Driving the Technology Innovation Ecosystem through Applied Research and Collaboration

Solutions for Today | Options for Tomorrow

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Director

Carbon Capture Utilization and Sequestration Roadshow
Washington, D.C. Workshop
January 28, 2020
MISSION

Discover, integrate and mature technology solutions to enhance the Nation’s energy foundation and protect the environment for future generations

- Effective Resource Development
- Efficient Energy Conversion
- Environmental Sustainability

VISION

Be the Nation’s renowned fossil-energy science and engineering resource, delivering world-class technology solutions today and tomorrow

- Technology Convener
- Knowledge and Technology Generation Center
- Responsible Steward
Evolving Topics in Coal

- **Upgrading the Existing Fleet**: Improving the performance, reliability, & efficiency of the existing coal-fired fleet
- **Advancing Next-Gen Power Plants**: Advancing small-scale, modular coal plants that are highly efficient, flexible, & near-zero emissions
- **Pioneering New Markets for Coal**: Enhancing the value of coal as a feedstock & deriving new value-added products from coal
- **Reducing the Cost of Carbon Capture**: Developing advanced computational & simulation tools, & transformational technologies, to reduce the cost of CO₂ capture
- **Reducing Water Use in Energy Production**: Addressing water quality, sustainability, & availability for power generation

U.S. DEPARTMENT OF ENERGY
Carbon Capture, Utilization and Storage (CCUS)

Program Areas

Fossil-Fuel Energy

Carbon Use and Reuse

Geological Storage

Enhanced Oil Recovery
Reducing the Cost of Carbon Capture

**Integrated R&D Approach**

**2017**
- Large Capture Pilots Initiated
- Initiate Storage Feasibility for Integrated CCS

**2020**
- R&D Completed for Carbon Capture 2nd Generation Technologies

**2022**
- Commercial-scale Storage Complexes Characterized

**2025**
- Integrated CCS Projects Deployed

**2035**
- Transformational Technologies Available for Deployment
Carbon Storage

Approaches

• Predicting and monitoring CO₂ plume and brine pressure front movement, stabilization, and impacts.
• Optimization of reservoirs for CO₂ storage capacity.
• Developing and validating risk-assessment strategies.
• Mitigating risks, such as leakage from old wells and induced seismicity.
• Carrying out (large-volume and Fit-for-Purpose) field tests for different storage types and depositional environments.
2nd Generation Pilot-scale Technologies

Reduced Cost
$100+/tonne

Reduced Energy Penalty
30% Penalty

Program Activity
180+ Projects

~50% Reduction

~20% Penalty

15 Technologies Tested at Pilot Scale

Technologies Tested at Pilot Scale

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<th>TECHNOLOGY HIGHLIGHTS</th>
<th>POST-COMBUSTION</th>
<th>PRINCIPAL DEVELOPER</th>
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<tr>
<td>Imbedded Amine Sorbent*</td>
<td>ADA-ES</td>
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<td>Water-lean Amine Solvent</td>
<td>Fluor/PNNL</td>
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<td>Hybrid Solvent/Membrane</td>
<td>Gas Technology Institute</td>
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<td>Amino-silicone Solvent*</td>
<td>General Electric Company</td>
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<td>Amine/Imidazole Solvent Mixture* (Large Pilot)</td>
<td>ION Engineering</td>
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<td>Advanced Amine Solvent Process*</td>
<td>Linde/BASF</td>
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<td>Advanced Membrane Process*</td>
<td>MTR</td>
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<td>Nozzle-based Solvent Contactor*</td>
<td>Neumann Systems Group</td>
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<td>Mixed Salt Solvent Process*</td>
<td>SRI International</td>
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<tr>
<td>Carbon-based Sorbent*</td>
<td>SRI International</td>
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<td>Alkalized Alumina Sorbent*</td>
<td>TDA Research</td>
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<td>Optimized Amine Solvent Process</td>
<td>University of Kentucky</td>
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<tr>
<td>Piperazine Solvent/Flash Stripper*</td>
<td>URS/University of Texas</td>
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<tr>
<td>PRE-COMBUSTION</td>
<td>SRI International</td>
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<tr>
<td>Ammonium Carbonate/Bicarbonate Solvent*</td>
<td>TDA Research</td>
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<tr>
<td>Integrated Sorbent Process</td>
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*Project Completed
Accelerating CCUS R&D Using Computational Methods

**Data Analytics, Machine Learning and Artificial Intelligence**

Driving Down the Cost of Carbon Capture

Transform subsurface engineering operations for geologic carbon storage

Computational/Experimental study of CO$_2$ to CO Conversion

**Science-informed Machine Learning for Accelerating Real Time Decisions in Subsurface Applications (SMART Initiative)**

Predicted properties for over a million possible MMMs

Reduce costs through faster, more efficient, analysis of information, and reduced uncertainty in operations decision-making

Predict Catalytic Activity of Yet-To-be-Synthesized Materials
THANK YOU!

