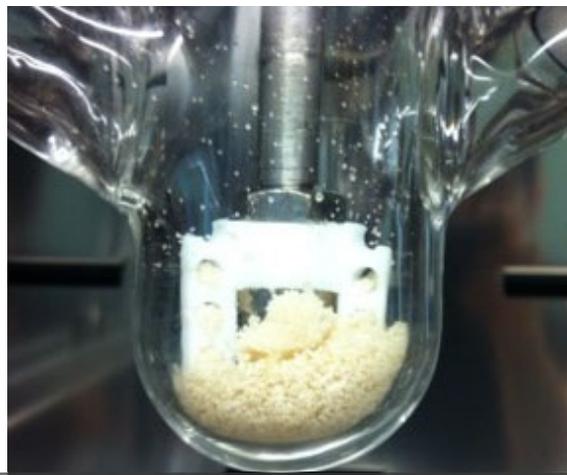




Solutions for Today | Options for Tomorrow



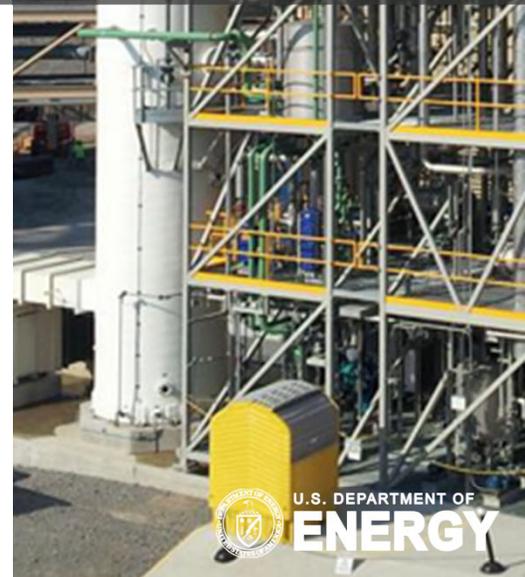
US DOE/NETL Point Source Carbon Capture Program



Industrial Processes Emissions Reduction Technology Workshop
March 2, 2023



Ron Munson
Point Source Carbon Capture
Technology Manager
National Energy Technology Laboratory



Point Source Capture Program...Mission



• Mission

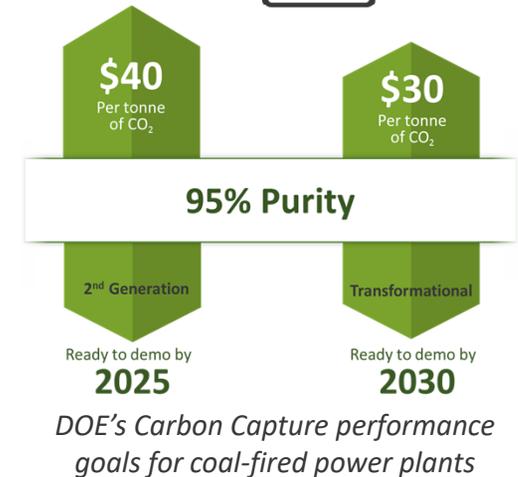
- Develop advanced cost-effective CO₂ capture technologies throughout the power-generation and industrial sectors
- Ensure the U.S. will continue to have access to safe, reliable, & affordable low-carbon energy generation

• Drivers/Challenges

- Reduce carbon capture CAPEX/OPEX under a wide range of feed conditions and high capture efficiencies
- Demonstrate first-of-a-kind carbon capture on power and industrial sectors coupled to dedicated and reliable carbon storage, that will lead to commercially viable nth-of-a-kind opportunities for widescale deployment

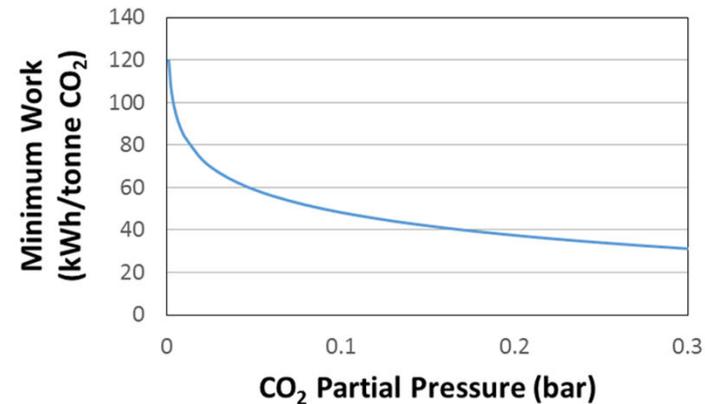
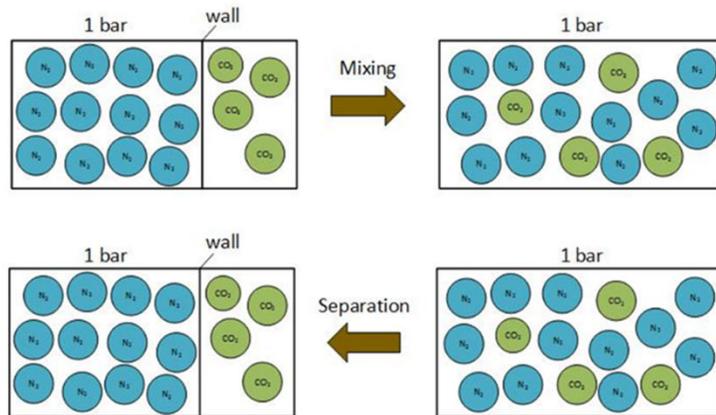
• Goal & Metrics

- Support U.S goal to achieve carbon pollution-free power sector by 2035 and zero-carbon economy by 2050 (facilitated by an interim goal of achieving 50% reductions by 2030)

