramic Membranes for Large-Scale Applications

Ceramic Membrane Tubes

Ceramic Membrane Containing High Pressure Vessel

Ceramic Membrane Bundle
Technology Background Cont’d

Hydrotalcite (HT) Adsorbents & Co/Mo-Based Sour-Shift Catalysts

Hydrotalcite (HT) Adsorbent:
- HT adsorbent shown to have a working CO\textsubscript{2} capacity of 3-4 wt.% during past (HAMR) MSR, WGS reaction studies. Theoretical capacity >16 wt.%.

Co/Mo-Based Sour Shift Catalyst:
- Commercial Co/Mo-based sour shift catalyst has been used in our past and ongoing lab-scale MR studies with simulated coal-derived and biomass-derived syngas. Shown to have stable performance for >1000 hr of continuous operation.
Technology Background Cont’d

Proposed Process Advantages vs. SOTA

Key Innovation:
• Highly-efficient, low-temperature, membrane/adsorptive reactor process for the water-gas-shift reaction of coal-gasifier syngas for pre-combustion CO₂ capture

Unique Advantages:
• No syngas pretreatment required: Ceramic membranes proven stable in past/ongoing studies to all gas contaminants present in coal-derived syngas.
• Improved WGS Efficiency: Enhanced reactor yield and selectivity via removal of both H₂ and CO₂ from the reacting phase.
• Significantly reduced catalyst weight usage requirements: Reaction rate enhancement (over conventional WGSR), due to removal of both products, potentially allows one to operate at lower W/F_CO (kg_cat/(mol/hr)).
• Efficient H₂ production, and superior CO₂ recovery and purity: The synergy of the MR and AR units makes the simultaneous satisfaction of the CO₂ recovery/purity, carbon utilization (CO conversion), and hydrogen recovery/purity goals, a potential reality.
Technology Background Cont’d

Key Technical Objectives and Focus

• Prepare and characterize membranes/adsorbents and validate their performance at the relevant experimental conditions.

• Validate catalyst performance at the relevant pressure conditions. Verify applicability of global reaction kinetics.

• Complete construction of lab-scale MR-AR experimental system and test the individual MR and AR subsystems.

• Develop and experimentally validate mathematical model.
Potential use of a TSA/PPSA regeneration scheme allows high pressure CO₂ recovery

MR-AR process overcomes limitations of stand-alone systems (WGSR, WGS-MR, WGS-AR)
Budget Period 1 (BP1):

Task 1.0 – Project Management and Planning

Task 2.0 – Materials Preparation and Characterization

Task 3.0 – Design and Construction of the Lab-Scale Experimental System

Task 4.0 – Initial Testing and Modeling of the Lab-Scale Experimental System
Progress and Current Status of Project, Cont’d

Current Project Tasks

Budget Period 2 (BP2):

Task 5.0 - Integrated Testing and Modeling of the Lab-Scale Experimental System.

# Technical Approach/Project Scope, Cont’d

## Milestone Log

<table>
<thead>
<tr>
<th>Budget Period</th>
<th>ID</th>
<th>Task</th>
<th>Description</th>
<th>Planned Completion Date</th>
<th>Actual Completion Date</th>
<th>Verification Method</th>
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<tr>
<td>1</td>
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<td>1</td>
<td>Updated PMP submitted</td>
<td>10/31/2015</td>
<td>10/29/2015</td>
<td>PMP document</td>
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<tr>
<td>1</td>
<td>b</td>
<td>1</td>
<td>Kick-off meeting convened</td>
<td>12/31/2015</td>
<td>11/16/2015</td>
<td>Presentation file/report documents</td>
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<tr>
<td>1</td>
<td>c</td>
<td>3</td>
<td>Construction of the lab-scale MR-AR experimental system (designed for pressures up to 25 bar) completed</td>
<td>3/31/2016</td>
<td>3/31/2016</td>
<td>Description and photographs provided in the quarterly report</td>
</tr>
<tr>
<td>1</td>
<td>d</td>
<td>2</td>
<td>Preparation/characterization of the CMS membranes at the anticipated process conditions (up to 300ºC and 25 bar total pressure) completed</td>
<td>6/30/2016</td>
<td>6/30/2016</td>
<td>Results reported in the quarterly report</td>
</tr>
<tr>
<td>1</td>
<td>e</td>
<td>2</td>
<td>Preparation/characterization of the HT-based adsorbents at the anticipated process conditions (300-450ºC and up to 25 bar total pressure) completed. Adsorbent working capacity, adsorption/desorption kinetics determined. Global rate expression for Co/Mo-based sour shift catalysts at the anticipated process conditions (up to 300ºC and 25 bar total pressure) generated</td>
<td>12/31/2016</td>
<td>12/31/2016</td>
<td>Results reported in the quarterly report</td>
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# Technical Approach/Project Scope, Cont’d

