



Solutions for Today | Options for Tomorrow

Carbon Capture Program Overview



Carbon Capture Annual
Project Review
October 5, 2020



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Acknowledgements



- **NETL**

- NETL Research: [David Hopkinson](#)
- CCSI²: [Benjamin Omell/ Mike Matuszewski](#)
- TEA Analyst: [Timothy Fout](#)
- Carbon Capture Team: [José Figueroa](#), [Andrew Jones](#), [Andrew O'Palko](#), [Naomi O'Neil](#), [David Lang](#), [Isaac Aurelio](#), [Carl Laird](#), [Katharina Daniels](#)
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- **FE HQ**

- Division Director: [Mark Ackiewicz](#)
- Program Manager: [Lynn Brickett](#)

Carbon Capture Program.. Mission

- **Mission**

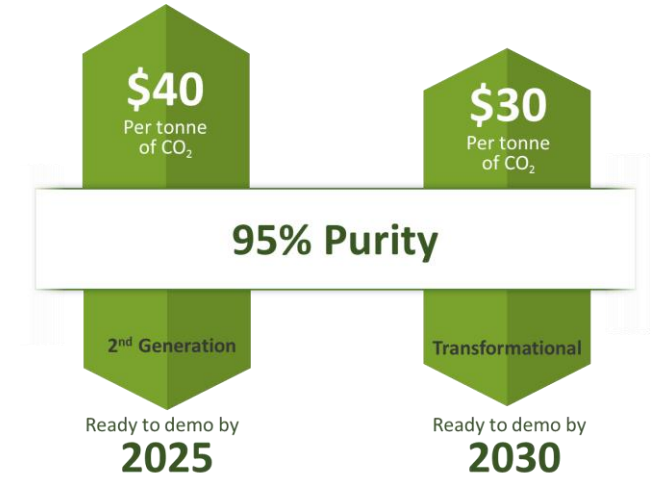
- Develop advanced cost-effect CO₂ capture technologies throughout the power-generation sector
- Ensure the U.S. will continue to have access to safe, reliable, & affordable energy from fossil fuels

- **Drivers/Challenges**

- Coal-based & gas-based power are the 1st & 2nd largest stationary sources of CO₂ emissions
- Reduce CO₂ capital & operating costs
- Increase efficiency & reduce cost of CO₂ compression

- **Goal & Metrics**

- By 2030, COE at least 30% lower than a supercritical PC with CO₂ capture



National Carbon Capture Center
Photo Source: Southern Company Services

Carbon Capture Program.. Evolution

1st and 2nd Generation Technologies

2025: \$40/tonne CO₂



Petra Nova

2008 -

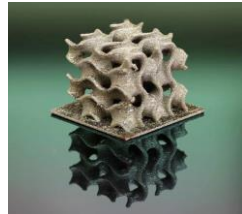
- ✓ Lower CAPEX/OPEX
- ✓ Reduced regeneration energy
- ✓ Increased working capacity

Transformational Technologies

2030: \$30/tonne CO₂



Hollow Fibers



3D Print



Biphasic Solvent

2015 -

- ✓ Water Lean Solvents
- ✓ Adv. Amines/Membranes
- ✓ Hybrid
- ✓ Process Intensification

