SPE Workshop: Oil and Gas Technology for a Net-Zero World – Defining Our Grand Challenges for the Next Decade

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Carbon Capture Technologies: Status and Challenges

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Strategic Systems Analysis and Engineering

Preface

This presentation provides an overview of a Fossil Energy and Carbon Management (FECM) R&D Program that is implemented based on both Administration priorities and Congressional direction. Plans for future technology development reflect expected trajectories of current R&D, but these plans are subject to change. Furthermore, some stages of future technology development, although necessary for commercialization, may not be financially supported by the government.

NETL: THE Fossil Energy and Carbon Management Laboratory

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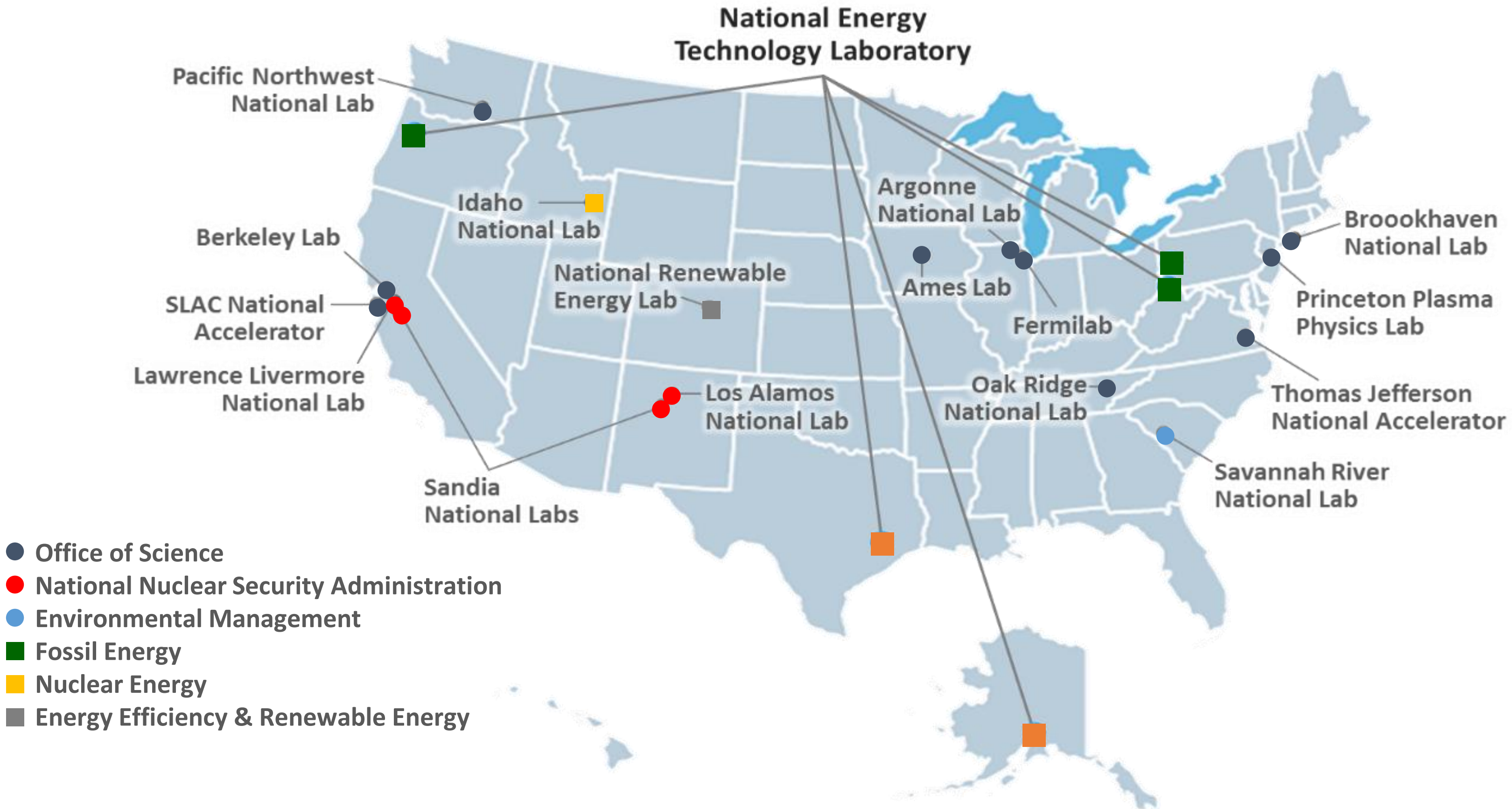

NETL's mission is to discover, integrate, and mature technology solutions to enhance the Nation's energy foundation and protect the environment for future generations

Presentation Outline

- Capture Overview
- Post-Combustion Capture
  - Approaches
  - Challenges
  - Costs and Resources
- Direct Air Capture – Sorbents
- Direct Air Capture – Solvents

Capture Overview

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Carbon Dioxide Reducing vs Carbon Removal

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Carbon Reducing.. CCS for Power Generation and Industrial Sectors

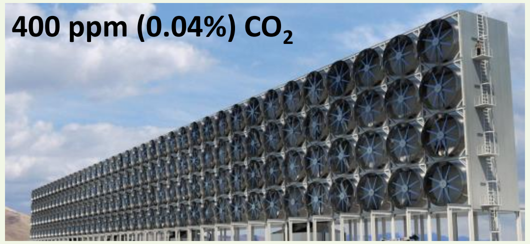
Power Plants

Cement Plants

Iron and Steel Plants

Hydrogen Plants

Carbon Dioxide Removal from Atmosphere



Direct Air Capture


Direct Ocean Capture


Biomass Carbon Removal and Storage


Enhanced Mineralization

CO_2 Partial Pressure and Capture Cost

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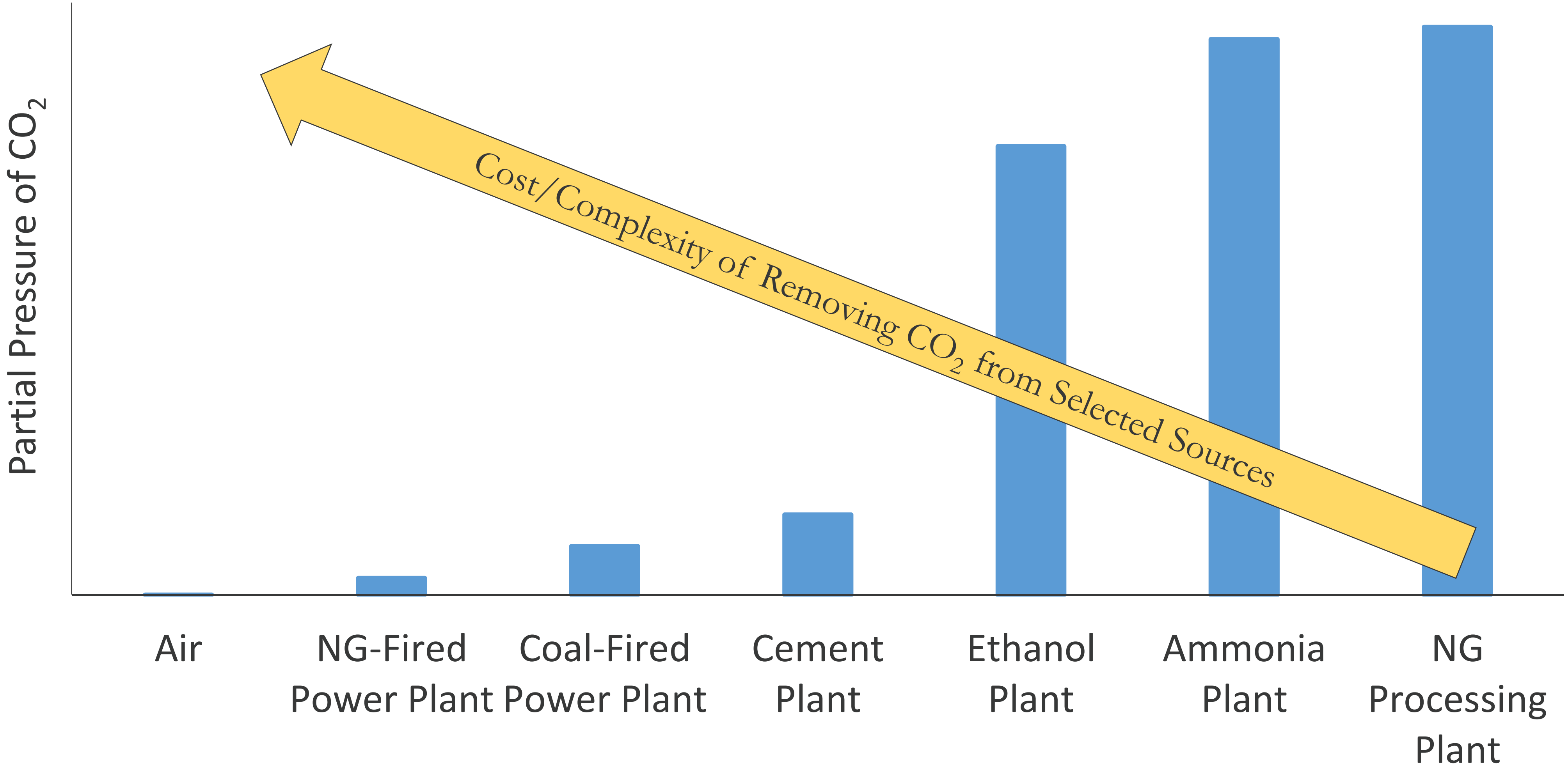

Cost of Capturing CO_2 from Industrial Sources, January 10, 2014, DOE/NETL-2013/1602