## Milestone Log

<table>
<thead>
<tr>
<th>Budget Period</th>
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<th>Task</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>f</td>
<td>4</td>
<td>MR subsystem testing and reporting of key parameters (permeance, selectivity, catalyst weight, temperature, pressures, residence time, CO conversion, effluent stream compositions, etc.) completed</td>
</tr>
<tr>
<td></td>
<td>g</td>
<td>4</td>
<td>AR subsystem testing and reporting of key parameters (adsorbent and catalyst weight, temperatures, pressures, residence time, desorption mode, working capacity, energy demand, effluent stream compositions, etc.) completed</td>
</tr>
<tr>
<td></td>
<td>h</td>
<td>4</td>
<td>Mathematical model modifications to simulate the hybrid MR-AR process and validate model using experimental MR and AR subsystem test results completed</td>
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</table>

<table>
<thead>
<tr>
<th></th>
<th>Planned Completion Date</th>
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<td>3/31/2017</td>
<td>3/31/2017</td>
<td>Results reported in the quarterly report</td>
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<tr>
<td>1 g 4</td>
<td>3/31/2017</td>
<td>3/31/2017</td>
<td>Results reported in the quarterly report</td>
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<tr>
<td>1 h 4</td>
<td>3/31/2017</td>
<td>3/31/2017</td>
<td>Results reported in the quarterly report</td>
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## Technical Approach/Project Scope, Cont’d

### Milestone Log

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<th>Budget Period</th>
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<th>Actual Completion Date</th>
<th>Verification Method</th>
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<tr>
<td>2</td>
<td>i</td>
<td>5</td>
<td>Parametric testing of the integrated, lab-scale MR-AR system and identification of optimal operating conditions for long-term testing completed</td>
<td>9/30/2017</td>
<td></td>
<td>Results reported in the quarterly report</td>
</tr>
<tr>
<td>2</td>
<td>j</td>
<td>5</td>
<td>Short-term (24 hr for initial screening) and long-term (&gt;100 hr) hydrothermal and chemical stability (e.g., NH₃, H₂S, H₂O, etc.) materials evaluations at the anticipated process conditions completed</td>
<td>3/31/2018</td>
<td></td>
<td>Results reported in the quarterly report</td>
</tr>
<tr>
<td>2</td>
<td>k</td>
<td>5</td>
<td>Integrated system modeling and data analysis completed</td>
<td>3/31/2018</td>
<td></td>
<td>Results reported in the quarterly report</td>
</tr>
<tr>
<td>2</td>
<td>l</td>
<td>5</td>
<td>Materials optimization with respect to membrane permeance/selectivity and adsorbent working capacity at the anticipated process conditions (up to 300ºC for membranes and 300-450ºC for adsorbents, and up to 25 bar total pressure) completed</td>
<td>6/30/2018</td>
<td></td>
<td>Results reported in the quarterly report</td>
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</table>
## Technical Approach/Project Scope, Cont’d