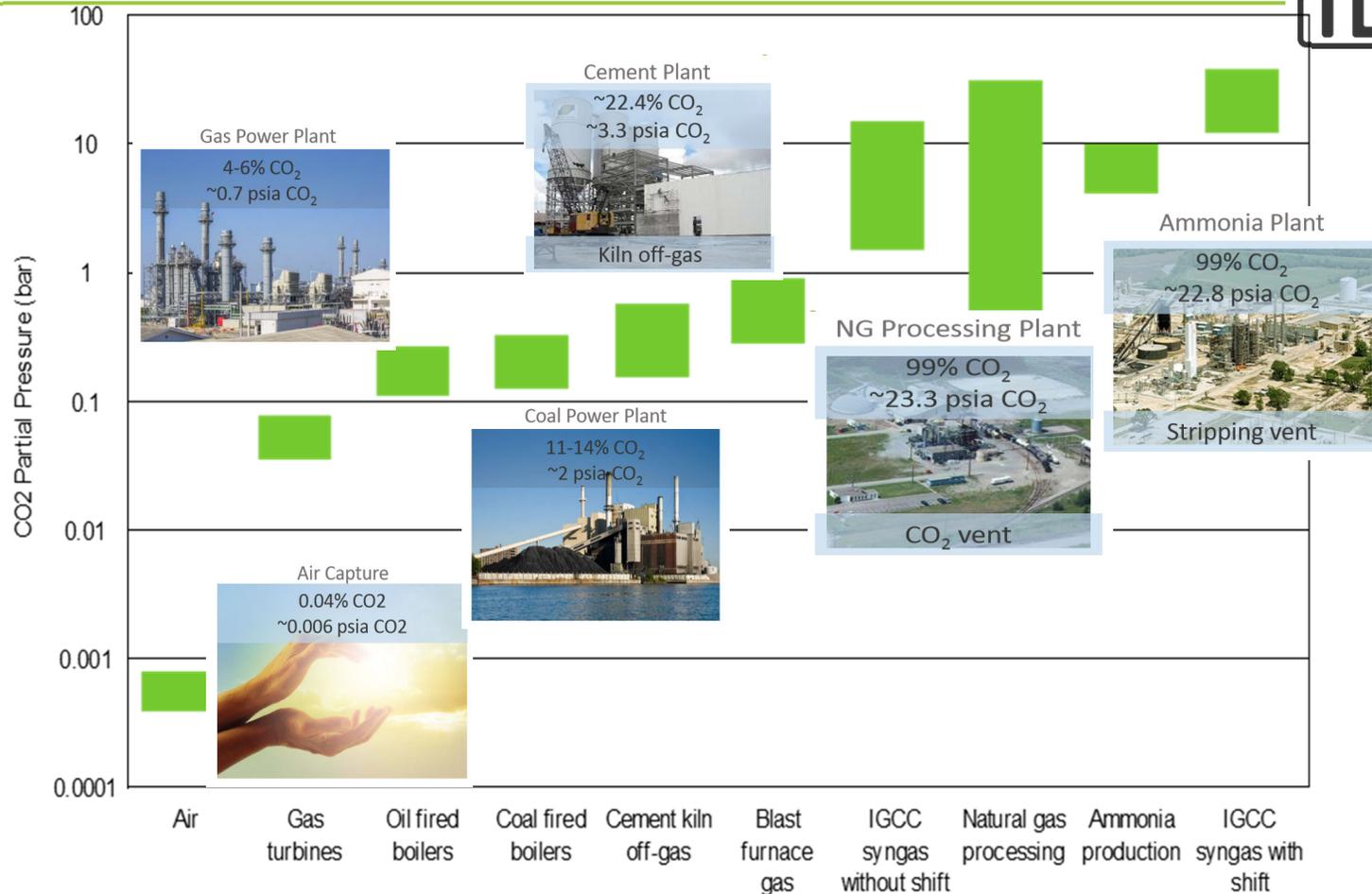


Carbon Capture Definition

Separation of the CO_2 from a gas stream produced in a power station or an industrial process to obtain pure CO_2 for geological storage or further use



CO₂ Concentrations: Select Sources



Carbon Capture Program.. Evolution

1st and 2nd Generation Technologies

2025: \$40/tonne CO₂



2008 -

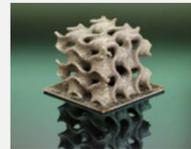
- ✓ Lower CAPEX/OPEX
- ✓ Reduced regeneration energy
- ✓ Increased working capacity

Transformational Technologies

2030: \$30/tonne CO₂



Hollow Fibers



3D Print



Biphase Solvent

2015 -

- ✓ Water Lean Solvents
- ✓ Adv. Membranes
- ✓ Hybrid Systems
- ✓ Process Intensification