Post-Combustion Capture

Approaches to Post-Combustion CO_2 Capture

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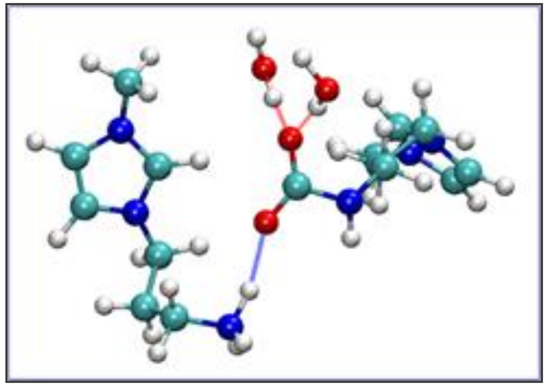
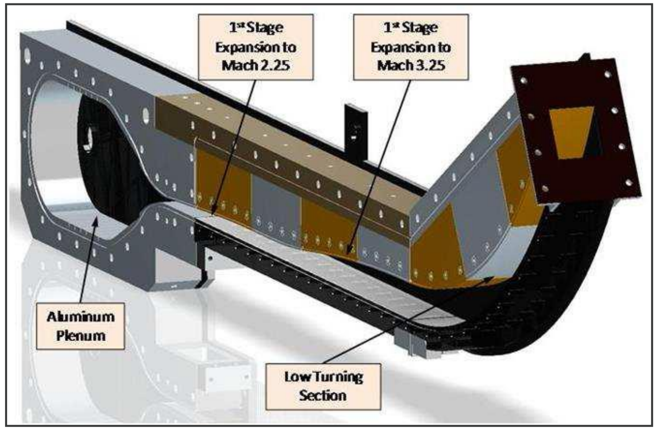
Solvents



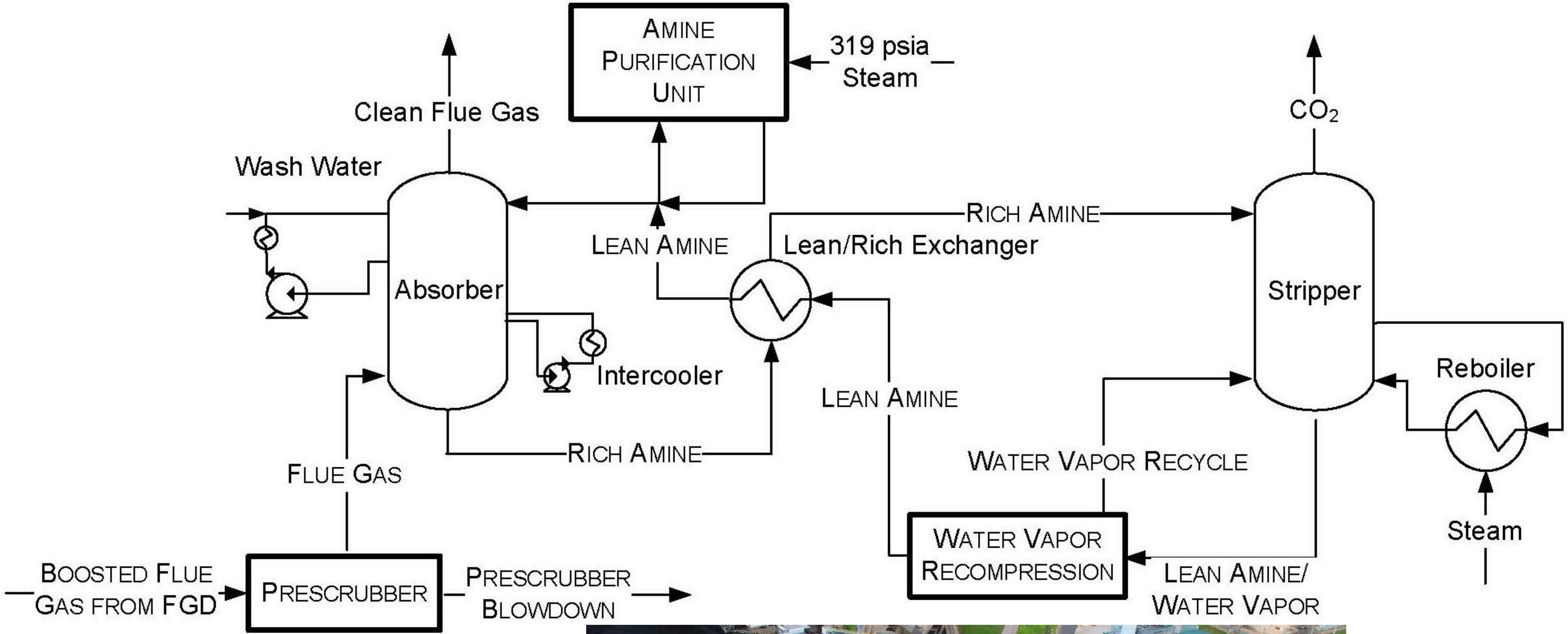
Sorbents

Membranes

Novel Concepts



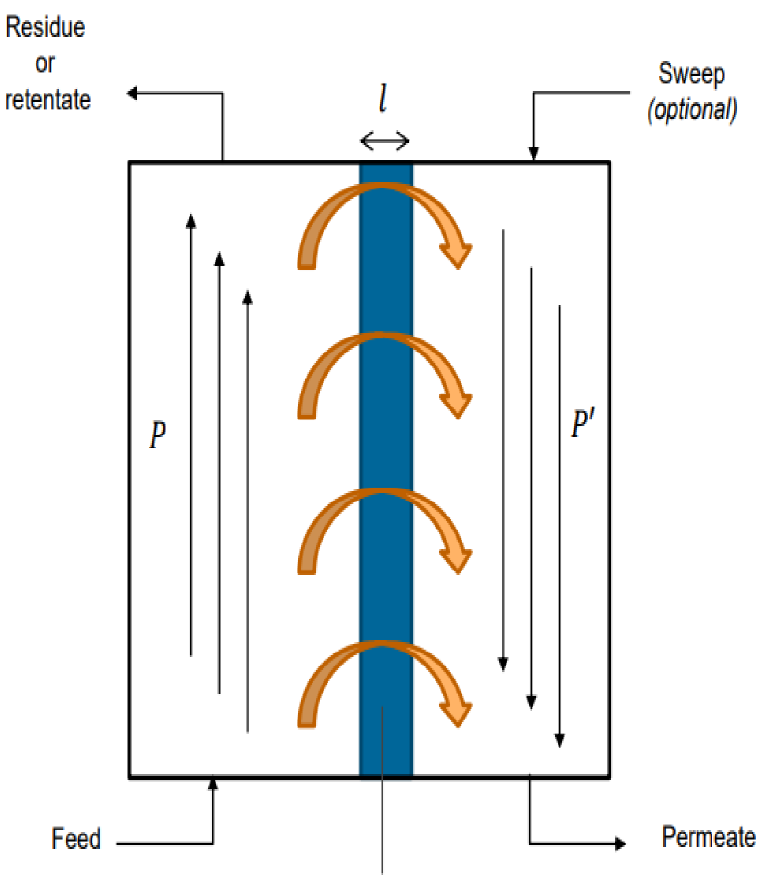
Solvent Capture Systems



Solvent System Considerations

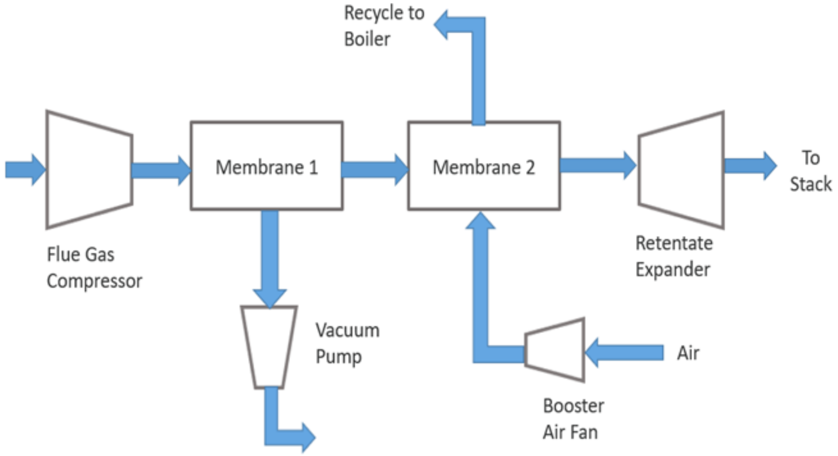
- Aqueous/non-aqueous
- Physical or Chemical solvent
- Operational temperature
  - Volatile solvent
  - Viscosity
- Regenerator Type
  - Stripper
  - Flash Unit
- Novel Absorber/Regenerator Equipment
  - Rotating Beds
  - Membrane Contactors

Membrane Capture Processes



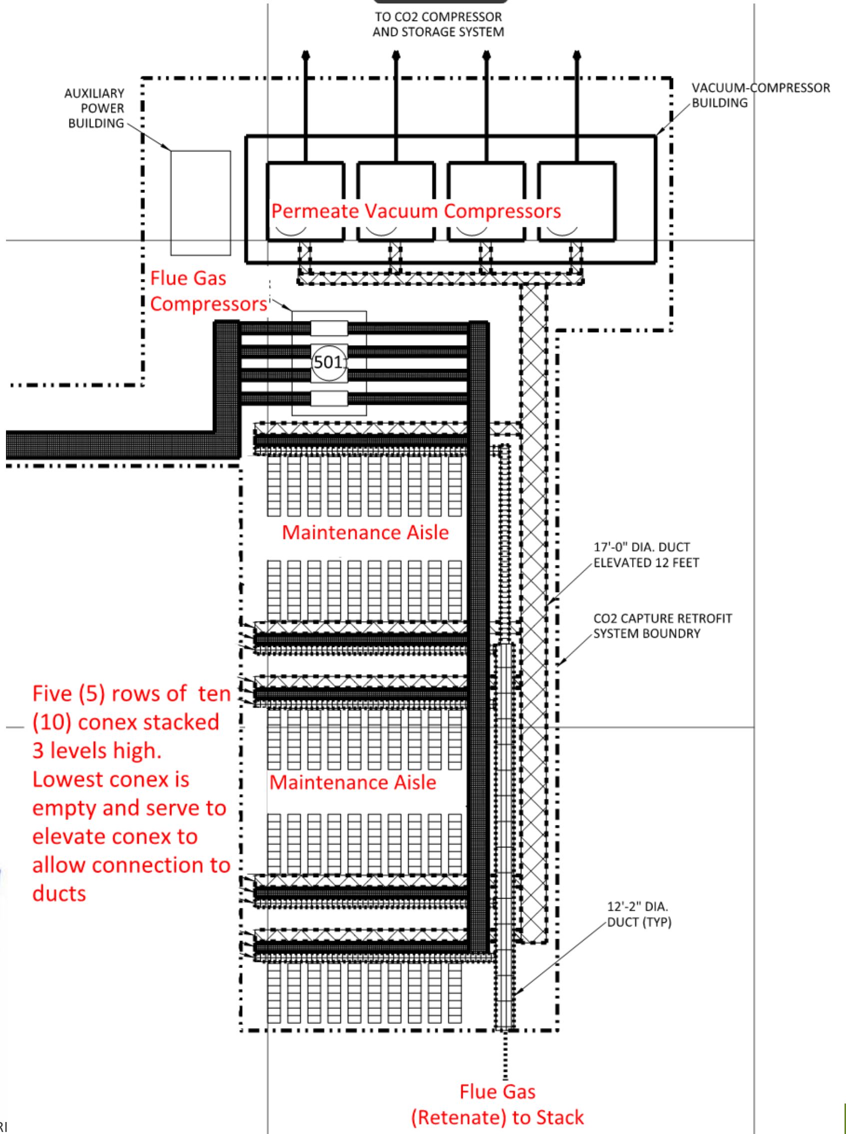
Gases dissolve into the membrane material, diffuse across, and enter the gas on the other side