Scale-up



TCM

2018 -

- ✓ Engineering Scale testing
- ✓ FEED studies

Negative Emissions Technologies & Industrial



Carbon Engineering, DAC

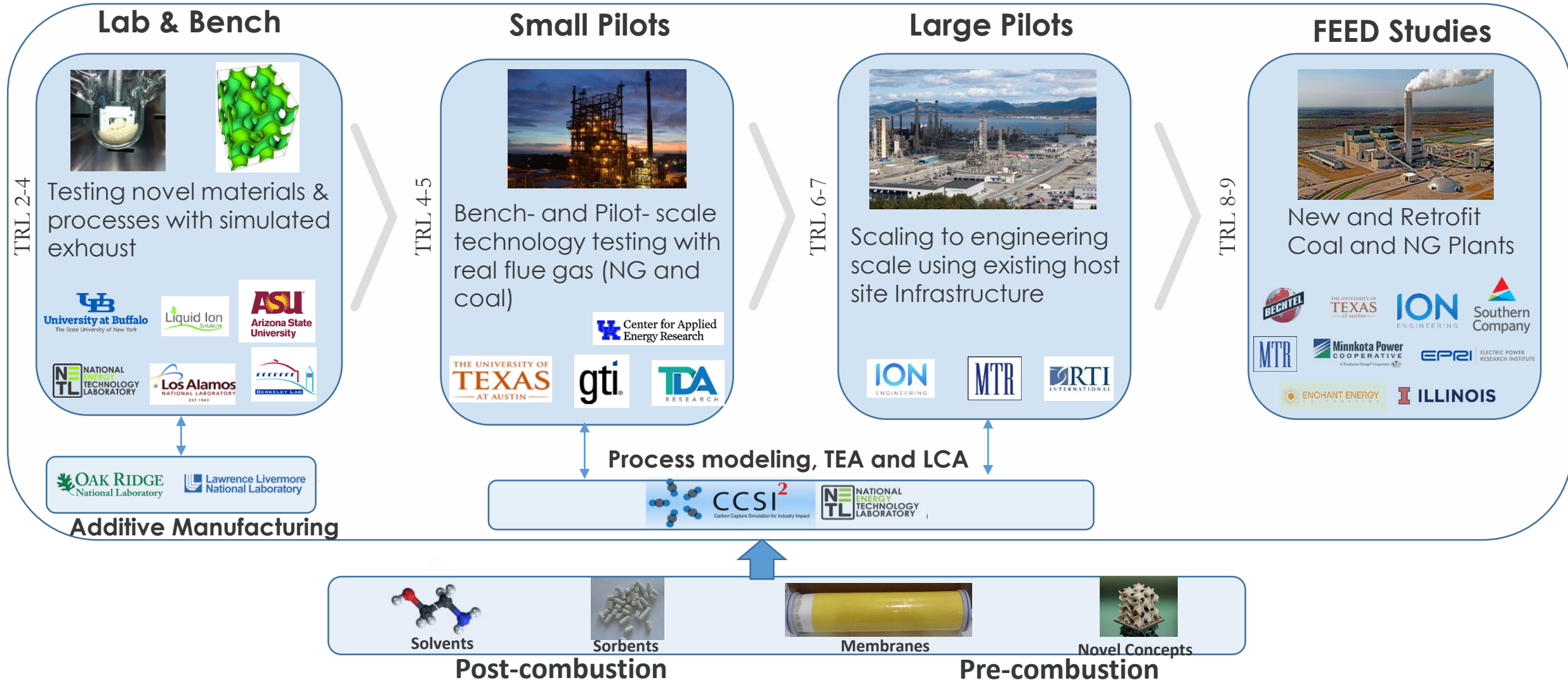


Ethanol Plant

2020 -

- ✓ Coal FIRST
- ✓ DAC & BECCS
- ✓ Industrial, NG

Carbon Capture.. Program Structure

