NETL Carbon Capture Retrofit Analyses

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Solutions for **Today** | **Options** for **Tomorrow**

Systems Engineering & Analysis (SEA)

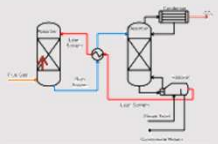
Teams and Scope

NATIONAL ENERGY TECHNOLOGY LABORATORY

Energy Process Analysis

Energy Process Design, Analysis, and Cost Estimation

- Plant-level modeling, performance assessment
- Cost estimation for plant-level systems
- General plant-level technology evaluation and support



Advanced Technology Design & Cost Estimation

Energy Systems Analysis

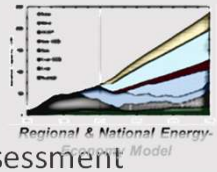
Resource Availability and Cost Modeling

- CO_2 storage (saline and EOR)
- Fossil fuel extraction
- Rare earth elements
- General subsurface technology evaluation and support

Grid modeling and analysis

Environmental Life Cycle Analysis

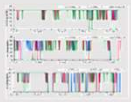
Energy Markets Analysis



Regional & National Energy-Economy Model

Energy Economy Modeling and Impact Assessment

- Enhanced fossil energy representation
- Multi-model scenario/policy analysis
- Infrastructure, energy-water



Grid, Infrastructure, & Energy Reliability

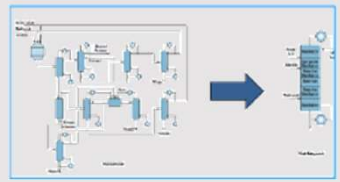
- Economic impact assessment
- General regulatory, market and financial expertise

Process Systems Engineering Research

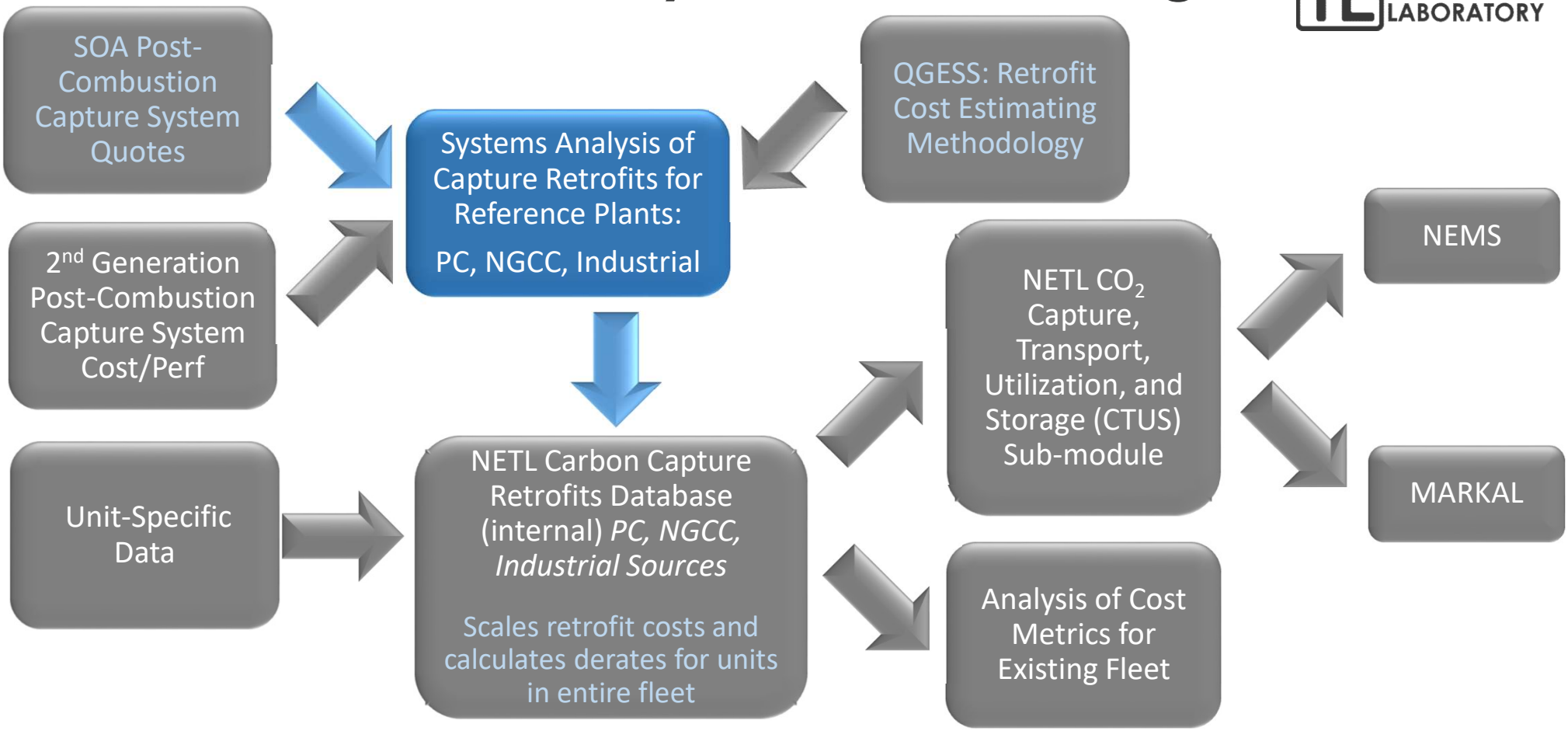
- Process synthesis, design, optimization, intensification
- Steady state and dynamic process model development
- Uncertainty quantification
- Advanced process control

Design, optimization, and modeling framework to be expanded to all SEA "systems"

Advanced Energy Systems through Process Systems Engineering



NETL CCS Retrofit Analysis and Modeling



Why Analyze CCS Retrofits?