Source: EPRI



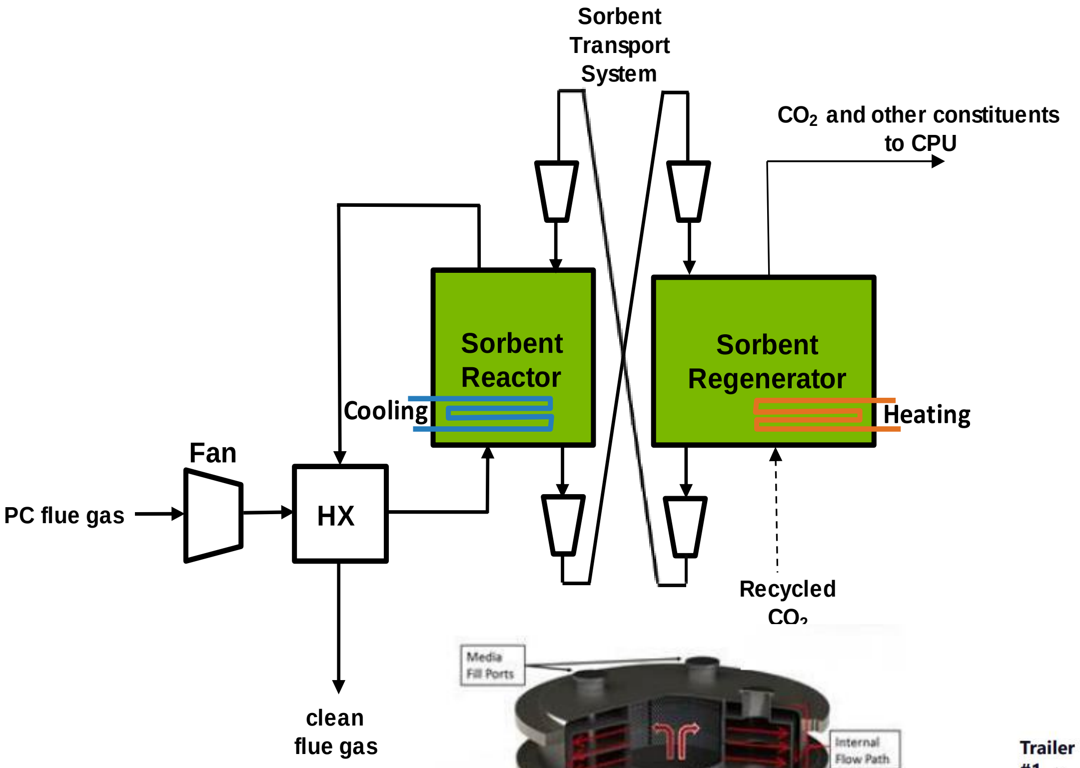
Membrane System Considerations

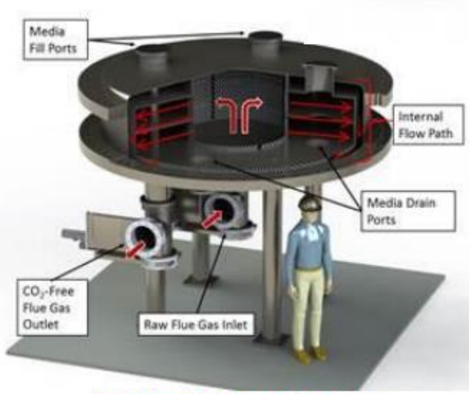
- Membrane Material
  - Separation Layer
  - Support Layer(s)
- Membrane Configuration
  - Flat Sheet
  - Spiral Wound
  - Hollow Fiber



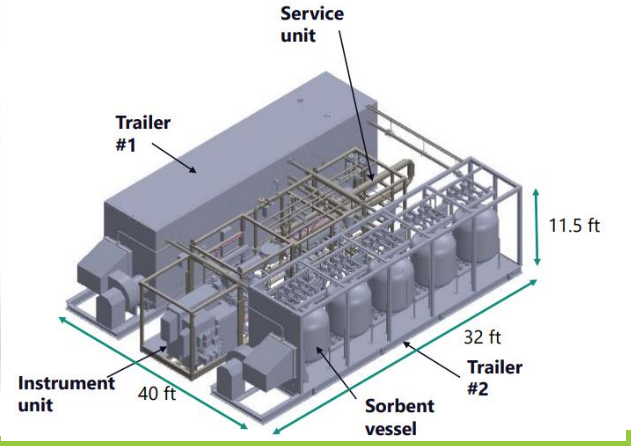
Source: MTRI

Sorbent Capture Processes





TDA's Sorbent System



Sorbent System Considerations

- Sorbent Type
  - Physical or Chemical
- Regeneration Mode
  - Temperature
  - Pressure (Vacuum)
  - Sweep Gas
  - Combination
- Bed type
  - Circulating
  - Bubbling
  - Packed
  - Moving

Carbon Capture Challenges

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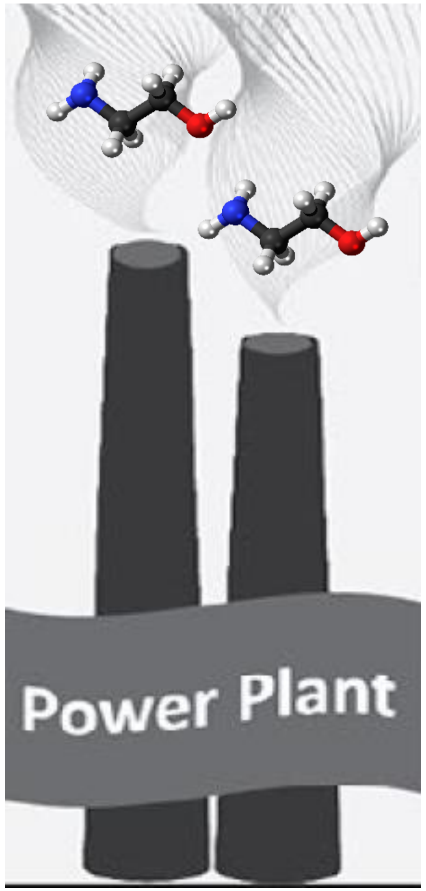
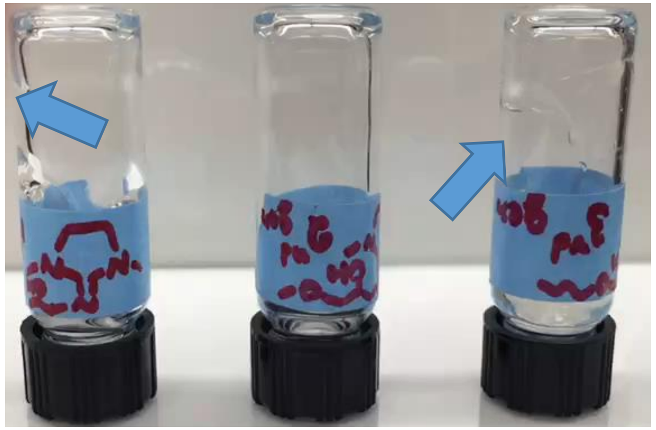
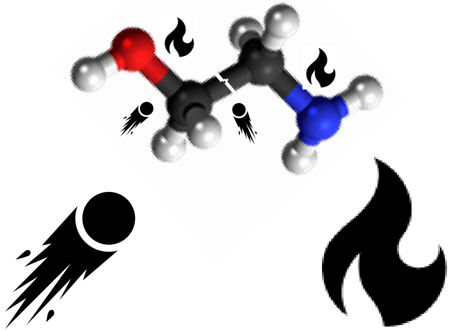
Aerosols