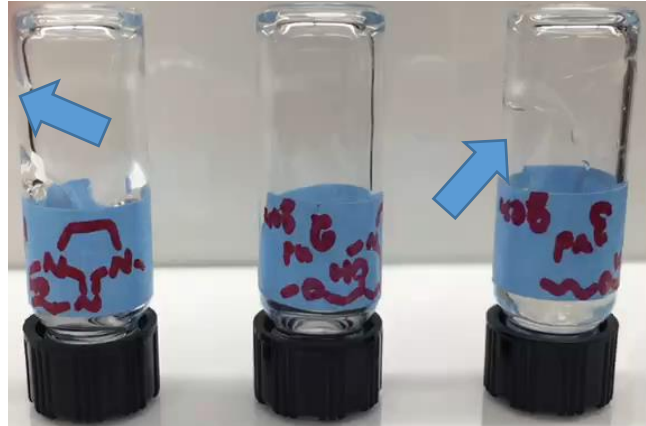


Carbon Capture.. Challenges

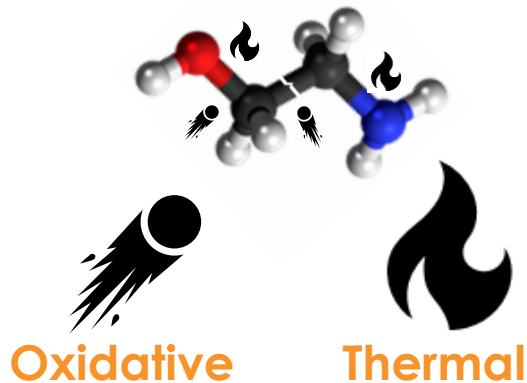
Aerosols



Viscosity



Degradation



Attrition



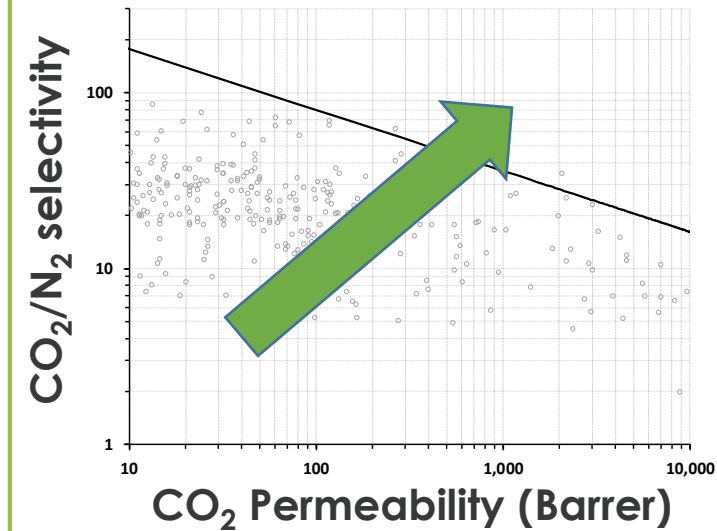
Corrosion



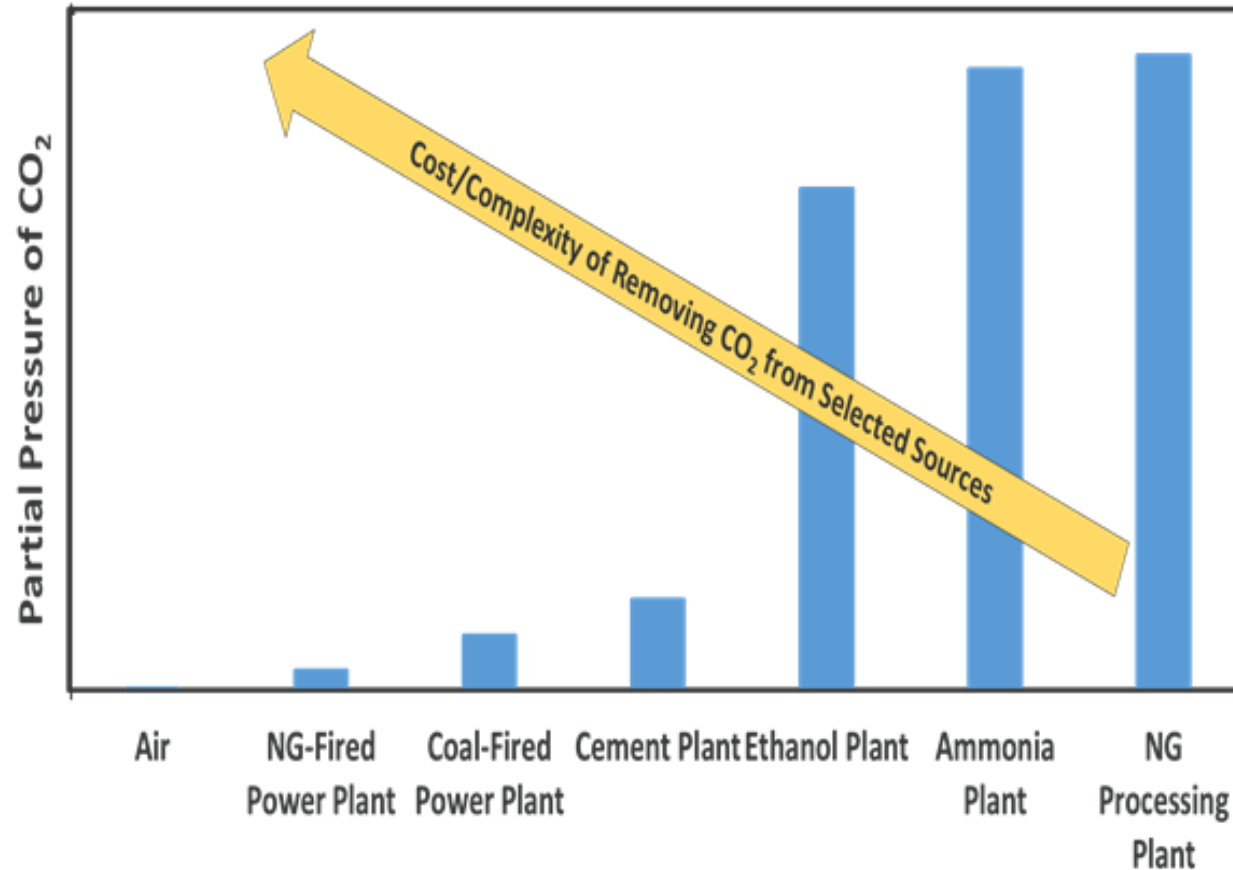
Disposal & Loss



Selectivity and Flux



Carbon Capture.. New Challenges



