Carbon Capture Program Overview

Carbon Capture Annual Project Review
October 5, 2020

NATIONAL ENERGY TECHNOLOGY LABORATORY

Dan Hancu
Carbon Capture Technology Manager
National Energy Technology Laboratory

Acknowledgements

- **NETL**
  - NETL Research: David Hopkinson
  - CCSI^2: 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
  - NETL Site Support: Lynn Manfredo

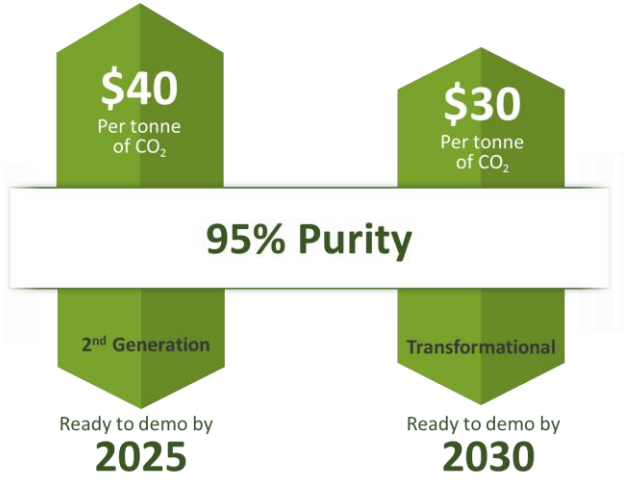
- **FE HQ**
  - Division Director: Mark Ackiewicz
  - Program Manager: Lynn Brickett

Carbon Capture Program.. Mission

- **Mission**
  - Develop advanced cost-effect CO_2 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 CO_2 emissions
  - Reduce CO_2 capital & operating costs
  - Increase efficiency & reduce cost of CO_2 compression

- **Goal & Metrics**
  - By 2030, COE at least 30% lower than a supercritical PC with CO_2 capture



National Carbon Capture Center

Photo Source: Southern Company Services

Carbon Capture Program.. Evolution

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1st and 2nd Generation Technologies

2025: $40/tonne CO_2

Petra Nova

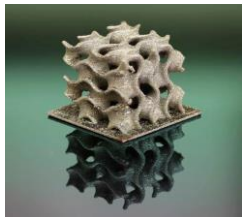
2008 -

- ✓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

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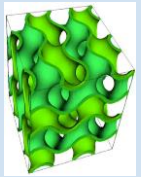
Lab & Bench

TRL 2-4



Testing novel materials & processes with simulated exhaust

University at Buffalo · Liquid Ion Solutions · Arizona State University · NETL · Los Alamos National Laboratory · Berkeley Lab

Oak Ridge National Laboratory · Lawrence Livermore National Laboratory

Additive Manufacturing

Small Pilots

TRL 4-5

Bench- and Pilot- scale technology testing with real flue gas (NG and coal)

Center for Applied Energy Research · The University of Texas at Austin · gti · TDA Research

Large Pilots

TRL 6-7

Scaling to engineering scale using existing host site Infrastructure

ION Engineering · MTR · RTI International

Process modeling, TEA and LCA

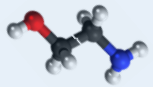
CCSI² Carbon Capture Simulation for Industry Impact · NETL

FEED Studies

TRL 8-9

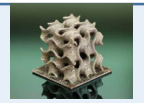
New and Retrofit Coal and NG Plants

Bechtel · The University of Texas at Austin · ION Engineering · Southern Company · MTR · Minnkota Power Cooperative · EPRI Electric Power Research Institute · Enchant Energy · University of Illinois


Solvents


Sorbents


Membranes


Novel Concepts

Post-combustion

Pre-combustion

Carbon Capture.. Challenges

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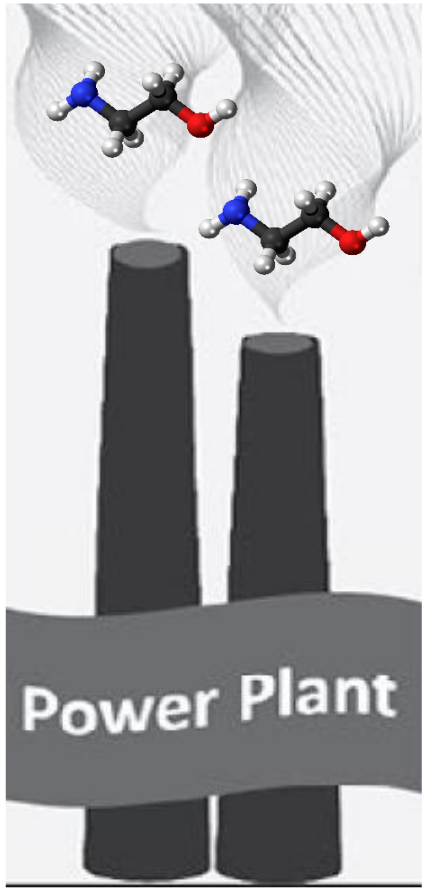
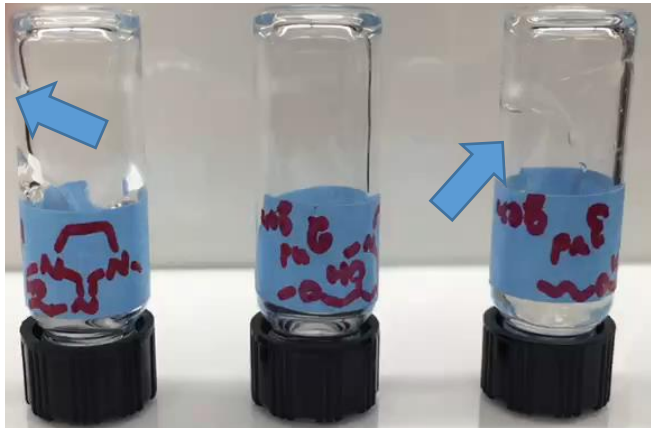
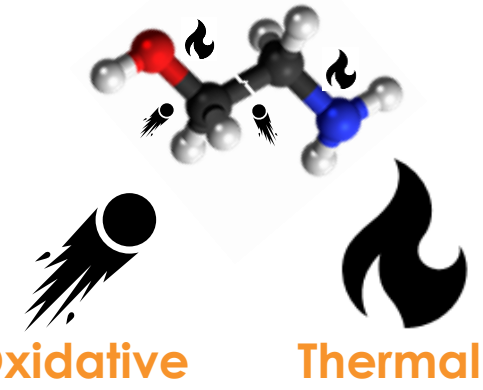
Aerosols