Scale-up



TCM

2018 -

- ✓ Engineering Scale testing
- ✓ FEED studies

Negative Emissions Technologies & Industrial



Carbon Engineering, DAC

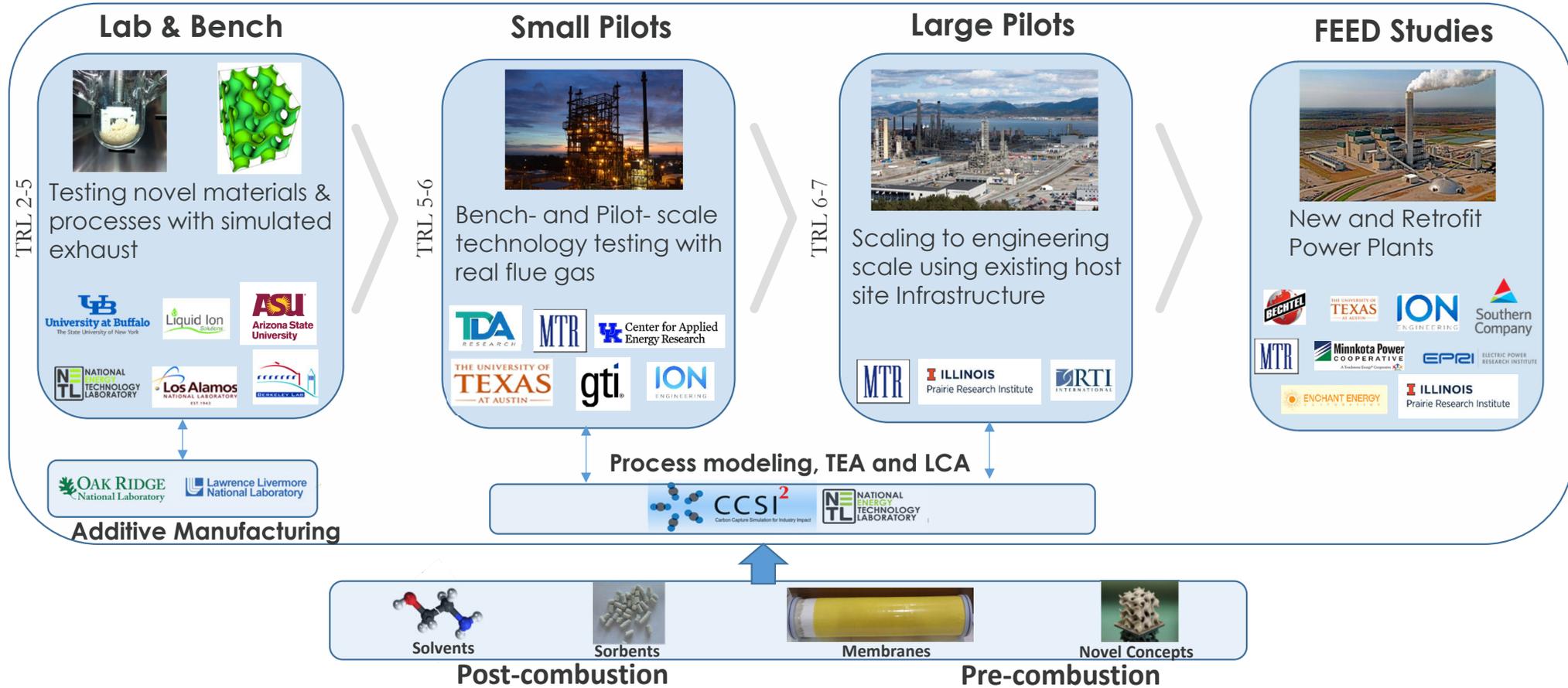


Ethanol Plant

2020 -

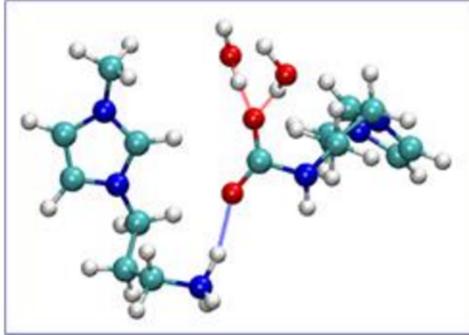
- ✓ DAC & BECCS
- ✓ Industrial
- ✓ NG

Carbon Capture.. Program Structure



Carbon Capture Approaches

Solvents



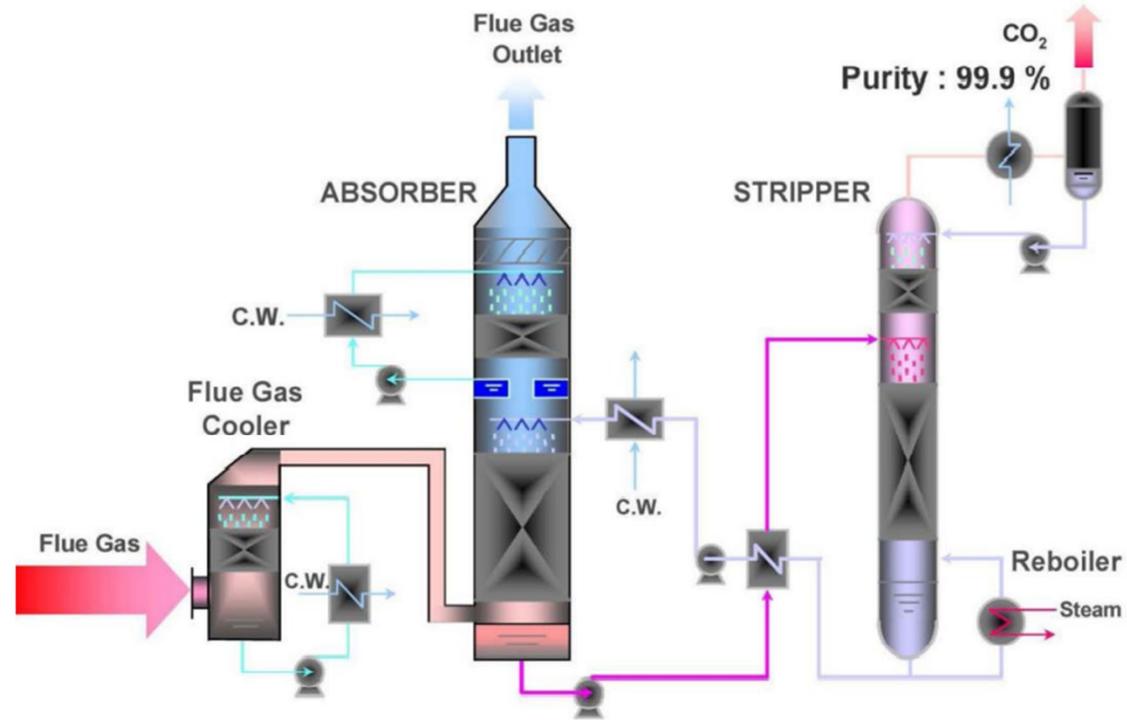
Sorbents



Membranes