- Evaluate scenarios where there is a price on CO_2 emissions
- Consider economic feasibility of power plants or industrial sources that sell CO_2 for Enhanced Oil Recovery (EOR)
- Analyze benefits of CO_2 capture R&D on existing fleet of power plants and industrial sources

Carbon Capture Retrofit Modeling Overview

NATIONAL ENERGY TECHNOLOGY LABORATORY

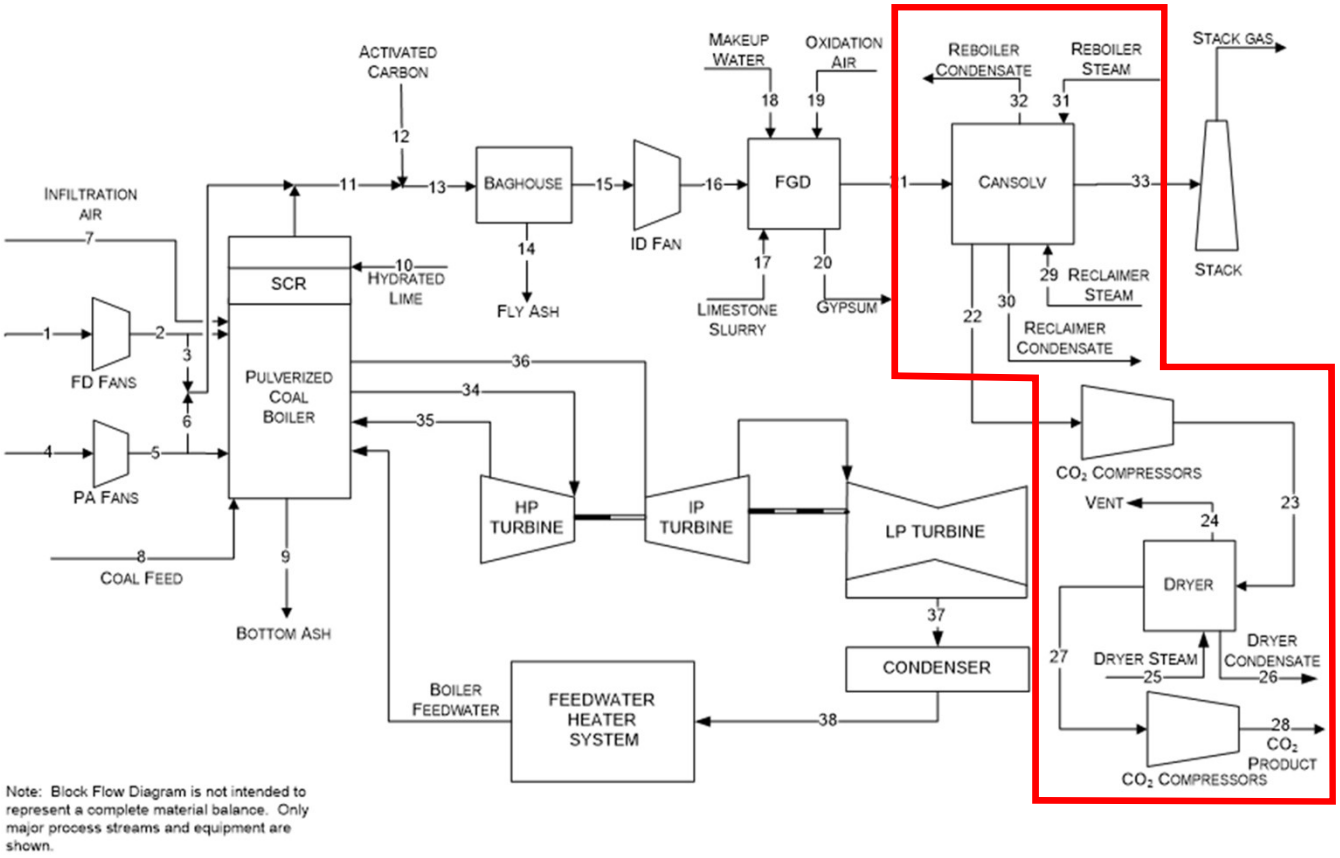
- 264 GW of existing coal and 242 GW of existing NGCC capacity in U.S.*
- CO_2 also available for capture from industrial sources; publicly available information from EPA's Greenhouse Gas Reporting Program
- Access to heat rate, nameplate capacity, O&M costs, CO_2 emissions, pollution controls, online date, other relevant data from which to estimate CCS retrofit costs
- Based on similar results of NETL studies, employ a factored approach to existing fleet to estimate cost, performance impact of CCS retrofits
- Determine sensitivity to capacity factor or financing assumptions, evaluate impact of advanced CCS R&D, assess benefits of EOR opportunities

*https://www.eia.gov/electricity/monthly/

CO_2 Capture Retrofit – Existing Coal Units

- Study in progress – Carbon Capture Retrofit of Existing Coal Units
- Expected publication late 2017