Viscosity



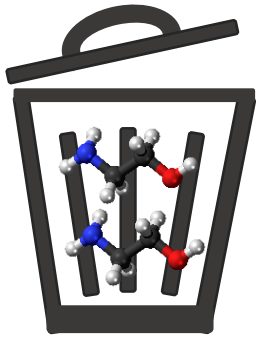
Degradation



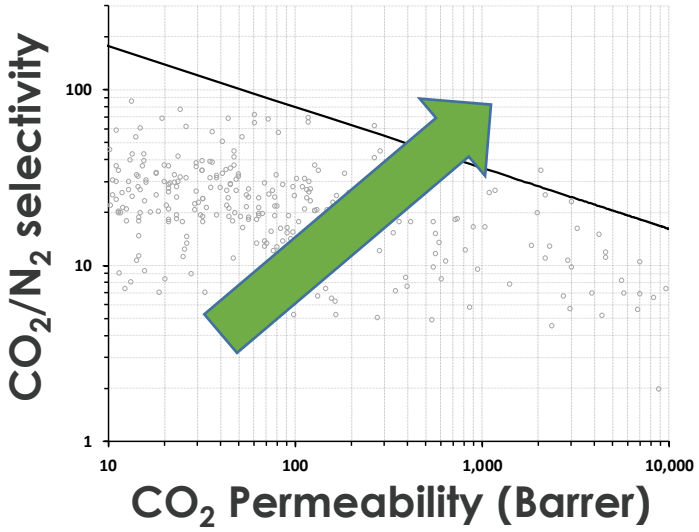
Attrition

Corrosion

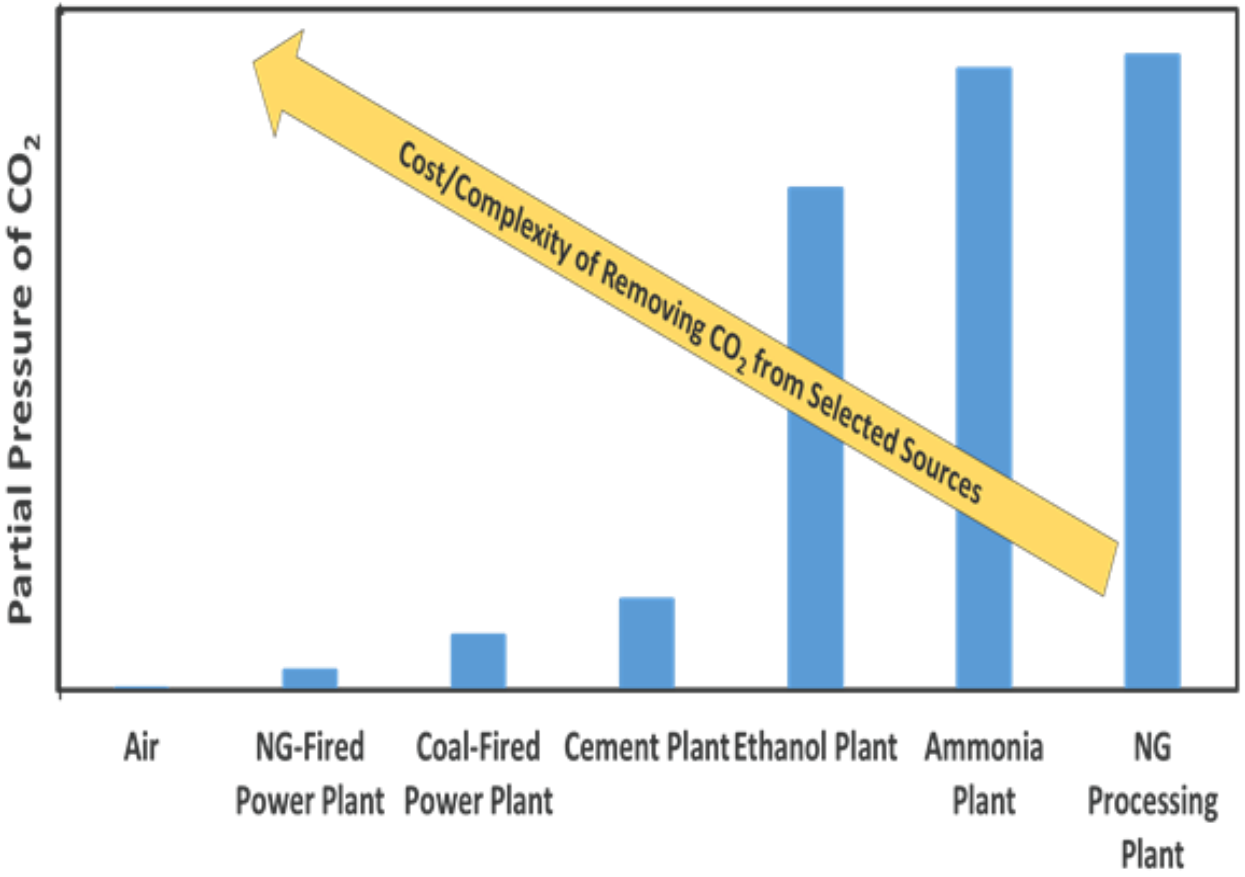
Disposal & Loss



Selectivity and Flux



Carbon Capture.. New Challenges



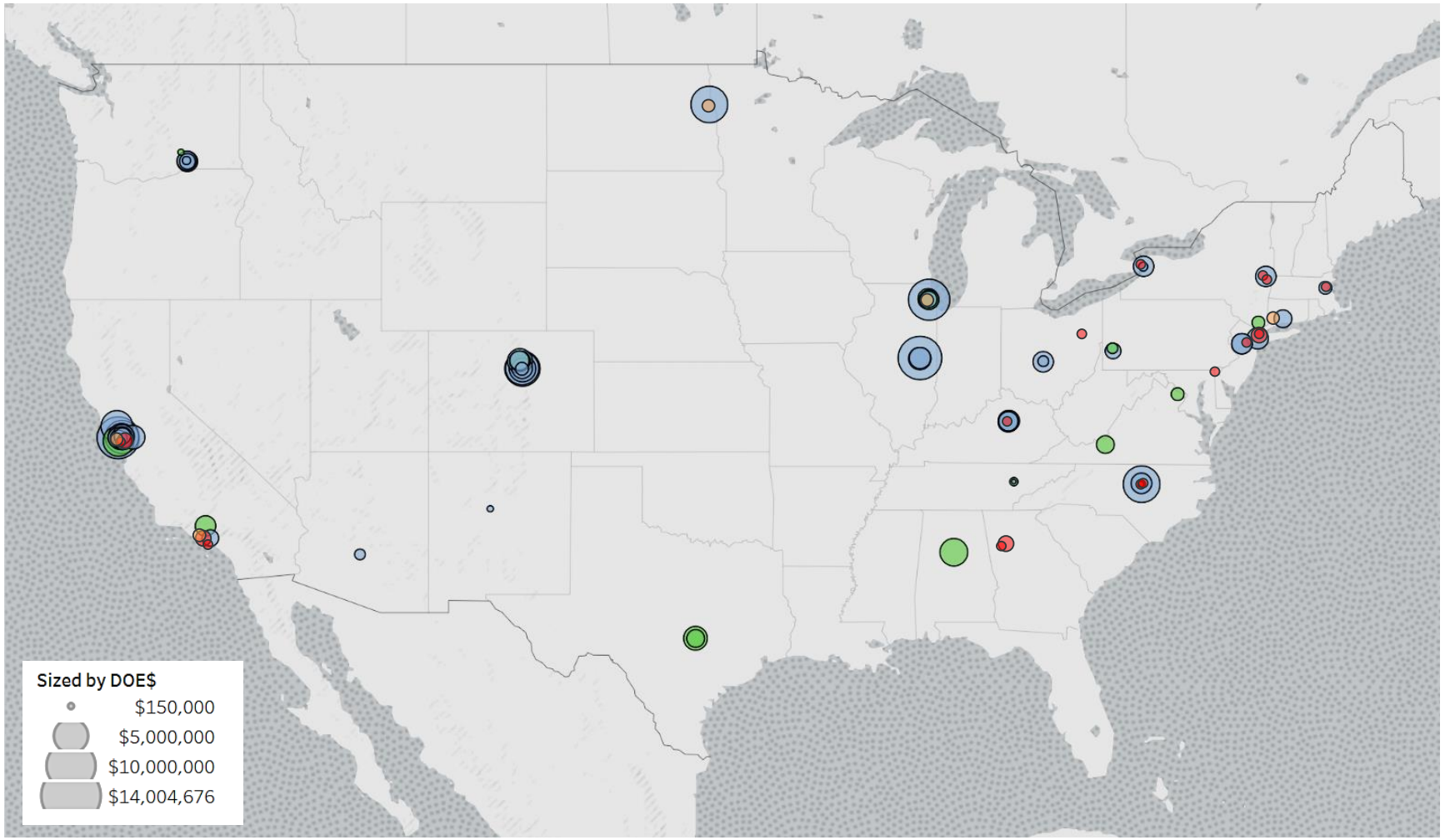
- **DAC**.. Increased cost and complexity due to low CO_2
- **NGCC**.. Increased oxidative degradation due to higher O_2%
- **Industrial**.. Heat integration & impurities
- **Coal FIRST**.. Load following operation & low utilization factors

