Recent Point Source Capture Techno-economic Analysis

NATIONAL ENERGY TECHNOLOGY LABORATORY

Solutions for Today | Options for Tomorrow

Sally Homsy[2], Tim Fout[1]
[1]National Energy Technology Laboratory (NETL)
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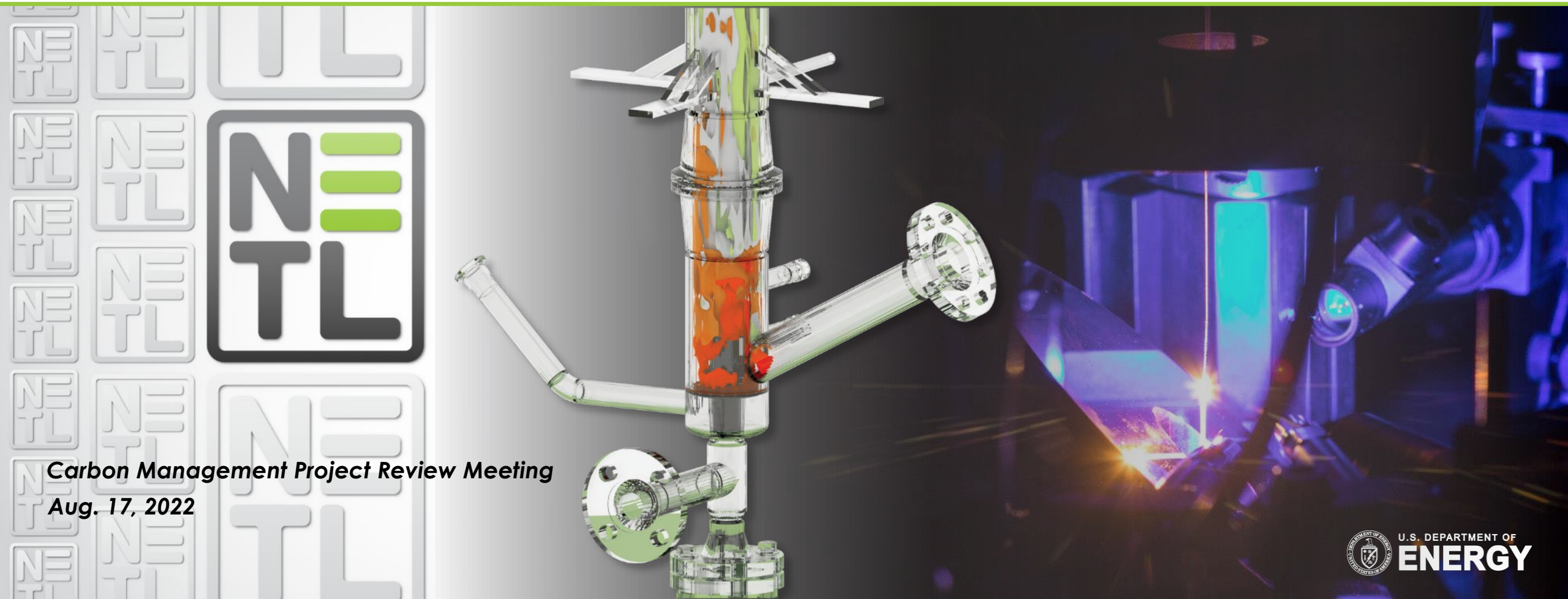


Carbon Management Project Review Meeting
Aug. 17, 2022

U.S. DEPARTMENT OF ENERGY

Overview

1. NETL's "Cost of Capturing CO_2 from Industrial Sources" report, published in 2014[1], is being updated. The methodology and performance and cost results will be highlighted in this presentation.

2. Other ongoing techno-economic analyses will also be highlighted. This includes upcoming updates to legacy point-source capture reports, novel point-source capture reports, and carbon dioxide removal reports.

[1]W. Summers, S. Herron and A. Zoelle "Cost of Capturing CO_2 from Industrial Sources," National Energy Technology Laboratory, Pittsburgh, January 10, 2014.

RESULTS NOT FINAL, CURRENTLY UNDER REVIEW

Cost of Capturing CO_2 from Industrial Sources – Revision 1

Sydney Hughes[2], Alex Zoelle[3], Mark Woods[2], Sam Henry[2], Sally Homsy[2], Sandeep Pidaparti[2], Norma Kuehn[2], Hannah Hoffman[2], Katie Forrest[2], Travis Shultz[1], Tim Fout[1], Robert James[1], W. Morgan Summers[1], Steve Herron[3]

[1]NETL
[2]NETL support contractor
[3]Former NETL support contractor

Industrial Capture Report

Introduction

- The purpose of this study is to update a 2014 NETL study[1] that quantifies the cost and performance associated with capturing point-source CO_2 from industrial plants.
- Representative plant sizes and CO_2 available for capture are presented:

	Industrial Plant Type	Representative Industrial Plant Size (product)	CO_2 Available (tonnes/year)	CO_2 Concentration (mol%)
"High-Purity" Sources	Ammonia	394,000 tonnes/year	486,255	97
	Ethylene Oxide	364,500 tonnes/year	121,500	100
	Ethanol	50 M gallons/year	143,108	100
	Natural Gas Processing	330 MMSCFD	649,198	99
	Coal-to-Liquids (CTL)	50,000 BPD	8,740,000	100
	Gas-to-Liquids (GTL)	50,000 BPD	1,860,000	100
"Low-Purity" Sources	Refinery Hydrogen	87,000 tonnes/year	404,700	12.9
	Cement	1.29 M tonnes/year	1,210,000	22.4
	Iron/Steel	2.54 M tonnes/year	3,740,000	23.5

[1]W. Summers, S. Herron and A. Zoelle "Cost of Capturing CO_2 from Industrial Sources," National Energy Technology Laboratory, Pittsburgh, January 10, 2014.

RESULTS NOT FINAL, CURRENTLY UNDER REVIEW

Industrial Capture Report

Design Assumptions

- 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.
- Retrofit costs were estimated for all base cases, excluding coal-to-liquids and gas-to-liquids, by applying a factor to total plant cost.
  - Low-purity retrofit factor: 1.05
  - High-purity retrofit factor: 1.01
- High-purity cases require compression and associated cooling water systems for intercooling/aftercooling.
- In addition to compression and intercooling/aftercooling systems, low-purity cases require carbon capture; amine-based CO_2 capture systems and required balance-of-plant systems, including steam production via a natural gas-fired industrial boiler, are modeled.
  - Shell's Cansolv post-combustion capture: Cement and Iron/Steel cases.
  - Shell's ADIP-Ultra pre-combustion capture: Refinery Hydrogen case.

RESULTS NOT FINAL, CURRENTLY UNDER REVIEW

Industrial Capture Report

Cost of CO_2 Capture

- The cost of capture, excluding transport and storage (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 the application of CO_2 capture.
  - CCF – Capital charge factor based on financial assumptions developed from industry-specific market data.
  - FOM – Annual fixed operating and maintenance (O&M) costs.
  - VOM – Annual variable O&M costs.
  - PF – Purchased fuel.
  - PP – Purchased power.

RESULTS NOT FINAL, CURRENTLY UNDER REVIEW

Industrial Capture Report

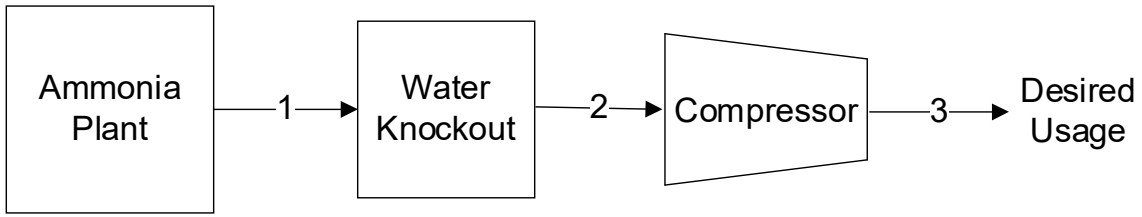
Case Description: Ammonia (NH_3)

Representative Plant Capacity:

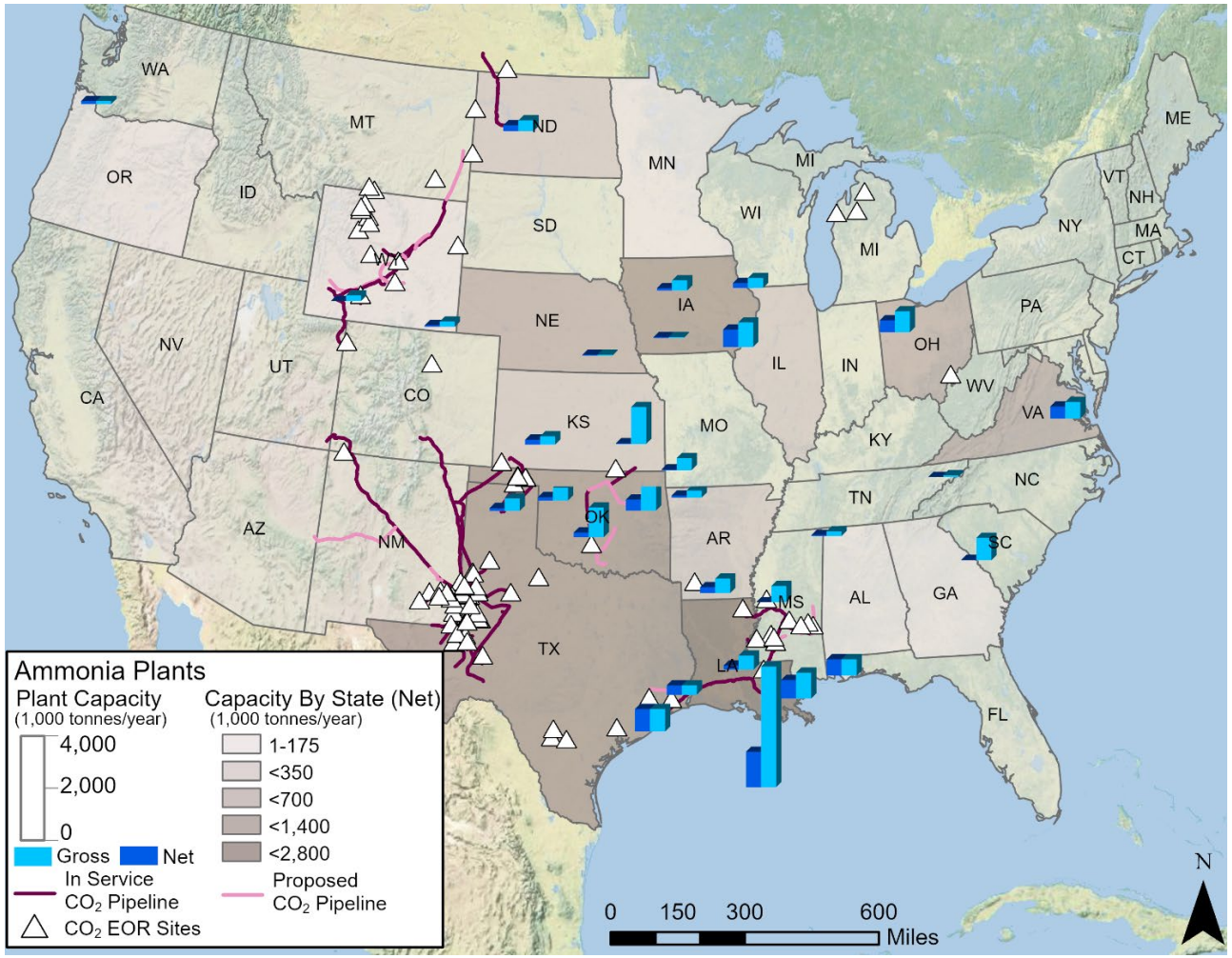
- 394,000 tonnes NH_3/year.