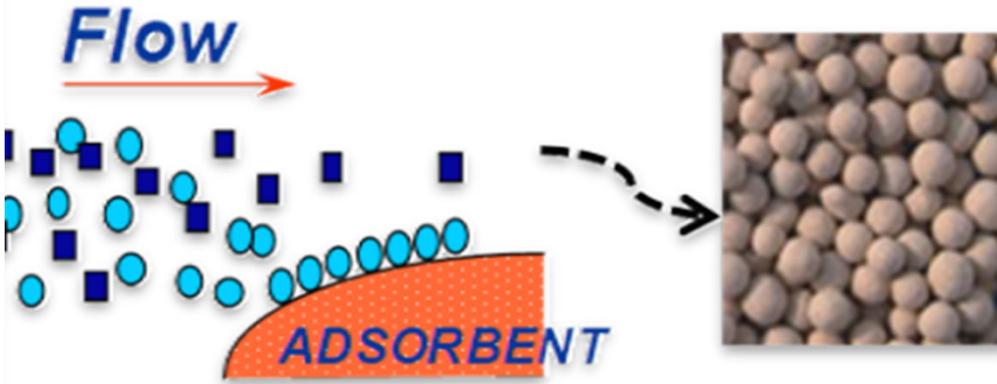
Solvent-Based Carbon Capture



MHI: KM-CDR Process

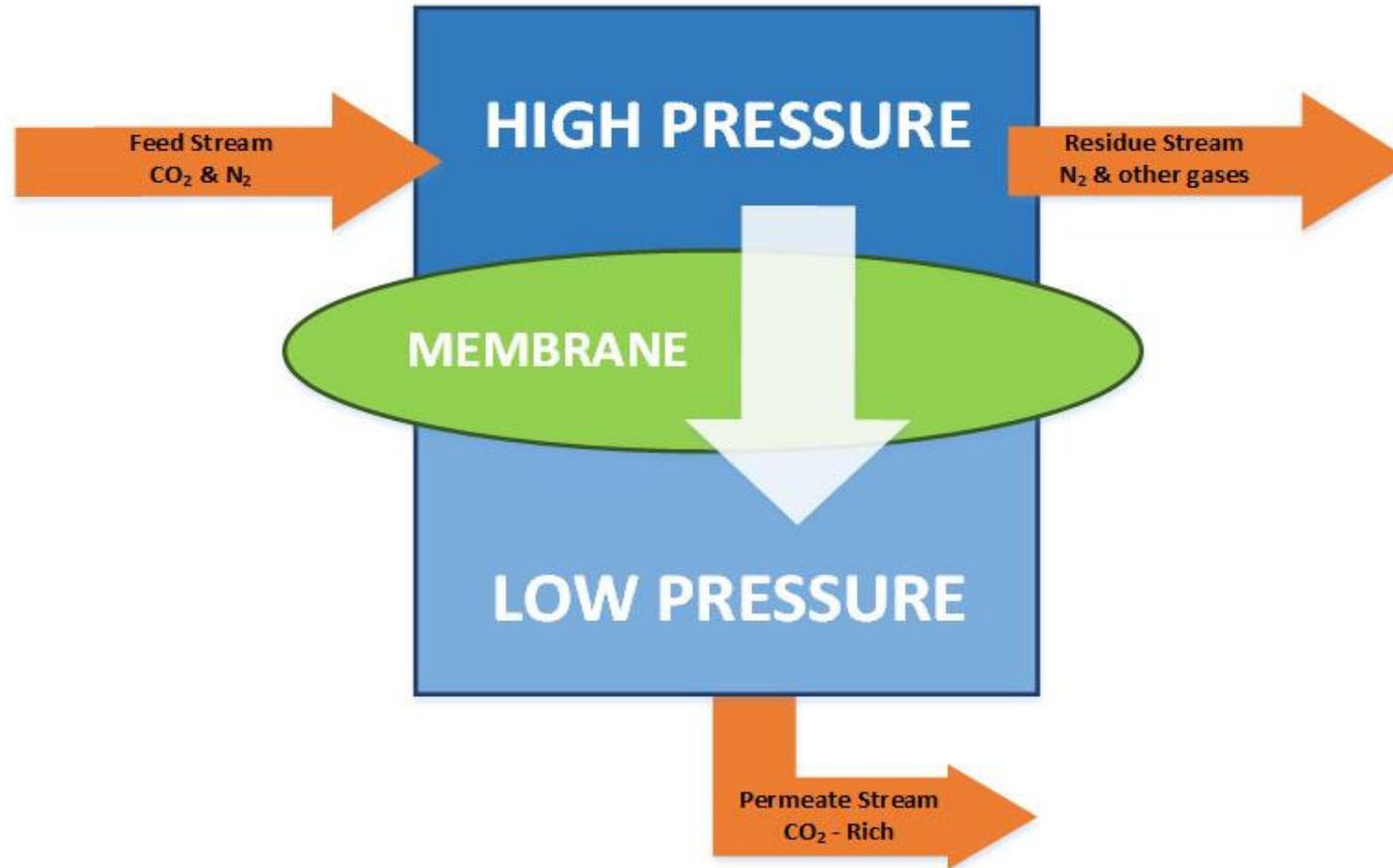
<https://www.netl.doe.gov/sites/default/files/netl-file/FE0003311.pdf>

Sorbent-Based Carbon Capture



- Adsorption
 - Gas sticks to the surface of porous solid material
 - Chemical and physical adsorption
 - Many types – zeolites, carbon-based, carbonates
 - Varying process design options – fixed bed, fluidized bed, PSA, TSA