Viscosity



Degradation



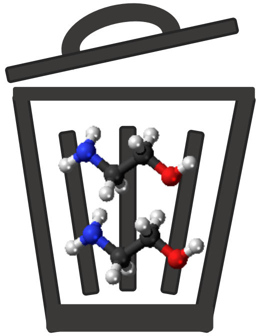
Oxidative

Thermal

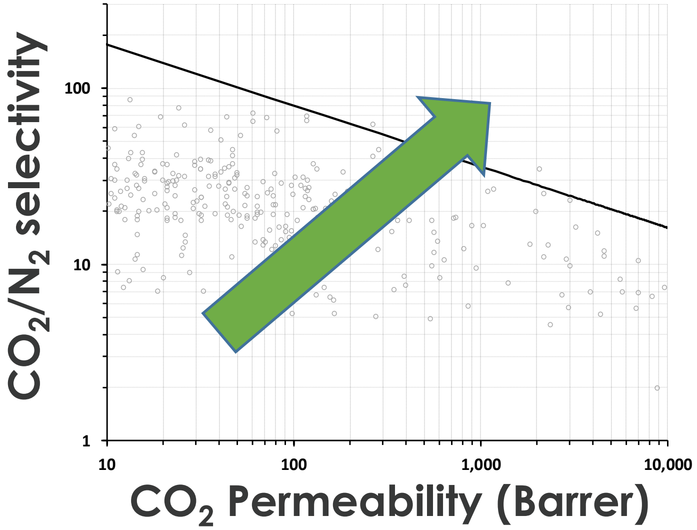
Attrition

Corrosion

Disposal & Loss



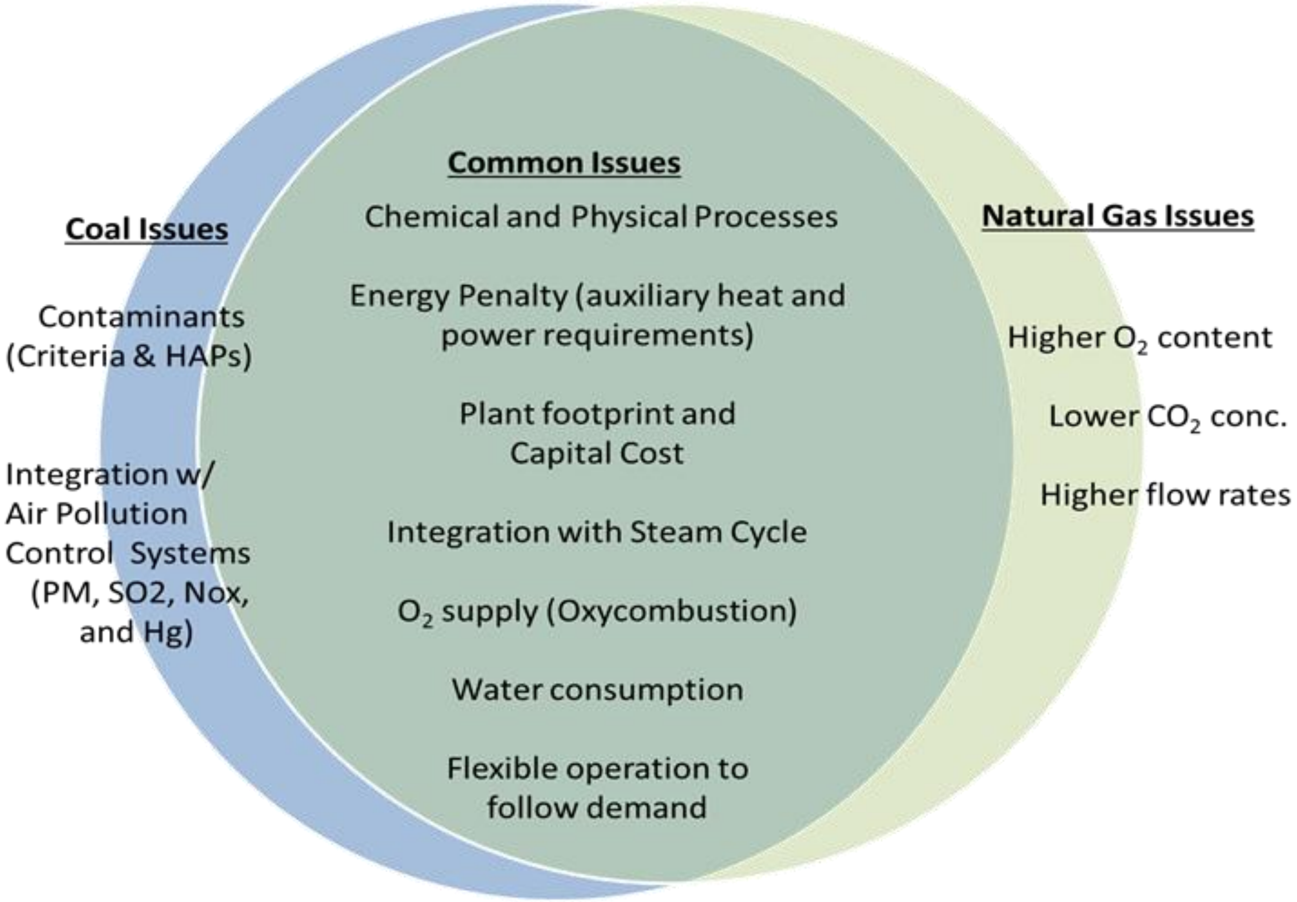
Selectivity and Flux



Lloyd M. Robeson, Journal of Membrane Science, 320, 2008, 390-400

Natural Gas Carbon Capture

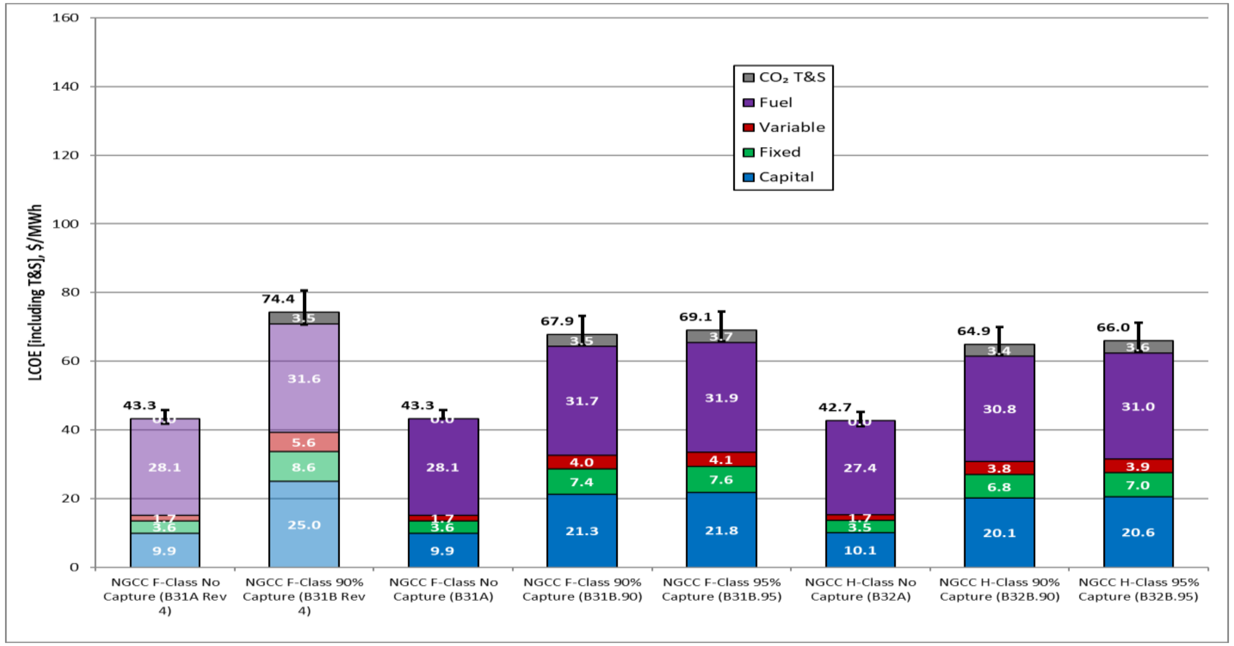
- In the future, it is anticipated that natural gas-fired facilities will also be expected to capture CO_2 and this research will focus on the unique technical challenges
- R&D is necessary to address

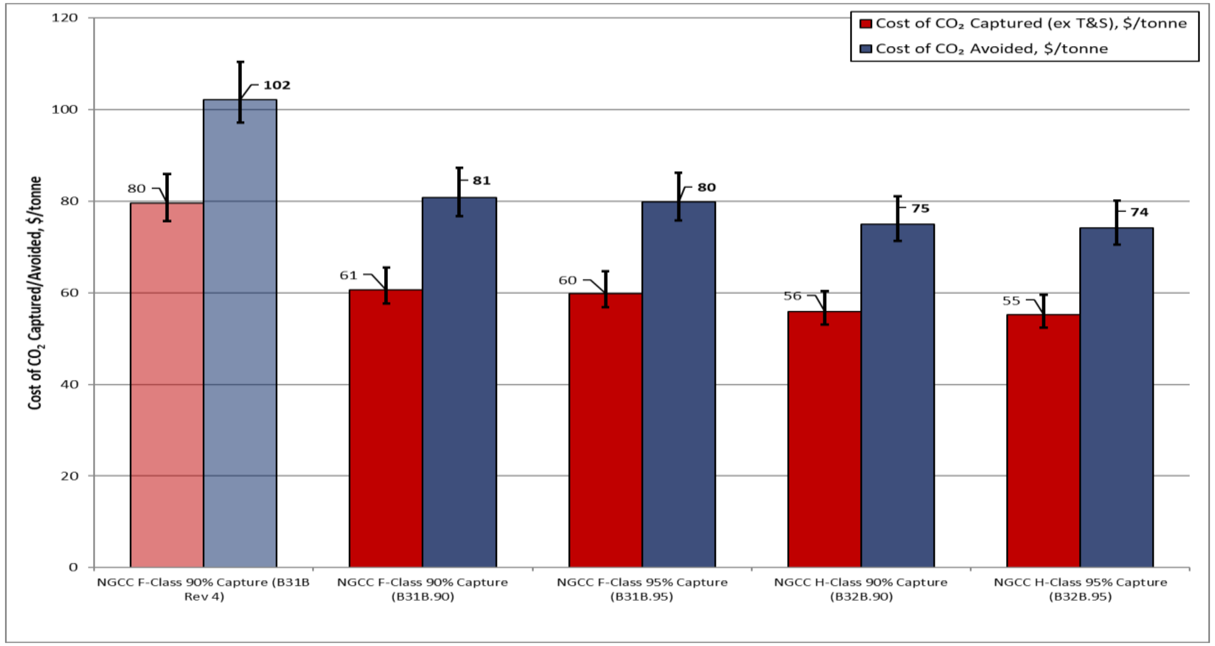


Common and Distinct Issues for Carbon Capture Technology for Coal and Natural Gas-fired Power Systems

Natural Gas Combined Cycle (NGCC) Cases

LCOE, Cost of CO_2 Capture, and Cost of CO_2 Avoided*





- Rev 4 to Rev 4A (2016 and 2021 capture system quotes, respectively)
  - No change in LCOE for the F-class base plant (no CCS)
  - Note that the H-class NGCC is new for Rev 4A
  - F-class NGCC with 90% capture: 9% decrease in LCOE and 23% decrease in cost of CO_2 capture
    - The primary driver is a reduction in the capital cost for the Shell CANSOLV capture system (now uses same solvent as coal system)
- 95% capture increases LCOE ~2% relative to 90% capture, cost of CO_2 capture is unchanged
- H-class NGCC with 90% CCS has a LCOE 4.4% below the F-class system, and a $5/tonne cost of CO_2 capture advantage