CO_2 Available for Capture:

- 486,255 tonnes/year.
- 97.09 mol% CO_2 at 23.52 psia and 69°F.



Inlet water knockout size and cost developed using general design heuristics[1]; reciprocating compressor scaled from a vendor quote; cooling tower, triethylene glycol (TEG) dryer, ancillary equipment and materials are scaled using performance and cost data from legacy NETL studies[2].



Source: NETL

[1]Turton, Richard, et al. (2018). Analysis, Synthesis, and Design of Chemical Processes (5th ed.). Boston, MA: Pearson Education.
[2]NETL, Cost and Performance Baseline for Fossil Energy Plants Volume 1: Bituminous Coal and Natural Gas to Electricity, U.S. DOE/NETL, Pittsburgh, 2019.

RESULTS NOT FINAL, CURRENTLY UNDER REVIEW

Industrial Capture Report

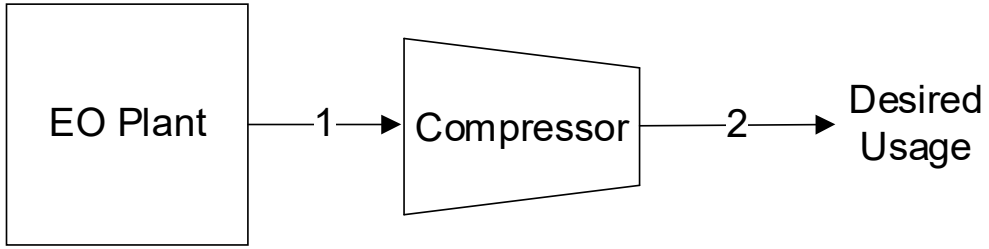
Case Description: Ethylene Oxide (EO)

Representative Plant Capacity:

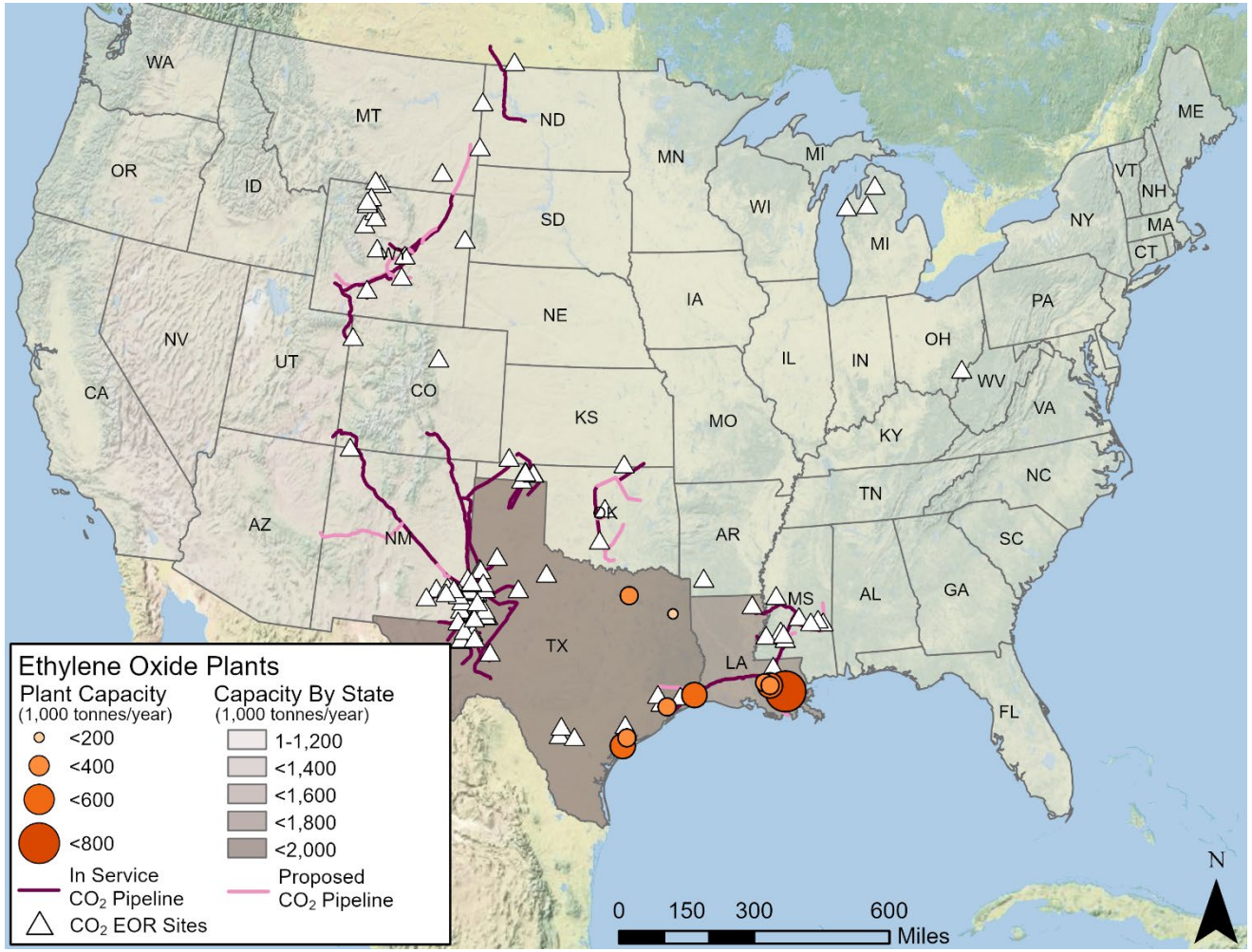
- 364,500 tonnes EO/year.

CO_2 Available for Capture:

- 121,500 tonnes/year.
- 100 mol% CO_2 at 43.5 psia and 96°F.



Reciprocating compressor scaled from vendor quote; cooling tower and ancillary equipment and materials scaled using performance and cost data from legacy NETL studies[1].



Source: NETL

[1]NETL, Cost and Performance Baseline for Fossil Energy Plants Volume 1: Bituminous Coal and Natural Gas to Electricity, U.S. DOE/NETL, Pittsburgh, 2019.

RESULTS NOT FINAL, CURRENTLY UNDER REVIEW

Industrial Capture Report

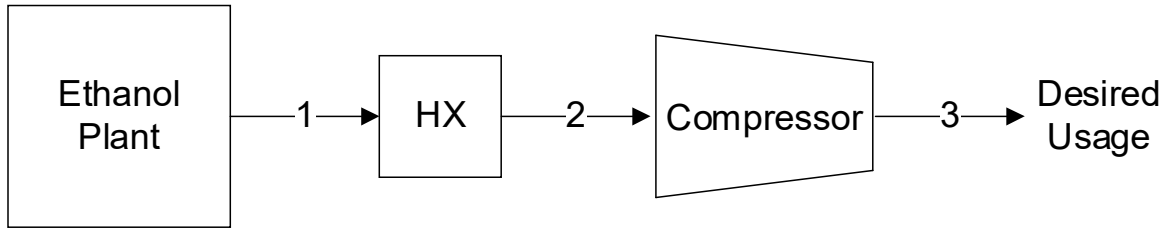
Case Description: Ethanol (EtOH)

Representative Plant Capacity:

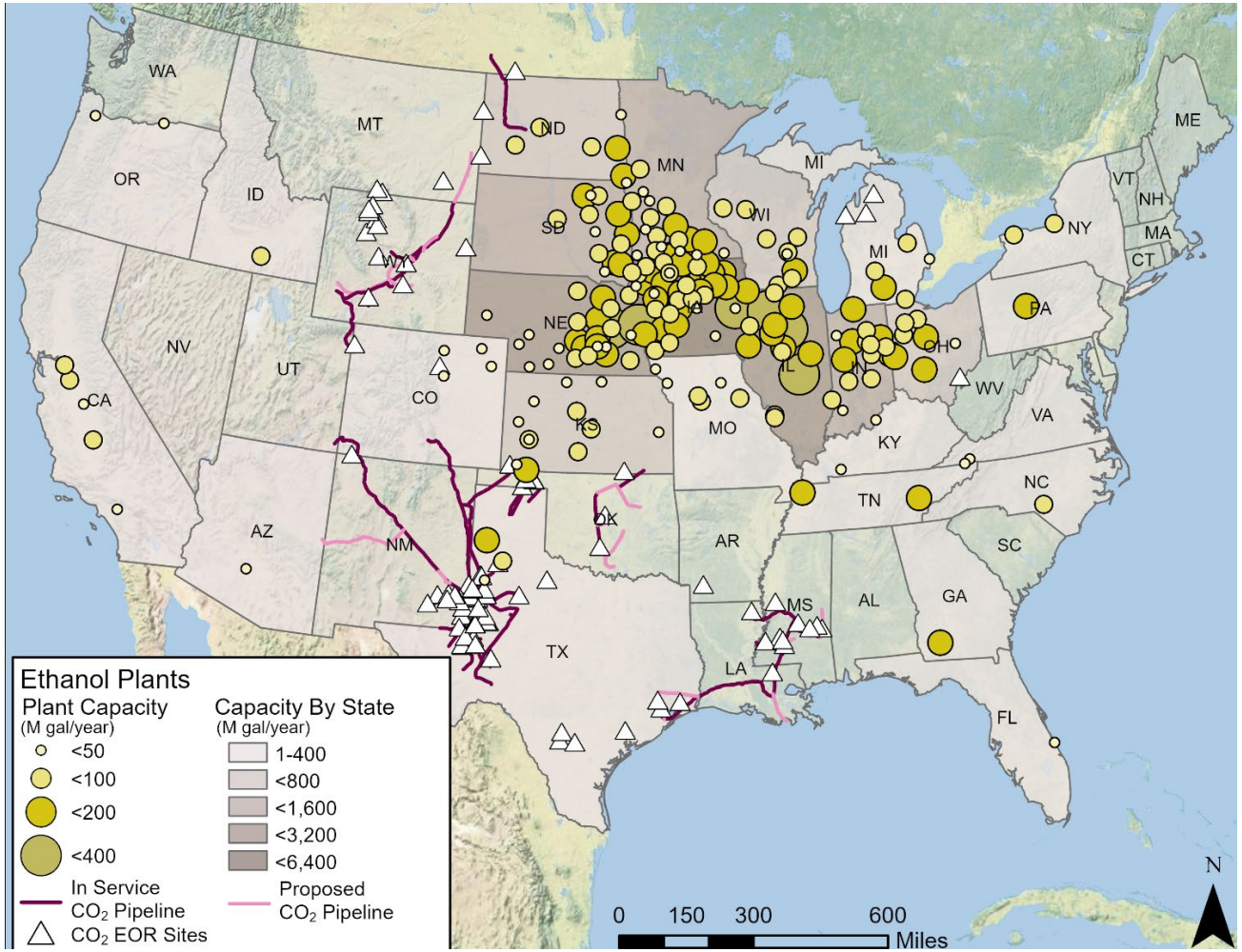
- 50,000,000 gallons EtOH/year.

CO_2 Available for Capture:

- 143,108 tonnes/year.
- 100 mol% CO_2 at 17.4 psia and 320°F.



Inlet cooler size and cost developed using general design heuristics[1]; reciprocating compressor scaled from a vendor quote; cooling tower, ancillary equipment and materials are scaled using performance and cost data from legacy NETL studies[2].



[1]NETL, Cost and Performance Baseline for Fossil Energy Plants Volume 1: Bituminous Coal and Natural Gas to Electricity, U.S. DOE/NETL, Pittsburgh, 2019.
[2]Turton, Richard, et al. (2018). Analysis, Synthesis, and Design of Chemical Processes (5th ed.). Boston, MA: Pearson Education.