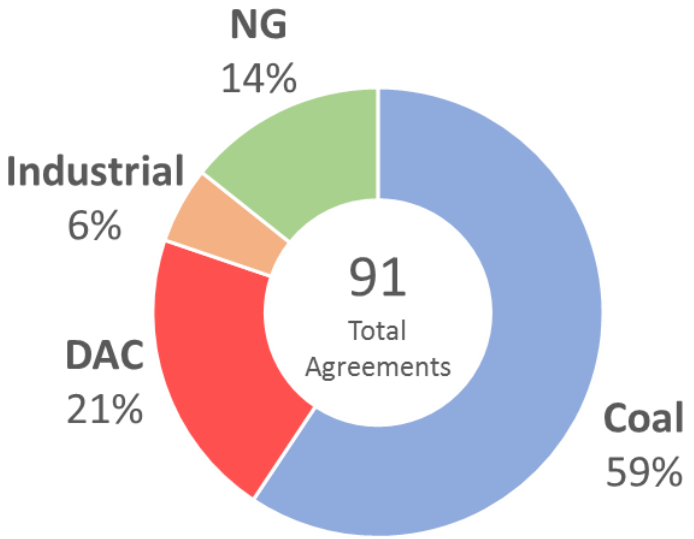
FOAs Issued in FY19 and FY20

FOA Title/Awards	Issue Date
Front-End Engineering Design Studies for Carbon Capture Systems on Coal and Natural Gas Power Plants • 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 • AOI 1: Lab-scale testing of novel materials (TRL 2) for direct air capture of CO_2 • AOI 2: Field testing of existing 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 • AOI 1: Initial engineering design of technologies for CO_2 capture from industrial sources with CO_2 concentrations higher than coal-based flue gas • AOI 2: Engineering-scale testing of transformational CO_2 capture technologies (TRL 4) on actual coal-derived flue gas and/or NGCC flue gas	4/23/2020

Carbon Capture Program.. Project Distribution

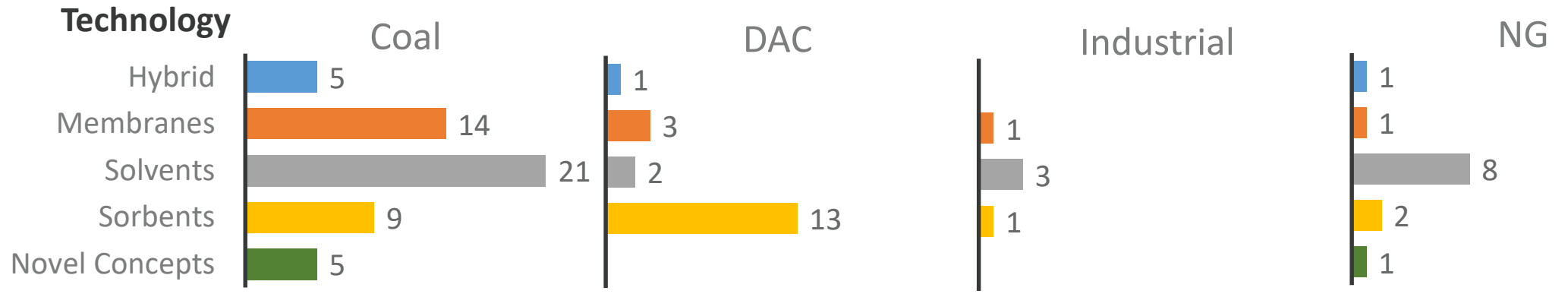
US Location – sized by DOE $ & colored by application