Subcritical Pulverized Coal with CO_2 Capture

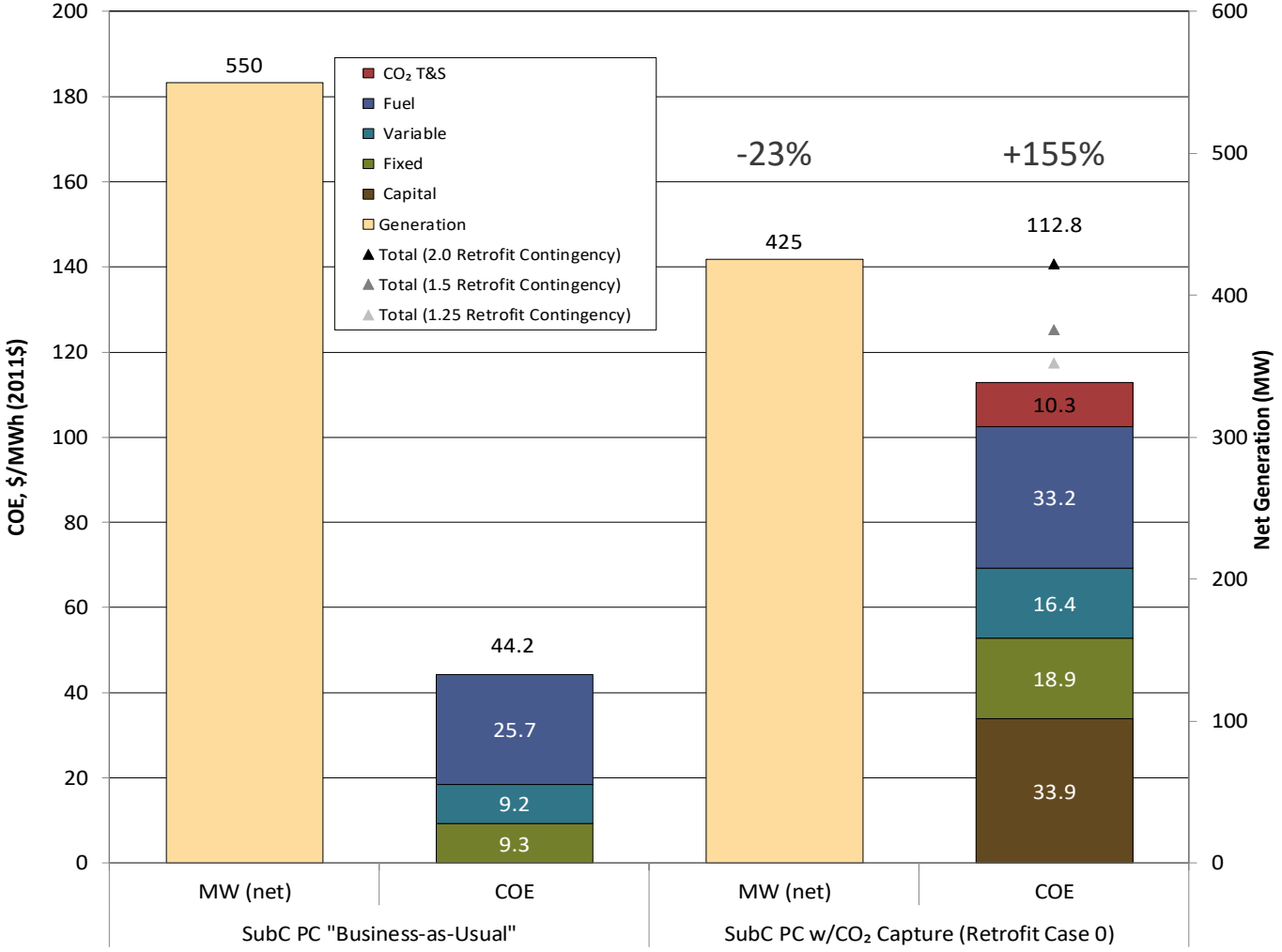


Note: Block Flow Diagram is not intended to represent a complete material balance. Only major process streams and equipment are shown.

Pulverized Coal Retrofit Study Assumptions

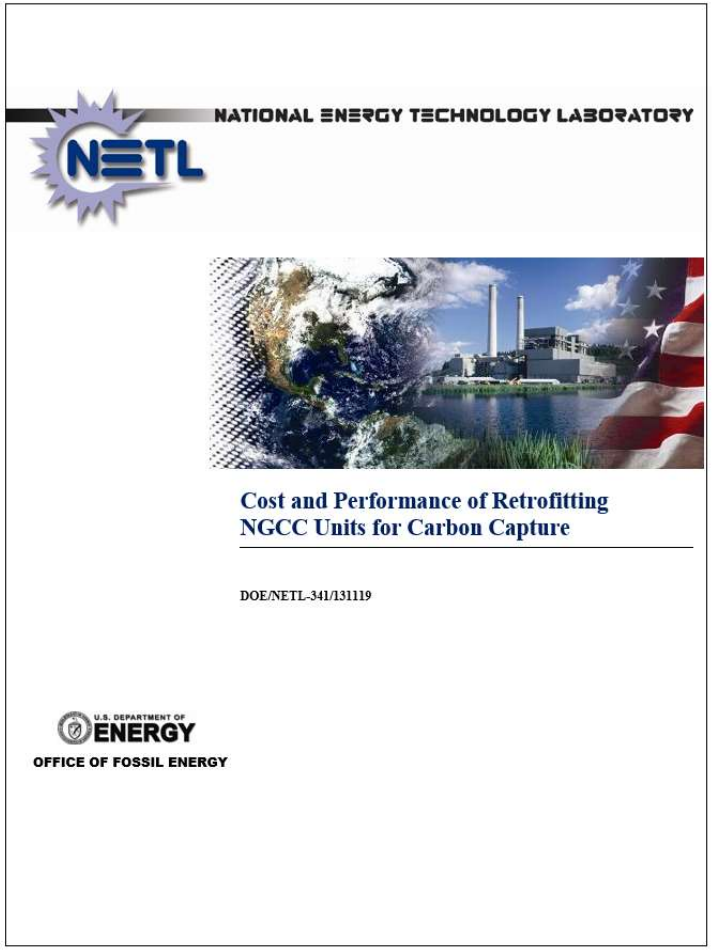
Steam Conditions (psig/ºF/ºF)	2,400/1,050/1,050
Coal	Illinois #6 Bituminous
Condenser Pressure	2” Hg
SO_2 Control	Wet FGD
NOx Control	Low NOx burner with overfire air, SCR
Particulate Control	Fabric filter
Hg Control	ACI
CO_2 Control	Cansolv
CO_2 Capture Efficiency	90%
CO_2 Fate	Offsite saline storage
CO_2 Pipeline Transport Distance	100 km

Subcritical PC Retrofit Results



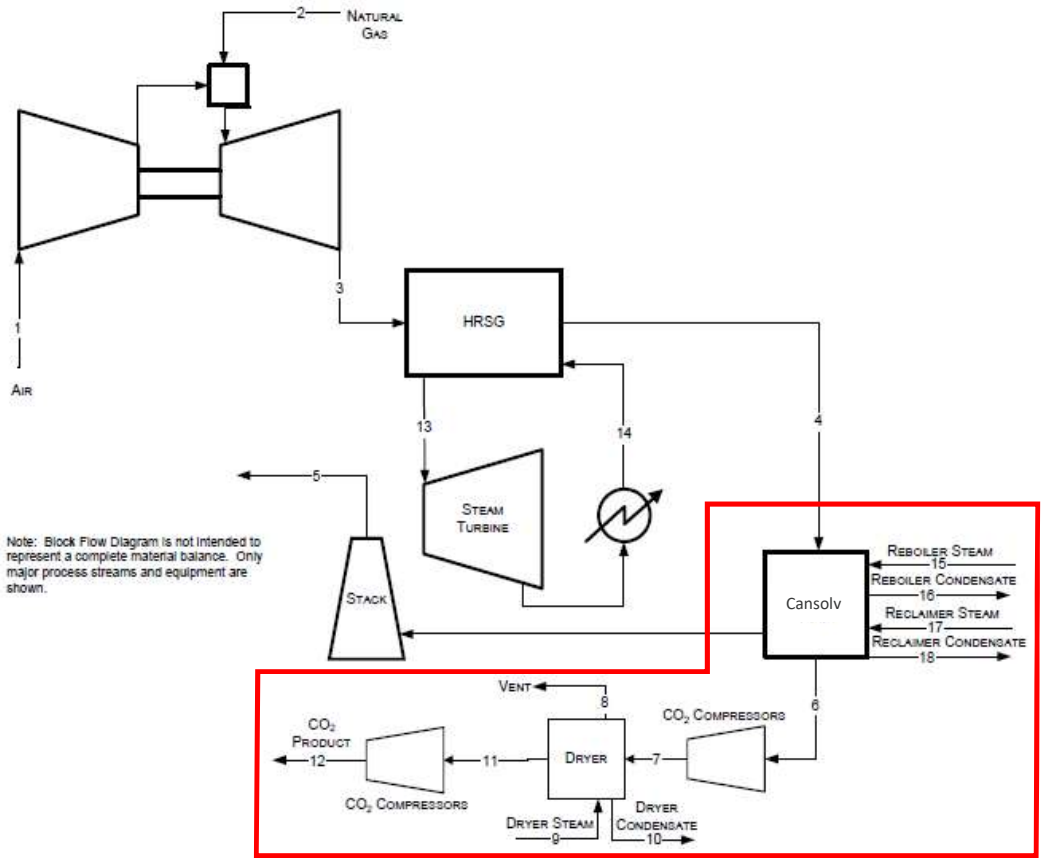
Retrofit Capex	$726,600,000
Heat Rate (pre retrofit)	8,740 Btu/kWh
Heat Rate (post retrofit)	11,300 Btu/kWh
CO_2 Capture Rate	240,218 Lb CO_2/hr
Energy Penalty	≈0.14 kWh/Lb CO_2 captured
Incremental O&M	$18.8/MWh