Source: NETL

RESULTS NOT FINAL, CURRENTLY UNDER REVIEW

Industrial Capture Report

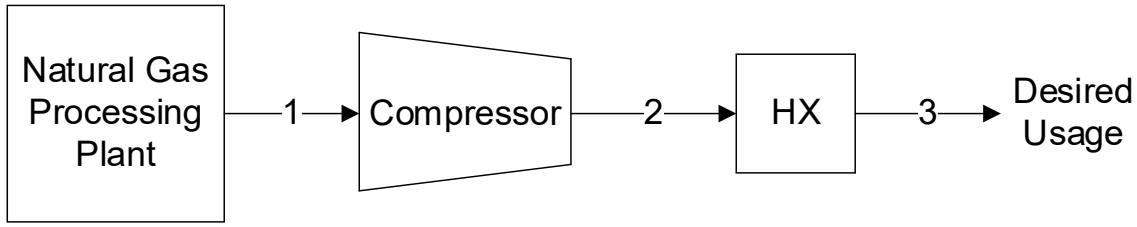
Case Description: Natural Gas Processing

Representative Plant Capacity:

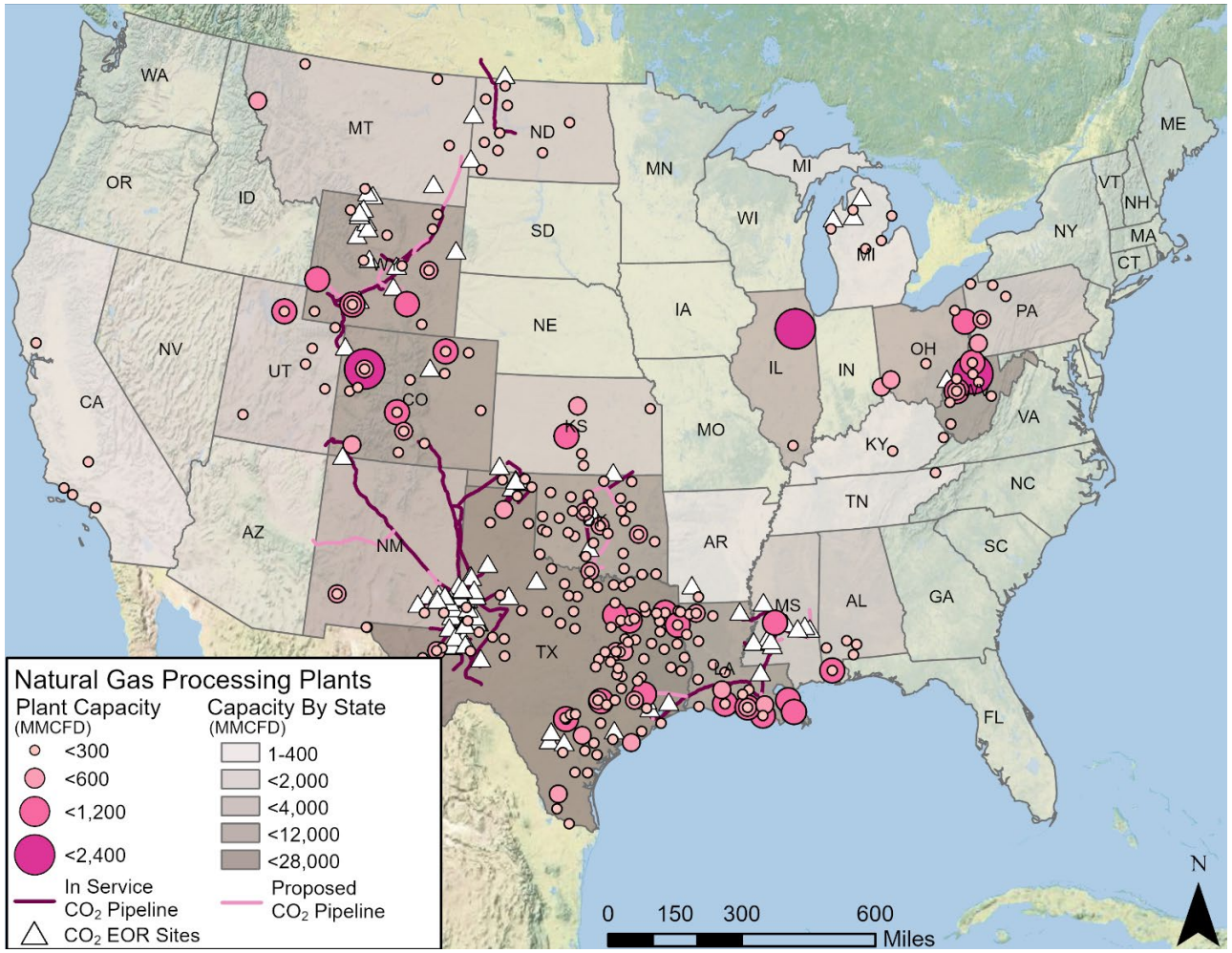
- 330 MMSCFD Natural Gas.
- Assume 10.2 mol% CO_2 natural gas; this value varies widely across the industry.

CO_2 Available for Capture:

- 649,198 tonnes/year.
- 99 mol% CO_2 at 23.52 psia and 69°F.



Integrally-geared centrifugal compressor (includes intercooling, TEG dryer, and interstage water knockouts), outlet cooler, ancillary equipment and materials scaled using performance and cost data from legacy NETL studies[1].



Source: NETL

[1]NETL, Cost and Performance Baseline for Fossil Energy Plants Volume 1: Bituminous Coal and Natural Gas to Electricity, U.S. DOE/NETL, Pittsburgh, 2019.

RESULTS NOT FINAL, CURRENTLY UNDER REVIEW

Industrial Capture Report

Coal-to-Liquids

Representative Plant Capacity:

- 50,000 BPD Fischer-Tropsch liquids.

CO_2 Available for Capture:

- 8.74 M tonnes/year.
- Gasification sources: 100 mol% CO_2 at 160 psia and 60°F; 100 mol% CO_2 at 300 psia and 60°F.
- Fischer-Tropsch: 100 mol% CO_2 at 265 psia and 100°F.

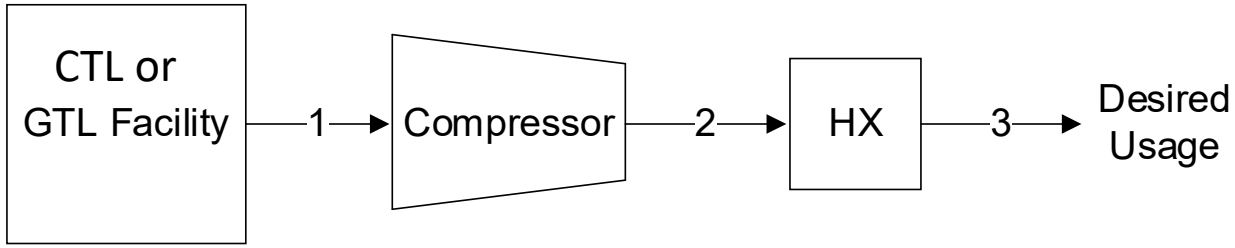
Gas-to-Liquids

Representative Plant Capacity:

- 50,000 BPD Fischer-Tropsch liquids.

CO_2 Available for Capture:

- 1.86 M tonnes/year.
- Fischer-Tropsch source: 100 mol% CO_2 at 265 psia and 100°F.



Compressor, after cooler, water cooler, ancillary equipment and materials scaled using performance and cost data from legacy NETL studies[1,2,3].

[1]NETL, Cost and Performance Baseline for Fossil Energy Plants Volume 4: Coal-to-Liquids via Fischer-Tropsch Synthesis, U.S. DOE/NETL, Pittsburgh, 2014.
[2]NETL, Cost and Performance Baseline for Fossil Energy Plants Volume 1: Bituminous Coal and Natural Gas to Electricity, U.S. DOE/NETL, Pittsburgh, 2019.
[3]NETL, Analysis of Natural Gas-to-Liquid Transportation Fuels via Fischer-Tropsch, U.S. DOE/NETL, Pittsburgh, 2013.

RESULTS NOT FINAL, CURRENTLY UNDER REVIEW

Industrial Capture Report

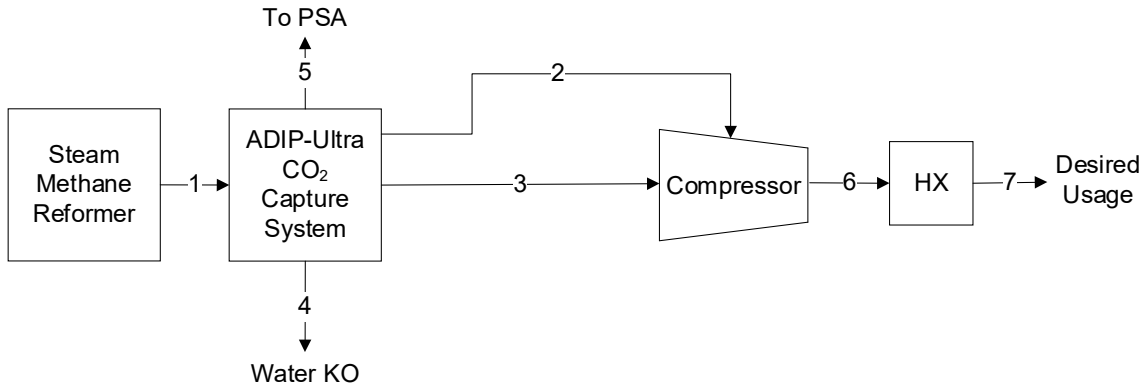
Case Description: Refinery Hydrogen

Representative Plant Capacity:

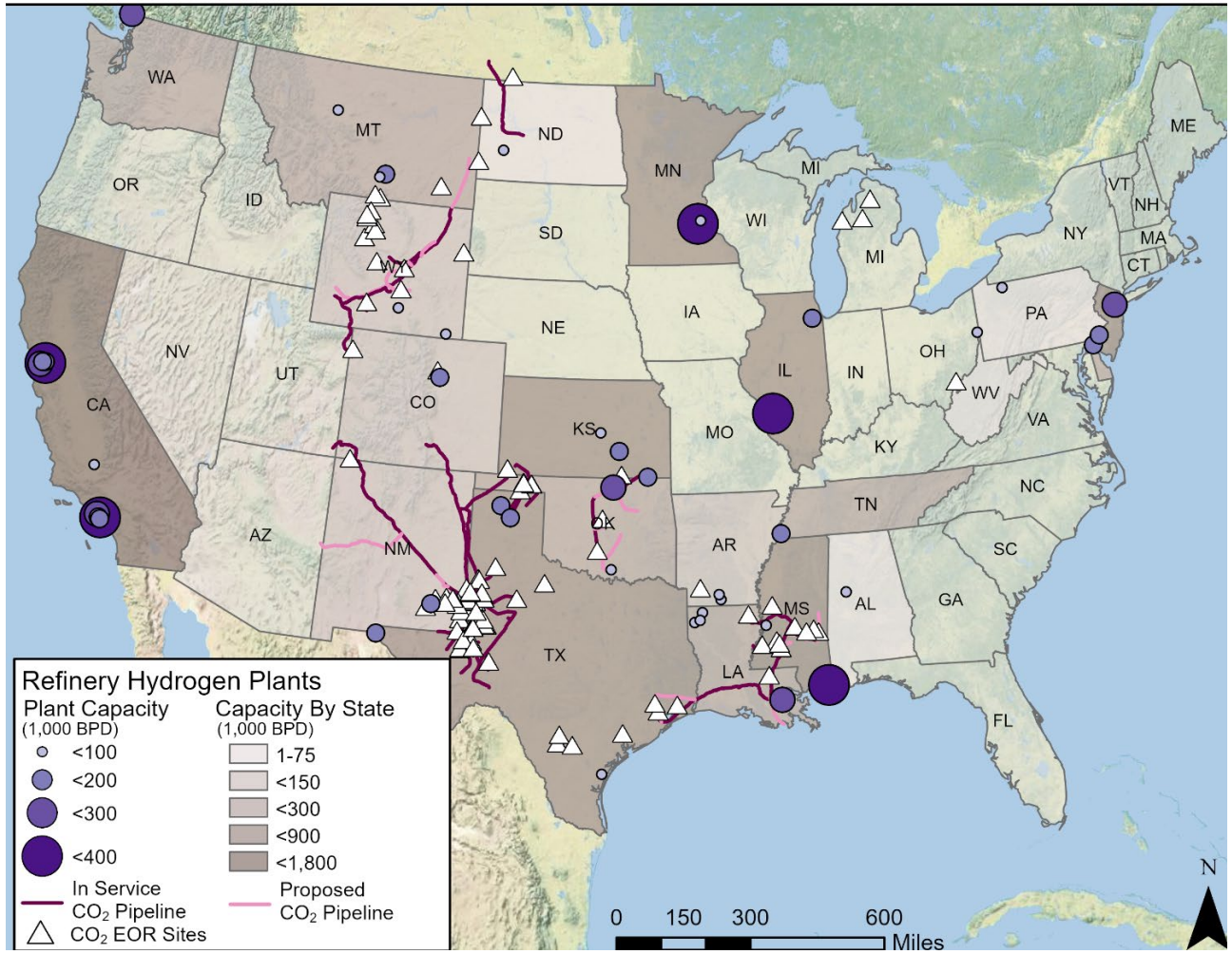
- 87,000 tonnes/year.

