NETL's Cost of Capturing CO_2 from Industrial Sources and Industrial Carbon Capture Retrofit Database

USEA Webinar

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Agenda

- Overview
- Design Assumptions
- Financial Methodology
- Results Summary
- Industrial Carbon Capture Retrofit Database
- Limitations
- CCRD Demonstration
- Discussion

Overview

- This study quantifies the performance of CO_2 capture systems and their greenfield and retrofit costs when applied at nine representative industrial sources
- Representative plant sizes and CO_2 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 CO_2 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)

Design Assumptions

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- Retrofit costs were estimated for all cases, excluding CTL and GTL, by applying a factor to total plant cost (TPC)
  - High-purity retrofit factor: 1.01
  - Low-purity retrofit factor: 1.05
- High purity cases require compression and associated cooling water systems for intercooling/aftercooling
  - In some high purity cases, triethylene glycol dehydration is required to meet T&S quality specifications
- In addition to compression and intercooling/aftercooling systems, low purity cases require purification via amine-based CO_2 capture, which necessitates steam production for solvent regeneration, provided by a natural gas-fired boiler
  - In 2021, Shell provided quotes for two amine-based capture systems
    - CANSOLV post-combustion capture: Cement and Iron/Steel cases
    - ADIP-Ultra pre-combustion capture: Refinery Hydrogen case
  - Each system was quoted at 90 and 99 percent capture rates

Financial Methodology

Capital Cost Estimates and Scaling Methodology

- Capital costs were scaled per guidance in the latest revision of NETL's *QGESS Capital Cost Scaling Methodology: Revision 4 Report**
- Natural gas-fired boiler costs were scaled from a vendor quote provided in support of report development
- Compression costs were scaled from updated vendor quotes or from prior NETL study cases
- Inlet water knockout vessels and heat exchangers were considered as needed for feed streams with water content and/or temperature exceeding compressor inlet requirements
  - The costs for these equipment accounts were estimated using heuristic equations
- All cases include scaled costs for ancillary accounts such as a cooling water system, accessory electrical plant, instrumentation and control systems, site work, buildings and structures
  - These accounts were scaled from NETL's *Eliminating the Derate of Carbon Capture Retrofits***
- Operator labor is assumed with the addition of CO_2 capture in each facility; all other labor (maintenance, foreman, etc.) is considered available within the existing workforce in the reference plant for each case
  - High purity cases: 1 additional operator
  - Low purity cases: 2.3 additional operator, the difference between a supercritical pulverized coal power plant with and without 90% post-combustion capture, as shown in NETL's *Cost and Performance Baseline for Fossil Energy Plants Volume 1: Bituminous Coal and Natural Gas to Electricity*
    - Iron/Steel case adds 4.6 additional operators, as there are two separate capture and compression systems in this case

*NETL maintains a library of Quality Guidelines for Energy Systems Studies (QGESS) that is used to guide technoeconomic analyses. The QGESS documents are referenced within the report and the CCRD tool and are publicly accessible via https://netl.doe.gov/node/7513
***Eliminating the Derate of Carbon Capture Retrofits* is publicly accessible via https://www.osti.gov/biblio/1510790
****Cost and Performance Baseline for Fossil Energy Plants Volume 1: Bituminous Coal and Natural Gas to Electricity* is publicly accessible via https://netl.doe.gov/energy-analysis/details?id=e818549c-a565-4cbc-94db-442a1c2a70a9

Financial Methodology

Calculating the Cost of CO_2 Capture in Industrial Cases

- The cost of capture, excluding T&S, is calculated using the equation below, where T&S costs would be an additive cost if included

$$\left(\frac{\$}{tonne\ CO_2}\right) = \frac{TOC * CCF + FOM + VOM + PF + PP}{tonnes\ CO_2\ captured\ per\ year}$$

- Where:
  - TOC – Total overnight costs of all equipment added to support capture application
  - CCF – Capital charge factor, based on industry-specific financial assumptions
  - FOM – Annual fixed operating & maintenance (O&M) costs
  - VOM – Annual variable O&M costs
  - PF – Purchased natural gas fuel, $4.42/MMBtu
    - Used in the low purity cases to fuel the supplemental boiler required to raise steam for solvent regeneration heating needs
  - PP – Purchased power, $60/MWh
    - Grid electricity is purchased in all cases to meet the auxiliary loads of all equipment added (i.e., no on-site power generation is considered)