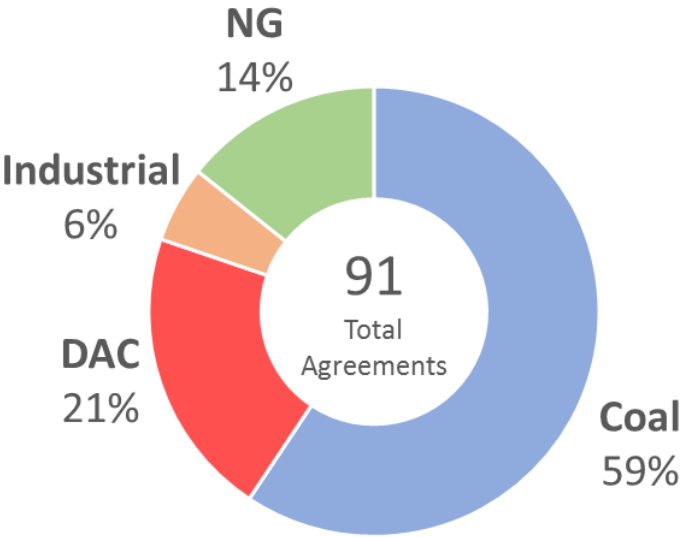
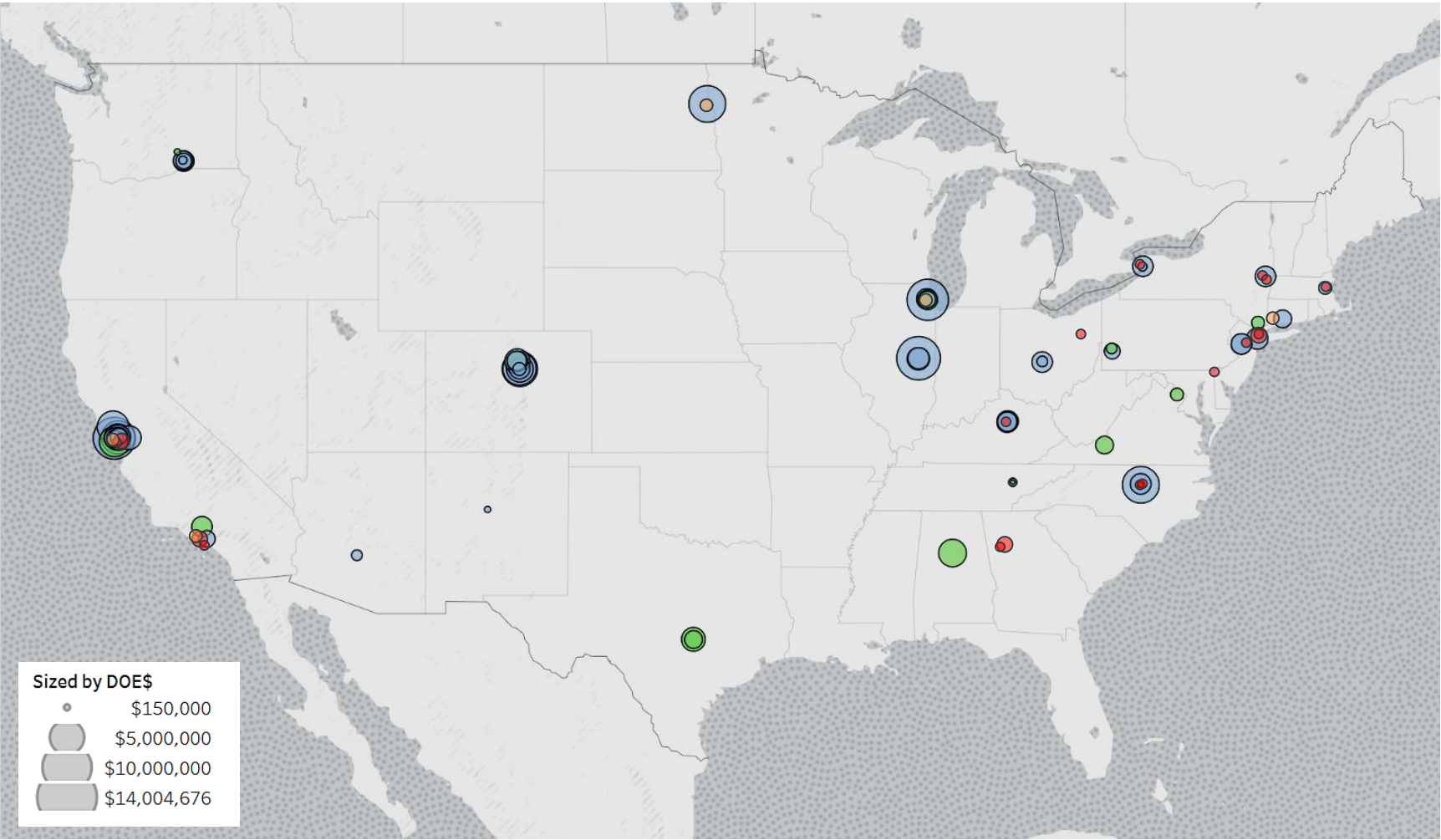
- **DAC..** Increased cost and complexity due to low CO₂
- **NGCC..** Increased oxidative degradation due to higher O₂%
- **Industrial..** Heat integration & impurities
- **Coal FIRST..** Load following operation & low utilization factors