CO_2 Available for Capture:

- 404,700 tonnes/year.
- 12.7 mol% at 400 psia and 102°F.



Integrally-geared intercooled centrifugal compressor with TEG dryer and industrial boiler scaled from recent vendor quotes. CO_2 capture system scaled from a Shell ADIP-Ultra quote. Ancillary equipment scaled using data from legacy NETL studies[1].



Source: NETL

[1]NETL, Cost and Performance Baseline for Fossil Energy Plants Volume 1: Bituminous Coal and Natural Gas to Electricity, U.S. DOE/NETL, Pittsburgh, 2019.

RESULTS NOT FINAL, CURRENTLY UNDER REVIEW

Industrial Capture Report

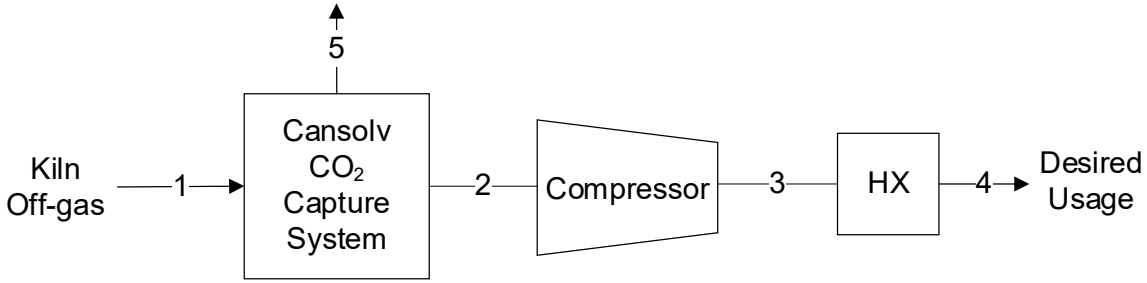
Case Description: Cement

Representative Plant Capacity:

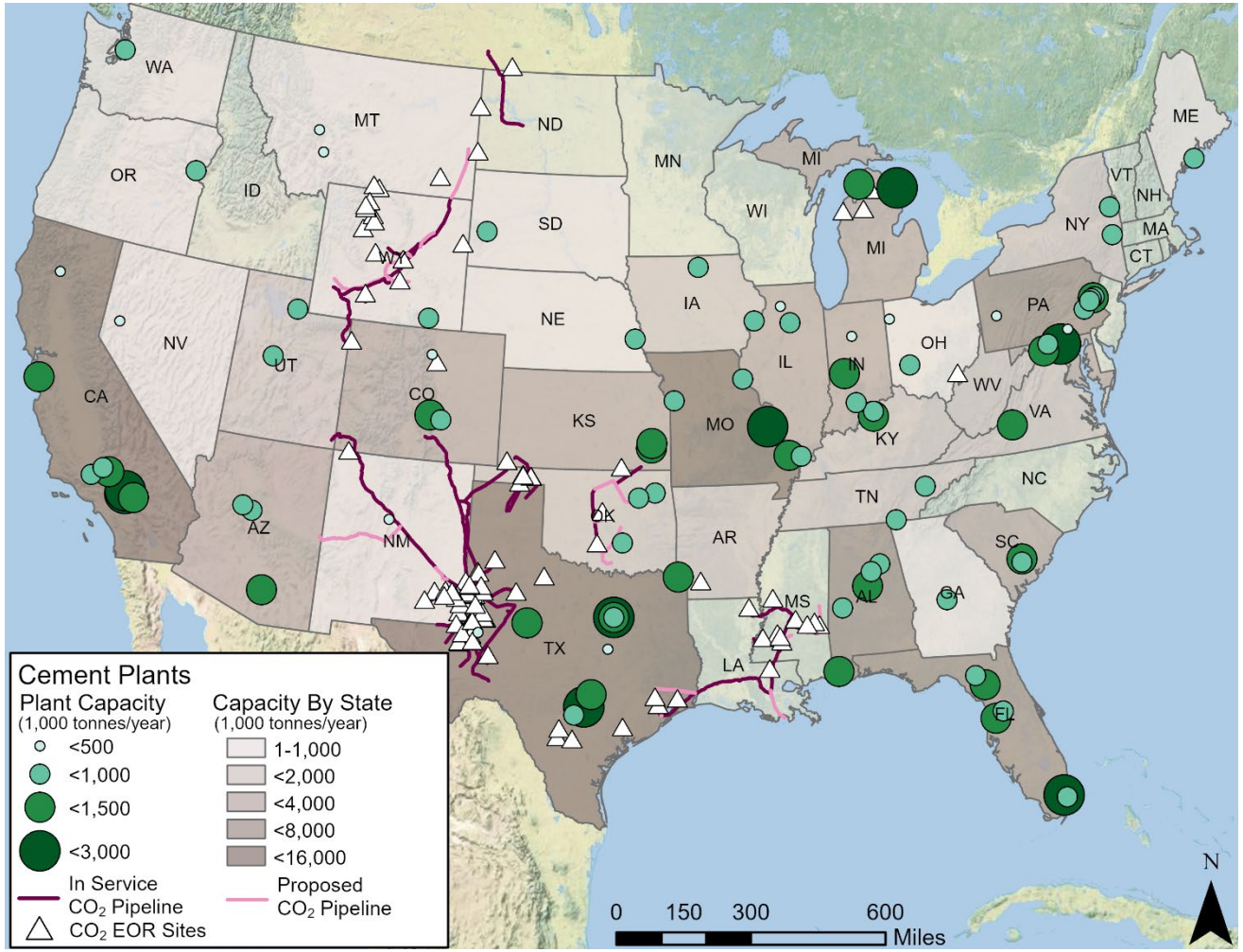
- 1.29 M tonnes/year.

CO_2 Available for Capture:

- 1.21 M tonnes/year.
- 22.4 mol% CO_2 at 14.7 psia and 320°F.



Integrally-geared intercooled centrifugal compressor with a TEG dryer, outlet cooler, cooling tower, ancillary equipment and materials scaled using data from legacy NETL studies[1]. CO_2 capture system scaled from a recent Shell Cansolv quote. Natural gas-fired industrial boiler scaled from a recent quote.



Source: NETL

[1]NETL, Cost and Performance Baseline for Fossil Energy Plants Volume 1: Bituminous Coal and Natural Gas to Electricity, U.S. DOE/NETL, Pittsburgh, 2019.

RESULTS NOT FINAL, CURRENTLY UNDER REVIEW

Industrial Capture Report

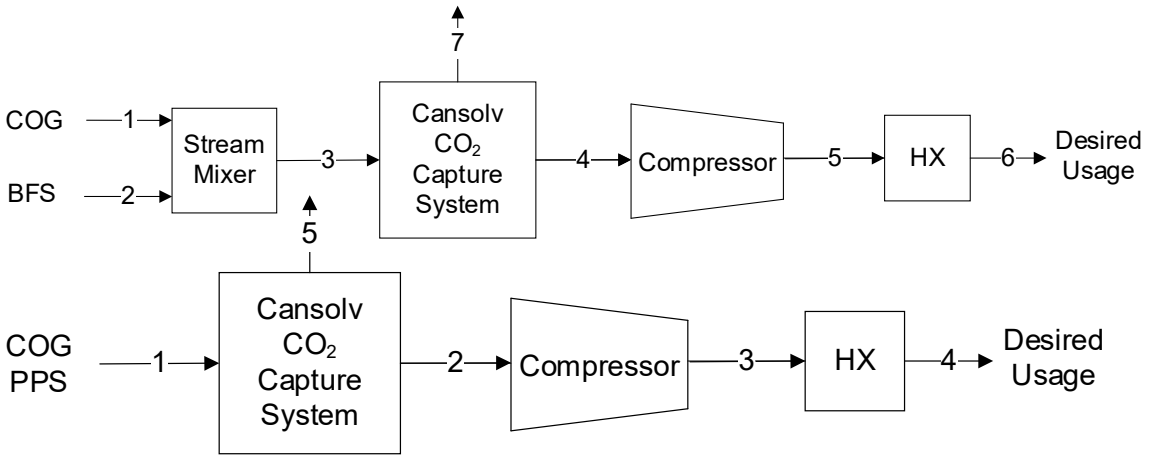
Case Description: Iron/Steel

Representative Plant Capacity:

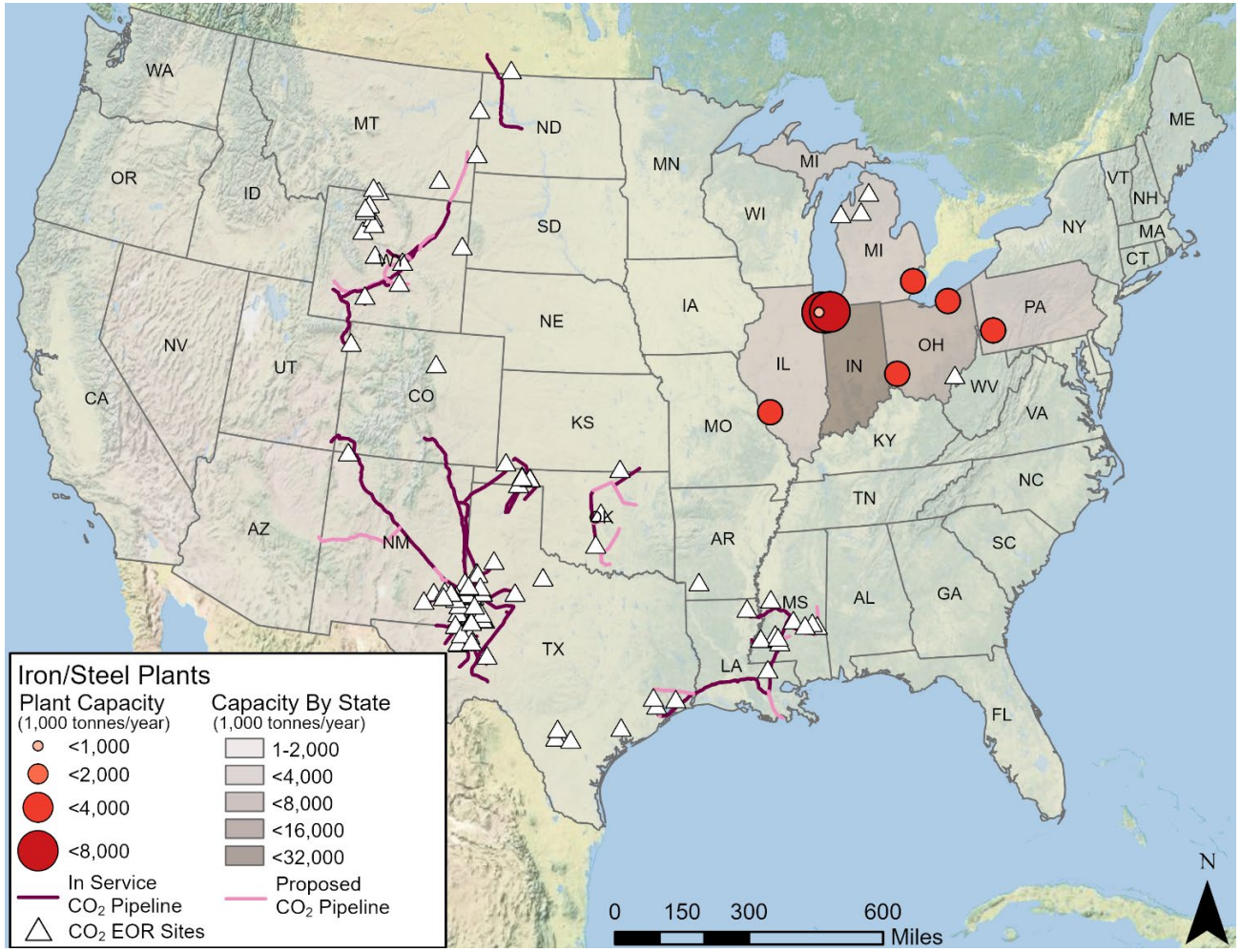
- 2.54 M tonnes/year.

CO_2 Available for Capture:

- 3.74 M tonnes/year.
- Coke oven gas (COG) and blast furnace stove (BFS): 26.42 mol% at 14.7 psia and 247°F.
- COG power plant stack (PPS): 23.23 mol% at 14.7 psia and 572°F.



System components are analogous to the cement case.



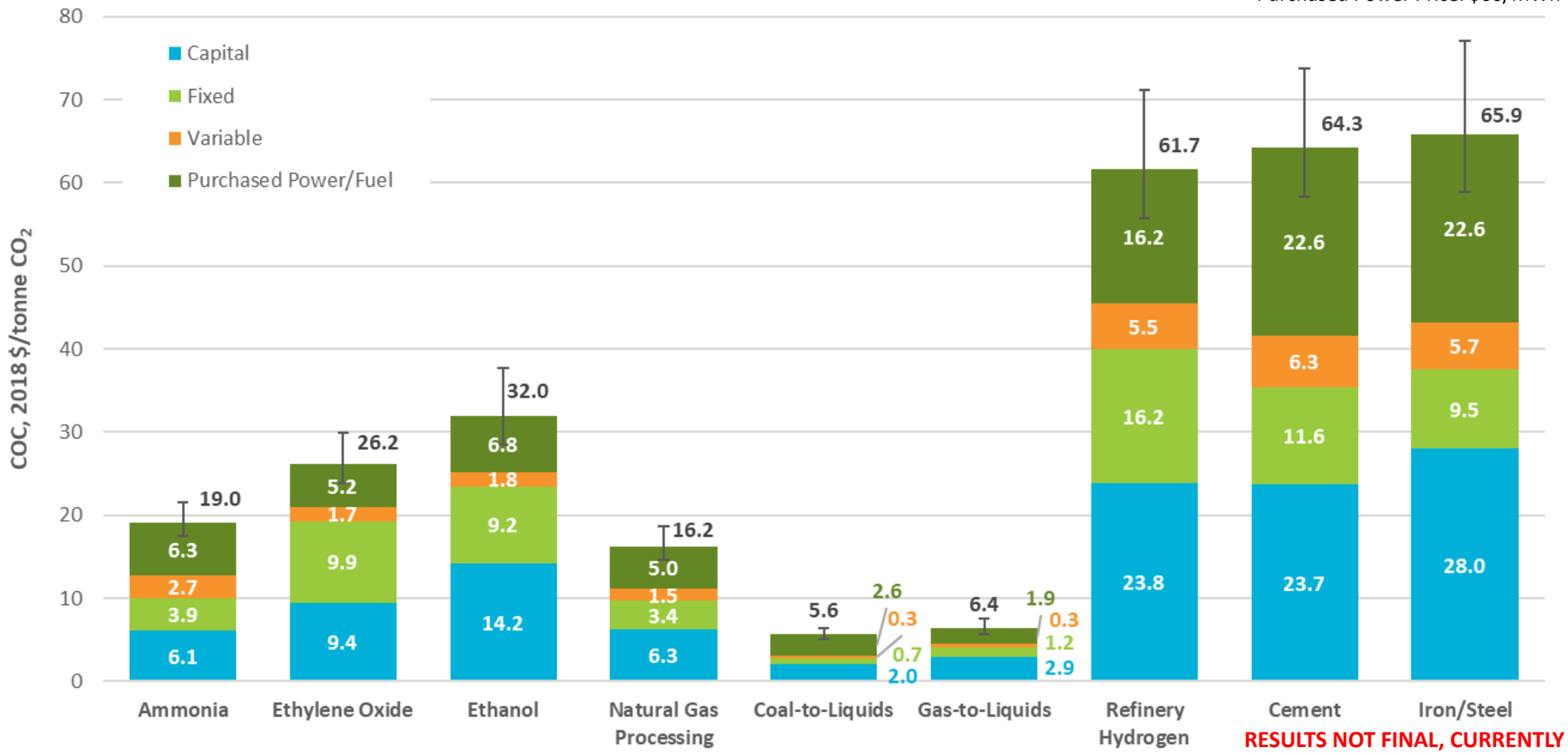
Source: NETL

RESULTS NOT FINAL, CURRENTLY UNDER REVIEW

Industrial Capture Report

Cost of CO_2 Capture for Industrial Cases

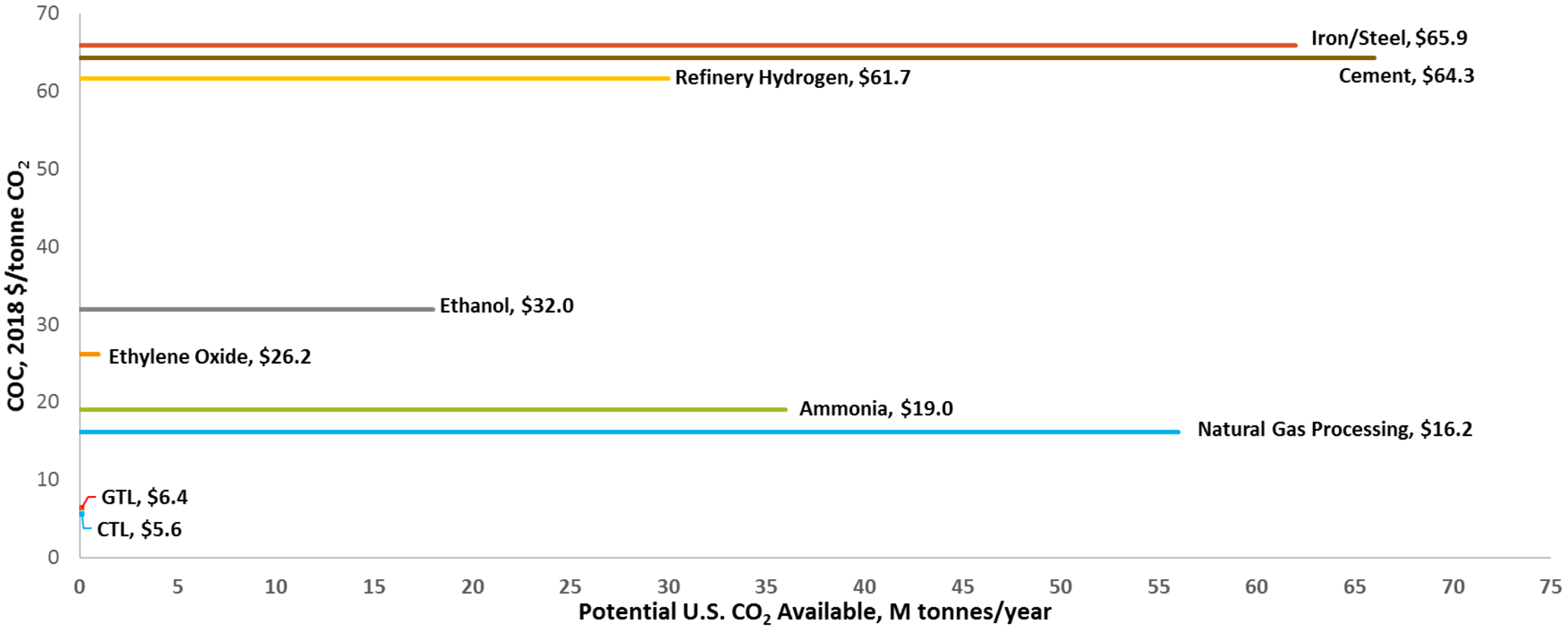
Purchased Power Price: $60/MWh



RESULTS NOT FINAL, CURRENTLY UNDER REVIEW

Industrial Capture Report

Cost of CO_2 Capture and Approximate U.S. Supply per Industry



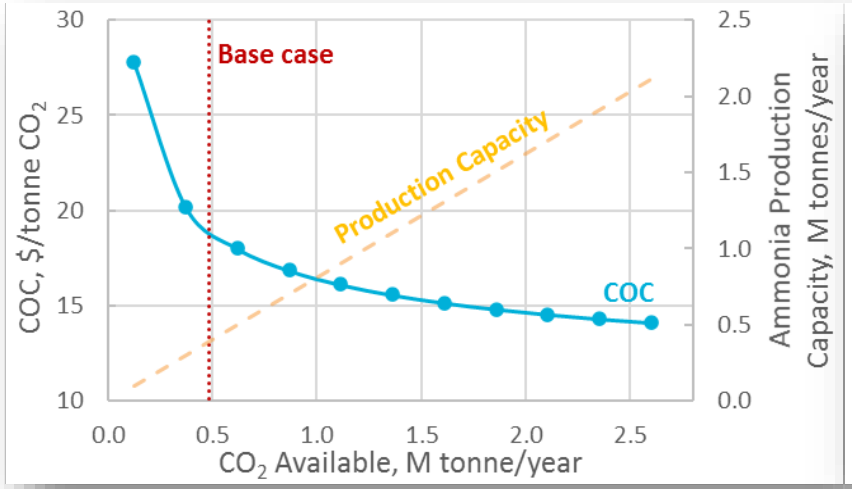
Available CO_2 based upon EPA FLIGHT Database other than Ethylene Oxide, which is based on Statista, "Ethylene oxide production in the United States from 1990 to 2019," Statista, 28 January 2022. [Online]. Available: https://www.statista.com/statistics/974787/us-ethylene-oxide-production-volume/