Financial Methodology

Case-Specific Financial Parameters

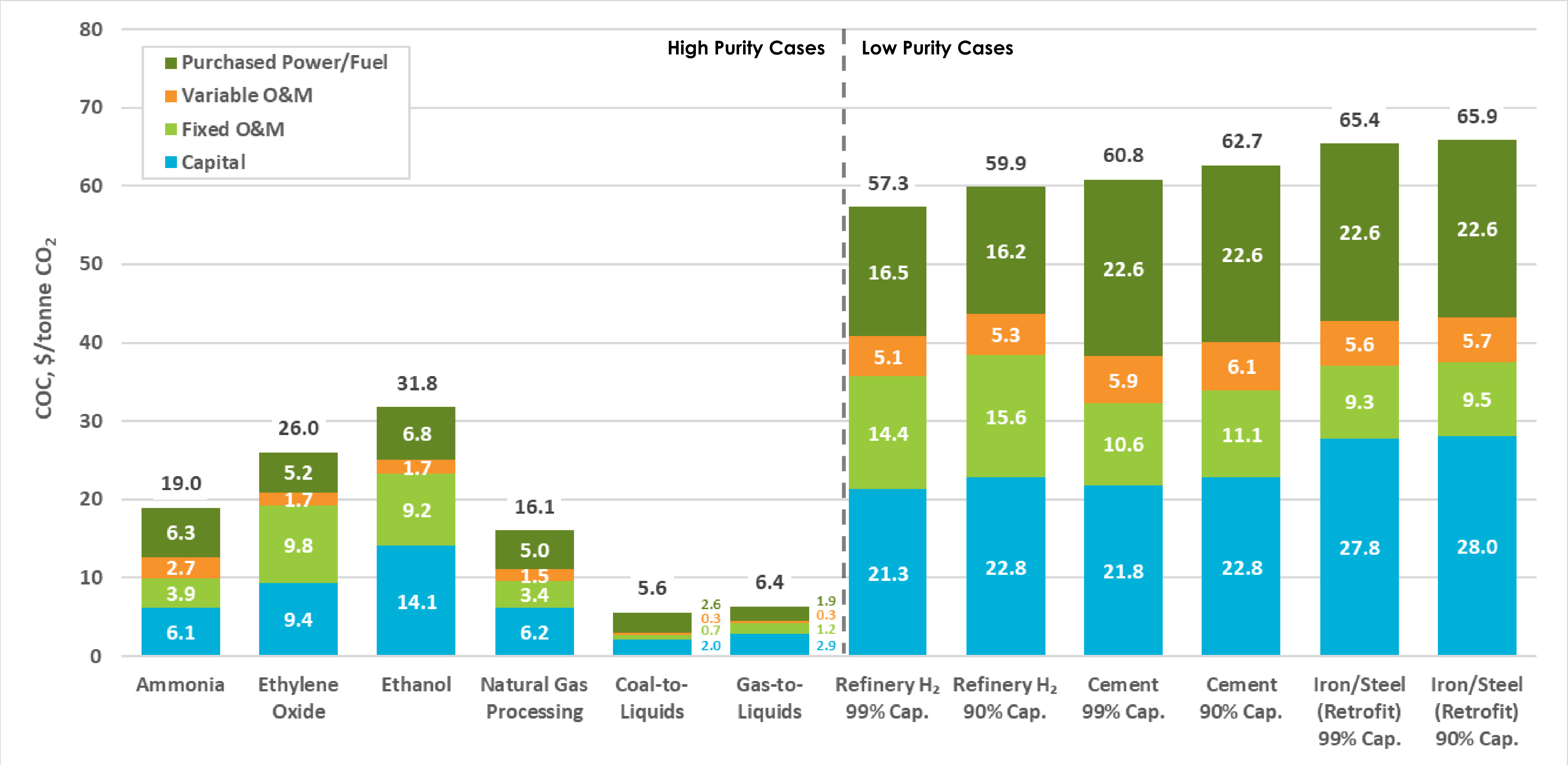
- NETL developed industry-specific financial parameters for use in the study
- A sensitivity to the resulting capital charge factors (CCFs) is provided to demonstrate the effects of market volatility on the estimated COCs

Applicable Case(s)	Ammonia	Ethylene Oxide	Ethanol	NGP	CTL/GTL	Refinery Hydrogen	Cement	Iron & Steel
CCF = TASC/TOC * FCR	**5.51%**	**4.74%**	**6.96%**	**6.05%**	**7.71%**	**4.55%**	**5.35%**	**7.53%**
FCR	5.33%	4.63%	6.64%	5.82%	7.32%	4.39%	5.08%	6.90%
TASC/TOC	1.035	1.025	1.047	1.039	1.054	1.036	1.054	1.091
Debt/Equity	54/46	48/52	36/64	43/57	32/68	33/67	42/58	39/61
Levered ROE	1.50%	0.04%	4.51%	2.96%	5.54%	0.41%	1.42%	5.02%
Pre-tax WACC	3.46%	2.49%	4.74%	3.90%	5.41%	0.87%	2.99%	5.07%
Payback Period	30-year operational period							
Interest on Debt	5.15%							
Capital Expenditure Period	1 year					3 years		
Capital Distribution	1st year – 100%					1st year – 10% 2nd year – 60% 3rd year – 30 %		

FCR = fixed charge rate; TASC = total as-spent cost; TOC = total overnight cost; WACC = weighted average cost of capital; Note: All values represent real dollars.