FOAs Issued in FY19 and FY20

FOA Title/Awards	Issue Date
Front-End Engineering Design Studies for Carbon Capture Systems on Coal and Natural Gas Power Plants <ul style="list-style-type: none">• AOI 1: FEED studies for existing coal power plants (≥ 150 MWe) with CCS (TRL ≥ 6)• AOI 2: FEED studies for installing CCS (TRL ≥ 6) on new or existing domestic NGCC (375 MWe) or new PC ≥ 150 MWe)	3/13/2019
Novel Research and Development for the Direct Capture of Carbon Dioxide from the Atmosphere <ul style="list-style-type: none">• AOI 1: Lab-scale testing of <u>novel</u> materials (TRL 2) for direct air capture of CO₂• AOI 2: Field testing of <u>existing</u> materials/components (TRL4) in integrated DAC system in a relevant environment	3/30/2020
Carbon Capture R&D: Engineering Scale Testing From Coal and Natural Gas-Based Flue Gas and Initial Engineering Design for Industrial Sources <ul style="list-style-type: none">• AOI 1: Initial engineering design of technologies for CO₂ capture from industrial sources with CO₂ concentrations higher than coal-based flue gas• AOI 2: Engineering-scale testing of transformational CO₂ capture technologies (TRL 4) on actual coal-derived flue gas and/or NGCC flue gas	4/23/2020

Carbon Capture Program.. Project Distribution

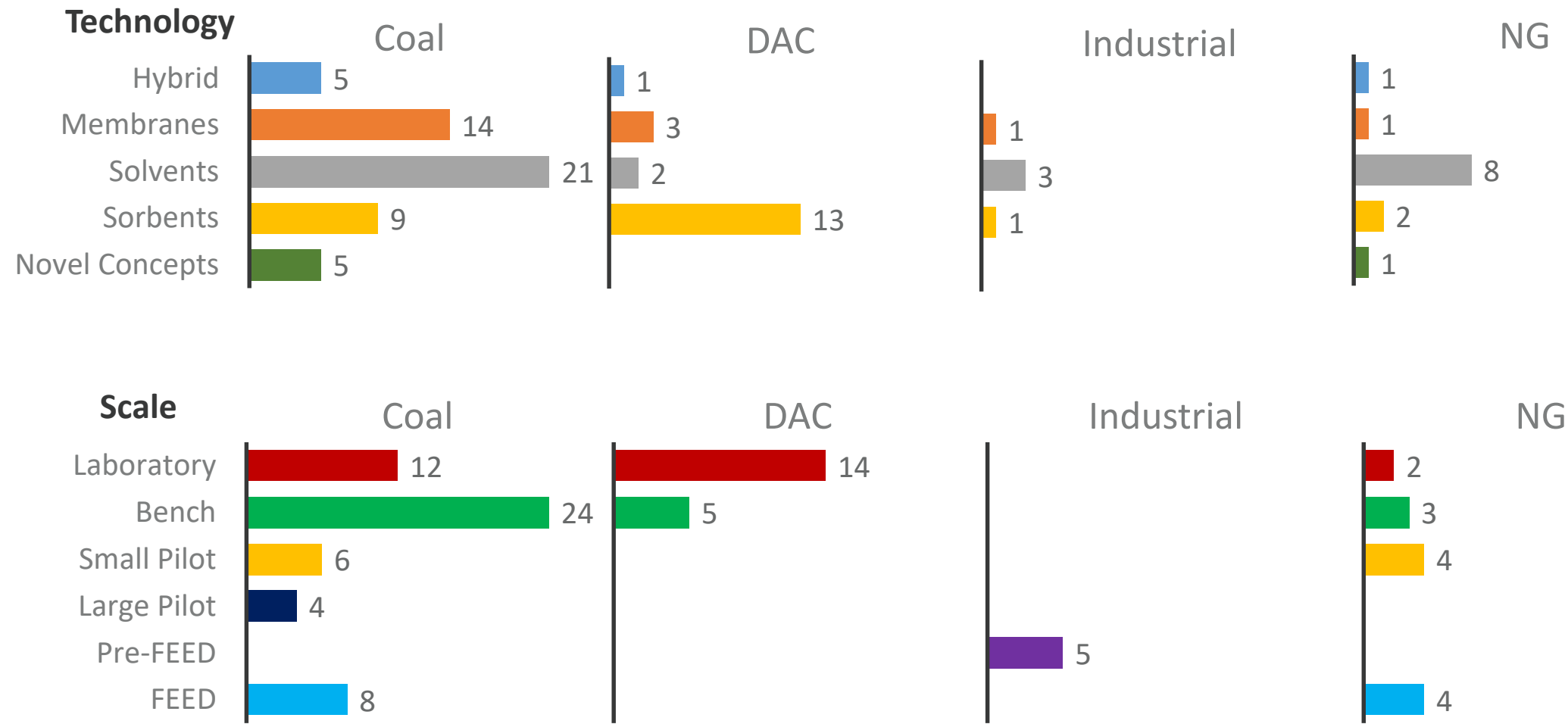
US Location – sized by DOE \$ & colored by application