CO_2 Capture Retrofit – Existing NGCC Units



- Study in progress – Carbon Capture Retrofit of Existing NGCC Units
- Expected publication late 2017

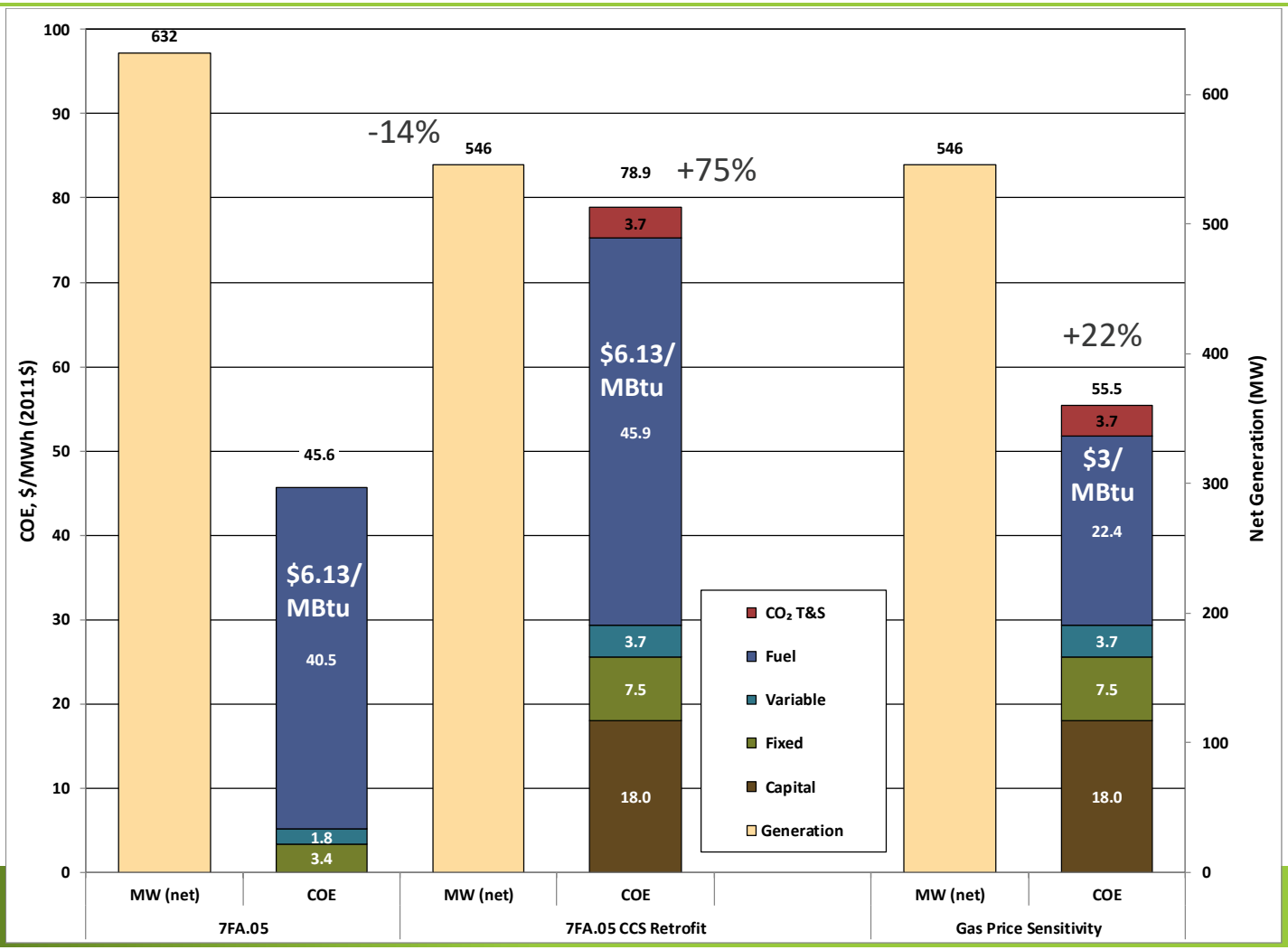
NGCC with CO_2 Capture



NGCC CCS Retrofit Study Assumptions

Steam Conditions (psig/ºF/ºF)	2,400/1,050/1,050
Gas Turbine	2 x GEE 7FA
Turbine lnlet Temperature	2,479 ºF
CO_2 Control	Cansolv
CO_2 Capture Efficiency	90%
CO_2 Fate	Offsite saline storage
CO_2 Pipeline Transport Distance	100 km

NGCC Retrofit Results



- NGCC cost of electricity highly sensitive to gas price!

Retrofit Capex	$647,300,000
Heat Rate (pre retrofit)	6,629 Btu/kWh
Heat Rate (post retrofit)	7,466 Btu/kWh
CO_2 Capture Rate	445,486 Lb CO_2/hr
Energy Penalty	≈0.19 kWh/Lb CO_2 captured
Incremental O&M	$6.15/MWh

CO_2 Capture Retrofit Difficulty Factor

- Power plant retrofits typically space constrained
- A retrofit "difficulty factor" can be applied to capital costs to reflect site-specific challenges
- Factor only applied to capex, so impact on total cost of electricity can be easily assessed
- NETL Quality Guidelines for Energy System Studies – "Estimating Plant Costs Using Retrofit Difficulty Factors*"

* https://www.netl.doe.gov/energy-analyses/temp/QGESSRetrofitDifficultyFactors_083013.pdf

Incidental Retrofit Project Costs

- Existing coal units may require other environmental upgrades when adding CO_2 capture equipment

- Cost for NOx (SCR), SO_2 (FGD) upgrades should be considered to reflect all-in project cost