RESULTS NOT FINAL, CURRENTLY UNDER REVIEW

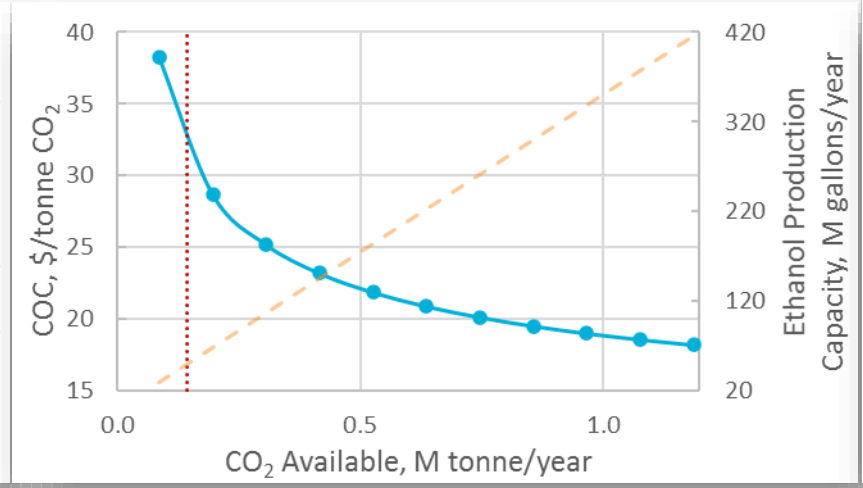
Industrial Capture Report

Plant Size Sensitivity

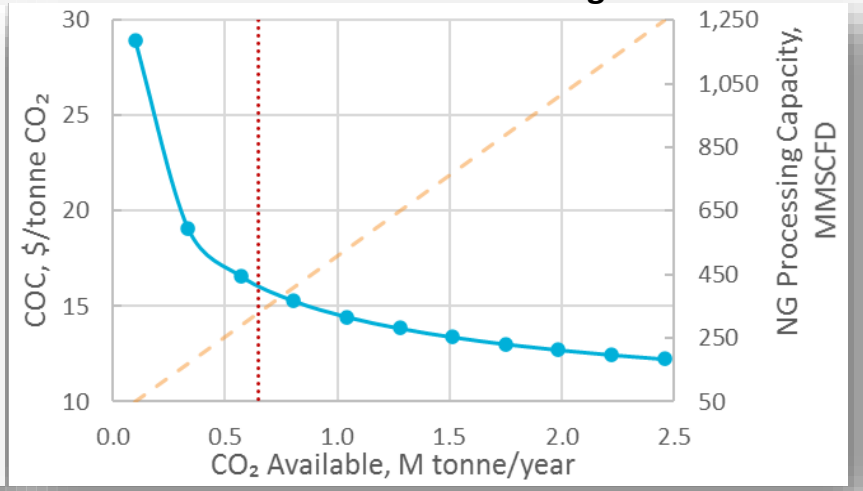
Ammonia



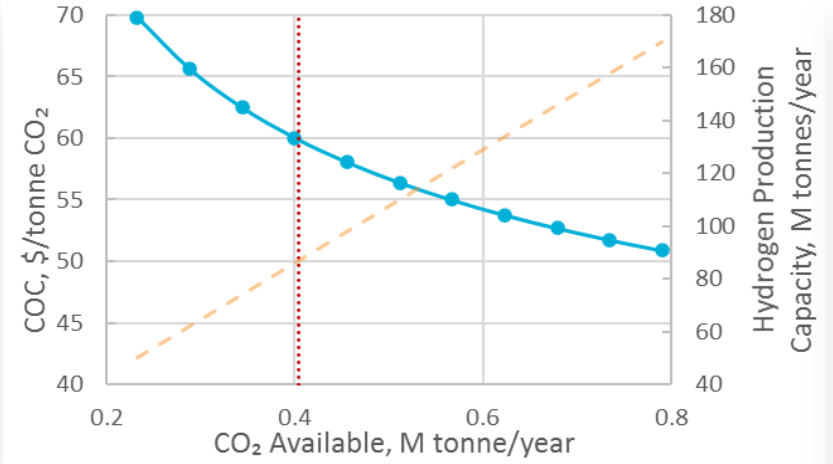
Ethanol



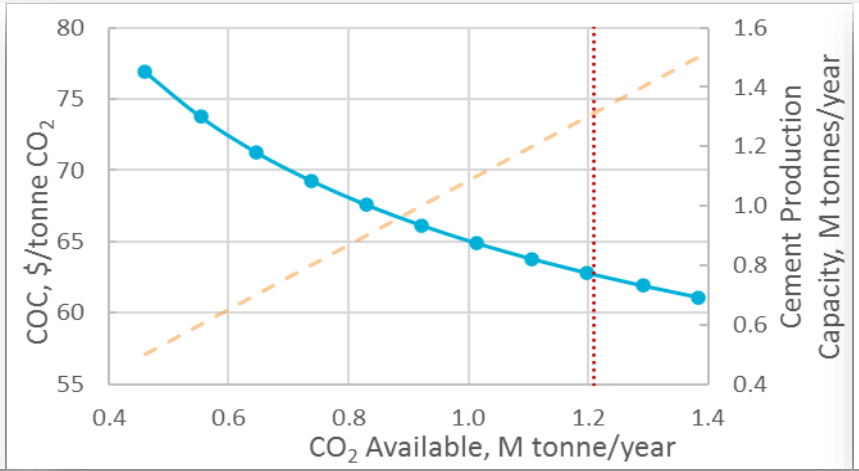
Natural Gas Processing



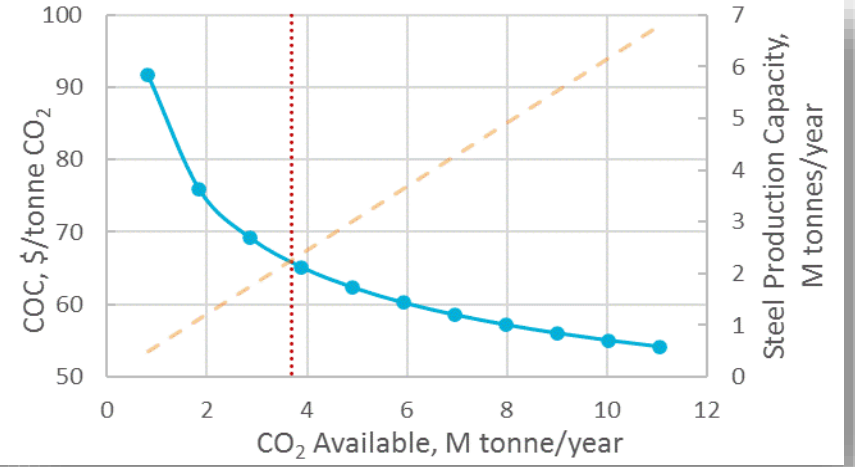
Refinery Hydrogen



Cement

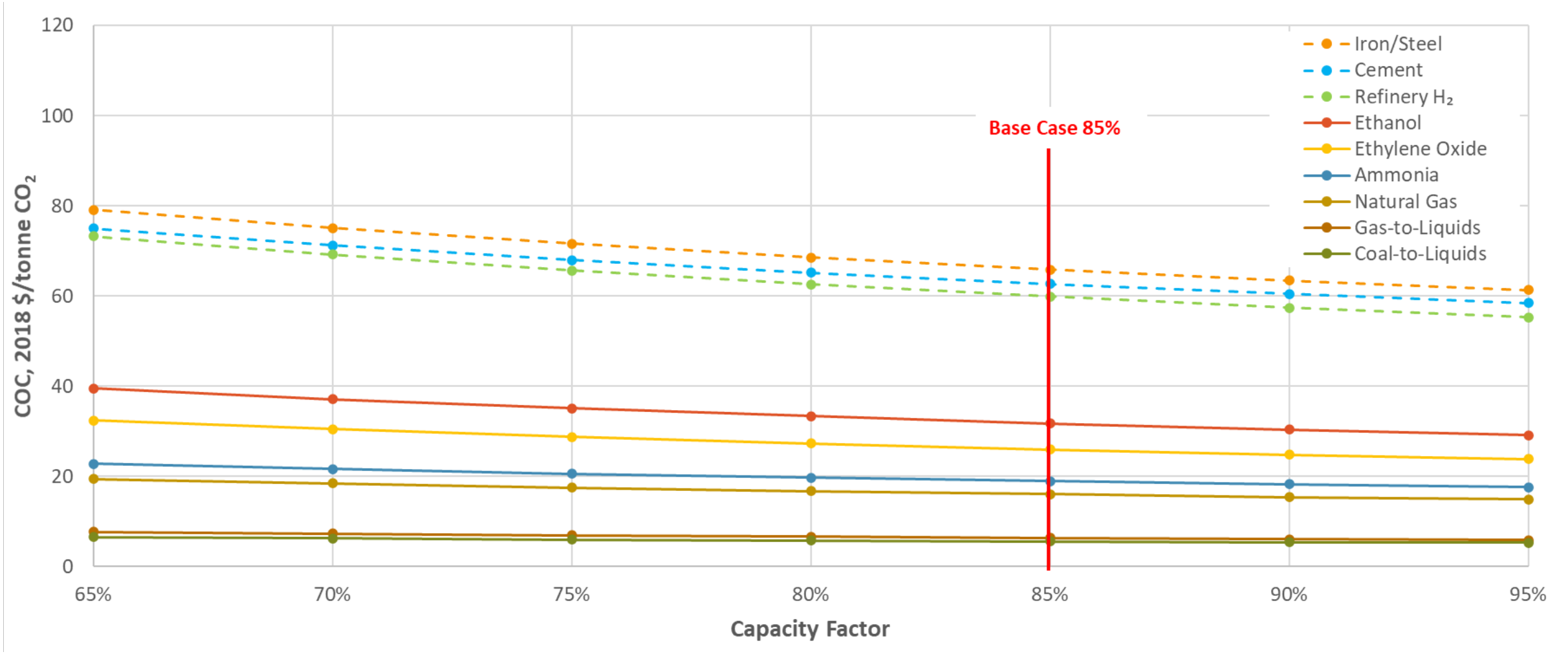


Iron/Steel



Industrial Capture Report

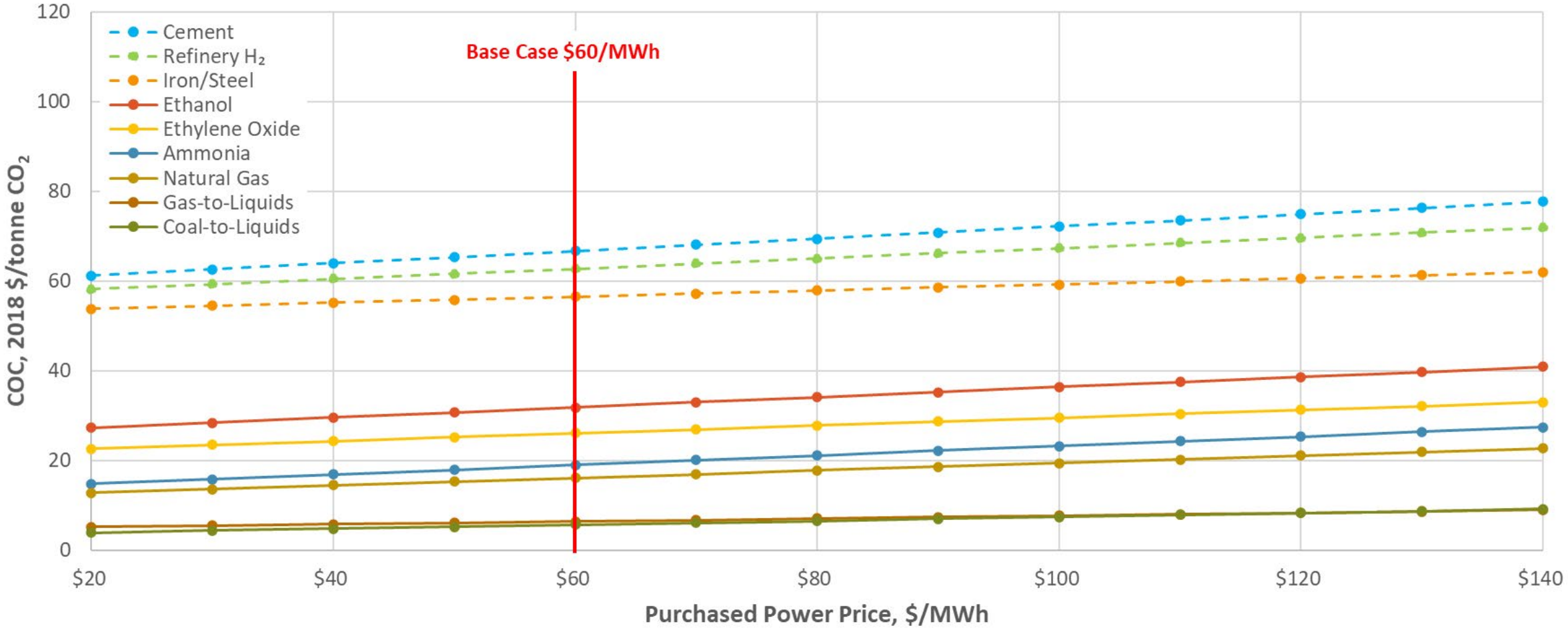
Capacity Factor Sensitivity



RESULTS NOT FINAL, CURRENTLY UNDER REVIEW

Industrial Capture Report

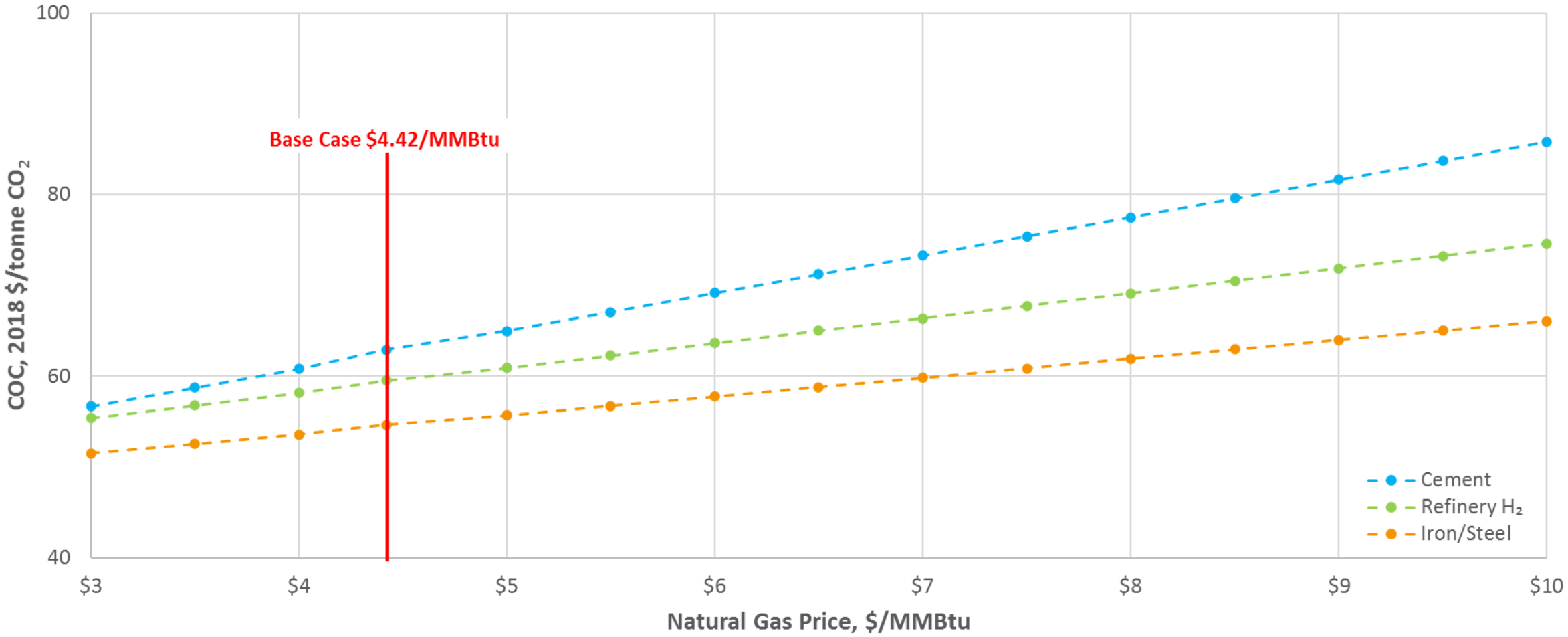
Purchased Power Price Sensitivity



RESULTS NOT FINAL, CURRENTLY UNDER REVIEW

Industrial Capture Report

Natural Gas Price Sensitivity



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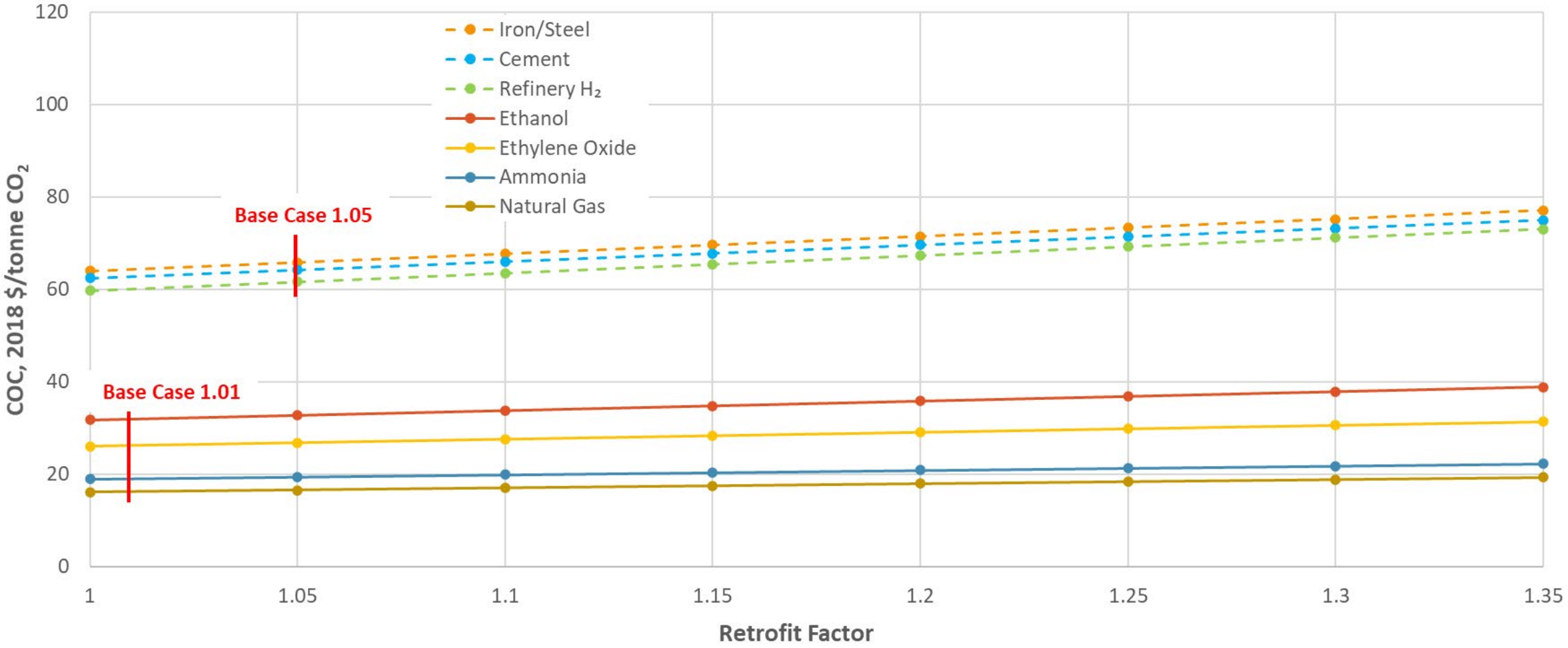
Industrial Capture Report

Retrofit Difficulty Factor Sensitivity



RESULTS NOT FINAL, CURRENTLY UNDER REVIEW


Ongoing Activities

Upcoming Novel Reports

- Carbon Capture Retrofits for Cement Plants
  - ***Sydney Hughes***[2], ***Patricia Cvetic***[2], ***Sally Homsy***[2], ***Mark Woods***[2], ***Charles White***[2], ***Sandeep Pidaparti***[2], ***Norma Kuehn***[2], ***Travis Shultz***[1], ***Tim Fout***[1], ***Eric Grol***[1], ***Robert James***[1], ***Richard Bohan***[3]
- Direct Air Capture Case Studies: Sorbent System
  - ***Jessica Valentine***[3], ***Alexander Zoelle***[3], ***Sally Homsy***[2], ***Hari C. Mantripragada***[2], ***Mark Woods***[2], ***Naksha Roy***[2], ***Aaron Kilstofte***[2], ***Mike Sturdivan***[2], ***Mark Steutermann***[2], ***Tim Fout***[1]