Carbon Capture Program.. Technology Area



Count by technology & scale



Pre-Commercial.. Coal/NG FEEDS (TRL 6+)



DE-FOA-0002058

Closed 05/13/2019

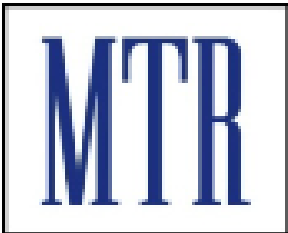
9 awards/\$54M total DOE funding

AOI 1: Retrofitting Existing, Domestic Coal Power Plants with Carbon Capture

AOI 2: Commercial-Scale Carbon Capture Units on New or Existing Domestic Gas-Fired Power Plants or New Domestic Coal Plants

I ILLINOIS

ION
ENGINEERING



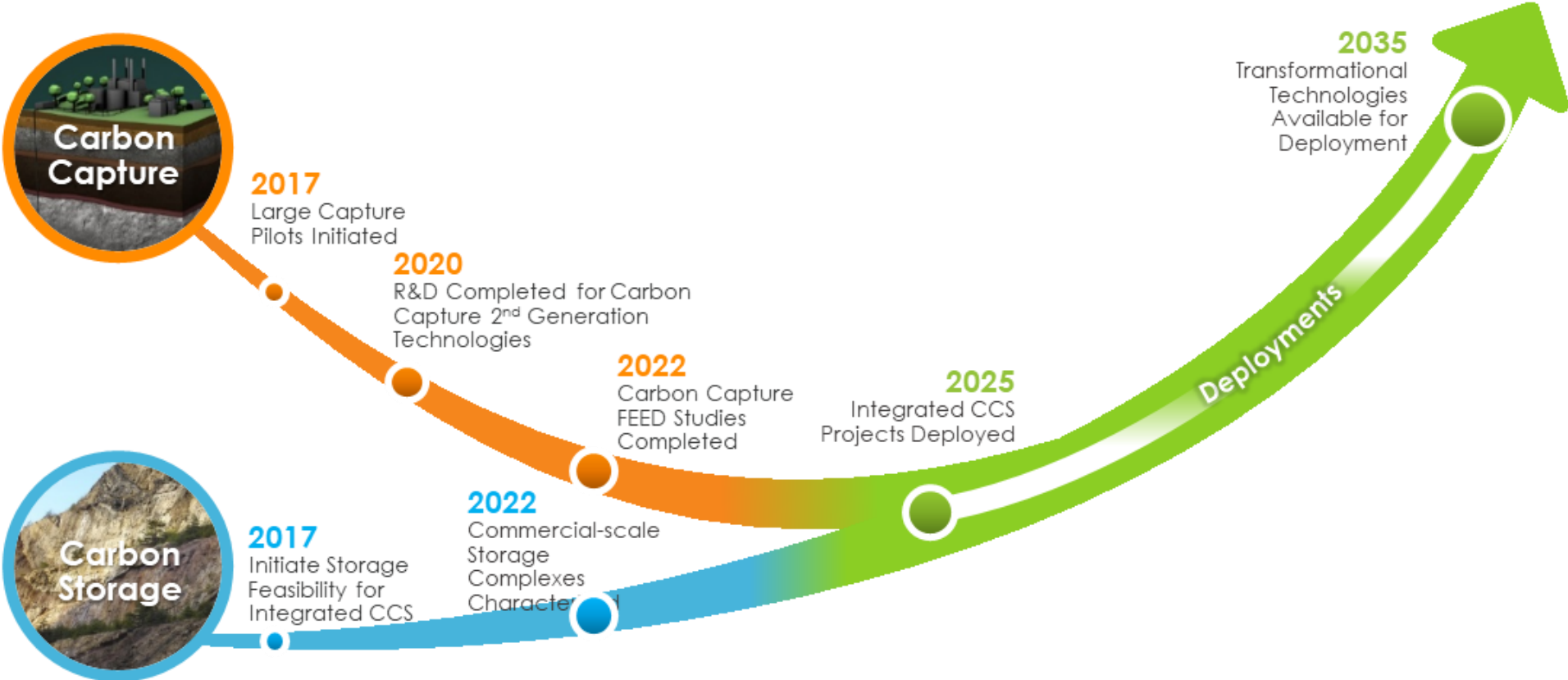
THE UNIVERSITY OF
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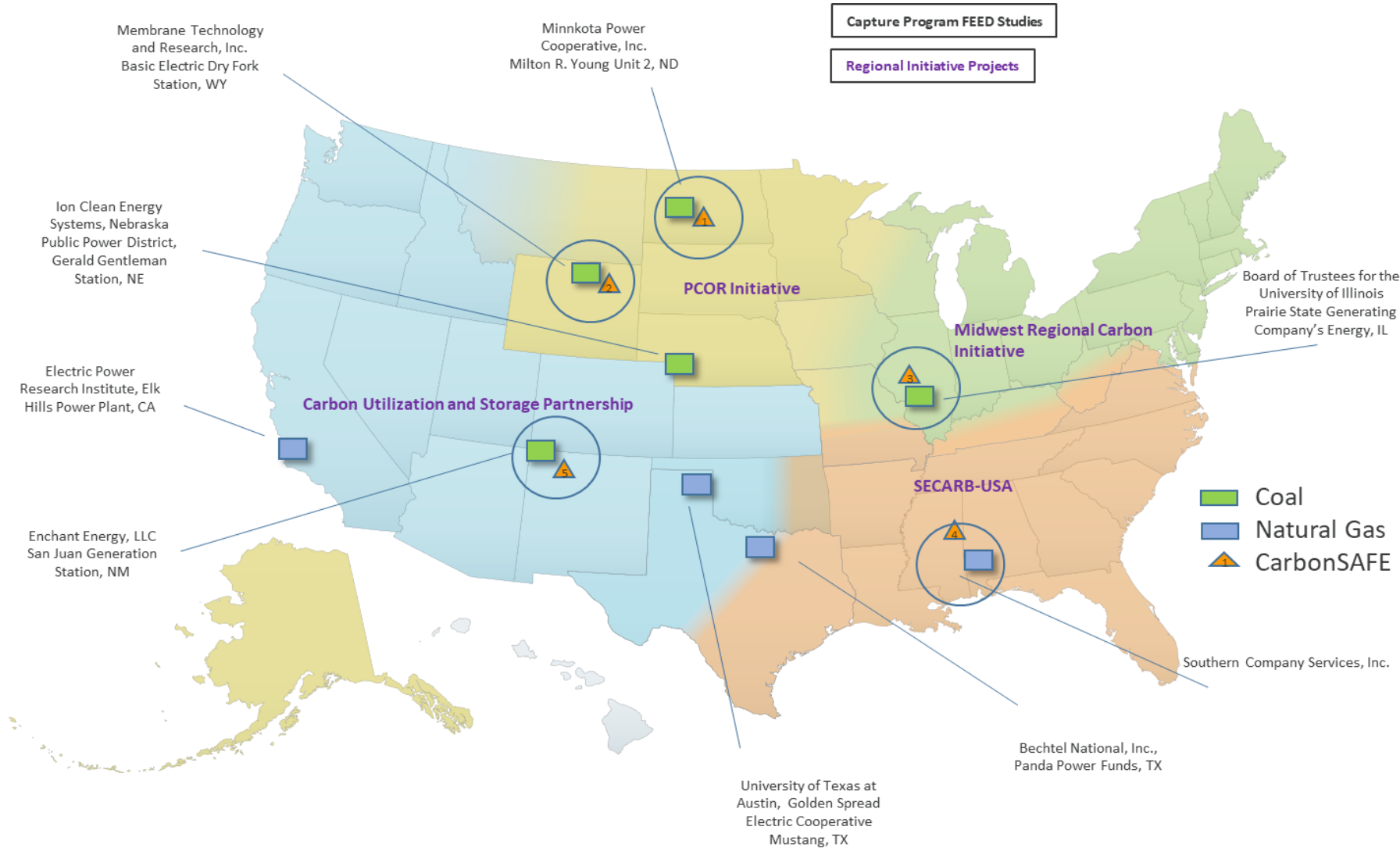
ELECTRIC POWER
RESEARCH INSTITUTE

Capture & Storage.. Timeline Integration



<https://netl.doe.gov/2020CCUS-proceedings>

Capture & Storage.. Regional Integration



2nd Generation Solvents.. Water-Lean (TRL 6)

Research Triangle Institute

Water-Lean Solvent Process



Technology Centre Mongstad (TCM)

CHALLENGE:

- Current solvent technologies: ~30% amines & ~70% water (negative energy impacts)

SOLUTION:

- Replace water (for ~5-10% total) with a hydrophobic non-aqueous solvent

SIGNIFICANT RESULTS

Techno-economic analyses indicate:

- **Reduced Capital Costs:** Smaller columns, heat exchangers, & footprint
- **Reduced Operating Costs:** Lower energy requirements



Lab/Bench Scale Development – 2009

- Proof of concept/feasibility (2009)
- Lab-scale testing (2010)
- Bench-scale testing (2014)
 - TEA ~capture cost ≤ \$40/tonne



Scale-Up Testing – 2016

- SINTEF's Tiller Plant (60 kWe).. 1500+ hrs.
- NCCC (50 kWe).. 570 hrs



Large Pilot-Scale Testing – 2018

- ~12 MWe scale testing at TCM
- Additional operational testing with RTI solvent

2nd Generation Solvents.. Flash Stripper(TRL 6)



University of Texas

Concentrated Piperazine Solvent Process



Pilot absorber/stripper system with high temperature flash skid

CHALLENGE:

- Low MEA absorption rate, working capacity, & thermal stability

SOLUTION:

- *Piperazine*.. Enhanced absorption kinetics, low degradation
- Flash stripper.. Increased working capacity & desorption pressure

