Resin Wafer-Electrodeionization for Flue Gas Carbon Dioxide Capture

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Lead Recipient: Nalco Company
Project Title: Energy Efficient Capture of CO₂ from Coal Flue Gas
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Presented by Jitendra T. Shah and Wayne M. Carlson
Strategy:

- **Addresses CO₂ absorption & release**
  - Resin Wafer-Electrodeionization designed and developed to capture and release CO₂ (CO₂_RW-EDI)
  - Kinetics enhanced with carbonic anhydrase enzyme

- **Employs electrochemical pH control**
  - pH shifts capture and release CO₂ in separate cells
  - Water splitting enables in-situ pH control for optimum activity
  - Eliminates the need for acids and bases

- **Decreases parasitic energy load**
  - Avoids temperature and/or pressure swings for regeneration
  - Avoids the use of steam and vacuum
Project goals will significantly advance CO$_2$ capture technology

**Project Goals**

- Develop Resin Wafer-Electrodeionization technology for CO$_2$ capture
- Target 90% CO$_2$ capture and released CO$_2$ with 90% purity
- Establish a prototype demonstration of a pilot system that captures CO$_2$ at an effective rate of 1 tonne/day, Technology Readiness Level 6 (TRL-6)
Project benefits for the environment & consumers

- Energy-efficient CO₂ capture to mitigate climate change
- Minimize the impact on cost of electricity (by as much as 50% to keep coal-fired power production affordable)
- Easily retrofitted to existing industrial facilities and compatible with carbon storage technologies
- Make clean CO₂ available for beneficial uses such as algal biofuels, renewable plastics, etc.
- Develop advanced manufacturing capabilities in the U.S.
What is RW-EDI?

RW-EDI is based on a progression of water purification technologies

- Ion Exchange (IX)
- Electrodialysis (ED)
- Electrodeionization (EDI)

Resin-Wafer Electrodeionization (RW-EDI)

- Liquid Systems
- Gas/Liquid Systems
Single RW-EDI cell

Scanning electron microscope image of an ion-exchange resin wafer

Resin wafer held within a gasket
Close-up view of a single RW-EDI cell

Water splitting provides ions that continuously regenerate the ion-exchange resin and enables electrochemical solution pH control.
The platform is a unique adaptation of deionization technology

The RW-EDI uses the electrochemical pH shifts to capture CO₂ from the flue gas and to release the CO₂.

Advantages:
- Electrochemical pH control
- Carbonic anhydrase enzyme drives kinetics for faster capture and release of CO₂
- Energy efficient CO₂ capture
- Minimizes impact on cost of electricity

Configuration of RW-EDI CO₂ Capture Device

- Basic Resin Wafer for Capture
- Acidic Resin Wafer for Release
- BP: Bipolar Membrane
- CEM: Cation Exchange Membrane
- Two cell pairs are shown*
- *A production unit would have more than 100 cell pairs
Capture resin wafer (basic pH)
\[ \text{CO}_2 + \text{OH}^- \rightleftharpoons \text{HCO}_3^- \]

Release resin wafer (acidic pH)
\[ \text{HCO}_3^- + \text{H}^+ \rightleftharpoons \text{CO}_2 + \text{H}_2\text{O} \]

BP: Bipolar Membrane
CEM: Cation Exchange Membrane
Lab-scale system with one cell pair

‘Head-on’ view

Pure CO₂ collection tank

Exit from release

Power supply

Flue gas & liquid into capture

Cathode

Flue gas & liquid exit from capture

Waste gas separation tank

Anode

Carbon-enriched liquid into release

Exit from release

Carbon-enriched liquid into release
Critical performance attributes in the research plan

- **Gas-Liquid Delivery System**
  - Introduction of gas-liquid to the RW-EDI
  - Distribution of gas and liquid among multiple cell pairs
  - Mixing
  - Gas-liquid separation

- **Power Consumption Optimization**
  - pH control
  - Effective catalyst loading
  - Pressure drop

- **Effects of Flue Gas Characteristics on Performance**
  - Fine particles, NO$_x$, SO$_x$
  - Temperature

Computational fluid dynamics modeling of flow distribution in 6 parallel wafers in an RW-EDI stack.
## Proof of concept results

<table>
<thead>
<tr>
<th>Capture Cell pH</th>
<th>Release Cell pH</th>
<th>% CO₂ Captured</th>
<th>% CO₂ Released</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.22</td>
<td>5.91</td>
<td>49</td>
<td>78</td>
<td>No Catalyst @ 25ºC</td>
</tr>
<tr>
<td>7.87</td>
<td>5.94</td>
<td>44</td>
<td>82</td>
<td>No Catalyst @ 25ºC</td>
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</tbody>
</table>
Resin wafer fabrication

Ion-exchange resin wafers (RW) are used as the reaction chambers for CO\textsubscript{2} capture from flue gas and release as pure CO\textsubscript{2} gas. Engineering scale-up of RW fabrication was achieved and the RW properties shown below have reached the development targets.

- RW thickness and size: 6 & 13 mm in 11”x11” and 17”x20” sizes
- RW void space: 20% to 40% of volume
- RW ionic conductivities: 1.5 mS/cm to 4.0 mS/cm with 500 ppm NaCl
- Types of IX in RW: macroreticular resin & gel resin
- Resin particle sizes used in RW: range from 50 um to 400 um
Efficiency improvements & macroeconomic benefits

- **COE**
  - Targeted in the range of 25 to 35%

- **CO$_2$ purity**
  - System has potential to produce >97% purity
  - Further upgrading to pipeline or utilization requirements possible

- **Potential costs**
  - Initially targeted at $20 - $40/tonne pure CO$_2$
  - Costs likely to decrease with commercial deployment

- **Potential integration with end use**
  - Bicarbonate production
  - Atmospheric CO$_2$
  - Pipeline CO$_2$
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Project Team

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