- Direct Air Capture Case Studies: Solvent System
  - ***Jessica Valentine***[3], ***Alexander Zoelle***[3], ***Sally Homsy***[2], ***Mark Woods***[2], ***Aaron Kilstofte***[2], ***Mike Sturdivan***[2], ***Mark Steutermann***[2], ***Tim Fout***[1]

[1]NETL
[2]NETL support contractor
[3]Former NETL support contractor

RESULTS NOT FINAL, CURRENTLY UNDER REVIEW

Upcoming Updates to Reports

- NETL's 2013, "Cost and Performance of Retrofitting Existing NGCC Units for Carbon Capture"
  - ***Tommy Schmitt*[2], *Sally Homsy*[2], *Norma Kuehn*[2], *Mark Woods*[2], *Travis Shultz*[1], *Tim Fout*[1]**
- Natural Gas Combined Cycle Power Plants with Carbon Capture and Exhaust Gas Recycle (EGR). Previous EGR work published in NETL's 2013 "Current and Future Technologies for Natural Gas Combined Cycle (NGCC) Power Plants"
  - ***Norma Kuehn*[2], *Kyle Buchheit*[2], *Tommy Schmitt*[2], *Marc Turner*[2], *Hari C. Mantripragada*[2], *Sally Homsy*[2], *Mark Woods*[2], *Tim Fout*[1]**
- NETL's Carbon Capture Retrofit Databases (CCRD)
  - ***Norma Kuehn*[2], *Mark Woods*[2], *Travis Shultz*[1], *Tim Fout*[1], *Eric Grol*[1], *Robert James*[1]**
- NETL's 2021 "Technoeconomic and Life Cycle Analysis of Bio-energy with Carbon Capture and Storage (BECCS) Baseline"
  - ***Hari C. Mantripragada*[2], *Kyle Buchheit*[2], *Sally Homsy*[2], *Mark Woods*[2], *Derrick Carlson*[2], *Travis Shultz*[1], *Tim Fout*[1]**

[1]NETL; [2]NETL support contractor

RESULTS NOT FINAL, CURRENTLY UNDER REVIEW

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RESULTS NOT FINAL, CURRENTLY UNDER REVIEW

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RESULTS NOT FINAL, CURRENTLY UNDER REVIEW