Membrane-Based Carbon Capture



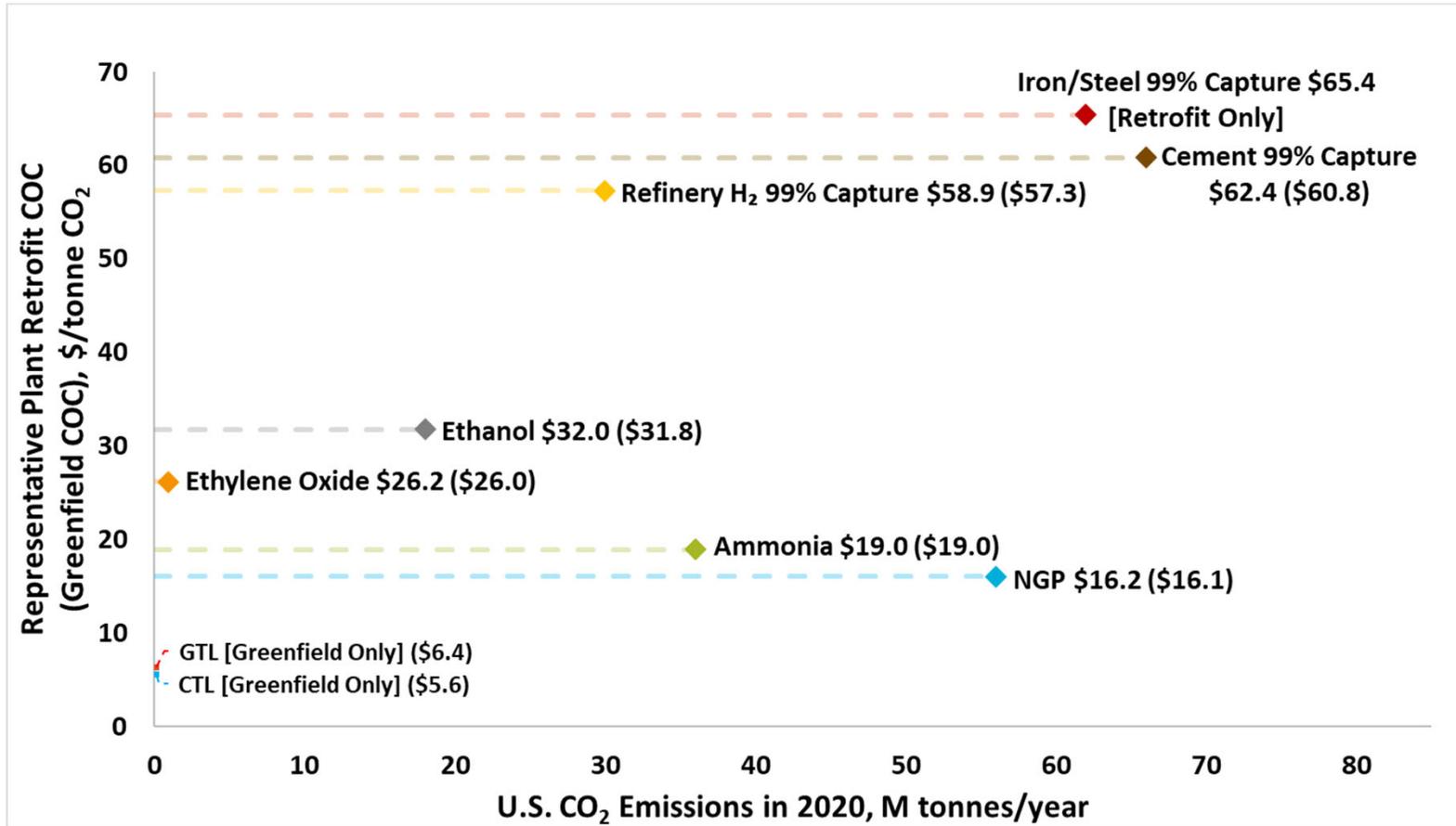
Industrial Capture Analysis

- This study quantifies the performance of CO₂ capture systems and their greenfield and retrofit costs when applied at nine representative industrial sources
- Representative plant sizes and CO₂ available for capture from each industrial plant were chosen based on literature review, vendor input, and other NETL studies, where appropriate
- This study does not characterize reference industrial plants beyond the flowrate and stream characteristics of the available CO₂ stream. The production costs of each plant's product before and after retrofit are not considered

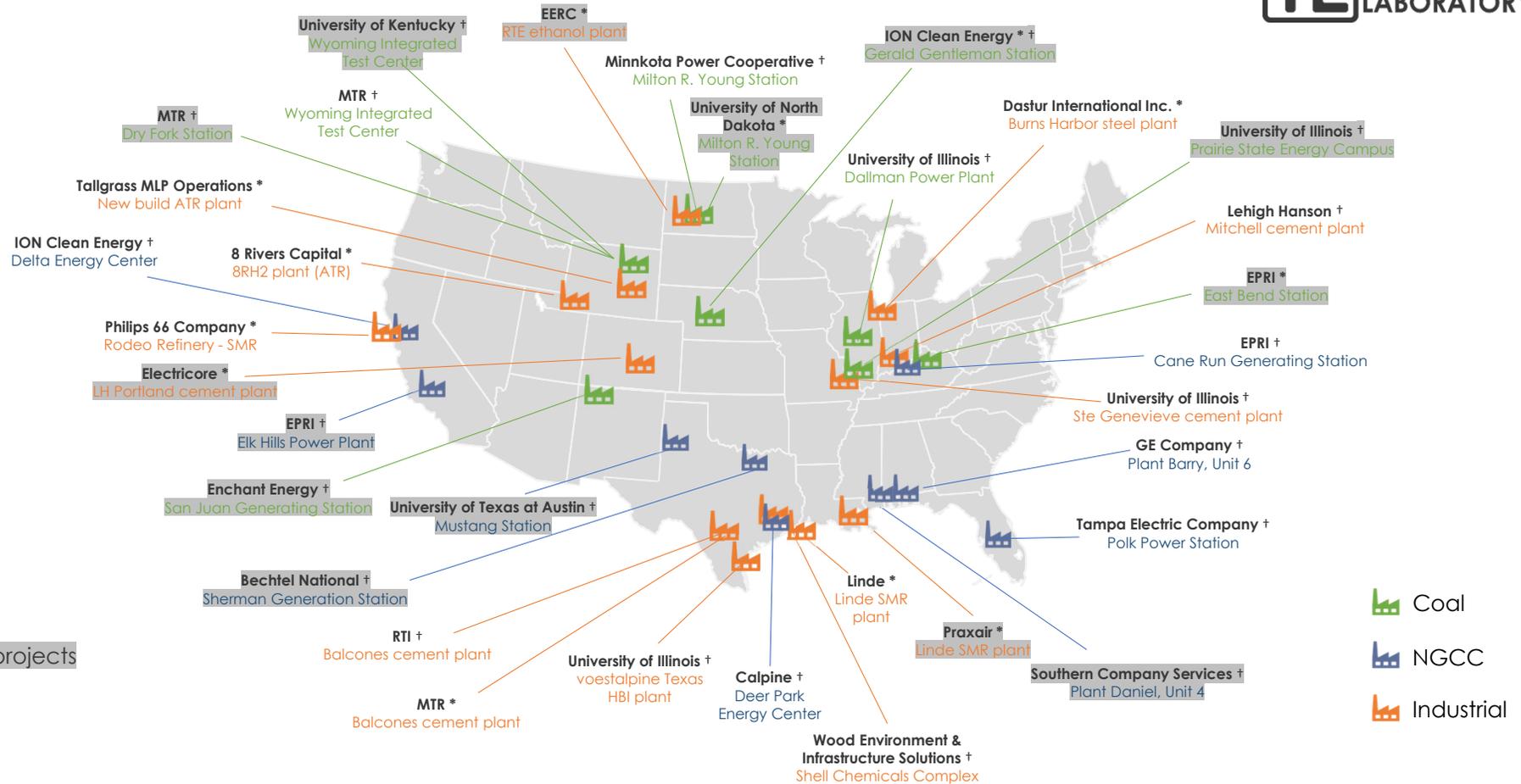
Case Class	Process	Plant Capacity	Capture Stream Description	CO ₂ Available for Capture (M tonnes CO ₂ /year)
High Purity	Ammonia	394,000 tonnes/year	Stripping vent: 23.52 psia	0.486
	Ethylene Oxide	364,500 tonnes/year	Acid gas removal CO ₂ stream: 43.5 psia	0.122
	Ethanol	50 M gal/year	Fermenter off-gas: 17.40 psia	0.143
	Natural Gas Processing	330 MMSCFD	CO ₂ vent: 23.52 psia	0.649
	Coal-to-Liquids	50,000 BPD	Acid gas removal CO ₂ streams: 160 psia, 265 psia, and 300 psia	8.74
	Gas-to-Liquids	50,000 BPD	Acid gas removal CO ₂ stream: 265 psia	1.86
Low Purity	Refinery Hydrogen	87,000 tonnes/year	Raw syngas from steam methane reforming: 399.9 psia	0.405
	Cement	1.3 M tonnes/year	Kiln Off-gas: 14.7 psia	1.21
	Steel/Iron	2.54 M tonnes/year	Coke oven power plant stack: 14.7 psia Coke oven gas/blast furnace stack: 14.7 psia	3.74 (total of both point sources)