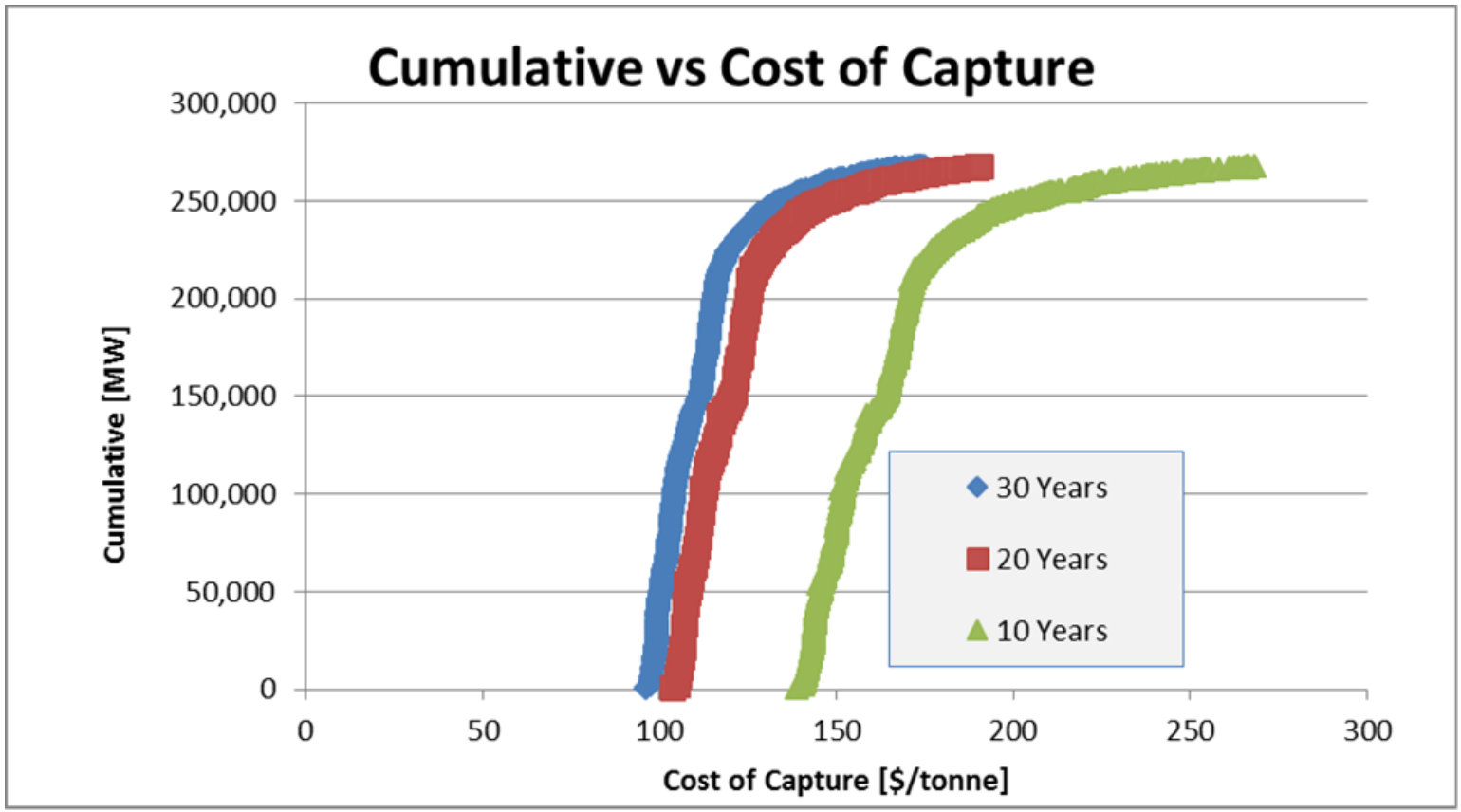
- CCS retrofit is a long-term bet on plant viability, may also want to consider cost for conversion from wet to dry cooling in certain regions (50% water consumption increase when capturing 90% CO_2)

Retrofit Financing Considerations

- NETL studies typically assume 30 year economic life (reflected in capital charge factor)
- What is expected remaining useful life of an existing coal unit retrofitted with CCS? Majority of existing coal fleet built in the 1970's.
- Financing assumptions needed to reflect scenarios shorter than 30-year default

Retrofit Financing Considerations

Impact of economic life on cost results



Opportunity Cost of CCS Retrofits

- In addition to incremental capital, O&M costs, lost power sales revenue due to plant derate needs to be considered

- Useful way to determine minimum CO_2 EOR sale price to justify CCS retrofit

Annualized Capital and Incremental O&M Costs for Retrofit + Annual Revenues Foregone Due to Lost Generation (Derate) ≤ Annual Revenues from Sale of Captured CO_2

Cost Scaling Methodology

- Capital costs for CO_2 capture equipment scaled from reference plant costs, based on amount of CO_2 removed; do NOT scale based on plant output
- Operation and maintenance costs scaled from reference plant costs, based on total plant capital cost
- Retrofit difficulty factor can be applied to capital costs
- Year dollar basis can show historic market fluctuations
- NETL Quality Guidelines for Energy System Studies – "Capital Cost Scaling Methodology*"

* https://www.netl.doe.gov/energy-analyses/temp/QGESSCapitalCostScalingMethodology_013113.pdf