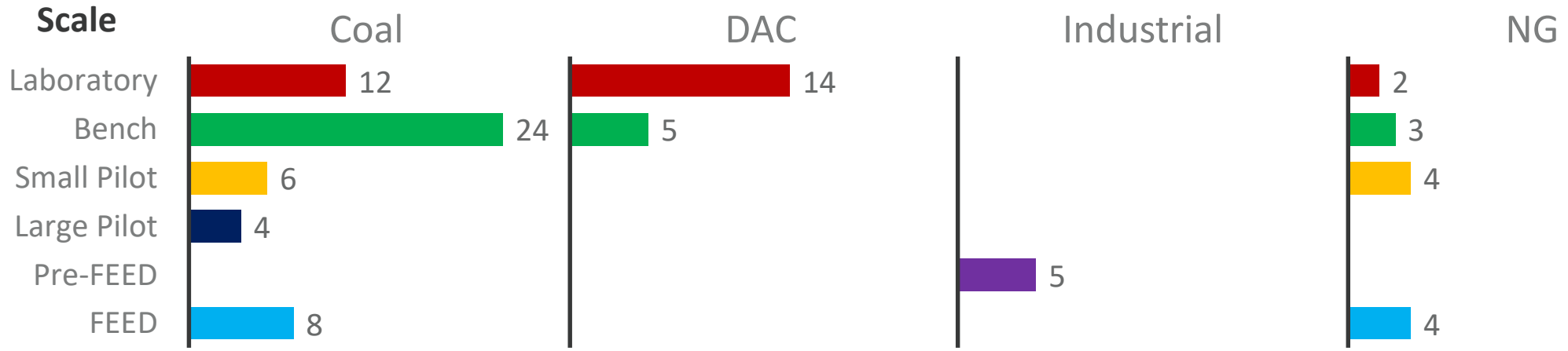




Carbon Capture Program.. Technology Area

Count by technology & scale





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

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DE-FOA-0002058 **Closed 05/13/2019** **9 awards/$54M total DOE funding**

