Scaling Up-Direct Air Capture (DAC): Learnings From Traditional Capture Projects

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Briefing Panel: Environmental and Energy Study Institute
May 25, 2022
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Skilled in transitioning from lab scale to build/operate scale

UNIVERSITY OF ILLINOIS / PRI: LEADER IN CAPTURE R&D
Prairie Research Institute (PRI): Addressing Societal Issues
UIUC / PRI Network

*Multi-organizational team is required*

- Relationships and access to host sites in the region / US
- Network of Engineering Procurement and Construction (EPC) firms, OEMs, etc.
- Infrastructure in place (financial, project management, etc.) to meet US Department of Energy (DOE) requirements
- Typically functions as “prime” for projects
- “Agnostic” approach to technology, i.e. willing to work with any technology as long as it works
Pathway to Scaling-Up Capture Technologies

Traditional Capture Provides Good Lessons Learned for DAC scale-up

### Feasibility
- Is it economical?
- Any regulatory barriers?
- Any technical barriers?

### PreFEED
- Basic design
- Detailed design
- Regulatory resolved
- Financing complete
- Ready for construction, i.e. “shovel ready”

### FEED
- FEED = Front-End Engineering and Design

### Build / Operate
- “Breaking ground”

### Notes:
- FEED = Front-End Engineering and Design
## UIUC Project Portfolio

*Color code: Complete / In Process*

<table>
<thead>
<tr>
<th>Lab</th>
<th>Small Pilot</th>
<th>Large Pilot / Full Scale</th>
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<tbody>
<tr>
<td>Next generation DAC materials</td>
<td>0.5 MW Capture w/Mixed Salts</td>
<td>816 MW capture plant (largest capture FEED in the world)</td>
</tr>
<tr>
<td></td>
<td>40 kW – Biphasic Capture System</td>
<td>10 MW – Build / Operate (largest capture pilot in the world)</td>
</tr>
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<td>0.5 MW aerosol reduction technologies</td>
<td>350 MW – Capture, energy storage, algae, hybrid coal/NG</td>
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<td>FGD blown-down water recycle</td>
<td>1 MW- Build/operate Utilize CO2 from flue gas for algae growth</td>
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<tr>
<td>Capture from Cement Plant (largest single kiln in North America)</td>
<td>Direct Air Capture (DAC) + renewables 100,000 tCO2/yr, 3 sites</td>
<td></td>
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<td></td>
<td>Direct Air Capture (DAC) + geothermal 5,000 tCO2/yr.</td>
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<td></td>
<td>Direct Air Capture (DAC) + nuclear 5,000 tCO2/yr.</td>
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<td>DAC + excess heat from steel plant+ utilization of CO2 for cement applications (DACU) 5,000 tCO2/yr.</td>
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<td>400 MWh energy storage using NG</td>
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Scale-up studies and considerations

DIRECT AIR CAPTURE (DAC)
Some Engineering Scale-Up Considerations

*Post combustion vs DAC*

- Capture unit located before stack
- Heat / power from plant drives capture unit
- Capture CO₂ from flue gas
- CO₂ levels ~11% in flue gas
- Residuals could be present: NOx, SOx, etc.
- Industrial > 100,000; power generation >1,000,000 tCO₂/yr. captured

- Capture unit location flexible
- Heat / power can be from multiple sources
- Capture CO₂ from atmosphere
- CO₂ levels in ppm range
- Residuals seen in post combustion not present
Direct Air Capture-Based Carbon Dioxide Removal with Low-Carbon Energy and Sinks

US Department of Energy (DOE) Funded Project

Goals:
- Initial engineering design for system that captures 100,000 tCO₂/yr.
- Evaluate effect of various climates within the US on engineering design for three sites
- Estimate cost and timeline for construction of facility
- Technoeconomics, Life Cycle Analysis, and Business Case at all three host sites

Total Project Funding: $3.1 MM
Project Duration: 18 months

Louisiana  California  Wyoming
# Effect of Power Source and Climate on DAC Design

*Evaluates impact of various factors on scale-up*

<table>
<thead>
<tr>
<th>Site Location</th>
<th>Volume CO₂ Captured (tCO₂/yr.)</th>
<th>Power Source</th>
<th>Existing vs New Power Source</th>
<th>Operator</th>
<th>Climate</th>
<th>Storage Site</th>
<th>Transport to Storage Site</th>
</tr>
</thead>
<tbody>
<tr>
<td>Louisiana</td>
<td>100,000</td>
<td>Solar (SunPower)</td>
<td>New</td>
<td>Gulf Coast Sequestration</td>
<td>Hot &amp; Humid</td>
<td>Deep Subsurface Rock</td>
<td>Co-located with DAC</td>
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<tr>
<td>California</td>
<td>100,000</td>
<td>Geothermal</td>
<td>Existing</td>
<td>Ormat</td>
<td>Hot &amp; Dry</td>
<td>Saline Aquifer</td>
<td>Rail / Pipeline</td>
</tr>
<tr>
<td>Wyoming</td>
<td>100,000</td>
<td>Waste Heat (Gas plant) &amp; Wind</td>
<td>Existing</td>
<td>North Shore Exploration &amp; Production, LLC</td>
<td>Warm &amp; Dry / Cold &amp; Dry</td>
<td>Depleted Oil &amp; Gas Reservoir</td>
<td>Co-located with DAC</td>
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Direct Air Capture + Utilization = DACU

Waste heat from Steel plant and utilize captured CO₂ for cement

US Steel Gary Works Facility Host Site Aerial View

Waste Heat

Captured CO₂

CO₂ incorporated into cement

5,000 tCO₂/yr.

Total Project Funding: $ 3.5 MM
Project duration: 18 months
Strategies / Tools to Assist in DAC Scale-up

Many under development by NETL / DOE

• Use FEED study results to drive R&D funding
  – Uncover the technology “gaps” that inhibit scale-up

• Build pilot scale systems to accelerate learnings
  – Building systems has demonstrated for many energy technologies the ability to transition on the “learning curves”

• Technoeconomic Analysis (TEA) standards for DAC
  – Patterned after those established for Post Combustion Capture

• Standardized scale-up pathway
  – Equivalent for post combustion: bench-scale / lab-scale / small pilot / large pilot / demonstration

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1 Edward S. Rubin; Margaret R. Taylor; Sonia Yeh; David A. Hounshell, Learning curves for environmental technology and their importance for climate policy analysis, Energy 29 (2004) 1551-1559
3 COST AND PERFORMANCE BASELINE FOR FOSSIL ENERGY PLANTS VOLUME 1: BITUMINOUS COAL AND NATURAL GAS TO ELECTRICITY (Sept. 2019, NETL-PUB-22638)
# Acknowledgements

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<tr>
<td>Krista Hill</td>
<td>National Energy Technology Laboratory / US Department of Energy</td>
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<tr>
<td>Dirk Nuber, Daniel Sutter, Karina Veloso</td>
<td>Climeworks</td>
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<tr>
<td>Vinod Patel, Jason Dietsch, Chinmoy Baroi</td>
<td>Prairie Research Institute / University of Illinois</td>
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<td>Matt Thomas, Scott Vargo, Bob Sletthaugh</td>
<td>Kiewit</td>
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<td>Roger Aines, Bill Bourcier, Joshuah Stolaroff</td>
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<td>ORMAT</td>
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<td>Mike Whitezell</td>
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This project is supported by the U.S. Department of Energy / National Energy Technology Laboratory (DOE/NETL) through Cooperative Agreement No. DE-FE0032100