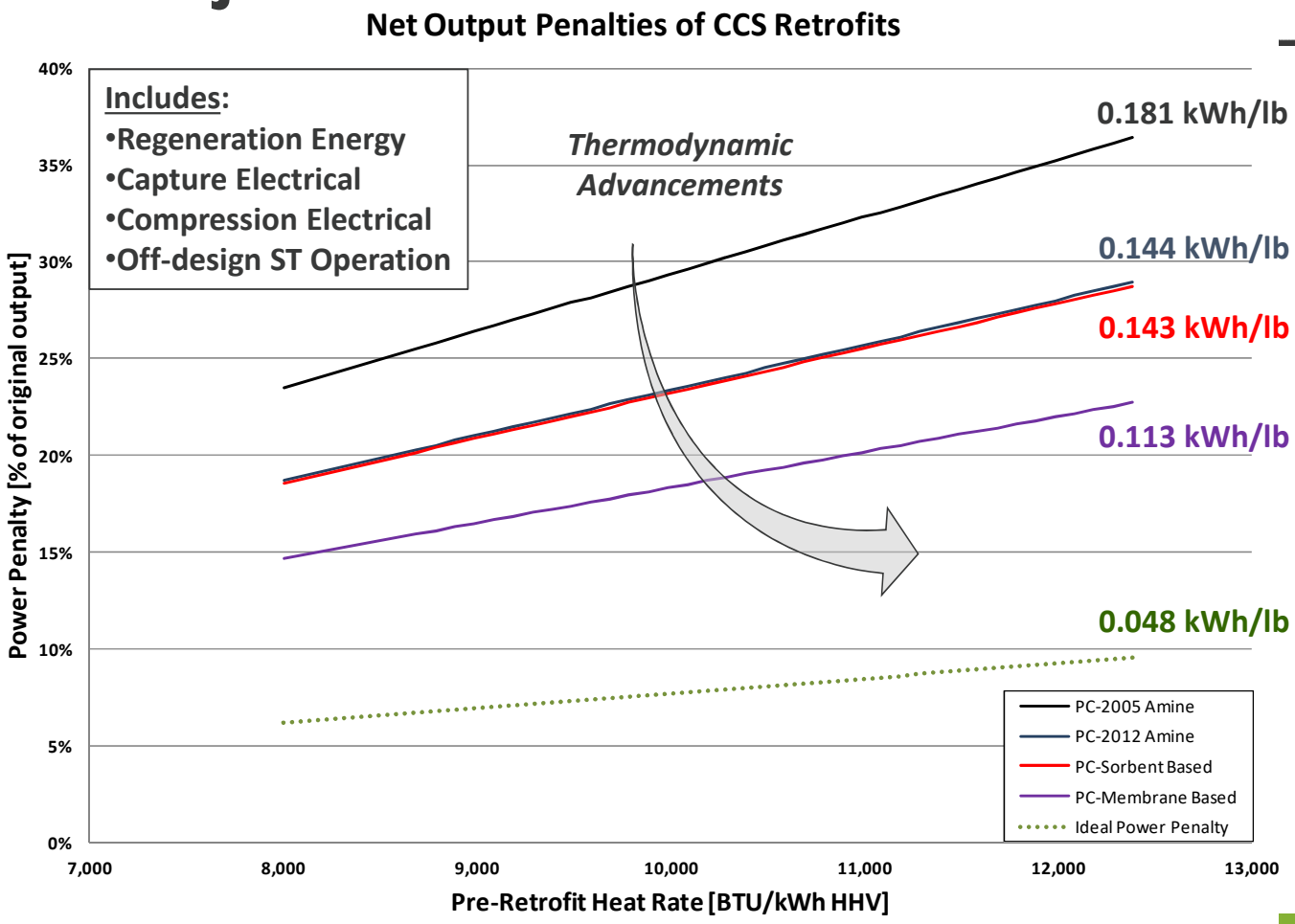
Parasitic Power Load Scaling Methodology

- Parasitic power load for retrofitted units can be scaled from reference cases, based on CO_2 captured (Lb/hr); do NOT simply add a % derate of net power

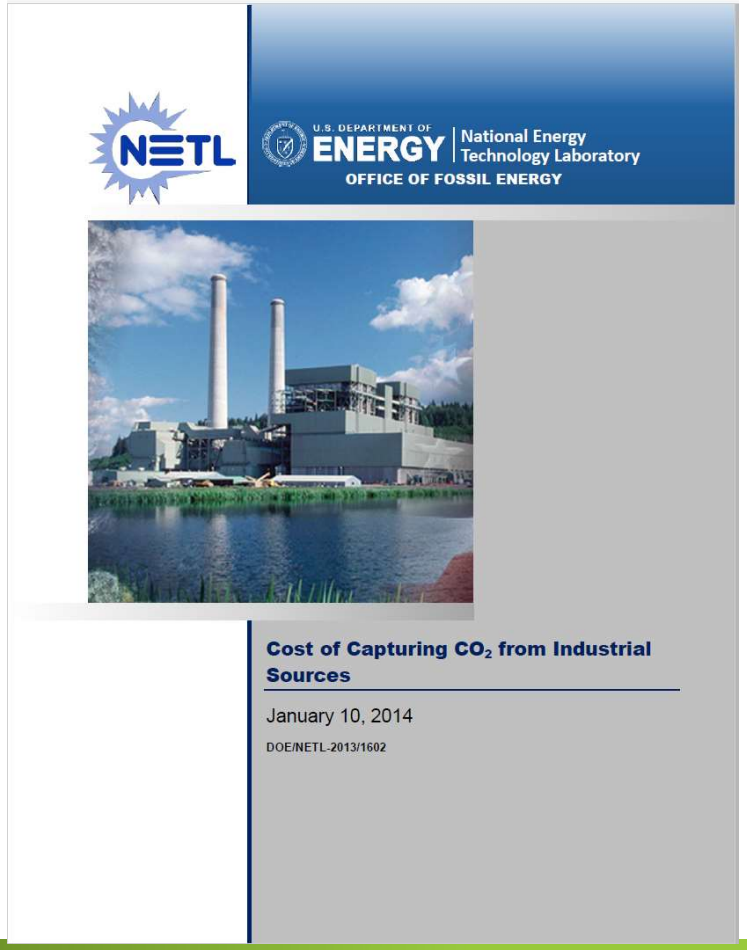
- Energy Penalty (kWh/Lb CO_2) = $\frac{MWh_{non-capture} - MWh_{capture}}{CO_2\ captured\ \left(\frac{lb}{year}\ @100\%\ CF\right)}$

- Allowances for other environmental (or other) upgrades (SCR, FGD, dry cooling) can also be made as needed

Net Derate Projections



CO_2 Capture Retrofit – Industrial Sources



- CO_2 Capture from Industrial Sources* – Public Report

* https://www.netl.doe.gov/energy-analyses/temp/CostofCapturingCO2fromIndustrialSources_011014.pdf

Industrial Source CO_2 Capture

- Does the industrial source represent a target rich opportunity?
- CO_2 concentration in stack gas is a consideration
- Do industrial source capture conditions (temperature, pollutant levels) align with capabilities of current CO_2 capture technologies?