* Calculated for 85% capacity factor (CF), reported in 2018 $

T. Schmitt, S. Leptinsky, M. Turner, A. Zoelle, M. Woods, T. Shultz, and R. James "Fossil Energy Baseline Revision 4a," National Energy Technology Laboratory, Pittsburgh, October 14, 2022. https://netl.doe.gov/projects/files/CostAndPerformanceBaselineForFossilEnergyPlantsVolume1BituminousCoalAndNaturalGasToElectricity_101422.pdf

Industrial Sources – Post-Combustion Capture

Case Class	Process	Captured CO_2 Stream Purity (mol %)	Point Sources (mol %, where shown)[1]	Base Plant Capacity	CO_2 Available for Capture (M tonnes CO_2/year)
High Purity[7]	Ammonia	99	Primary reformer flue gas[2], ammonia CO_2 stripper vent (99)	394,000 tonnes/year	0.486
	Ethylene Oxide	100	Ethylene oxide CO_2 stripper vent	364,500 tonnes/year	0.122
	Ethanol	100	Fermentation off gas	50 M gal/year	0.143
	Natural Gas Processing	96-99[3]	CO_2 acid gas removal discharge	330 MMSCFD	0.649
	Coal-to-Liquids	100	Gasification, F-T acid gas removal[4]	50,000 BPD	8.74
	Gas-to-Liquids	100	Acid gas removal discharge	50,000 BPD	1.86
Low Purity	Refinery Hydrogen	12	Steam methane reformer syngas	87,000 tonnes/year	0.405
	Cement	22	Kiln off gas	1.3 M tonnes/year	1.21
	Iron/Steel	23[5], 23	Power plant stack (23), coke oven gas (27), blast furnace stove (21), sinter stack[6], blown oxygen steelmaking stack[6], hot strip mill stack[6], plate mill stack[6], kiln off gas[6]	2.54 M tonnes/year	3.74 (total of both point sources)

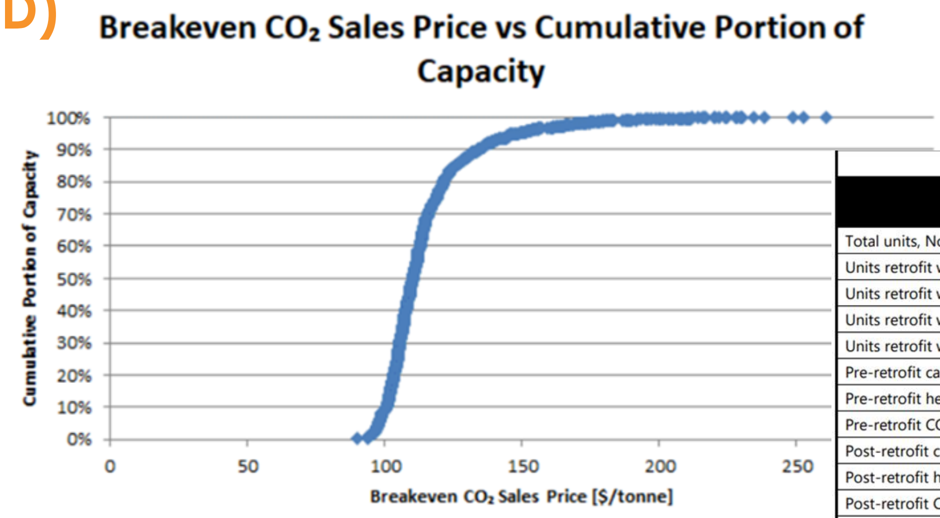
[1]This study neglects CO_2 emissions generated by miscellaneous plant process heating, or CO_2 emissions arising from steam generation required for solvent regeneration
[2]This stream is not considered as part of this study but could be considered as a separate capture stream in future work.
[3]Varies depending on raw natural gas composition
[4]Combined into a single high-purity CO_2 stream
[5]Coke oven gas, blast furnace stove combined into a single stream; two separate capture systems required for iron/steel cases
[6]CO_2 concentration comparable to that of fossil fuel-fired power generation flue gas, and so not considered as part of this study
[7]High purity cases require compression only and, in some cases, glycol dehydration
Note: MMSCFD = million standard cubic feet per day; BPD = U.S. barrels per day

S. Hughes and A. Zoelle, "Cost of Capturing CO2 from Industrial Sources," National Energy Technology Laboratory, Pittsburgh, July 15, 2022. https://netl.doe.gov/projects/files/CostofCapturingCO2fromIndustrialSources_071522.pdf

PC/NGCC CO_2 Capture Analysis Products

Carbon Capture Retrofit Databases (CCRD)

- Spreadsheet tools available to calculate CO_2 capture costs for natural gas and pulverized coal electricity generation facilities
- Users can vary parameters to evaluate impact on capture cost (capture rate, financing assumptions, utility pricing, etc.)
- Allows for scenario analysis based on inputs and assumptions set by user



Parameter	Units	Value		
		SCENARIO #1	SCENARIO #2	SCENARIO
CO_2 Capture Rate	Choose Option	Default	Default	Default
	%	90%	90%	90%
CO_2 Capture Technology	Choose Option	Amine Based	Amine Based	Amine Base
Pre-Retrofit Capacity Factor	Choose Option	User Input	User Input	User Input
	%	85%	75%	65%
Post-Retrofit Capacity Factor	Choose Option	Delta	Delta	Delta
	% or Reduction Delta	10%	10%	10%
Retrofit Unit Capacity Applicability Limit	Choose Option	Default	Default	Default
	MW	25	25	25
Retrofit Cost Factor	Choose Option	Default	Default	Default
		1.10	1.10	1.10
Capital Charge Factor	Choose Option	High Risk	High Risk	High Risk
	Choose Option	30-Year	30-Year	30-Year
		0.111	0.111	0.111

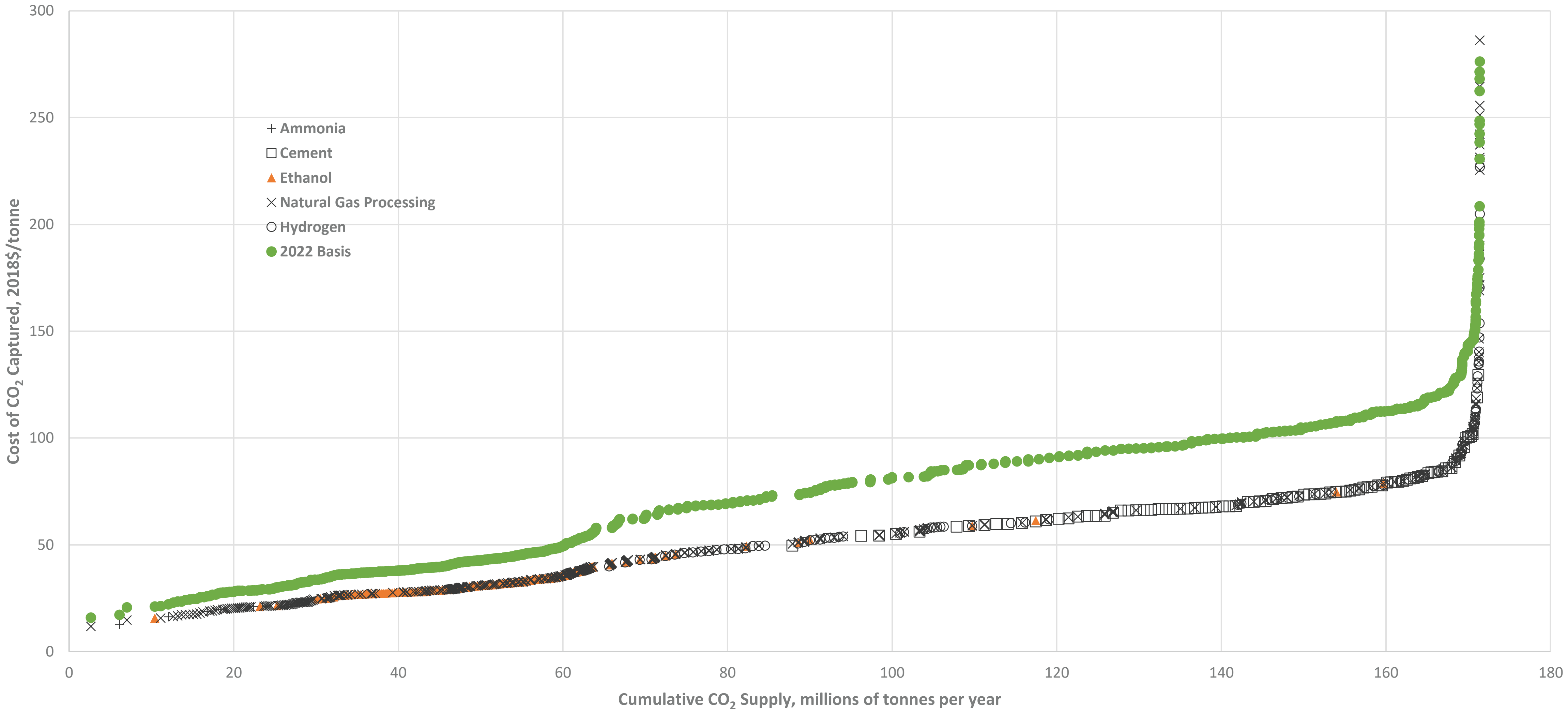
Parameter	SCENARIO #1 Total Fleet	SCENARIO #1 Average Unit
Total units, No.	964	–
Units retrofit with CCS, No.	714	–
Units retrofit with dry cooling, No. Entries	143	–
Units retrofit with SCR, No.	588	–
Units retrofit with FGD, No.	473	–
Pre-retrofit capacity, MW	283,466	397
Pre-retrofit heat rate, Btu/kWh	–	10,767
Pre-retrofit CO_2 emissions, x1,000 TPY	2,209,470	3,094
Post-retrofit capacity, MW	206,071	289
Post-retrofit heat rate, Btu/kWh	–	14,656
Post-retrofit CO_2 emissions, x1,000 TPY	194,953	273
Retrofit CO_2 capture, x1,000 TPY	1,754,579	2,457
Retrofit parasitic load, MW	77,396	108.4
Makeup/Excess power, x1,000 MW/yr	–	–
Retrofit capital cost (TOC), $/10^6	713,001	999
Retrofit 1st year COE, $/MWh	–	84.7
Breakeven CO_2 Sales Price, $/tonne	–	66.5
Breakeven CO_2 Emissions Penalty, $/tonne	–	110.0
Scenario Assumptions:		
CO_2 capture rate, %	90%	
CO_2 capture technology	Amine Based	
Average pre-retrofit capacity factor	85%	
Average post-retrofit capacity factor	75%	
Retrofit unit capacity applicability limit, MW	25	
Retrofit cost factor	1.05	
Capital charge factor	0.124	
CO_2 emissions rate, lb/MMBtu	N/A	
Maximum CO_2 capture rate per train, TPD	15,772	
Plant capacity metric	Nameplate	