### Milestone Log

<table>
<thead>
<tr>
<th>Budget Period</th>
<th>ID</th>
<th>Task</th>
<th>Description</th>
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<th>Verification Method</th>
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<tr>
<td>2</td>
<td>m</td>
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<td>Operation of the integrated lab-scale MR-AR system for at least 500 hr at the optimal operating conditions to evaluate material stability and process operability completed</td>
<td>6/30/2018</td>
<td></td>
<td>Results reported in the quarterly report</td>
</tr>
<tr>
<td>2</td>
<td>n</td>
<td>6</td>
<td>Preliminary process design and optimization based on integrated MR-AR experimental results completed</td>
<td>9/30/2018</td>
<td></td>
<td>Results reported in Final Report</td>
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<tr>
<td>2</td>
<td>o</td>
<td>6</td>
<td>Initial technical and economic feasibility study and sensitivity analysis completed</td>
<td>9/30/2018</td>
<td></td>
<td>Results reported in Final Report</td>
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<table>
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<td>Each quarter</td>
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<td>Quarterly Report files</td>
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<td>1</td>
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<td>2</td>
<td>10/31/2018</td>
<td></td>
<td>Draft Final Report file</td>
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# Progress and Current Status of Project

## Materials Preparation and Characterization

### Carbon Molecular Sieve (CMS) Membrane Preparation, Characterization

#### Performance Assessment

**Project Targets for CMS Membranes**

\[ \text{H}_2 \text{ permeance at } \geq 550 \text{ GPU} ; \text{H}_2/\text{CO at } \geq 80 \text{ to } 100 \]

**Performance of Selected CMS Membranes at 250ºC**

<table>
<thead>
<tr>
<th></th>
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<th></th>
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<th></th>
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<tbody>
<tr>
<td>HMR-41(10”)</td>
<td>482</td>
<td>5.7</td>
<td>367</td>
<td>5.7</td>
<td>145</td>
<td>121-126</td>
<td>65</td>
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<tr>
<td>HMR-44(10”)</td>
<td>645</td>
<td>4.2</td>
<td>722</td>
<td>11.3</td>
<td>172</td>
<td>143-150</td>
<td>64</td>
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<tr>
<td>HMR-45(10”)</td>
<td>366</td>
<td>0.85</td>
<td>400</td>
<td>3.2</td>
<td>471</td>
<td>392-410</td>
<td>126*</td>
</tr>
<tr>
<td>HMR-46(10”)</td>
<td>684</td>
<td>4.7</td>
<td>-</td>
<td>12.0</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<tr>
<td>HMR-52(10”)</td>
<td>556</td>
<td>3.8</td>
<td>539</td>
<td>14.3</td>
<td>148</td>
<td>123-129</td>
<td>38</td>
</tr>
<tr>
<td>HMR-39(10”)</td>
<td>381</td>
<td>4.4</td>
<td>-</td>
<td>-</td>
<td>86</td>
<td>72-75</td>
<td>-</td>
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<tr>
<td>HMR-47(10”)</td>
<td>846</td>
<td>4.5</td>
<td>819</td>
<td>4.9</td>
<td>179</td>
<td>149-156</td>
<td>167*</td>
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<tr>
<td>HMR-49(10”)</td>
<td>434</td>
<td>1.7</td>
<td>427</td>
<td>8.3</td>
<td>249</td>
<td>207-216</td>
<td>51</td>
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<tr>
<td>HMR-48(10”)</td>
<td>418</td>
<td>4.4</td>
<td>451</td>
<td>6.8</td>
<td>102</td>
<td>85-89</td>
<td>68</td>
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<tr>
<td>HMR-42(10”)</td>
<td>368</td>
<td>1.0</td>
<td>364</td>
<td>0.7</td>
<td>361</td>
<td>301-314</td>
<td>540*</td>
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</table>
Progress and Current Status of Project, Cont’d

Materials Preparation and Characterization

Carbon Molecular Sieve Membrane Preparation & Characterization
Long-Term Stability Testing

HMR-52(10")

He/\text{N}_2$ Selectivity [\text{-}]$

He Permeance [\text{GPU}]$

Run Time [\text{Days}]$
Hydrotalcite Materials Preparation and Characterization

High-Pressure Adsorption Isotherm at 250°C

Excess sorption (wt%/g) vs. Pressure (bar)

Before correcting
After correcting
**Progress and Current Status of Project, Cont’d**