Results Summary

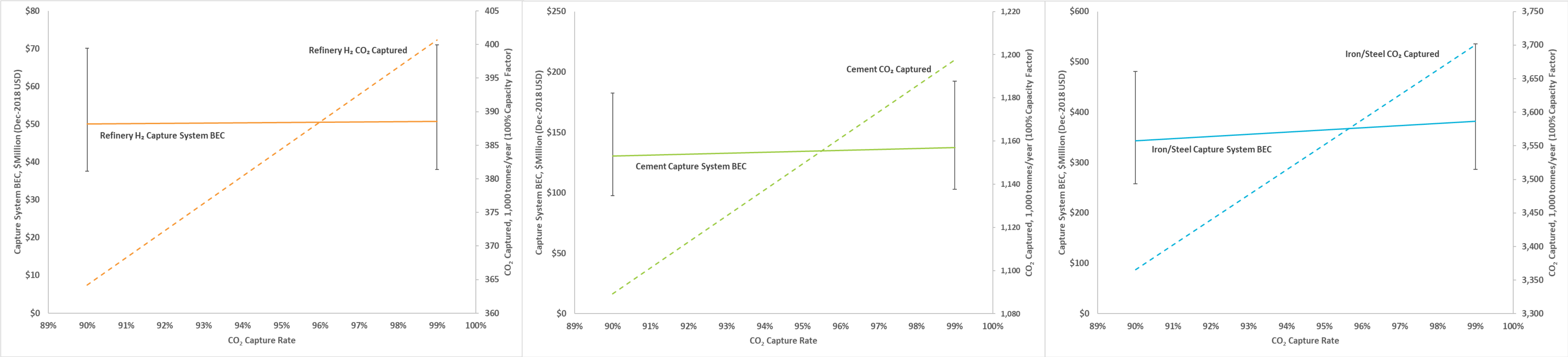
Cost of CO_2 Capture



Results Summary

Cost of Capture – Increasing Capture Rate

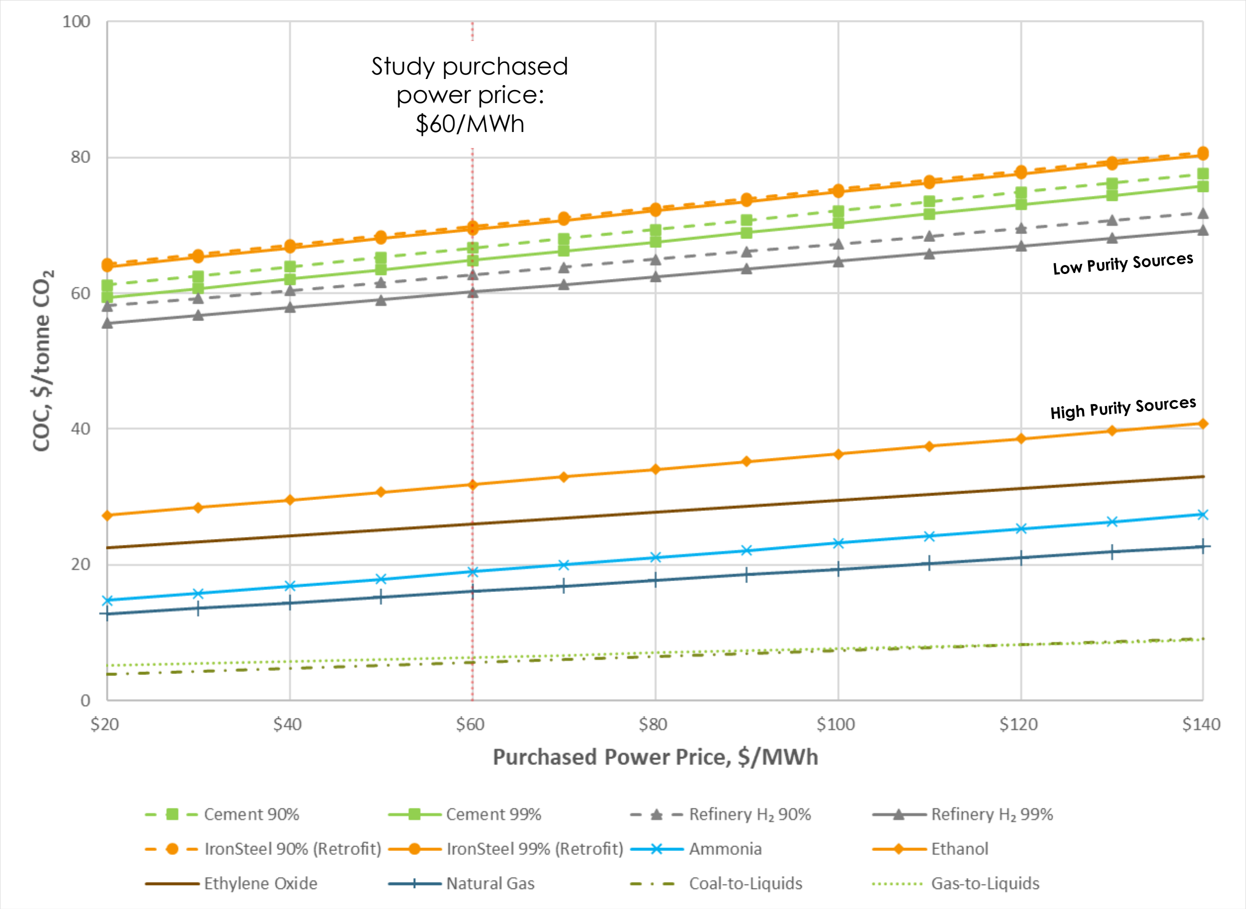
- Shell quotes a capital uncertainty range of -25/+40 percent; as such, it is reasonable to conclude that normalized cost of capture, as well as capture system BEC, are essentially the same at 90 and 99 percent capture
  - The report results are considered Class 4 estimates as defined by AACE International*
- The plots below show capture system BEC at each capture rate and the vendor's quoted range of uncertainty as error bars