U.S. DEPARTMENT OF ENERGY

"Pulverized Coal Carbon Capture Retrofit Database," NETL, April 2019
"Natural Gas Combined Cycle Carbon Capture Retrofit Database," NETL, April 2019

CCRD CO_2 Supply Curve

Individual Plant Cost of Capture – Industrial Report Parameters



Carbon Capture Program… Evolution

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1st and 2nd Generation Technologies

2025: $40/tonne CO_2

2008 -

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

Transformational Technologies

2030: $30/tonne CO_2

Hollow Fibers

3D Print

Biphasic Solvent

2015 -

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

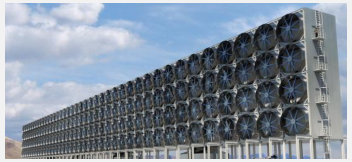
Scale-up

TCM

2018 -

- ✓ Engineering Scale testing
- ✓ FEED studies

Negative Emissions Technologies & Industrial



Carbon Engineering, DAC

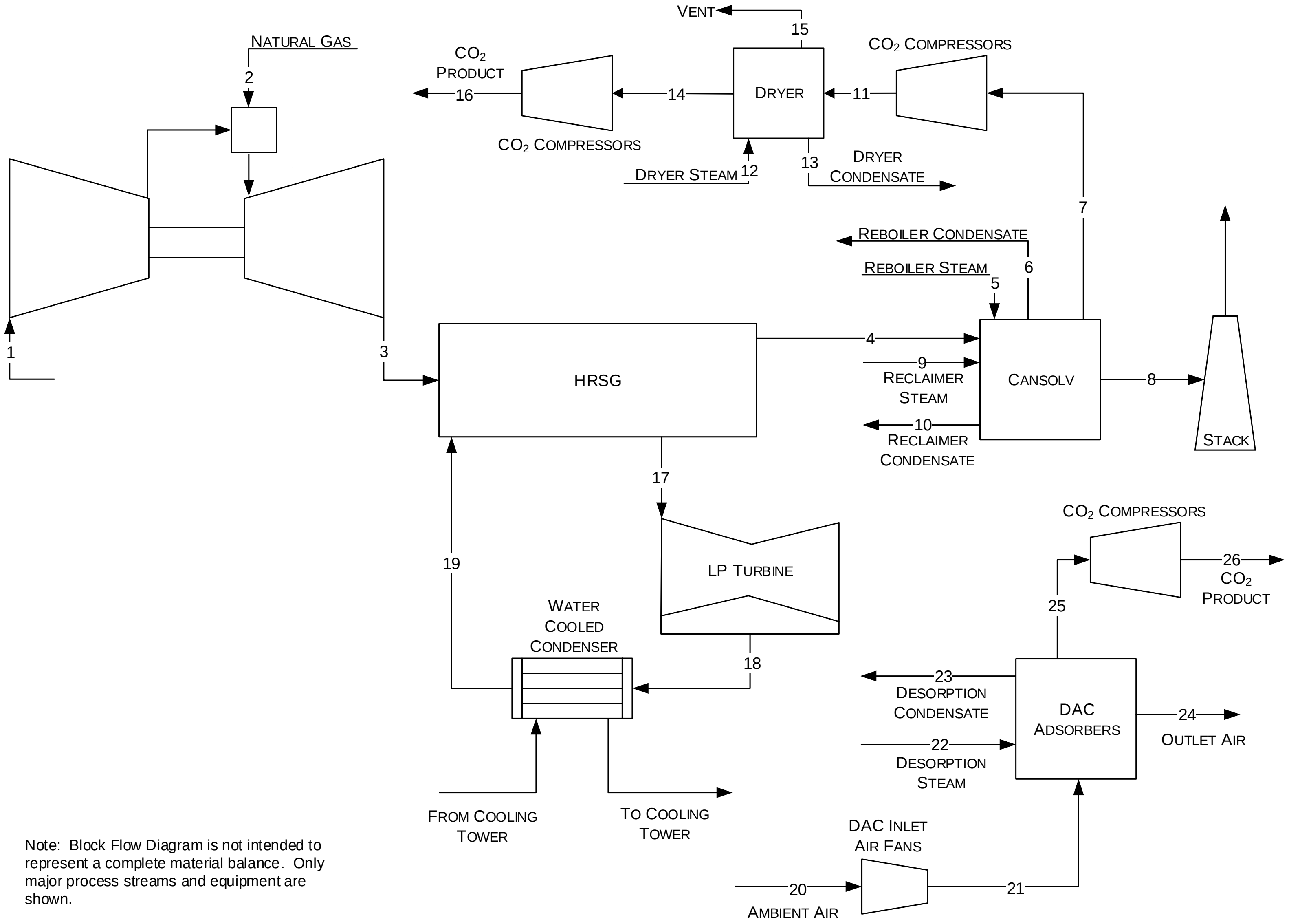
Ethanol Plant

2020 -

- ✓ DAC & BECCS
- ✓ Industrial
- ✓ NG

Direct Air Capture - Sorbent

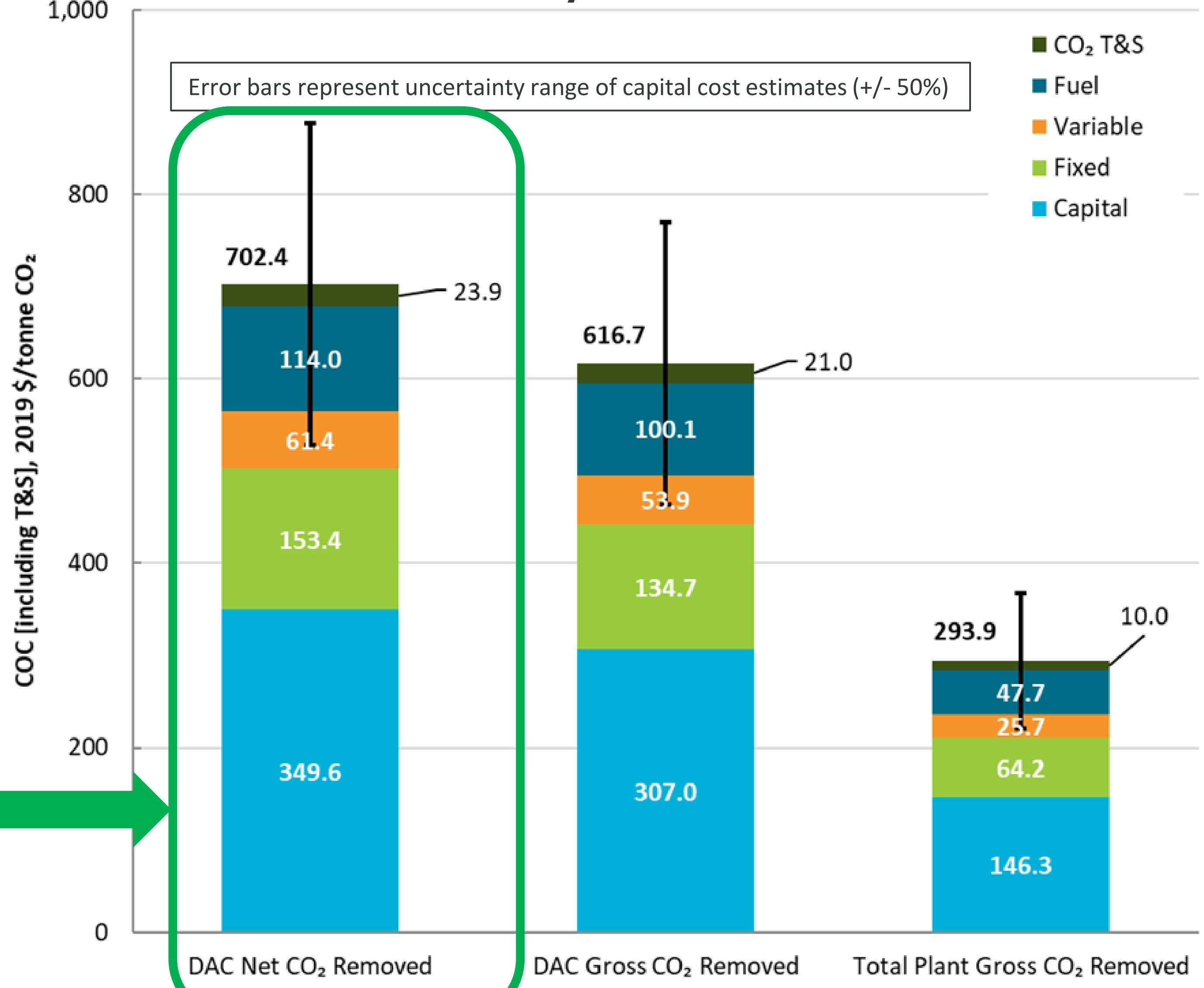
DAC Sorbent Block Flow Diagram



Source: NETL

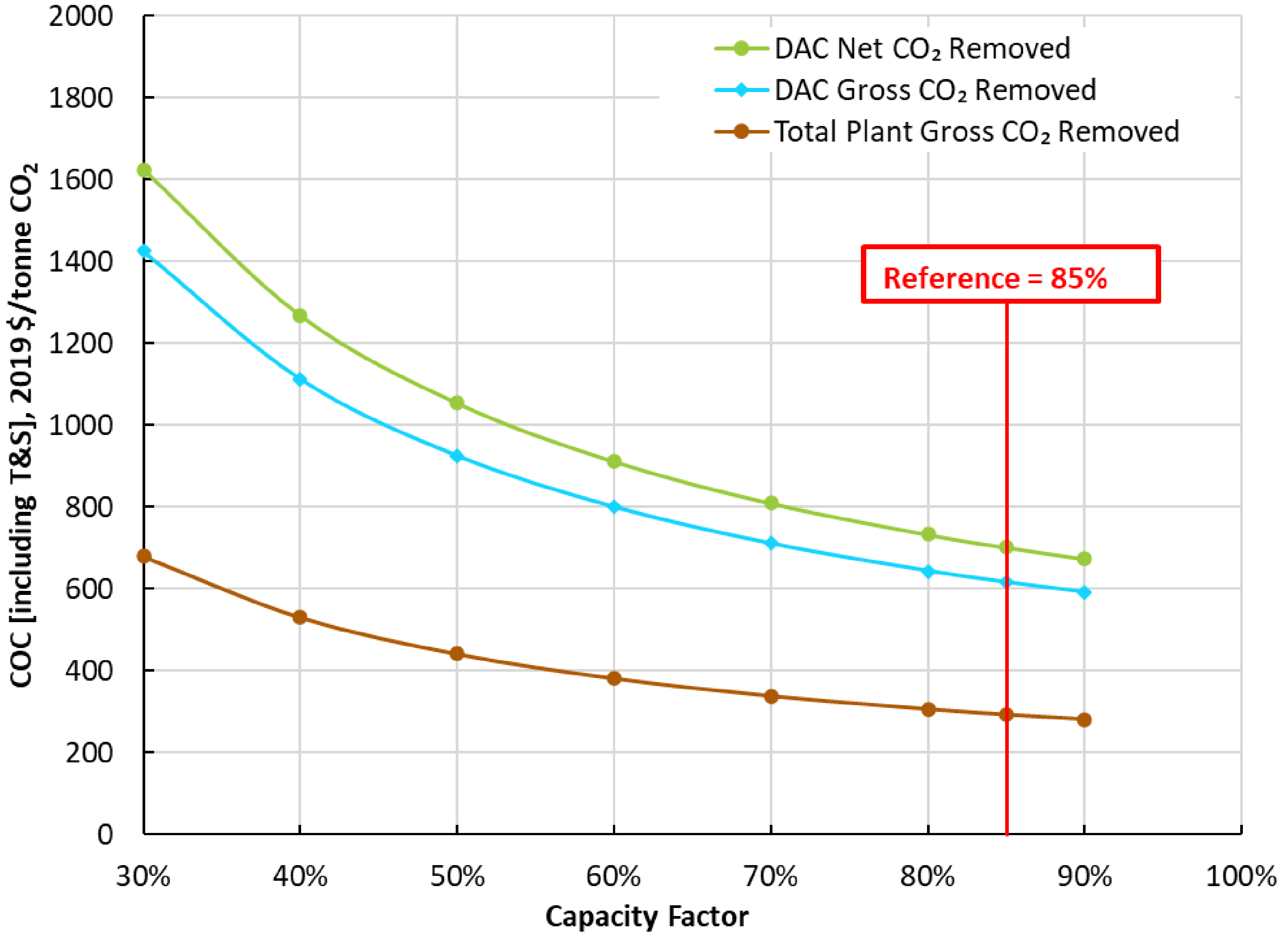
J. Valentine, A. Zoelle, "Direct Air Capture Case Studies: Sorbent System," National Energy Technology Laboratory, Pittsburgh, PA, July 8, 2022. https://netl.doe.gov/projects/files/DirectAirCaptureCaseStudiesSorbentSystem_070822.pdf