SIGNIFICANT RESULTS

Techno-economic analyses indicate:

- **Reduced Capital Costs:** Smaller reactors & Reduced compression
- **Reduced Operating Costs:** Reduced solvent make-up



Lab/Bench Scale Development – 2010-2017

- Proof of concept/feasibility (2009)
- Lab-scale testing (2010)
- Bench-scale testing (2014)
 - TEA ~capture cost ≤ \$40/tonne



Small Pilot-Scale Testing – 2018

- NCCC (0.5 MWe).. 2000 hours of testing
- Validated robustness of PZ solvent & adv. flash stripper process configuration



FEED Study– 2020

- NGCC Retrofit + Piperazine Solvent + Advanced flash stripper

Transformational CCS at NCCC.. TRL 5

- 110,000+ test hours, 60+ technologies tested, Developers from 7 countries
- 16 technologies in queue to test
- 7 scaled up (or ready) to 10+ MW

• **Process intensification**

- *Advanced contactors* (GTI, RPB)
- *Combined sorbents/HX* (Altex)

• **Advanced materials**

- *Membranes..* NETL, GTI, MTR, OSU, RPI, SUNY Buffalo
- *MOF sorbents..* PCI
- *Water-lean solvents..* CCSL, ION, PNNL, RTI
- *Corrosion-resistant coating..* LumiShield

Current Programs



National Carbon Capture Center
Photo Source: Southern Company Services

<https://netl.doe.gov/events/20VPRCU>

Coal FIRST / H₂ Generation.. Critical Components



Modular Pre-combustion Capture System for Coal FIRST Poly-generation Process

Pre-combustion sulfur/contaminant removal & capture process based on integration of low temperature WGS with high temperature physical adsorbent from coal-based poly-generation system that produces power & ammonia

Relevance and Outcomes/Impact

- Improve process efficiency by 3% by selectively removing CO₂ & trace contaminants
- Improves overall efficiency (net efficiency >40% on HHV basis) by reducing amount of water needed to shift equilibrium-limited reaction



Media and Process Technology Inc.

Advanced Ceramic Membranes/Modules for H₂ Production/CO₂ Capture for Coal-Based Polygeneration Plants

Extend current multiple tube “candle filter” membrane configuration to dual end (open both ends) design for use as a permeate purgeable support for inorganic membranes in pre-combustion CO₂ capture & poly-generation



Commercial dual end tubular ceramic membrane modules

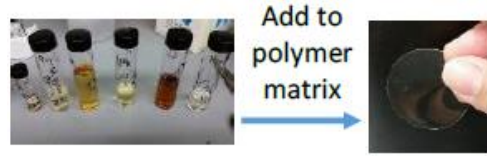
Relevance and Outcomes/Impact

- Microporous ceramic membranes are low cost, stable material for high temperature applications in harsh environments
- Development of inorganic membrane with “permeate purge” capability offers a breakthrough for scale-up & commercialization of inorganic membrane technology

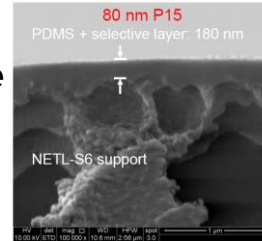
Transformational CCS at NETL.. TRL 3-4

Natural Gas Flue Gas/Industrial Capture

Facilitated Transport Ion Gel Membrane



High Permeance
Supports for Thin
Film Composites



Amine functionalized PIM polymer sorbent



CO₂ Capture for Modular Scale Gasification

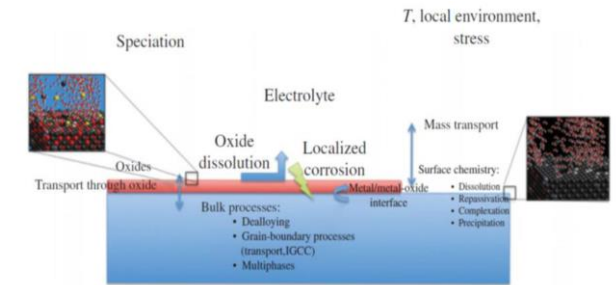


Modular CO₂ Capture Processes for Integration with
Modular Scale Gasification Technologies: Literature
Review & Gap Analysis for Future R&D

Authors
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² Carbon Capture Scientific