VISIT US AT: www.NETL.DOE.gov

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@NationalEnergyTechnologyLaboratory
Petra Nova CO2 EOR CCS Plant

**From Discovery to Commercialization**

**Government – Industry Partnership to Commercialization**

**Technology Maturation**

**Scale Technology Confidence Investment**

**From Discovery to Commercialization**

**NRG W.A. Parish Power Plant – Full Scale Integrated CCS**

**TRL 9**

Full Scale Commercialization

2016

Petra Nova – NRG W.A. Parish Power Plant
Thompsons, TX – 4,766 tons/day est.

**TRL 7-8**

First-of-a-kind Integrated Coal CCS Small Commercial Scale Plant

2011

First fully Integrated Coal CCS Plant – 500 tons/day
Alabama Power

**TRL 6-7**

Pre-Commercial Prototype Validated in Relevant Environment

2008

First Commercial Plant - w/ Improved KM CDR Process® - 400 tons/day

**TRL 4-5**

Component/Subsystem Validated – KM CDR Process and Improved Process Validated

1994 & 1999

**TRL 2-3**

Proof-of-Concept Developed – Initial Carbon Capture Development

Early 1990s

**KM CDR Process® Developed**

**COMMERCIALIZATION**

Technology available for wide-scale market use

**DEMONSTRATION**

System demonstrated in operational environment

**SYSTEM TESTING**

System performance confirmed at pilot-scale

**DEVELOPMENT**

Technology component validated/integrated

**DISCOVERY**

Concept identified/proven at laboratory-scale

**U.S. DEPARTMENT OF ENERGY**

**National Energy Technology Laboratory**

**10**
Reducing the Cost of Carbon Capture

<table>
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<tr>
<th>Year</th>
<th>Cost of CO₂ Capture (Per Tonne)</th>
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<tr>
<td>2012</td>
<td>$80-100</td>
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<tr>
<td>2016</td>
<td>$60</td>
</tr>
<tr>
<td>2020</td>
<td>$45</td>
</tr>
<tr>
<td>2025</td>
<td>$40</td>
</tr>
<tr>
<td>2030</td>
<td>$30</td>
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Transformational Target

2nd Generation Target

Direction of Fossil Energy Research
National Carbon Capture Center

- World Class Carbon Capture Technology Test Facility -

Post-combustion Technology Testing
- PC4 Facility – 4.3 MWe
- Actual PC flue gas
- Bench through pilot scale
- > 101,000 hours of testing
- > 30 Technologies tested
- US & 6 other countries

DRAFT – Will update numbers and partners with Andy O’Palko

- 5 year $150 Million of DOE Investment
- $100 Million Capture Funding
- Independent Test Facility
Maturing 2nd Generation Technologies

Research Triangle Institute’s Water-Lean Solvent Process

DOE/FE/NETL has sponsored highly successful second-generation technologies that will dramatically reduce CO₂ capture costs. Research Triangle Institute’s (RTI’s) Water-Lean Solvent Process is one of those technologies.

BACKGROUND

CHALLENGE:
• Current solvent capture technologies use mixtures of ~70% water and 30% amines to absorb CO₂
• The water has negative energy impacts and doesn’t capture any of the CO₂ - unlike the amines - but
  the water controls the corrosivity and viscosity of the amines

RTI’S SOLUTION:
• Replace water with a hydrophobic non-aqueous solvent
• Total water in the mixture goes from ~70% down to ~5-10%

SIGNIFICANT RESULTS

Techno-economic analyses indicate:

Reduced Capital Costs
• Enhanced solvent performance results in smaller columns, heat exchangers, and footprint

Reduced Operating Costs
• Lower energy requirements

Lab/Bench Scale Development
Initiated 2009/2010
• Proof of concept/feasibility in 2009 and lab-scale testing initiated in 2010
• Bench-scale testing initiated 2014
• Solvent formulation finalized
• Reboiler heat duty < 2.0 GJ/tonne
• Preliminary techno-economic analysis shows capture cost ≤ $40/tonne

Scale-Up Testing
Initiated 2016
• Testing at 60-kWe scale conducted using actual flue gas at SINTEF’s Tiller Plant pilot-testing facility in Norway
• 1500+ hours of parametric and long-term testing on coal derived flue gas
• Additional testing at the National Carbon Capture Center
• 570 hours at 50-kWe scale using coal-derived flue gas to evaluate operational issues

Large Pilot-Scale Testing
Initiated 2018
• ~12 MWe scale testing at Technology Centre Mongstad (TCM) to evaluate the viability of the RTI solvent as a drop-in replacement for conventional capture systems
• Additional testing will modify TCM’s existing equipment to evaluate optimized operation with the RTI solvent
Maturing 2nd Generation Technologies

Membrane Technology and Research Advanced Membrane Process

DOE/FE/NETL has sponsored highly successful second-generation technologies that will dramatically reduce CO2 capture costs. MTR’s Advanced Membrane Process is one of those technologies.