Industrial Source CO_2 Capture

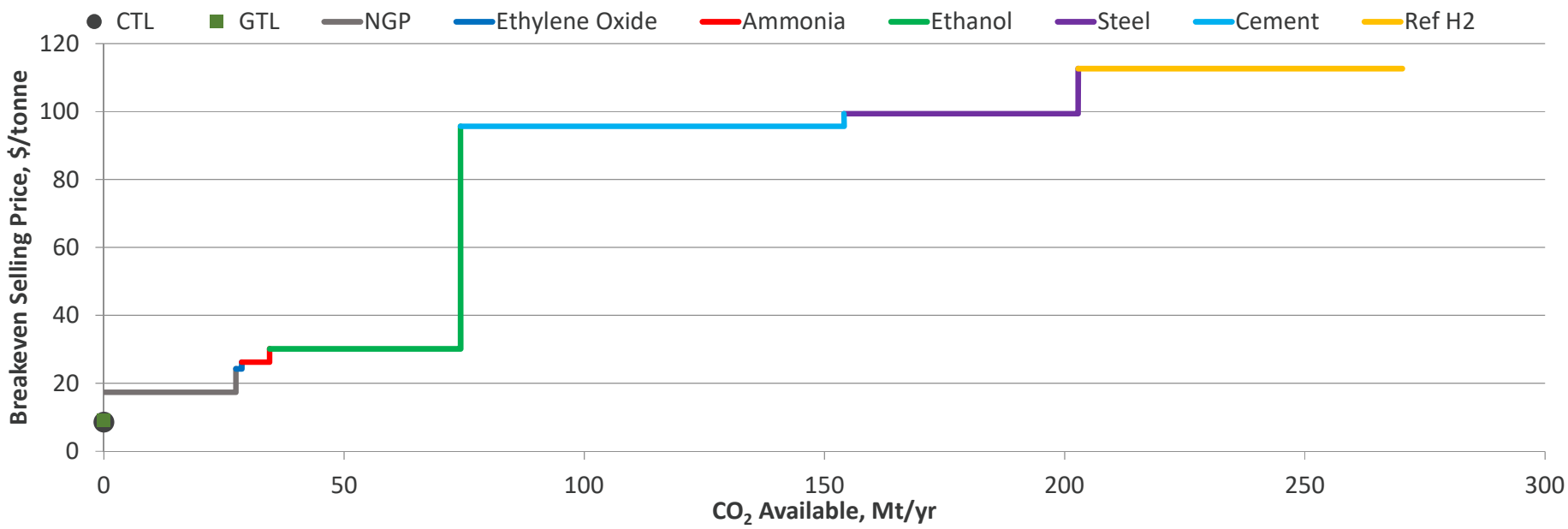
Industrial Process	Reference Plant Capacity	CO_2 Source Stream	CO_2 to Product Ratio (tonne CO_2/tonne Product)	Source Stream CO_2 Concentration (mol%)	Source Stream CO_2 Partial Pressure (psia)	CO_2 Available for Capture (M tonnes CO_2/year)		Breakeven Cost of Capturing CO_2 ($/tonne CO_2)
						Reference Plant	All U.S. sources	
High Purity Sources								
Ethanol	*50 M gal/year*	Distillation gas	0.96	100	18.4	0.14	40	30
Ammonia	*907,000 tonnes/year*	Stripping vent	1.9	99	22.8	0.458	6	27
Natural Gas Processing	*500 MMscf/d*	CO_2 vent	N/A[1]	99	23.3	0.649	27	18
Ethylene Oxide	*364,500 tonnes/year*	AGR product stream	0.33	100	43.5	0.122	1	25
Coal-to-Liquids (CTL)	*50,000 bbl/d*	AGR product stream	N/A[2]	100	265	8.74	-	9
Gas-to-Liquids (GTL)	*50,000 bbl/d*	AGR product stream	N/A[2]	100	265	1.86	-	9
Low Purity Sources								
Refinery Hydrogen	*59,000 tonnes/year*	PSA tail gas	10.5	44.5	8.9	0.274	68	118
Iron/Steel	*2.54 M tonnes/year*	Plant Total COG PPS COG/BFG[3]	2.2	N/A 23.2 26.4	N/A 3.4 3.9	3.9 2.75 1.16	49	99 99 101
Cement *SCR/FGD Sensitivity*	*992,500 tonnes/year*	Kiln Off-gas	1.2	22.4	3.3	1.14	80	100 *127*
Coal-fired power plants	*550 MW*	*Flue Gas*	*NA*	*13.5*	*2.0*	*4.13*	*2,545[4]*	*77[5,6]*

High/Low CO_2 Purity Results Comparison

	Refinery Hydrogen (Low CO_2 Purity)	Ethylene Oxide (High CO_2 Purity)
Source Stream CO_2 Purity	44.5 mol %	100 mol %
	Breakeven Cost, $/tonne CO_2	Breakeven Cost, $/tonne CO_2
Capital Charges	41.37	9.85
Fixed O&M	12.57	3.47
Variable O&M	18.86	5.20
Consumables	2.71	0.27
Purchased Power	11.24	5.49
Purchased Natural Gas	25.88	0.00
Total Breakeven Cost	112.64	24.28