*Materials Preparation and Characterization*

**Co-Mo/Al₂O₃ Sour-Shift Catalyst Characterization**

**Global Reaction Kinetics- Empirical Model and Comparison with Microkinetic Models**

\[-r_{co} = A \ e^{-\frac{E}{RT}} \ p_{CO}^{a} p_{H_2O}^{b} p_{CO_2}^{c} p_{H_2}^{d} (1 - \beta)\]

\[\beta = \frac{1}{K_{eq}} \left( \frac{P_{CO_2} \cdot P_{H_2}}{K_{eq} \cdot P_{CO} \cdot P_{H_2O}} \right) \]

\[K_{eq} = \exp\left(\frac{4577.8}{T} - 4.33\right)\]

<table>
<thead>
<tr>
<th>Reaction Type</th>
<th>RMSD</th>
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<tbody>
<tr>
<td>Direct oxidation</td>
<td>3.38</td>
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<tr>
<td>Associative</td>
<td>5.12</td>
</tr>
<tr>
<td>Formate intermediate</td>
<td>8.04</td>
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<tr>
<td>Empirical model</td>
<td>3.32</td>
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<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>(A) [mol/(atm(^{a+b+c+d}) \cdot h \cdot g)]</td>
<td>18957</td>
</tr>
<tr>
<td>(E) [J/mol]</td>
<td>58074</td>
</tr>
<tr>
<td>(a)</td>
<td>4</td>
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<tr>
<td>(b)</td>
<td>-1.46</td>
</tr>
<tr>
<td>(c)</td>
<td>0.13</td>
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<tr>
<td>(d)</td>
<td>-1.44</td>
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Progress and Current Status of Project, Cont’d

Design and Construction of the Lab-Scale MR-AR System.
Progress and Current Status of Project, Cont’d

Design and Construction of Lab-Scale Experimental System

AR sub-system

MR sub-system

Residual Gas Analyzer (RGA)
Progress and Current Status of Project, Cont’d

MR Sub-System Operation Testing

**MR Performance – Membrane HMR-52 (10”)**

Reactor pressure = 14.5 bar, Reactor temperature = 250°C, $H_2O:CO=1.1$

![Graph 1: CO Conversion vs. Weight of catalyst / Molar flow rate of CO](image1)

- **Empirical model**
- **Packed-bed reactor**

![Graph 2: H₂ Recovery vs. Weight of catalyst / Molar flow rate of CO](image2)

- **Empirical model**
Progress and Current Status of Project, Cont’d

AR Sub-System Operation Testing

Empty Reactor Dynamics
Reactor pressure = 25 bar, Oven temperature = 400°C, Flow rate = 500 sccm

Blank Experiments Using only Quartz
Reactor pressure = 5, 10, 15, 20, 25 bar, Oven temperature = 400°C, Flow rate = 500 sccm
Progress and Current Status of Project, Cont’d

AR Sub-System Operation Testing

**CO₂ Breakthrough Experiments**

Reactor pressure = 25 bar, Oven temperature = 400°C, Flow rate=500 sccm

- Blank exp using only quartz
- CO₂ Breakthrough exp

Reactor pressure = 5, 10, 15, 20, 25 bar, Oven temperature = 400°C, Flow rate=500 sccm

- 5 bar
- 10 bar
- 15 bar
- 20 bar
- 25 bar
**Progress and Current Status of Project, Cont’d**

*AR Sub-System Operation Testing*

**CO₂/ H₂O Breakthrough Experiments**
Reactor pressure = 25 bar, Oven temperature = 300°C, Total flow rate = 500 sccm, Various steam concentration (0, 10, 20, 40 vol.%)

![Graph showing CO₂ concentration over time for different steam concentrations.](image1)

**CO₂/ H₂S Breakthrough Experiments**
Reactor pressure = 25 bar, Oven temperature = 300°C, Total flow rate = 500 sccm, H₂S concentration (0, 1000 ppm)

![Graph showing CO₂ concentration over time for different H₂S concentrations.](image2)
Membrane Reactor Depiction

Multi-scale Modeling Approach

Advantages:

• In-situ removal of \( H_2 \) significantly enhances CO conversion and \( H_2 \) purity.
• Eliminates the need for excess steam in the reaction.
• Minimizes the need for downstream hydrogen purification.
• Reduces the amount of catalyst for a desired conversion level.
• Operates at lower reaction temperatures, reduces material costs, and increases operation safety.
Progress and Current Status of Project, Cont’d