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

ILLINOIS

ION ENGINEERING

MTR

ENCHANT ENERGY CORPORATION

Minnkota Power COOPERATIVE
A Touchstone Energy® Cooperative

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

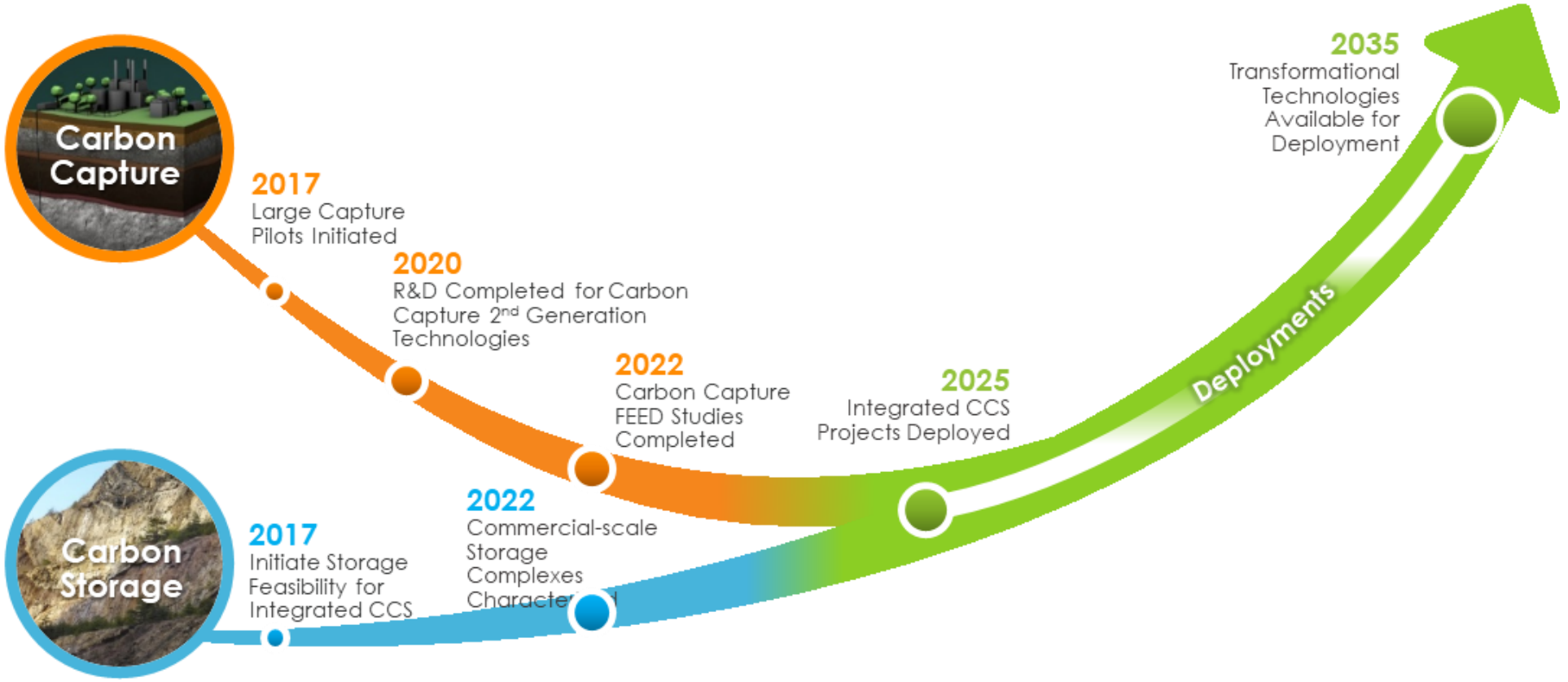
BECHTEL

Southern Company

THE UNIVERSITY OF TEXAS AT AUSTIN

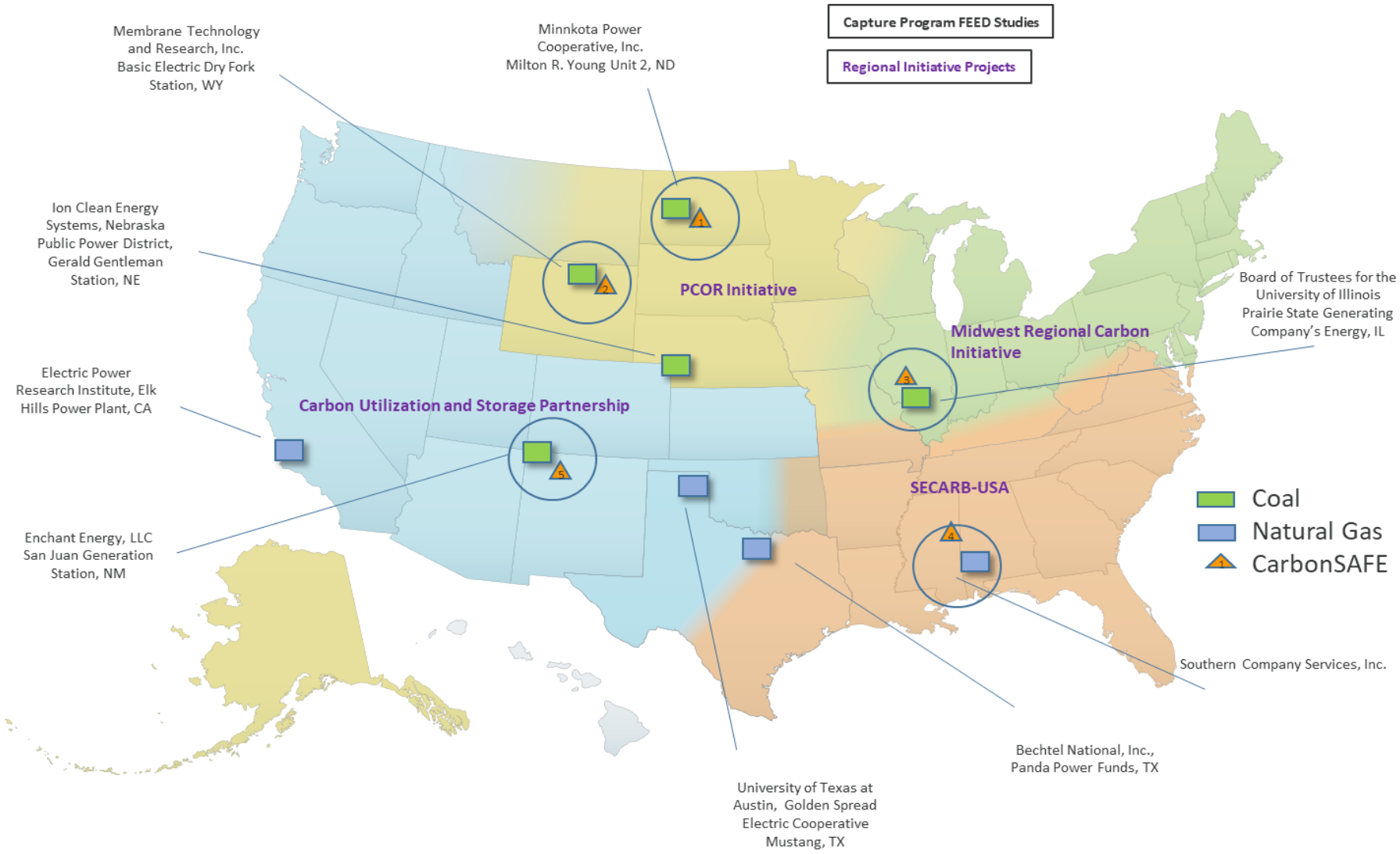
EPRI ELECTRIC POWER RESEARCH INSTITUTE

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)

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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

Current Programs

- **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

National Carbon Capture Center
Photo Source: Southern Company Services

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

Coal FIRST / H_2 Generation.. Critical Components