Estimated Capture Costs

COC and Approximate U.S. Supply per Industry



Pre-FEED and FEED Study Projects with Host Site Locations



Completed projects

* Pre-FEED

† FEED

Pre-FEED and FEED Study Projects with Host Site Locations

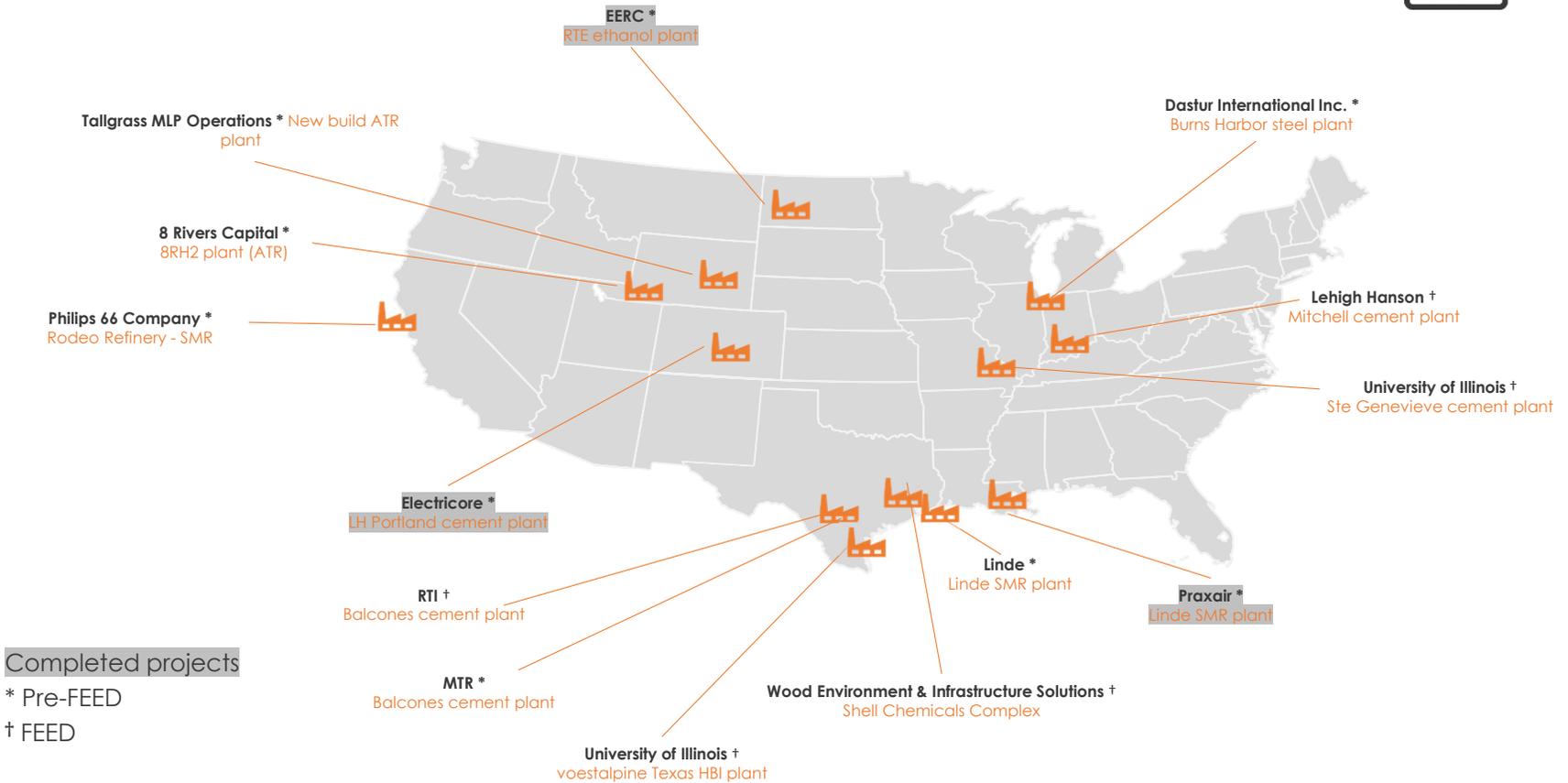
FEED Projects

Pre-FEED Projects

Project Title	Prime Performer	Host Site	Host Site Location	Project Status
Large Pilot Testing of Linde-BASF Advanced Post-Combustion CO2 Capture Technology at a Coal-Fired Power Plant	University of Illinois	City, Water, Light, and Power's Dallman Power Plant	Springfield, IL	Active*
Large Pilot Testing of the MTR Membrane Post-Combustion CO ₂ Capture Process	Membrane Technology and Research, Inc.	Wyoming Integrated Test Center (with support from Basin Electric Dry Fork Station)	Gillette, WY	Active*
Industrial Carbon Capture from a Cement Facility Using the Cryocap FG Process	University of Illinois	Holcim Ste Genevieve cement plant	Bloomsdale, MO	Active
FEED for Carbon Capture from Shell's Deer Park Chemical Complex	Wood Environment & Infrastructure Solutions	Shell Chemicals Complex	Deer Park, TX	Active
Deer Park Energy Center NGCC Carbon Capture System FEED Study	Calpine Texas CCUS Holdings	Calpine's Deer Park Energy Center	Deer Park, TX	Active
FEED for a CO2 Capture System at Calpine's Delta Energy Center	ION Clean Energy Inc.	Calpine's Delta Energy Center	Pittsburg, CA	Active
Retrofittable Advanced Combined Cycle Integration for Flexible Decarbonized Generation	GE Company – GE Gas Power	Southern Company's Plant Barry –Unit 6	Bucks, AL	Active
CO ₂ Capture at Louisville Gas & Electric Cane Run Natural Gas Combined Cycle Power Plant	Electric Power Research Institute (EPRI)	LG&E-KU Cane Run #7 NGCC unit	Jefferson County, KY	Active
FEED: Project Tundra Carbon Capture System	Minnkota Power Cooperative, Inc.	Square Butte Electric Cooperative's Milton R. Young Station, Unit 2	Center, ND	Active
UKY-CAER Heat-Integrated Transformative CO ₂ Capture Process for Pulverized Coal Power Plants	University of Kentucky Research Foundation	Wyoming Integrated Test Center (w/ support from Basin Electric Dry Fork Station)	Gillette, WY	Completed
Commercial Carbon Capture Design and Costing: Part Two (C3DC2)	ION Clean Energy, Inc.	NPPD's Gerald Gentleman Station	Sutherland, NE	Completed
Full-Scale FEED Study for Retrofitting the Prairie State Generating Station with an 816 MWe Capture Plant Using MHIA's PCC Technology	University of Illinois	Prairie State Generation Company's Station	Marissa, IL	Completed
FEED Study for Retrofit Post-Combustion Carbon Capture on a NGCC Power Plant	Electric Power Research Institute	California Resources Corporation's Elk Hills Power Plant	Kern County, CA	Completed
PiperaZine Advanced Stripper (PZAS) FEED	The University of Texas at Austin	Golden Spread Electric Cooperative's Mustang Station	Denver City, TX	Completed
Commercial-Scale FEED Study for MTR's Membrane CO ₂ Capture Process	Membrane Technology & Research, Inc.	Basic Electric's Dry Fork Station	Gillette, WY	Completed
Large-Scale Commercial Carbon Capture Retrofit of the San Juan Generating Station	Enchant Energy LLC	Public Service Company of New Mexico's San Juan Generating Station	Waterflow, NM	Completed