BACKGROUND

CHALLENGE:
• CO2 concentration in post-combustion flue gas was considered too low to provide sufficient driving force for membrane-based separation
• Permeance and selectivity of 1st generation membranes were too low for cost-effective separation of low-CO2-concentration gases

MTR’S SOLUTION:
• Materials development efforts increased permeance by 3x while maintaining selectivity
• Innovative process design resulted in increased CO2 concentration in membrane feed gas, enhancing driving force

SIGNIFICANT RESULTS

Establish Viability of Membrane-based Post-Combustion Capture
• Materials and process innovations overcome limitations of low driving force

Nature of Membrane Systems Provides Potential Solutions to Challenging Problems
• Inherently modular, low-cost, high-volume manufacturing; simplifies scale up

Lab/Bench Scale Development
Initiated 2007
• Development of advanced Polaris membrane with increased permeance 10x that of existing membranes and CO2/N2 selectivity > 20
• Novel countercurrent sweep CO2 recycle process design reduced the need for energy intensive compression
• 10,000 hours of stable testing at 1 tonne/day scale on actual flue gas confirmed improved permeance and selectivity

Small Pilot-Scale Testing
Initiated 2011
• Over 1,000 hours of testing at 1 MWe (20 tonnes/day) scale at the National Carbon Capture Center
• Validated countercurrent sweep process and a low pressure-drop sweep module that reduces parasitic energy losses
• Revealed effective boiler operation in the presence of recycled CO2 to increase flue gas CO2 concentration, reducing cost

Large Pilot-Scale Testing
Initiated 2018
• Detailed techno-economic analysis and preliminary plant design with engineering/cost estimates for construction of a 10 MWe pilot facility at the Wyoming Integrated Test Center
• Field-scale testing at Technology Centre Mongstad to demonstrate modular membrane concept for use in commercial-scale systems
With a speed of 3.608 PFLOPS, Joule 2.0 ranks:

- **55th** in the World
- **21st** in the United States

- **More** CPU cores (73,240 vs. 24,192)
- **More** memory (271 TB vs. 73 TB)
- **Faster** (3.608 PFLOPS vs. 0.5 PFLOPS)
- **Newer Technology** (40 cores per node vs. 16)

Integrated GPU and CPU will enhance machine learning and data analytic capabilities at all three research locations.
Driving Down the Cost of Carbon Capture

Computational tools to rapidly screening of novel carbon capture materials

- NETL in-house researchers used high-throughput computational methodology to screen over **1 million** possible mixed matrix membranes (MMMs).
- NETL-developed polymers were found to enhance mechanical stability.
- MMMs, with NETL developed polymer, were estimated to decrease the cost of carbon capture from **$63 to $48 per metric ton** of CO₂ removed.

University of Pittsburgh
Department of Chemical & Petroleum Engineering
Primary Goals

Real-Time Visualization
“CT” for the Subsurface

Rapid Prediction
Virtual Learning

Real-Time Forecasting
“Advanced Control Room”

Technical Team

Science-informed Machine Learning to Accelerate Real Time (SMART) Decisions in Subsurface Applications
Electrochemical CO\textsubscript{2} reduction reaction (CO\textsubscript{2}RR) is a promising approach for converting fossil fuel emissions into environmentally sustainable chemicals and fuels.

NETL researchers simulated Au-Cu nanoclusters under electrochemistry conditions using an in-house computational electrochemistry code.

- Experimental studies validated the computational predictions.

Density functional theory calculations were performed on NETL’s Joule supercomputer.

The alloys retained the activity and selectivity of pure gold with an approximately 50 percent reduction in precious metal content.
An Active Portfolio from Concept to Market Readiness

Technology Development Pathway

**COMMERCIALIZATION**
- Technology available for wide-scale market use

**DEMONSTRATION**
- System demonstrated in operational environment

**SYSTEM TESTING**
- System performance confirmed at pilot-scale

**DEVELOPMENT**
- Technology component validated/integrated

**DISCOVERY**
- Concept identified/proven at laboratory-scale

**KNOWLEDGE-BASED DECISION MAKING**
- Systems Engineering and Integration
  - Engineering analysis
  - Pre-FEED/FEED studies
  - NEPA
- Decision Science and Analysis
  - Screening studies
  - Techno-economic analysis
  - Technology Readiness Assessments

**TECHNOLOGY MATURATION**
- Scale
- Technology Confidence
- Investment
- Private Sector Cost Share

**Fundamental Studies**

**Tools**