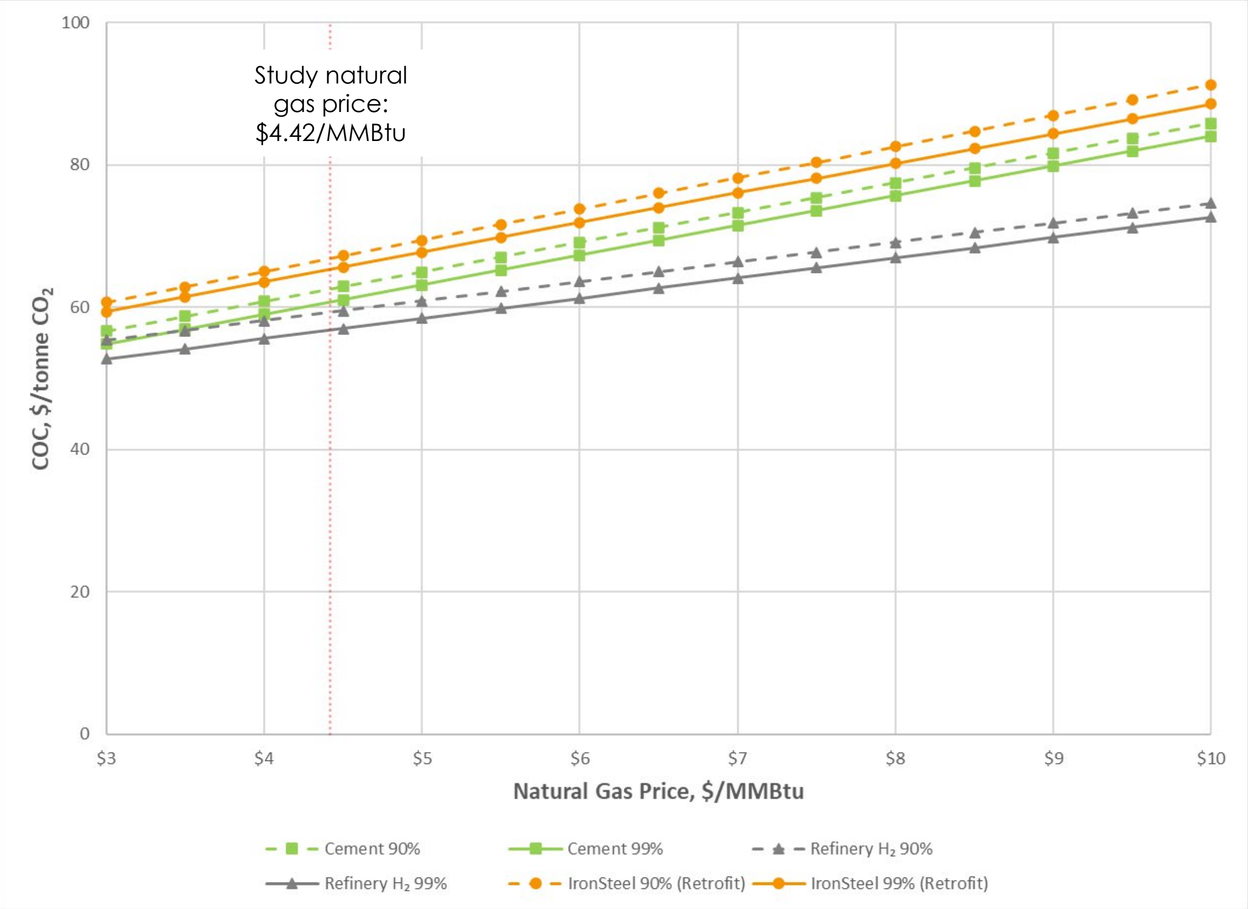


*Formerly known as The Association for the Advancement of Cost Engineering, AACE International provides cost estimate classifications in their Recommended Practice document series, accessible via https://web.aacei.org/resources/recommended-practices

Results Summary

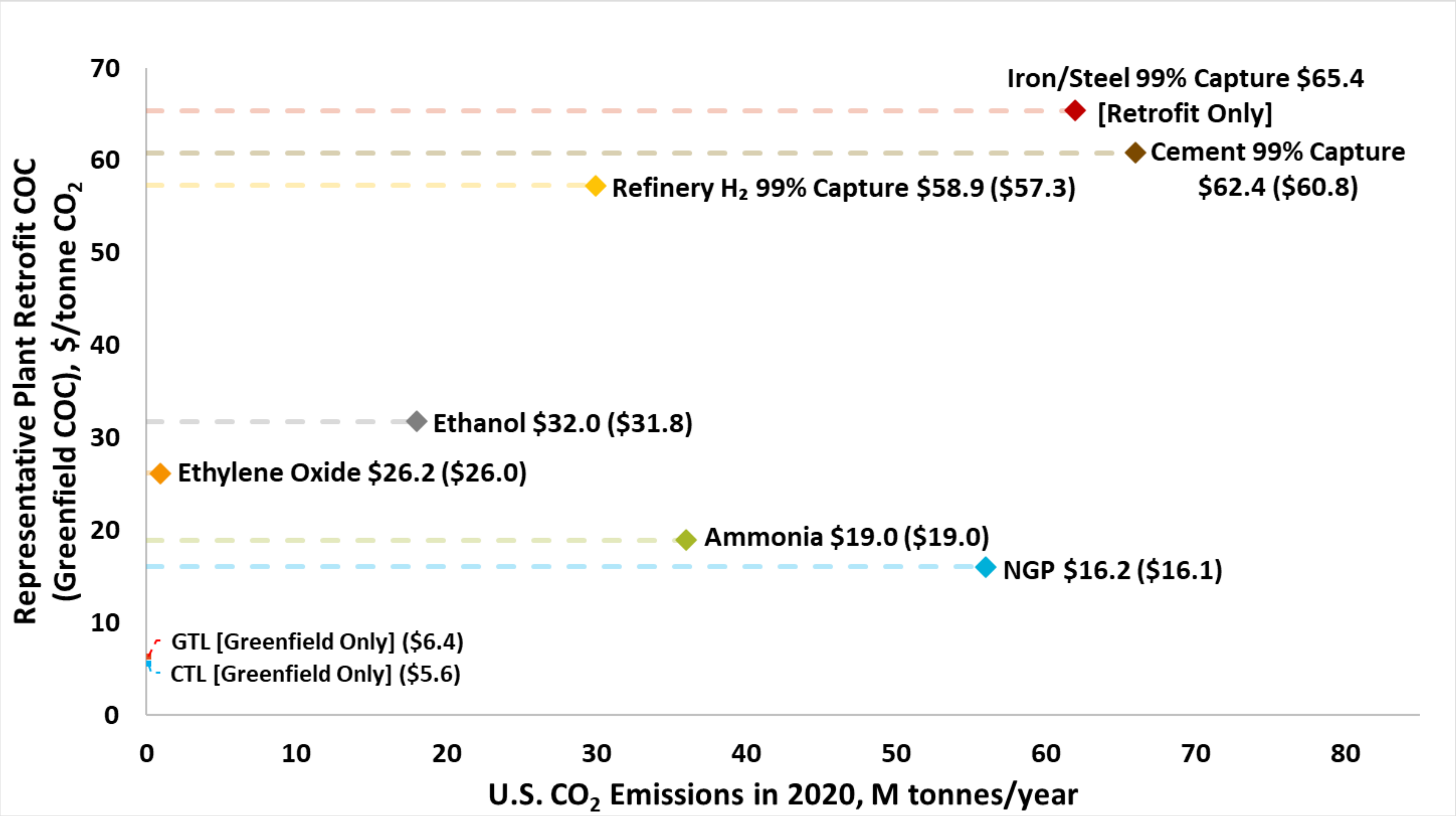
Sensitivity Analyses: Purchased Power Price and Natural Gas Price