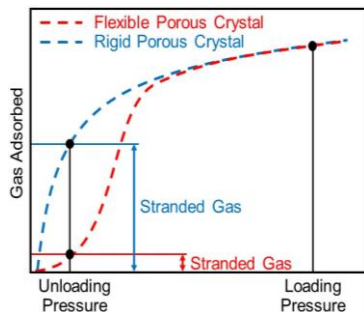
Blue H₂ / Pre-combustion

Corrosion of Steel in Pre-Combustion CO₂ Capture Absorption Equipment

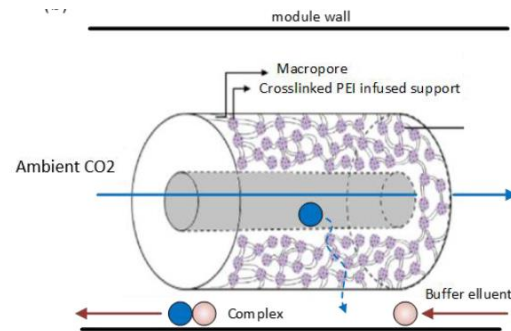


Direct Air Capture

Computational Screening of Sorbents for DAC

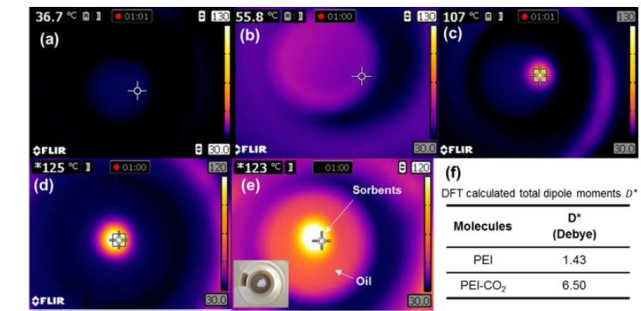
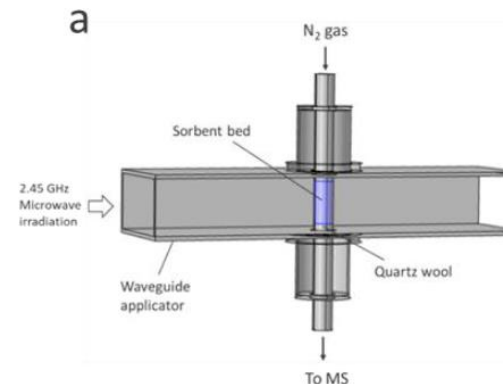


Hollow Fiber BIAS Sorbent for DAC



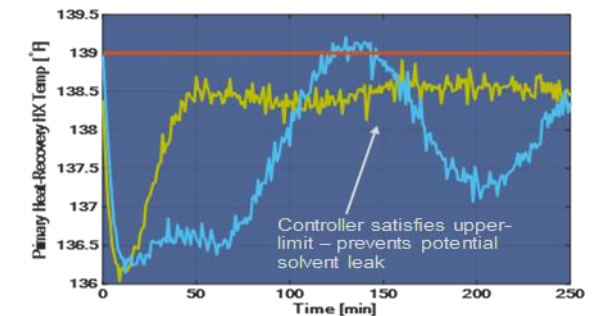
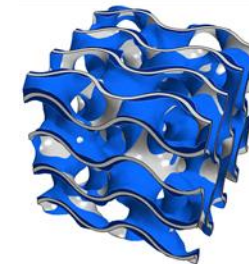
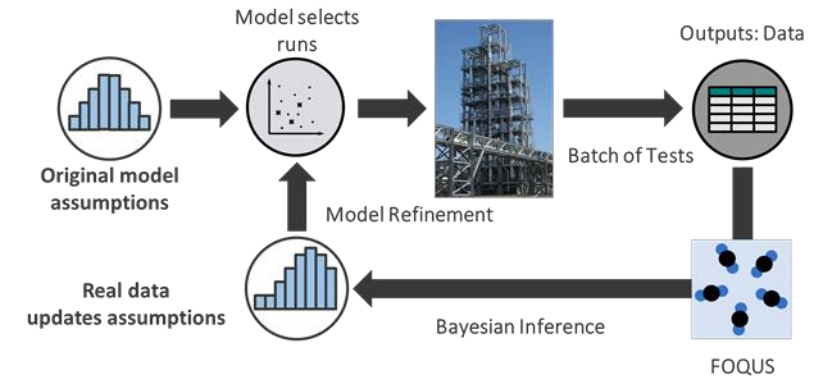
Coal FIRST

Microwave Assisted Sorbent Regeneration for Modular Scale CO₂ Capture



Enabling Capabilities.. CCSI²

Technology Area	Primary Objectives	CCSI ² Expertise
Direct Air Capture	Equipment/Materials design and Intensification; Pilot testing	<i>Machine Learning; Sorbent modeling; CFD/Equipment Design; Design of Experiments</i>
Industrial Capture	Optimize CCS integration; Process Intensification	<i>Process Optimization; CCS modeling; Equipment Design</i>
Blue H₂	Process Intensification & Optimization; Process Intensification	<i>Membrane/Sorbent/Reaction Modeling; Optimization; Multi-functional Equipment Design</i>
Coal FIRST	CCS load following; Process Intensification	<i>Dynamic/CCS Modeling; Polygen Optimization; Equipment Design</i>



Design of Advanced Energy Systems (IDAES)/Carbon Capture Simulation for Industry Impact (CCSI²) Stakeholder Workshop, Oct. 1-22 2020

https://lbln.zoom.us/webinar/register/WN_T9X0KwA5RkGSPYUbKVGQWg

Enabling Capabilities.. TEA & LCA

Historical Analysis Areas

Coal & Natural Gas for Power

- Baseline (Rev 2, 3)
- LCA
- Retrofit Studies
- Retrofit Databases
- Membrane, Solvent, Sorbent Evaluations

Current Analysis Topics

Coal and Natural Gas

- Baseline (Rev 4)
- NGCC with EGR Study Update
- Flexible Operation
- Dispatch models

Negative Emissions Technologies

- BECCS TEA and LCA
- Direct Air Capture Base Cases

Industrial Capture

- Development of Cement Specific Study
- Hydrogen Production
- LCA

Carbon Capture Program.. Outreach



Carbon Capture Newsletter



Carbon Capture Program R&D Compendium



Carbon Capture Program Website

CONCLUSIONS

- **Carbon Capture needs to be nimble..** Low CO₂ concentrations & Low capacity factors
 - FE technology portfolio is being leveraged for NETS, NGCC, and Industrial
 - Need transformational carbon capture systems to support Coal FIRST (polygen, load following capabilities)
- **Many advances in CAPEx & OpEx reduction...**
 - Recent advances in simulation, materials & additive manufacturing can decrease the overall cost of capture
- **LCAs and TEAs remain critical evaluation tools..**
 - Need to validate dynamic models with pilot data; start evaluating CCS within capacity expansion models
- **Carbon Capture/Utilization/Storage integration** across DOE and international programs is critical

Questions

<http://www.netl.doe.gov/research/coal/carbon-capture>

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