FEED of Linde-BASF Advanced Post-Combustion CO ₂ Capture Technology at a Southern Company Natural Gas-Fired Power Plant	Southern Company Services, Inc.	Mississippi Power's Plant Daniel, Unit 4	Moss Point, MS	Completed
FEED Study for a Carbon Capture Plant Retrofit to a Natural Gas-Fired Gas Turbine Combined Cycle Power Plant	Bechtel National Inc.	Sherman Generating Station	Sherman, TX	Completed
Carbon Capture Plant FEED Study for Cement Manufacturing	Research Triangle Institute	CEMEX Balcones cement plant	New Braunfels, TX	Not Awarded
Industrial Carbon Capture from an Existing Hot Briquetted Iron Manufacturing Facility Using the Cryocap™ FG Technology	Board of Trustees of the University of Illinois	voestalpine Texas Hot Briquetted Iron Plant	Portland, TX	Not Awarded
Mitchell Cement Plant Carbon Capture FEED	Lehigh Hanson, Inc.	Mitchell cement plant	Mitchell, IN	Not Awarded
Polk Power Station NGCC Carbon Capture FEED Study	Tampa Electric Company	Polk Power Station – Unit 2	Mulberry, FL	Not Awarded

Project Title	Prime Performer	Host Site	Host Site Location	Project Status
Enabling Production of Low Carbon Emissions Steel through CO2 Capture from Blast Furnace (BF) Gases	Dastur International, Inc.	Cleveland-Cliffs' Burns Harbor steel plant	Burns Harbor, IN	Active
Blue Bison ATR Advanced CCUS System	Tallgrass MLP Operations, LLC	ATR plant under construction	Douglas, WY	Active
The 8RH2 Process for Producing Clean Hydrogen with Autothermal Reforming and Carbon Capture	8 Rivers Capital, LLC	New build 8 Rivers Hydrogen (8RH2) plant	Evanston, WY	Active
Initial Engineering Design Study for Advanced CO2 Capture from Hydrogen Production Unit at Phillips 66 Rodeo Refinery	Phillips 66 Company	Rodeo refinery (green field)	Rodeo, CA	Active
Engineering Study of Svante's Solid Sorbent Post-Combustion CO2 Capture Technology at a Linde Steam Methane Reforming H2 Plant	Linde, Inc.	Linde SMR plant	Port Arthur, TX	Active
Engineering Design of a Polaris Membrane CO2 Capture System at a Cement Plant	Membrane Technology and Research, Inc.	CEMEX Balcones cement plant	New Braunfels, TX	Active
Initial Engineering and Design for CO2 Capture from Ethanol Facilities	University of North Dakota Energy and Environmental Research Center	RTE Ethanol plant	Richardton, ND	Completed
LH CO2MENT Colorado Project	Electricore, Inc.	LafargeHolcim's Portland cement plant	Florence, CO	Completed
Engineering Design of a Linde-BASF Advanced Post-Combustion CO2 Capture Technology at a Linde Steam Methane Reforming H2 Plant	Praxair, Inc.	Linde SMR plant	St James Parish, LA	Completed
Initial Engineering Design of a Post-Combustion CO2 Capture System for Duke Energy's East Bend Station Using Membrane-Based Technology	Electric Power Research Institute (EPRI)	Duke Energy's East Bend Station	Boone County, KY	Completed
ION Engineering Commercial Carbon Capture Design and Costing (C3DC)	ION Engineering, LLC	NPPD's Gerald Gentleman Station	Sutherland, NE	Completed
Initial Engineering, Testing, and Design of a Commercial-Scale, Post-Combustion CO2 Capture System on an Existing Coal-Fired Generating Unit	University of North Dakota	Milton R. Young Station	Center, ND	Completed