Cost Summary

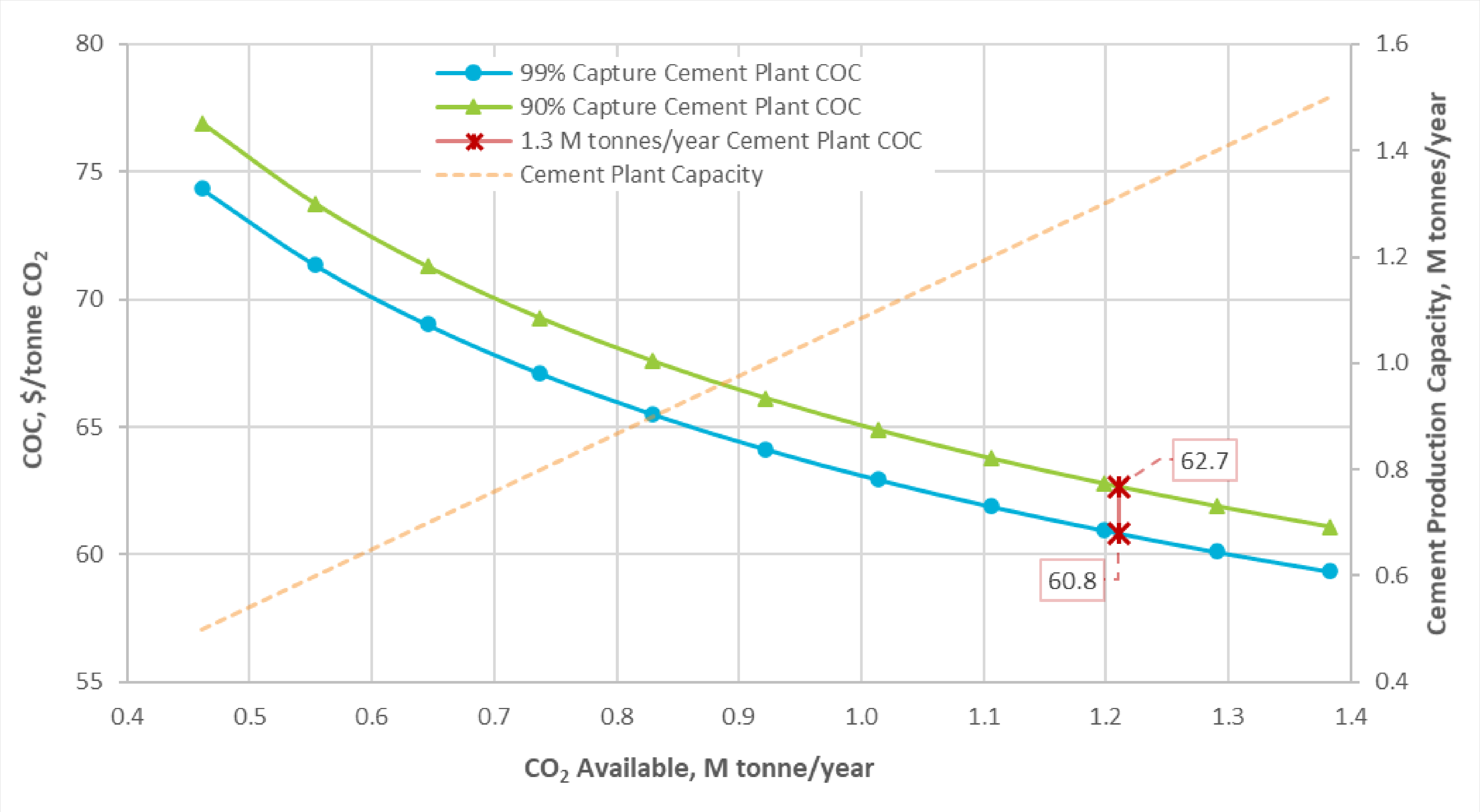
COC and Approximate U.S. Supply per Industry



CO_2 emissions as reported in 2020 obtained from the Environmental Protection Agency's (EPA) Facility Level Information on Greenhouse Gases Tool (FLIGHT). CO_2 emissions related to EO production are not reported in EPA FLIGHT; as such, the total emissions were estimated based on the total EO production as of 2019 and an emissions factor of 1:3 CO_2:EO on a molar basis, according to reaction stoichiometry.
Note: The COC for retrofit and greenfield capture in representative ammonia plant appear equivalent due to rounding.

Results Summary

Sensitivity Analysis: Cement Plant Size Sensitivity



Industrial Carbon Capture Retrofit Database

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- Publicly available spreadsheet tool to calculate high level estimates of cost of capture for a set of industrial facilities or for entire industrial sectors
- Allows for scenario analysis based on inputs and user-input assumptions
- Quickly determine cost impacts of different CO_2 capture rates, financing assumptions, utility pricing (i.e., supplemental natural gas and purchased power), etc.
- Companion tool to Cost of Capturing CO_2 from Industrial Sources, employing cost and performance assumptions developed for the report