Adsorptive Reactor (AR) and Multi-scale Modeling Approach

Advantages:
- In-situ removal of CO₂ significantly enhances CO conversion and CO₂ purity.
- Eliminates the need for excess steam in the reaction.
- Minimizes the need for downstream CO₂ purification.
- Reduces the amount of catalyst for a desired conversion level.
- Operates at lower reaction temperatures, reduces material costs, and increases operation safety.
Progress and Current Status of Project, Cont’d

Multi-scale MR/AR Model: Catalyst/Adsorbent Pellet-scale

Operation = \( \begin{cases} 
\text{steady – state if MR} \\
\text{dynamic if AR}
\end{cases} \)

Domain \( \alpha = \begin{cases} 
c \quad \text{catalyst pellet if MR} \\
c / a \quad \text{catalyst / adsorbent pellet if AR}
\end{cases} \)

• Component mass conservation

• Energy conservation

• Diffusion Flux (Dusty Gas Model) DGM
Progress and Current Status of Project, Cont’d
Multi-scale MR/AR Model: Reactor-scale, Reaction-domain

Operation = \[
\begin{cases}
\text{steady-state if MR} \\
\text{dynamic if AR}
\end{cases}
\]

Domain \( \alpha = \[
\begin{cases}
c & \text{catalyst pellet if MR} \\
c / a & \text{catalyst / adsorbent pellet if AR} \\
r & \text{reaction zone if MR / AR}
\end{cases}
\]

- Component mass conservation
- Energy conservation
- Momentum conservation (Ergun Equation)
- Diffusion Flux (Stefan-Maxwell Model) SMM
Progress and Current Status of Project, Cont’d

Multi-scale MR Model: Reactor-scale, Permeation Zone

Operation = \( \{ \text{steady state (MR)} \} \)

Domain \( \alpha = \begin{cases} r & \text{reaction zone} \\ \text{per} & \text{permeation zone} \end{cases} \)

- Component mass conservation
- Energy conservation
- Momentum conservation
Progress and Current Status of Project, Cont’d

*Pseudo-homogeneous AR Model: Reactor-scale*

**Operation** = \{\text{dynamic (AR)}\}

**Domain** $\alpha = \{r \text{ reaction zone}\}$

- Component mass conservation
- Energy conservation
- Momentum conservation
Conversion vs. W/F_{CO} for MR (feed pressure 14.1 bar, reactor temperature 300°C, sweep ratio = 0.1).

Conversion vs. W/F_{CO} for MR (feed pressure 14.1 bar, reactor temperature 300°C, sweep ratio = 0.3).
Progress and Current Status of Project, Cont’d
Adsorptive Separator (AS) Model Experimental Validation

CO₂ outlet concentration at the exit of the adsorber
(Experiment vs. Simulation). Temp. = 523.15 K, Pressure = 5 bar.

CO₂ outlet concentration at the exit of the adsorber
(Experiment vs. Simulation). Temp. = 523.15 K, Pressure = 15 bar.

CO₂ outlet concentration at the exit of the adsorber
(Experiment vs. Simulation). Temp. = 523.15 K, Pressure = 25 bar.
Molar ratio of H₂/CO at the AR outlet.  
(Experiment vs. Simulation).

Molar ratio of CO₂/CO at the AR outlet.  
(Experiment vs Simulation).
Progress and Current Status of Project, Cont’d
Membrane Reactor/Adsorptive Reactor Process

Combined MR + AR System
Progress and Current Status of Project, Cont’d
Membrane Reactor/Adsorptive Reactor Process
Progress and Current Status of Project, Cont’d

Membrane Reactor/Adsorptive Reactor Process

Water+H2 → Water → Water+CO2 → Carbon Depleted Syngas → Carbon Depleted Syngas → S-V → Water+CO2 → Syngas

CO2 Rich Syngas → Water
Progress and Current Status of Project, Cont’d

Proposed Process Scheme – UNISIM Implementation
Membrane Reactors are composed of several components
- Ceramic membrane tubes
- Bundles typically containing 85-100 ceramic membrane tubes
- Pressure Vessel typically containing 1500-3000 bundles
Progress and Current Status of Project, Cont’d