Pre-FEED and FEED Study Projects with Host Site Locations – Industrial Plants



Pre-FEED and FEED Study Projects with Host Site Locations – Industrial Plants



FEED Projects

Project Title	Prime Performer	Host Site	Host Site Location	Project Status
Industrial Carbon Capture from a Cement Facility Using the Cryocap FG Process	University of Illinois	Holcim Ste Genevieve cement plant	Bloomsdale, MO	Active
FEED for Carbon Capture from Shell's Deer Park Chemical Complex	Wood Environment & Infrastructure Solutions	Shell Chemicals Complex	Deer Park, TX	Active
Carbon Capture Plant FEED Study for Cement Manufacturing	Research Triangle Institute	CEMEX Balcones cement plant	New Braunfels, TX	Not Awarded
Industrial Carbon Capture from an Existing Hot Briquetted Iron Manufacturing Facility Using the Cryocap™ FG Technology	Board of Trustees of the University of Illinois	voestalpine Texas Hot Briquetted Iron Plant	Portland, TX	Not Awarded
Mitchell Cement Plant Carbon Capture FEED	Lehigh Hanson, Inc.	Mitchell cement plant	Mitchell, IN	Not Awarded

• Drivers

- Rigorous estimate of actual cost at actual plants
- Basis for evaluating impacts on cost of product

Pre-FEED Projects

Project Title	Prime Performer	Host Site	Host Site Location	Project Status
Enabling Production of Low Carbon Emissions Steel through CO2 Capture from Blast Furnace (BF) Gases	Dastur International, Inc.	Cleveland-Cliffs' Burns Harbor steel plant	Burns Harbor, IN	Active
Blue Bison ATR Advanced CCUS System	Tallgrass MLP Operations, LLC	ATR plant under construction	Douglas, WY	Active
The 8RH2 Process for Producing Clean Hydrogen with Autothermal Reforming and Carbon Capture	8 Rivers Capital, LLC	New build 8 Rivers Hydrogen (8RH2) plant	Evanston, WY	Active
Initial Engineering Design Study for Advanced CO2 Capture from H2 Production Unit at Phillips 66 Rodeo Refinery	Phillips 66 Company	Rodeo refinery	Rodeo, CA	Active
Engineering Study of Svante's Solid Sorbent Post-Combustion CO2 Capture Technology at a Linde Steam Methane Reforming H2 Plant	Linde, Inc.	Linde SMR plant	Port Arthur, TX	Active
Engineering Design of a Polaris Membrane CO2 Capture System at a Cement Plant	Membrane Technology and Research, Inc.	CEMEX Balcones cement plant	New Braunfels, TX	Active
Initial Engineering and Design for CO2 Capture from Ethanol Facilities	University of North Dakota Energy and Environmental Research Center	RTE Ethanol plant	Richardton, ND	Completed
LH CO2MENT Colorado Project	Electricore, Inc.	LafargeHolcim's Portland cement plant	Florence, CO	Completed
Engineering Design of a Linde-BASF Advanced Post-Combustion CO2 Capture Technology at a Linde Steam Methane Reforming H2 Plant	Praxair, Inc.	Linde SMR plant	St James Parish, LA	Completed

• Challenges

- Have technologies that have been tested on coal and gas but not on actual industrial flue gases
- Represents risk

Point Source Carbon Capture.. FOAs Issued



Fiscal Year	Funding Opportunity Announcement Number	Funding Opportunity Announcement Title	Issue Date	Close Date
2022	DE-FOA-0002515/Amendment 000002	<p>Carbon Capture R&D For Natural Gas and Industrial Point Sources, and FEED Studies for Carbon Capture Systems at Industrial Facilities and Natural Gas Plants (\$96M)</p> <p>AOI-4: Carbon Capture R&D: Laboratory-Scale Testing of Highly-Efficient Materials or Novel Concepts for Natural Gas Combined Cycle (NGCC) Power Plants</p> <p>AOI-5: Engineering-Scale Testing of Transformational Post-Combustion Carbon Capture Technologies for NGCC power plants</p> <p>AOI-6: Engineering-Scale Testing of Transformational Carbon Capture Technologies for Industrial Plants and Waste-to-Energy Plants</p> <p>AOI-7: Front-End Engineering Design Studies for Carbon Capture Systems at Existing (Retrofit) Domestic Industrial Facilities and NGCC Power Plants</p>	3/08/2022	4/11/2022
2022	DE-FOA-0002400/Modification 000007	<p>Clean Hydrogen Production, Storage, Transport and Utilization To Enable A Net Zero Carbon Economy (\$28.6M total; \$18M for AOI-8)</p> <p>AOI-8: Front-End Engineering Design Studies for Carbon Capture Systems at Domestic Industrial Facilities Producing H₂ from Natural Gas</p> <p>AOI-8A: Front-End Engineering Design Studies for Carbon Capture Systems at Domestic Steam Methane Reforming (SMR) Facilities Producing H₂ from Natural Gas</p> <p>AOI-8B: Front-End Engineering Design Studies for Carbon Capture Systems at Domestic Autothermal Reforming (ATR) Facilities Producing H₂ from Natural Gas</p>	2/07/2022	3/30/2022

PSCC Program Updates



NOI	Notice of Intent Title	Issue Date
DE-FOA-0003004	Notice of Intent to Issue Funding Opportunity Announcement No. DE-FOA-0002614 Title: Carbon Management (Round 3) AOI-3: Point Source Carbon Capture Technology AOI-3A: Engineering-Scale Testing of Transformational Carbon Capture Technologies for Industrial Plants AOI-3B: Front-End Engineering Design Studies for Carbon Capture Systems at Existing (Retrofit) Domestic Natural Gas (NG) Power Plants AOI-3C: Laboratory/Bench-Scale Testing of Transformational Carbon Capture Technologies for NGCC Power Plants	2/16/2023

❖ BIL: Carbon Capture Demonstration Projects Program

FOA 1

- FOA 2738 “FEED Studies for Integrated Carbon Capture, Transport, and Storage Systems” - [released September 22, 2022](#)
- \$189M; up to 20 projects

FOA 2

- FOA 2962 - [released February 23, 2023](#)
- Letters of Intent due 3/28; Applications due 5/23 @ 5pm
- \$1.7B; ~6 projects (transformational domestic, commercial-scale, integrated CCS, demonstration projects)
 - 2 projects at new or existing coal electric generation facilities
 - 2 projects at new or existing natural gas electric generation facilities
 - 2 projects at new or existing industrial facilities not purposed for electric generation

❖ BIL: Carbon Capture Large-Scale Pilot Program

- FOA 2963 - [released February 23, 2023](#)
- \$820M; up to 10 projects (transformational carbon capture technologies applied to existing coal or natural gas electric generation facilities and existing industrial facilities)

Questions

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

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