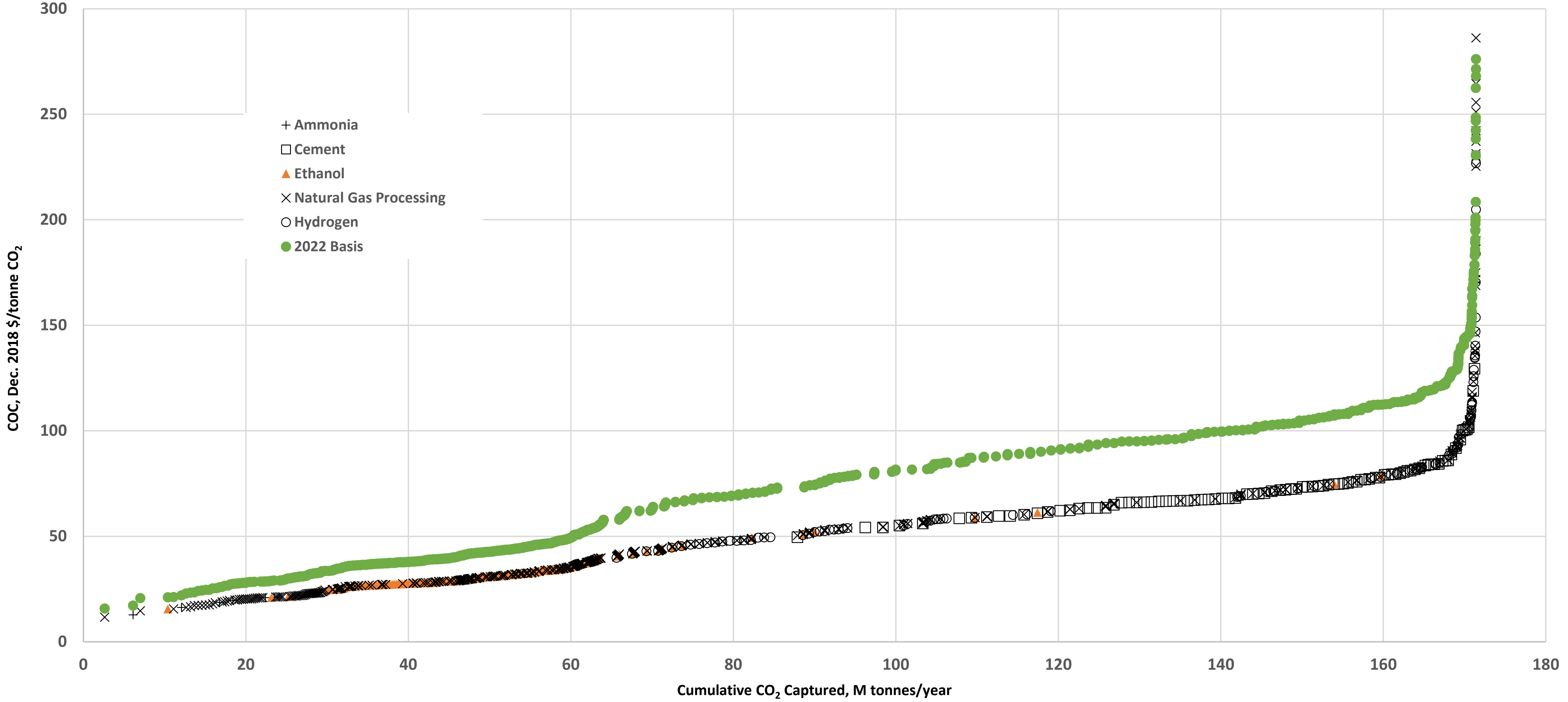
User Inputs and Constant

Input Desired Scenarios t

A	B	C	D	E	F	G	
Parameter	Units	Value					
		Ammonia	Cement	Ethanol	Hydrogen	Natural Gas	
CO_2 Capture Rate (Source 1)	Choose option	Default	Default	Default	Default	Default	Ca
	%	100%	90%	100%	99%	100%	Th
CO_2 Capture Rate (Source 2)	Choose option	Default	N/A	N/A	N/A	N/A	Ca
	%	90%	N/A	N/A	N/A	N/A	Th
Capacity Factor	Choose Option	Default	Default	Default	Default	Default	De
	%	84%	79%	84%	87%	61%	Ra
Retrofit Unit Capacity Applicability Limit	Choose Option	Default	Default	Default	Default	Default	Al
	TPD-CO_2	0	0	0	0	0	ra
Retrofit Cost Factor	Choose Option	Default	Default	Default	Default	Default	M
		1.05	1.05	1.05	1.05	1.05	
Capital Charge Factor	Choose Option	Default	Default	Default	Default	Default	An
	Choose Option	30-year	30-year	30-year	30-year	30-year	co
		0.055	0.054	0.070	0.046	0.060	va
Advanced Options							
Maximum CO_2 Capture Rate Per Train	Choose option	Default	Default	Default	Default	Default	If
	TPD	21,867	27,430	122,453	54,516	121,229	
Cost Year Basis	Choose Option	Default	Default	Default	Default	Default	Sc
	Year	2018	2018	2018	2018	2018	av
Cooling preference	Choose Option	State	State	State	State	State	St
Purchased Electricity Price	Choose Option	State	State	State	State	State	Pr
	$/MWh	Varies by State	Varies by State	Varies by State	Varies by State	Varies by State	th
Purchased Natural Gas Price	Choose Option	State	State	N/A	State	N/A	Pr
	$/MMBtu	Varies by State	Varies by State	N/A	Varies by State	N/A	ea
Additional Auxiliary Load Penalty	Choose Option	None	None	None	None	None	Th
	kW/TPD-CO_2	N/A	N/A	N/A	N/A	N/A	
CO_2 Transport and Storage Costs	Choose Option	Default	Default	Default	Default	Default	Th
	$/tonne captured	10	10	10	10	10	Th
Include Natural Gas Boiler Emissions in Capture Feed	Choose Option	Yes	Yes	N/A	Yes	N/A	If