Questions/ Comments

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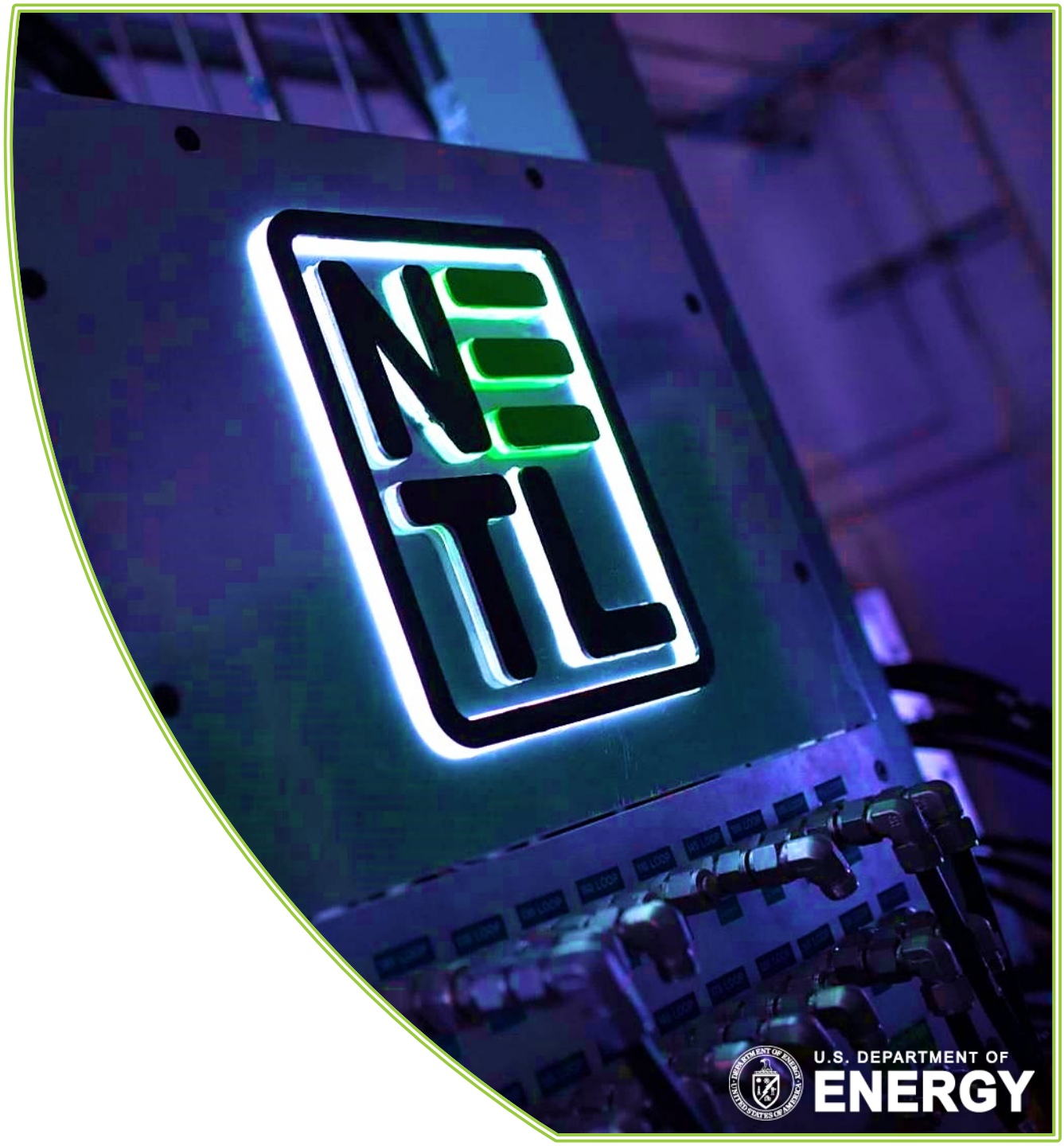


Supplemental Slides

Cost and Performance Summary

High-Purity Cases Compared to Supercritical Pulverized Coal (SCPC) Plant

	SCPC[A]	Industrial Source Facilities					
	B12B minus B12A	Ammonia	Ethylene Oxide	Ethanol	Natural Gas	Coal-to-Liquids	Gas-to-Liquids
PERFORMANCE							
Capacity Factor	**85%**	**85%**	**85%**	**85%**	**85%**	**85%**	**85%**
Representative Plant Size	650 MWnet	394,000 tonne/yr	364,500 tonne/yr	50 M gallon/yr	500 MMSCFD	50,000 BPD	50,000 BPD
CO_2 Captured, tonnes/year	5,092,409	486,075	121,500	143,108	649,194	8,743,323	1,858,767
CO_2 Captured, tonnes/hr	581	55	14	16	74	998	212
CO_2 Compressor Load, kW	44,380	5,770	1,180	1,810	5,990	43,480	6,700
Circulating Water Flow Rate, gpm	463,371	2,994	673	1,098	3,473	25,209	3,823
Cooling Tower Duty (calculated), MMBtu/hr	4,634	30	7	11	35	253	38
COST							
Total Plant Cost (2018$/1000)	1,104,341	37,347	16,636	20,187	46,690	162,840	49,170
Bare Erected Cost	733,368	26,487	11,799	14,317	33,114	115,490	34,872
Home Office Expenses	128,339	4,635	2,065	2,505	5,795	20,211	6,103
Project Contingency	162,441	6,225	2,773	3,364	7,782	27,140	8,195
Process Contingency	80,193	0	0	0	0	0	0
Total Overnight Cost (2018$MM)	1,345	46	20	25	57	197	60
Total Overnight Cost (2018$/1000)	1,344,639	45,587	20,385	24,672	56,764	196,924	59,661
Owner's Costs	240,298	8,240	3,749	4,485	10,074	34,084	10,491
Total As-Spent Cost (2018$/1000)	1,551,714	47,162	20,892	25,840	58,977	207,583	62,890
Capital Costs (2018$/tonne CO_2)[A]	22.7	6.1	9.4	14.1	6.2	2.0	2.9
Fixed Costs (2018$/tonne CO_2)[A]	6.7	3.9	9.8	9.2	3.4	0.7	1.2
Variable Costs (2018$/tonne CO_2)[A]	6.3	2.7	1.7	1.7	1.5	0.3	0.3
Purchased Power and/or Fuel (2018$/tonne CO_2)[B]	5.3	6.3	5.2	6.8	5.0	2.6	1.9
Cost of Capture ($/tonne CO_2)[A]	**45.7**	**19.0**	**26.0**	**31.8**	**16.1**	**5.6**	**6.4**

[A] SCPC comparison case capture system is based on 2016 vintage Shell Cansolv data at 90 percent capture; [B] 2018$/MWh for B12A/B; [C] Fuel in 2018$/MWh for B12A/B

Cost and Performance Summary

Low-Purity Cases Compared to SCPC Plant

	SCPC[A]			
	B12B minus B12A	Refinery H_2	Cement	Iron/Steel[D]
PERFORMANCE				
Capacity Factor	**85%**	**85%**	**85%**	**85%**
Representative Plant Size	650 MWnet	87,000 tonne/yr	1 M tonne/yr	2.54 M tonne/yr
CO_2 Captured, tonnes/year	5,092,409	364,174	1,089,168	3,365,508
CO_2 Captured, tonnes/hr	581	42	124	384
CO_2 Compressor Load, kW	44,380	3,160	9,570	29,410
Circulating Water Flow Rate, gpm	463,371	9,757	46,356	143,309
Cooling Tower Duty (calculated), MMBtu/hr	4,634	10	18	56
COST				
Total Plant Cost (2018$/1000)	1,104,341	127,184	322,871	878,803
Bare Erected Cost	733,368	82,950	210,137	571,122
Home Office Expenses	128,339	14,516	36,774	99,946
Project Contingency	162,441	21,197	53,812	146,467
Process Contingency	80,193	8,520	22,148	61,268
Total Overnight Cost (2018$MM)	1,345	155	394	1,064
Total Overnight Cost (2018$/1000)	1,344,639	154,978	394,192	1,063,524
Owner's Costs	240,298	27,794	71,320	184,720
Total As-Spent Cost (2018$/1000)	1,551,714	160,510	415,418	1,160,567
Capital Costs (2018$/tonne CO_2)[B]	22.7	22.8	22.8	28.0
Fixed Costs (2018$/tonne CO_2)[B]	6.7	15.6	11.1	9.5
Variable Costs (2018$/tonne CO_2)[B]	6.3	5.3	6.1	5.7
Purchased Power and/or Fuel (2018$/tonne CO_2)[C]	5.3	16.2	22.6	22.6
Cost of Capture ($/tonne CO_2)[B]	**45.7**	**59.9**	**62.7**	**65.9**

[A] SCPC comparison case capture system is based on 2016 vintage Shell Cansolv data at 90 percent capture; [B] 2018$/MWh for B12A/B; [C] Fuel in 2018$/MWh for B12A/B; [D] Retrofit costs.

Retrofit Cost Summary

High-Purity Cases

	Industrial Source Facilities			
	Ammonia	**Ethylene Oxide**	**Ethanol**	**Natural Gas**
PERFORMANCE				
Capacity Factor	**85%**	**85%**	**85%**	**85%**
Representative Plant Size	394,000 tonne/yr	364,500 tonne/yr	50 M gallon/yr	330 MMSCFD
CO_2 Captured, tonnes/year	486,075	121,500	143,045	649,194
CO_2 Captured, tonnes/hr	55	14	16	74
CO_2 Compressor Load, kW	5,770	1,180	1,810	5,990
Circulating Water Flow Rate, gpm	2,994	673	1,098	3,473
Cooling Tower Duty (calculated), MMBtu/hr	30	7	11	35
COST				
Total Plant Cost (2018$/1000)	37,721	16,802	20,388	47,157
Bare Erected Cost	26,752	11,916	14,460	33,445
Home Office Expenses	4,682	2,085	2,530	5,853
Project Contingency	6,287	2,800	3,398	7,860
Process Contingency	0	0	0	0
Total Overnight Cost (2018$MM)	46	21	25	57
Total Overnight Cost (2018$/1000)	46,007	20,555	24,885	57,298
Owner's Costs	8,287	3,753	4,497	10,140
Total As-Spent Cost (2018$/1000)	47,597	21,067	26,064	59,531
Capital Costs (2018$/tonne CO_2)	6.1	9.4	14.2	6.3
Fixed Costs (2018$/tonne CO_2)	3.9	9.9	9.2	3.4
Variable Costs (2018$/tonne CO_2)	2.7	1.7	1.8	1.5
Purchased Power (2018$/tonne CO_2)	6.3	5.2	6.8	5.0
Cost of Capture (excluding T&S), $/tonne CO_2	**19.0**	**26.2**	**32.0**	**16.2**

Retrofit Cost Summary

Low-Purity Cases

	Refinery H_2 90%	Cement 90%	Iron/Steel 90%
PERFORMANCE			
Capacity Factor	**85%**	**85%**	**85%**
Representative Plant Size	87,000 tonne/yr	1.29 M tonne/yr	2.54 M tonne/yr
CO_2 Captured, tonnes/year	364,174	1,089,168	3,365,508
CO_2 Captured, tonnes/hr	42	124	384
CO_2 Compressor Load, kW	3,160	9,570	29,410
Circulating Water Flow Rate, gpm	9,757	46,356	143,309
Cooling Tower Duty (calculated), MMBtu/hr	10	18	56
COST			
Total Plant Cost (2018$/1000)	133,543	339,015	878,803
Bare Erected Cost	87,098	220,644	571,122
Home Office Expenses	15,242	38,613	99,946
Project Contingency	22,257	56,502	146,467
Process Contingency	8,946	23,256	61,268
Total Overnight Cost (2018$MM)	162	410	1,064
Total Overnight Cost (2018$/1000)	161,918	410,449	1,063,524
Owner's Costs	28,375	71,434	184,720
Total As-Spent Cost (2018$/1000)	167,698	432,551	1,160,567
Capital Costs (2018$/tonne CO_2)	23.8	23.7	28.0
Fixed Costs (2018$/tonne CO_2)	16.2	11.6	9.5
Variable Costs (2018$/tonne CO_2)	5.5	6.3	5.7
Purchased Power and Fuel (2018$/tonne CO_2)	16.2	22.6	22.6
Cost of Capture (excluding T&S), $/tonne CO_2	**61.7**	**64.3**	**65.9**