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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 CO_2 & 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 H_2 Production/CO_2 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 CO_2 capture & poly-generation

Commercial dual end tubular ceramic membrane modules

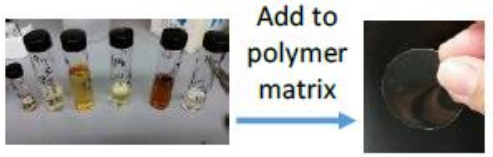
Relevance and Outcomes/Impact

- 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

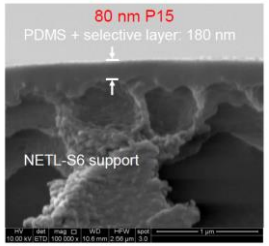
Transformational CCS at NETL.. TRL 3-4

Natural Gas Flue Gas/Industrial Capture

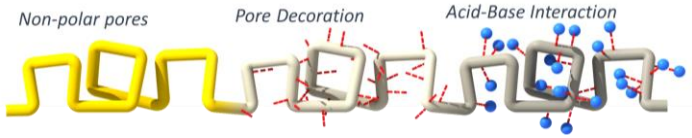
Facilitated Transport Ion Gel Membrane



High Permeance Supports for Thin Film Composites



Amine functionalized PIM polymer sorbent



Blue H_2 / Pre-combustion

CO_2 Capture for Modular Scale Gasification

NATIONAL ENERGY TECHNOLOGY LABORATORY

Modular CO_2 Capture Processes for Integration with Modular Scale Gasification Technologies: Literature Review & Gap Analysis for Future R&D