Industrial Carbon Capture Retrofit Database

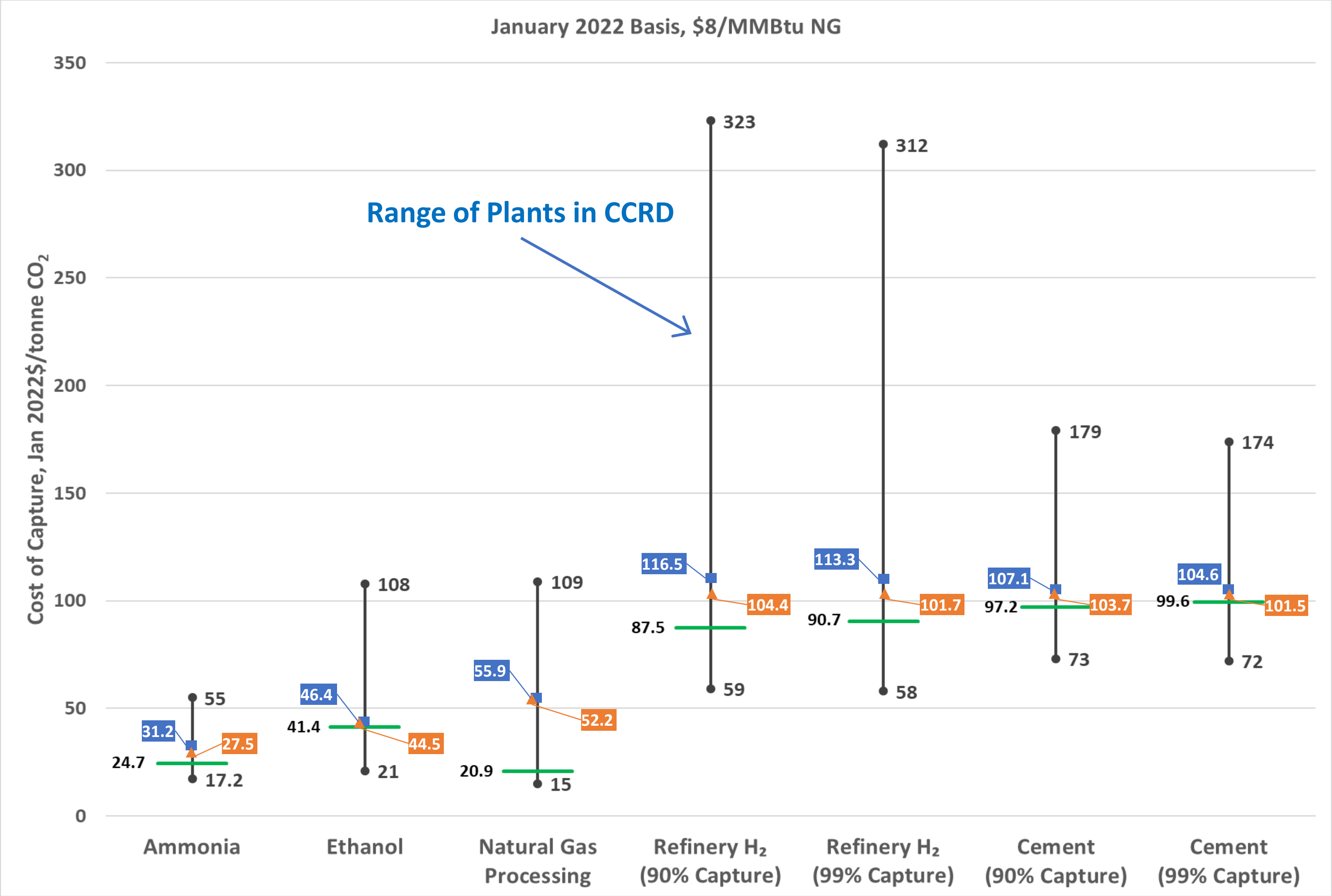
CCRD CO_2 Supply Curve using Industrial Report Parameters



Industrial Carbon Capture Retrofit Database

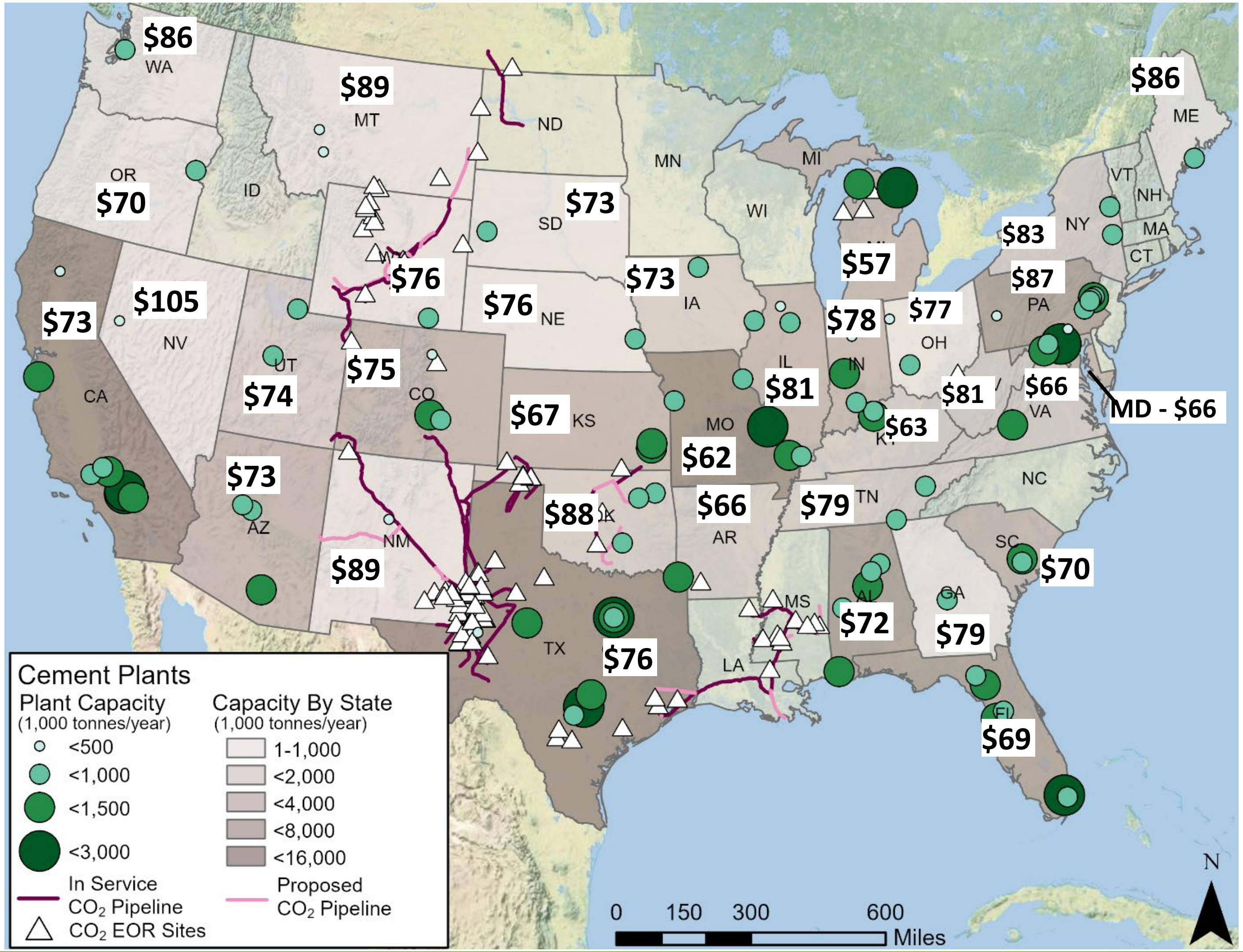
Comparison of Industrial Report Cases with Plant Database Range from CCRD