Sorbent DAC Case Study Results

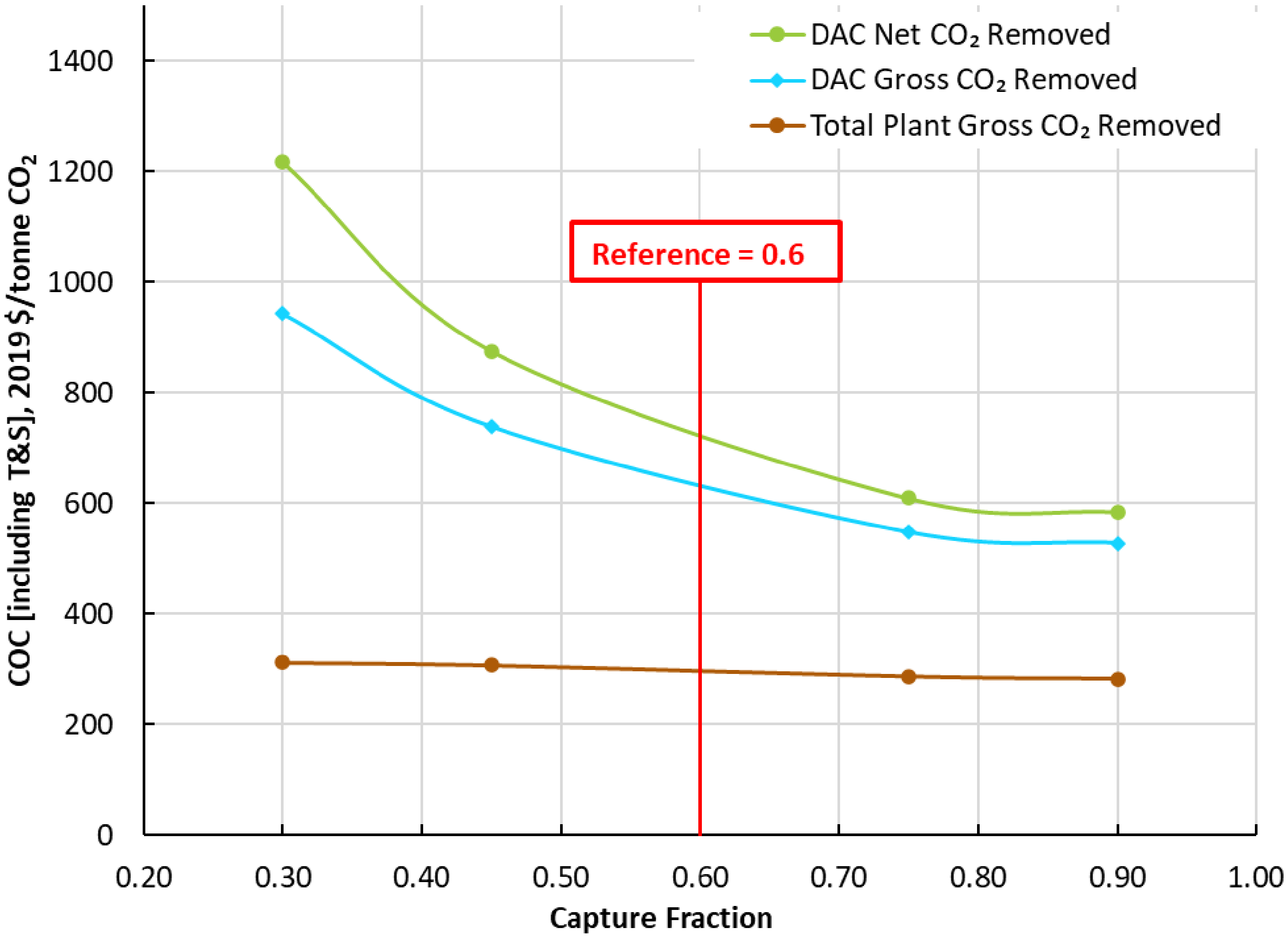


Preferred Metric for DAC

Sensitivity – Capacity Factor

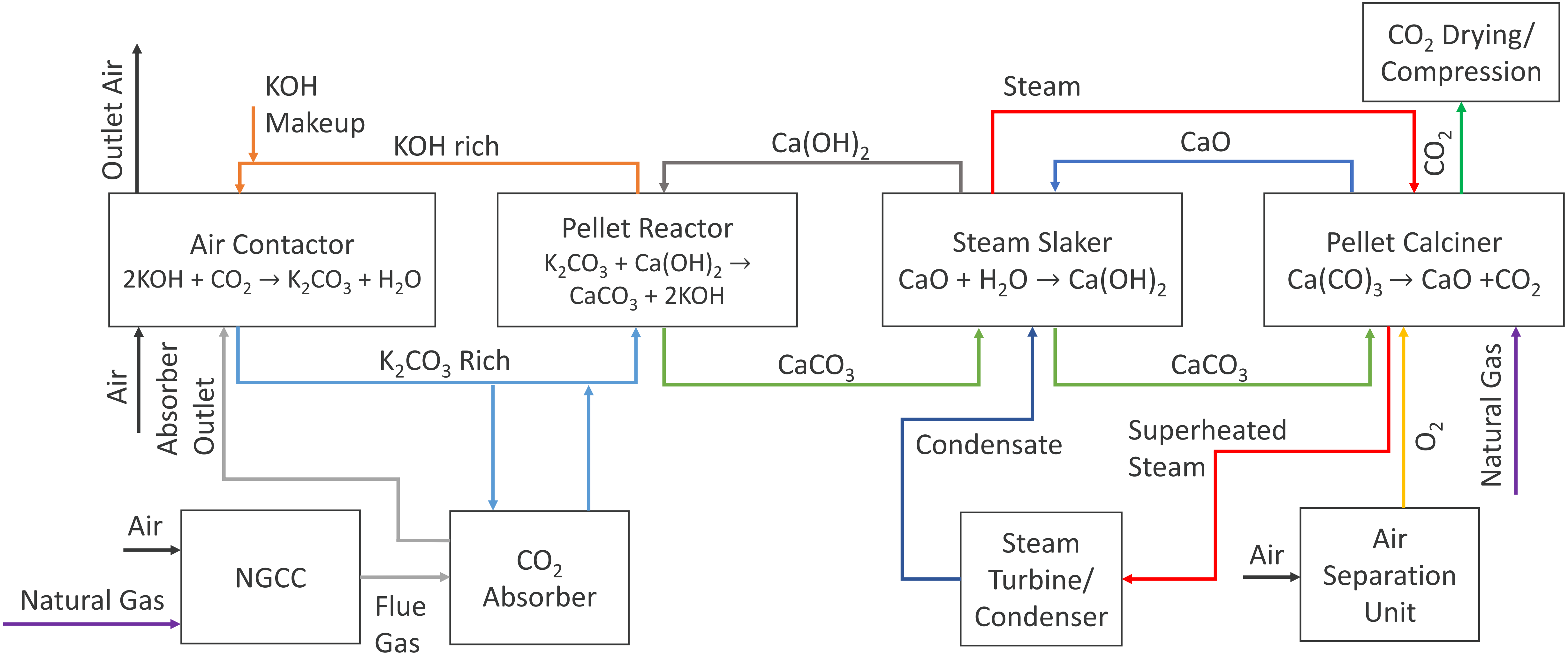


Sensitivity - Capture Fraction



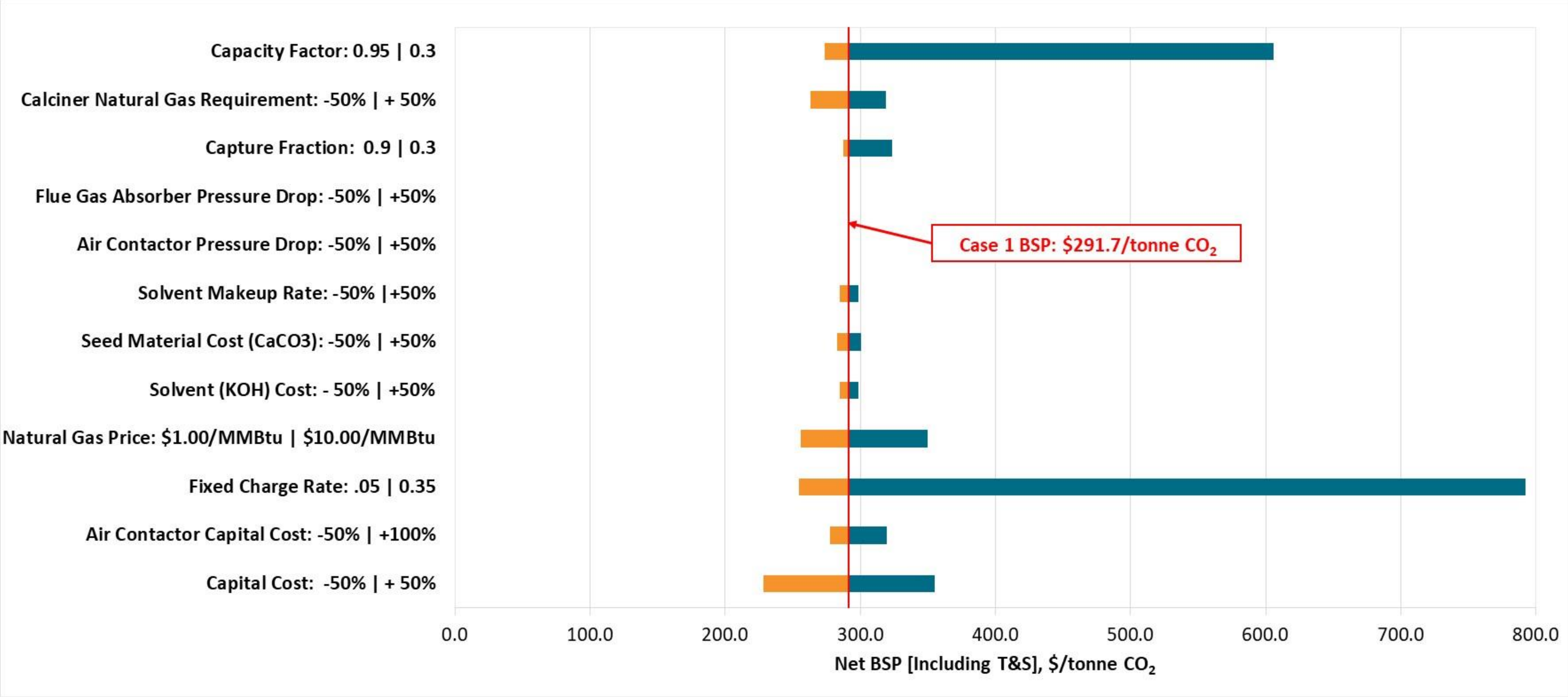
Direct Air Capture - Solvent

Solvent DAC: Simplified Block Flow Diagram



J. Valentine, and A. Zoelle, "Direct Air Capture Case Studies: Solvent System," National Energy Technology Laboratory, Pittsburgh, PA, August 31, 2022. https://netl.doe.gov/projects/files/DirectAirCaptureCaseStudiesSolventSystem_083122.pdf

Solvent DAC Results Summary



Carbon Dioxide Removal… Program Structure

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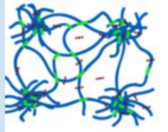
Materials

TRL 2-3

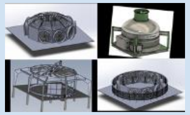



Testing novel materials & processes to efficiently remove CO_2 from atmosphere

parc A Xerox Company
HARVARD UNIVERSITY
Georgia Tech
NATIONAL ENERGY TECHNOLOGY LABORATORY