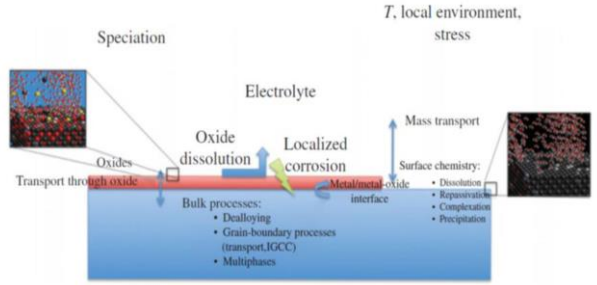
Authors

Kathryn Smith[2], Scott Chen[2], Nicholas Siefert[1]

[1] U.S. DOE National Energy Technology Laboratory

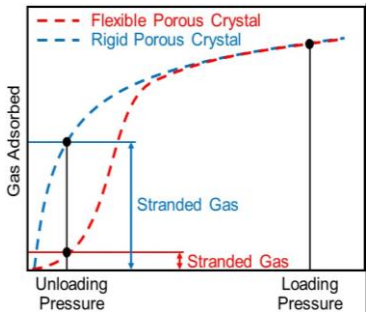
[2] Carbon Capture Scientific

Corrosion of Steel in Pre-Combustion CO_2 Capture Absorption Equipment

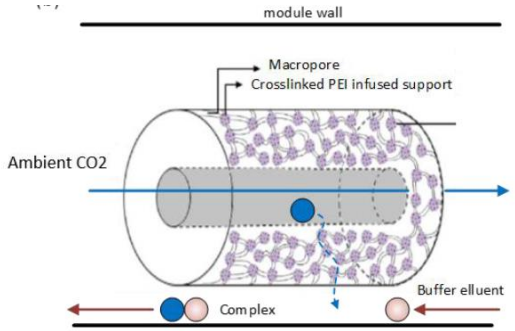


Direct Air Capture

Computational Screening of Sorbents for DAC

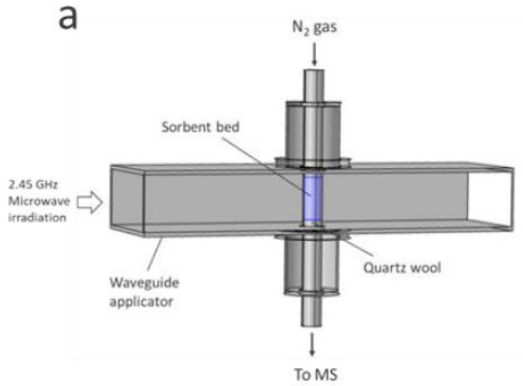


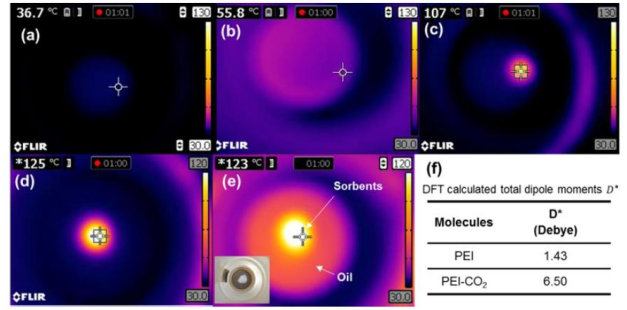
Hollow Fiber BIAS Sorbent for DAC



Coal FIRST

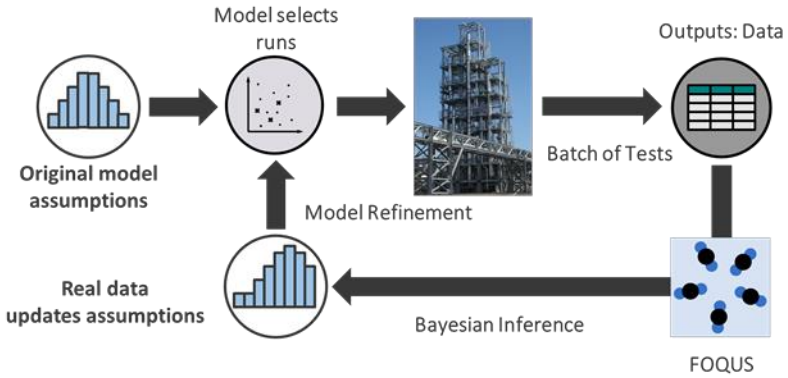
Microwave Assisted Sorbent Regeneration for Modular Scale CO_2 Capture