**Membrane Reactor Operating Modes**

- Membrane tube inner/outer flow pattern
  - Countercurrent
  - Co-current
- Bundle configuration in Pressure Vessels
  - Bundles in series
  - Bundles in parallel
  - Bundles networked

Membrane Reactor Operating Mode Used in TEA:

- Membrane tubes are operated countercurrently
- Bundles are configured in 300 parallel bundle series, each of which consists of 6 bundles
Progress and Current Status of Project, Cont’d

Membrane Reactor Vessel: Configuration 1
Progress and Current Status of Project, Cont’d

Membrane Reactor Vessel: Configuration 2
## Progress and Current Status of Project, Cont’d

Preliminary Technical-Economic Analysis (TEA) for MR-AR Technology
*(NETL Case Study)*

<table>
<thead>
<tr>
<th>Designs</th>
<th>Net Power Production (MWe)</th>
<th>CO2 Capture (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shell IGCC w/o CCS – 1-Stage Selexol</td>
<td>622</td>
<td>0</td>
</tr>
<tr>
<td>Shell IGCC w/ CCS– 2 Stage Selexol</td>
<td>543</td>
<td>90</td>
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<tr>
<td>MR-AR IGCC Plant</td>
<td>566</td>
<td>93.5</td>
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</table>
## Progress and Current Status of Project, Cont’d

Preliminary Technical-Economic Analysis (TEA) for MR-AR Technology

*(NETL Case Study)*

<table>
<thead>
<tr>
<th>System</th>
<th>Conversion</th>
<th>Catalyst Amount (ft³)</th>
<th>Adsorbent (kg)</th>
<th>Water Input (kmol/hr)</th>
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</thead>
<tbody>
<tr>
<td>MR-AR Combined System</td>
<td>98%</td>
<td>2,800</td>
<td>3830,000</td>
<td>0 (no excess water need be inputted)</td>
</tr>
<tr>
<td>IGCC WGS Reactor</td>
<td>97%</td>
<td>6,200</td>
<td>0</td>
<td>7,200</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>% CO Conversion</th>
<th>% H₂ Purity</th>
<th>% H₂ Recovery</th>
<th>% CO₂ Purity</th>
<th>% CO₂ Recovery</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target</td>
<td>&gt;95</td>
<td>&gt;95</td>
<td>&gt;90</td>
<td>&gt;95</td>
<td>&gt;90</td>
</tr>
<tr>
<td>MR-AR Realization</td>
<td>98.2</td>
<td>95.6</td>
<td>99</td>
<td>99.7</td>
<td>93.5</td>
</tr>
</tbody>
</table>
Progress and Current Status of Project, Cont’d

MR-AR Process Advantages

• Simultaneous CO conversion and H₂ and CO₂ separation

• MR-AR Compression Work: <20% of IGCC w/ CCS compression work

• Catalyst Amount: <50% of IGCC w/ CCS catalyst amount

• High Purity Hydrogen Produced: 95.6% Hydrogen Purity
Progress and Current Status of Project, Cont’d

Summary of Technical Accomplishments To Date

• Completed the construction of the lab-scale MR-AR experimental system.

• Prepared and characterized CMS membranes at the anticipated process conditions.

• Prepared and characterized adsorbents at the anticipated process conditions, and generated global rate expressions for the catalyst.

• Began testing of the individual MR and AR subsystems.

• Developed mathematical models and began validating their ability to fit the experimental data.
Progress and Current Status of Project, Cont’d
Future Plans

Budget Period 2 (BP2):

Task 5.0 - Integrated Testing and Modeling of the Lab-Scale Experimental System. -----M&PT, USC

   Subtask 5.1 - Materials Optimization and Scale-up.
   Subtask 5.2 - Integrated Testing.
   Subtask 5.3 - Model Simulations and Data Analysis.


   Subtask 6.2 - Sensitivity Analysis.
Acknowledgements

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Project Manager Andrew Jones

are gratefully acknowledged.