GE
Susteon
COLUMBIA UNIVERSITY

Components

TRL 4-5



Testing Structured Materials Systems & integrated bench scale systems

Global Thermostat
UK Center for Applied Energy Research
GE
CORMETECH RELIABILITY. DELIVERED.
RTI INTERNATIONAL

Field Validation

TRL 5-6

Scaling to engineering scale using existing host site infrastructure

ELECTRICORE POWERING THE FUTURE
IWVC
SOUTHERN STATES ENERGY BOARD

Pre-FEED/FEED Studies

TRL 6+

Regionally diverse CDR systems & low C energy source & Long duration C storage

SILICON KINGDOM HOLDINGS
BLACK & VEATCH
ILLINOIS

Process modeling, TEA and LCA

CCSI² Carbon Capture Simulation for Industry Impact
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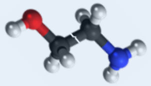

Solvents

Sorbents

Membranes

Novel Concepts

Questions/ Comments

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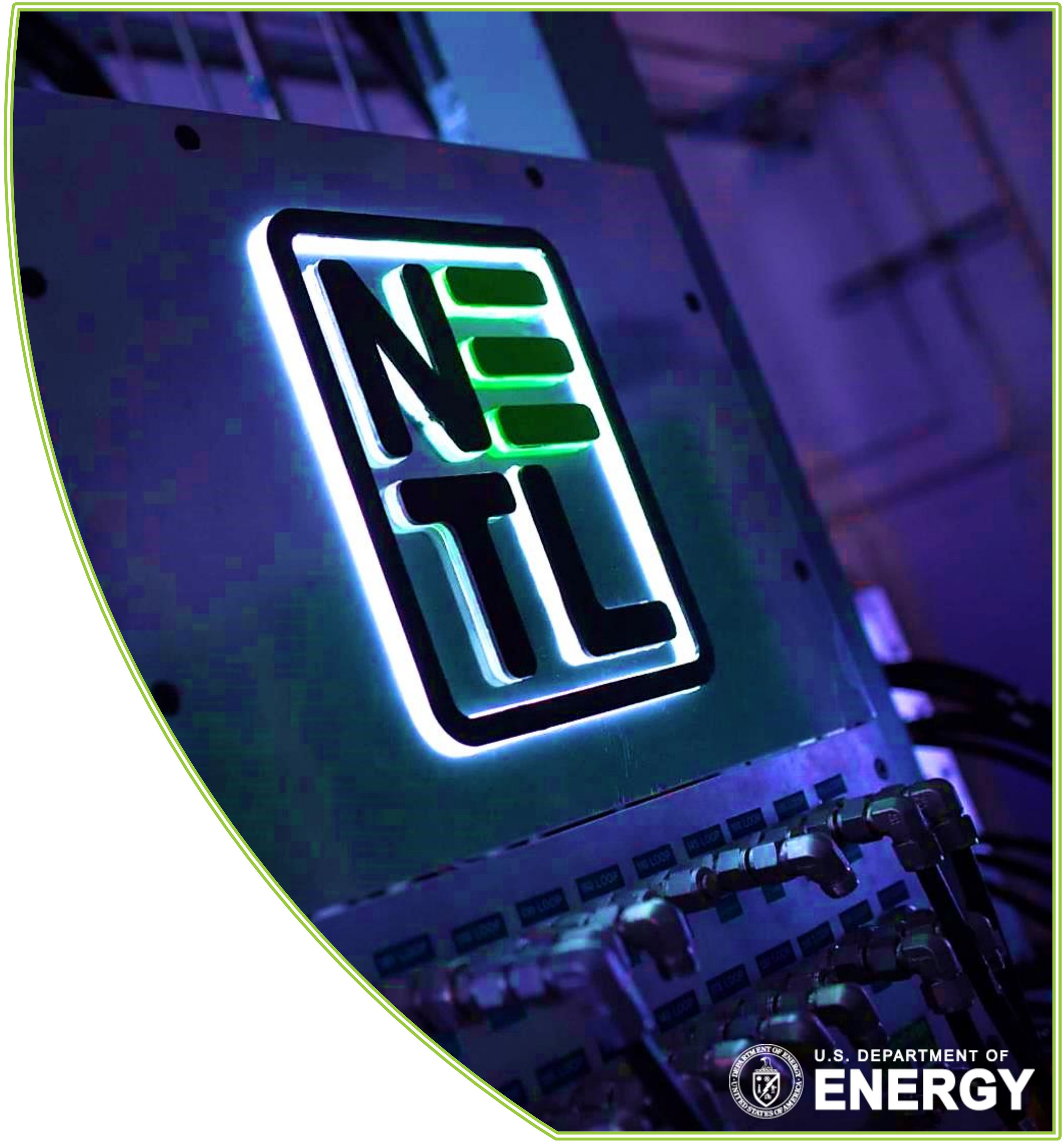

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