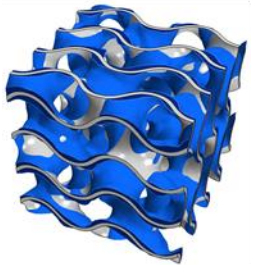


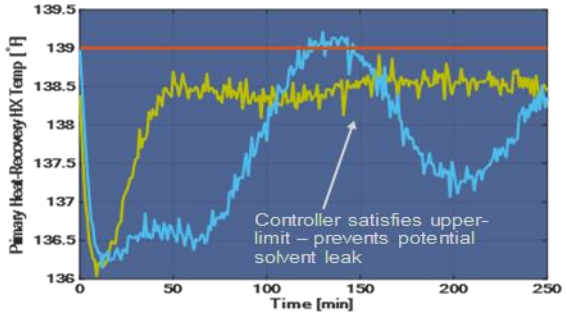


Enabling Capabilities.. CCSI²

Technology Area	Primary Objectives	CCSI² Expertise
Direct Air Capture	Equipment/Materials design and Intensification; Pilot testing	*Machine Learning; Sorbent modeling; CFD/Equipment Design; Design of Experiments*
Industrial Capture	Optimize CCS integration; Process Intensification	*Process Optimization; CCS modeling; Equipment Design*
Blue H_2	Process Intensification & Optimization; Process Intensification	*Membrane/Sorbent/Reaction Modeling; Optimization; Multi-functional Equipment Design*
Coal FIRST	CCS load following; Process Intensification	*Dynamic/CCS Modeling; Polygen Optimization; Equipment Design*







Design of Advanced Energy Systems (IDAES)/Carbon Capture Simulation for Industry Impact (CCSI2) Stakeholder Workshop, Oct. 1-22 2020
https://lbnl.zoom.us/webinar/register/WN_T9X0KwA5RkGSPYUbKVGQWg

Enabling Capabilities.. TEA & LCA

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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 CO_2 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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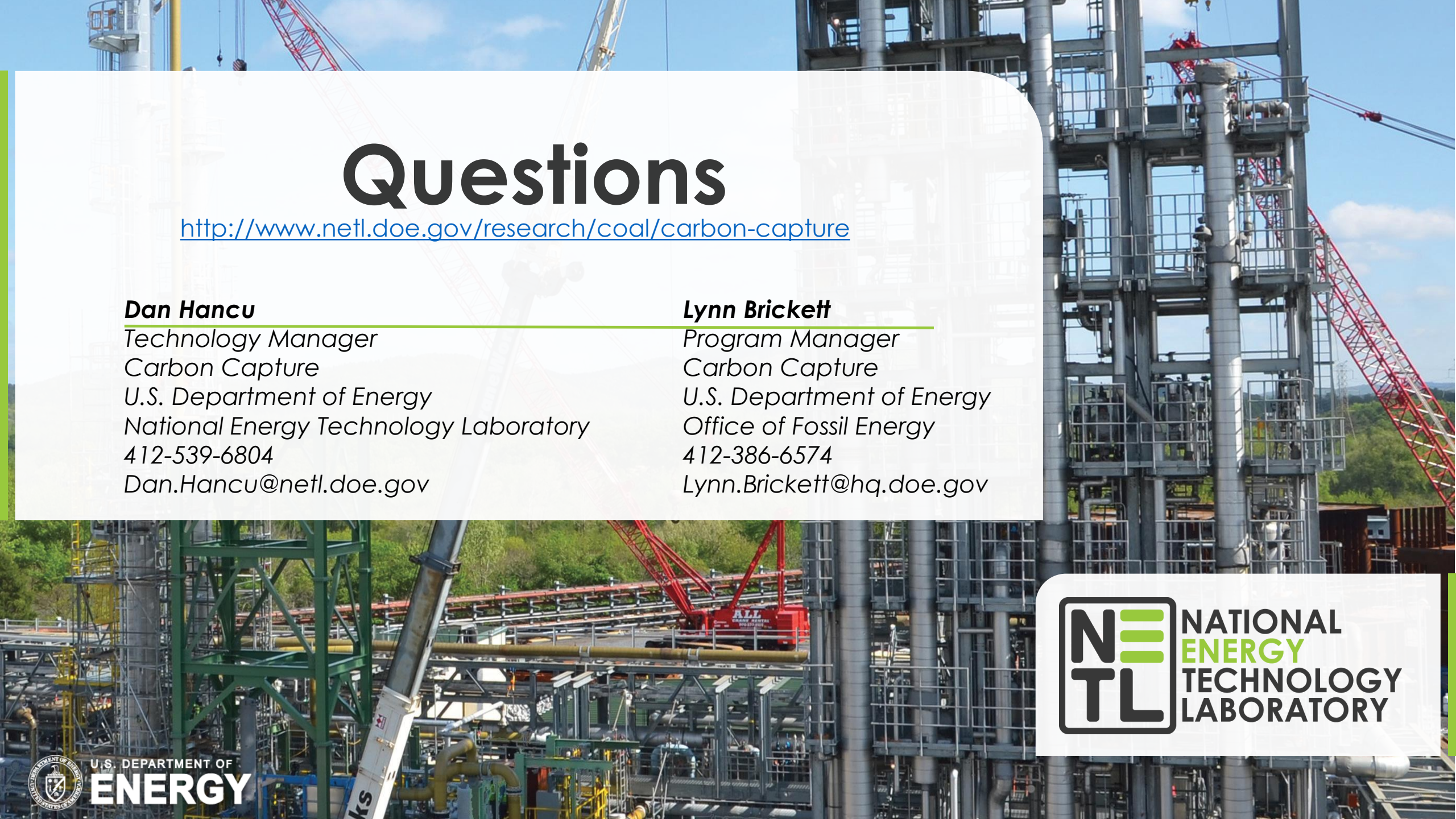

U.S. DEPARTMENT OF ENERGY

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