- Report Case
- CCRD Plant Range Median COC
- CCRD Plant Range Mean COC



Industrial Carbon Capture Retrofit Database

Cement Plants by State – Industrial Report Parameters



Source: NETL

Limitations

- The results of the industrial capture report are not meant to be representative of actual CO_2 capture costs in any industry evaluated
  - For all cases, assumptions regarding the base plant have been made. Some will be less impactful to COC (i.e., water content in a stream balanced by very high concentrations of CO_2); others (e.g., CO_2 content in the cement plant flue gas, CO_2 content in the raw natural gas inlet to the natural gas processing plant) will have significant impacts on COC
  - Capital costs in the report represent an AACE Class 4 estimate; significant additional study (i.e., front-end engineering design study) is needed to reduce uncertainty to the degree necessary for project authorization/budget decisions
- The Industrial CCRD is not meant to provide actual CO_2 capture costs for any industrial plant or sector but is a valuable tool for comparative analysis between plants within an industry or for one industry versus another (i.e., comparing capture in the ammonia sector versus the cement sector)

Content Links

Report: Cost of Capturing CO_2 from Industrial Sources, 2022
https://www.netl.doe.gov/energy-analysis/details?id=865aaad2-9252-44d9-a48a-95599b3072b4

User Guide: Industrial CCRD, 2022

https://www.netl.doe.gov/energy-analysis/details?id=e6179238-998a-4b5d-9585-52ff3eb9287e

Tool: Industrial CCRD, 2022

https://www.netl.doe.gov/energy-analysis/details?id=a9f14d58-52d3-4a06-85cc-33d5cba5c895

Questions/ Comments

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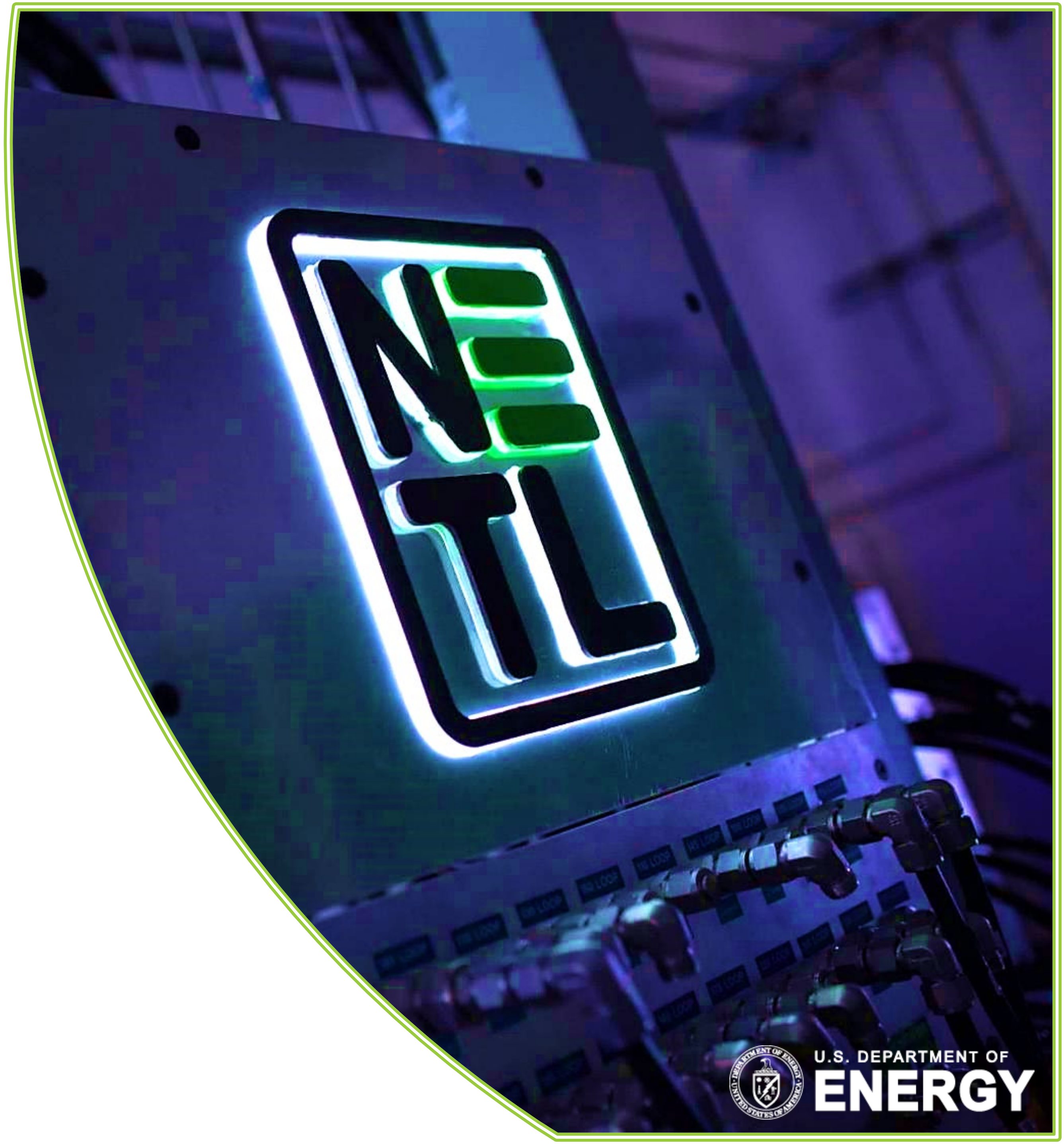

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This report was peer reviewed by three independent peer reviewers with various affiliations and from relevant scientific disciplines to ensure that information presented is based on sound and credible science and considered technically adequate, competently performed, properly documented, and in compliance with established quality requirements. As a step beyond standard internal quality assurance and quality control procedures, the U.S. Department of Energy (DOE) Office of Fossil Energy and Carbon Management (FECM)/NETL are committed to rigorous peer review of key work products to meet the quality standards of the research community. The following individuals served on the peer review panel:

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- **Technical expert (anonymity requested)**

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