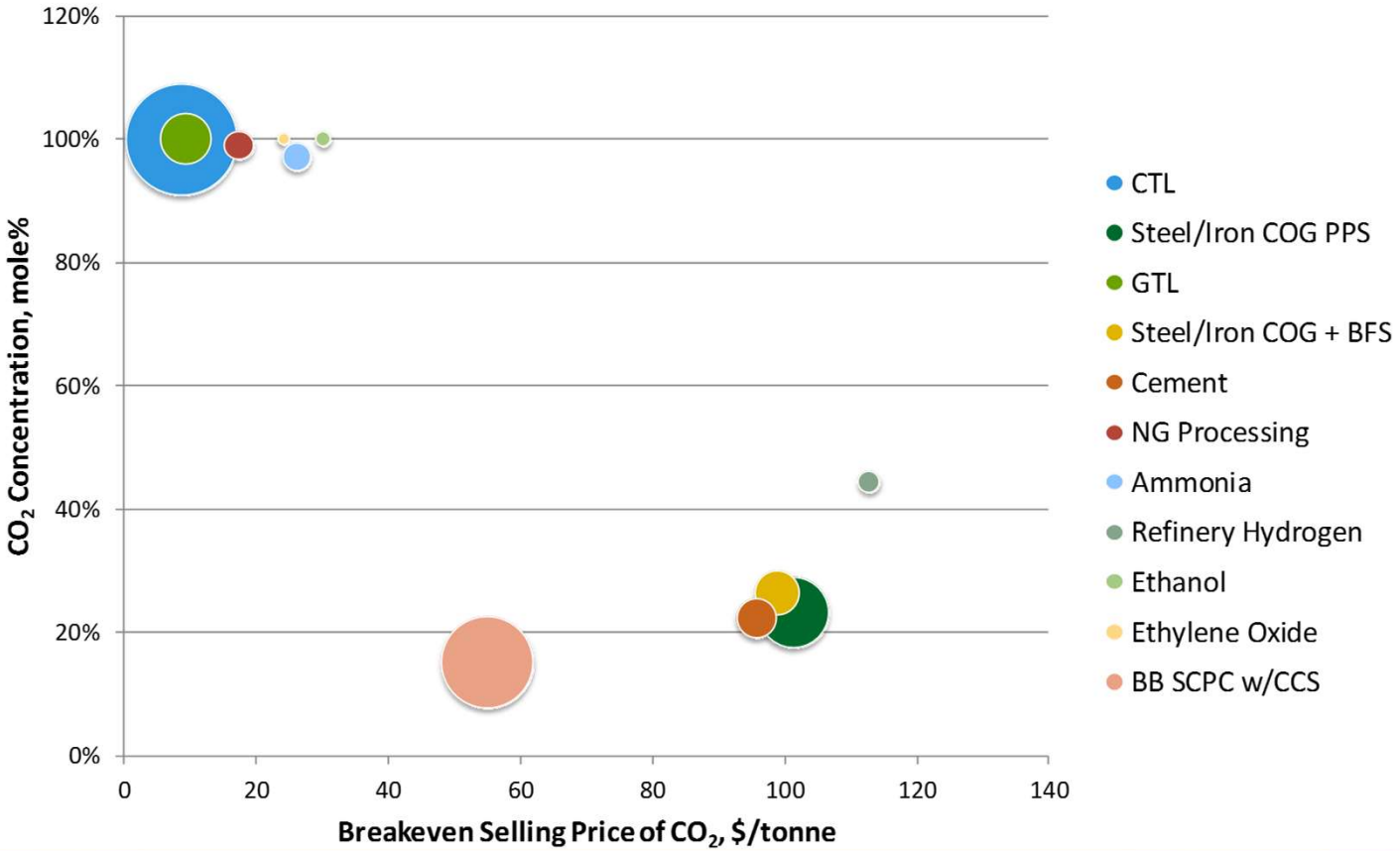
Capturing CO_2 from Industrial Sources

Incremental CO_2 Supply versus Breakeven Selling Price



Capturing CO_2 from Industrial Sources

Breakeven Selling Price as a Function of CO_2 Concentration



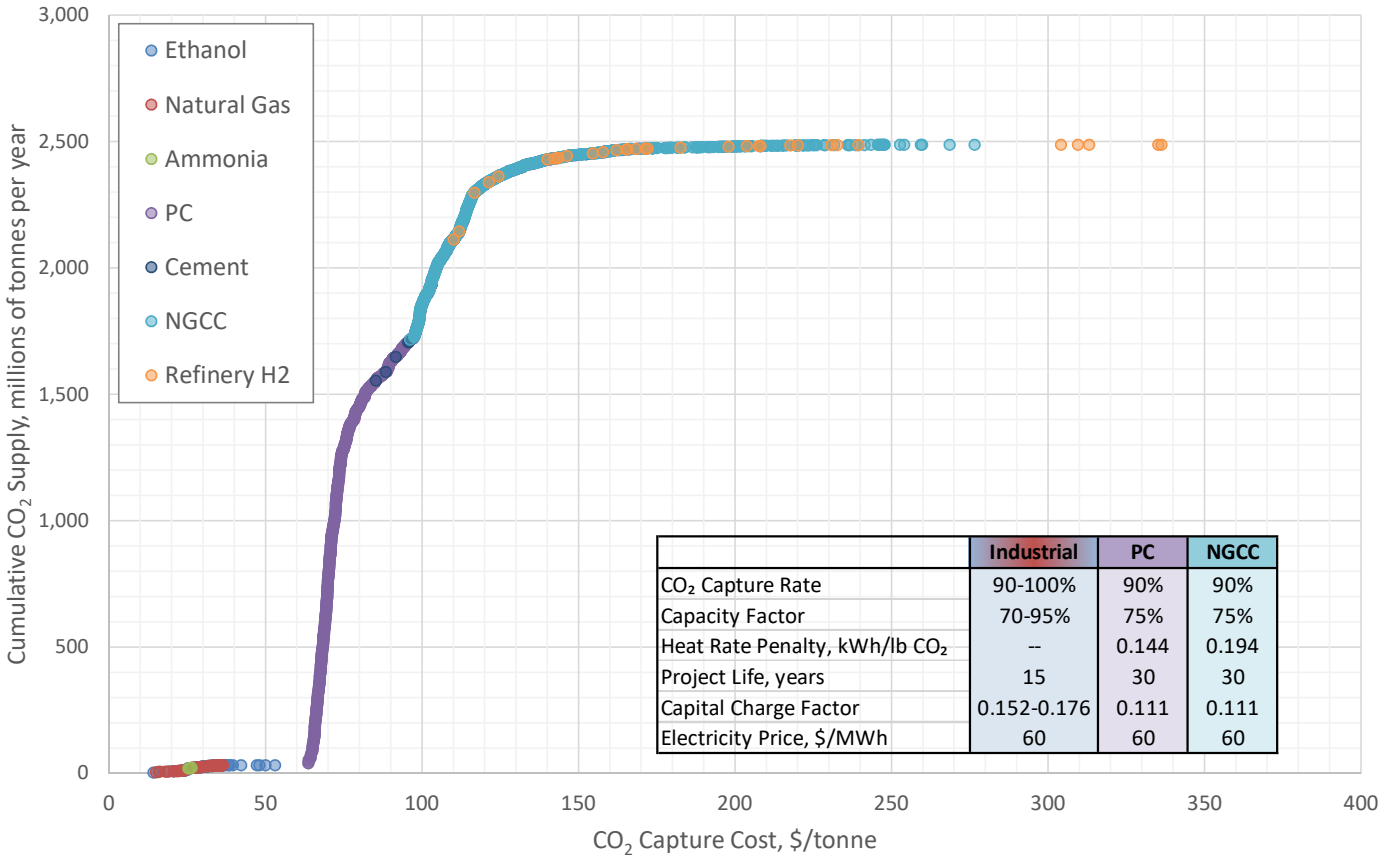
Industrial Source Retrofit Methodology

- Facility data for industrial sources based on EPA's Greenhouse Gas Reporting Program[1] and FLIGHT data[2]
- Plant capacity in report based on typical sizes, cost and performance post-retrofit based on source report, and applied using a scaled approach
- Key parameters of interest include payback period, financing structure, supplemental power or natural gas price

1. https://www.epa.gov/ghgreporting/ghgrp-reported-data
2. https://ghgdata.epa.gov/ghgp/main.do#

Cumulative CO_2 Supply

Large capacity available, at increasing cost of capture



	Industrial	PC	NGCC
CO_2 Capture Rate	90-100%	90%	90%
Capacity Factor	70-95%	75%	75%
Heat Rate Penalty, kWh/lb CO_2	--	0.144	0.194
Project Life, years	15	30	30
Capital Charge Factor	0.152-0.176	0.111	0.111
Electricity Price, $/MWh	60	60	60

Future Work

- Finalization of existing coal, NGCC retrofit source reports
- Continued development of internal version of retrofit model
- Development of public version of retrofit model

Contact Information

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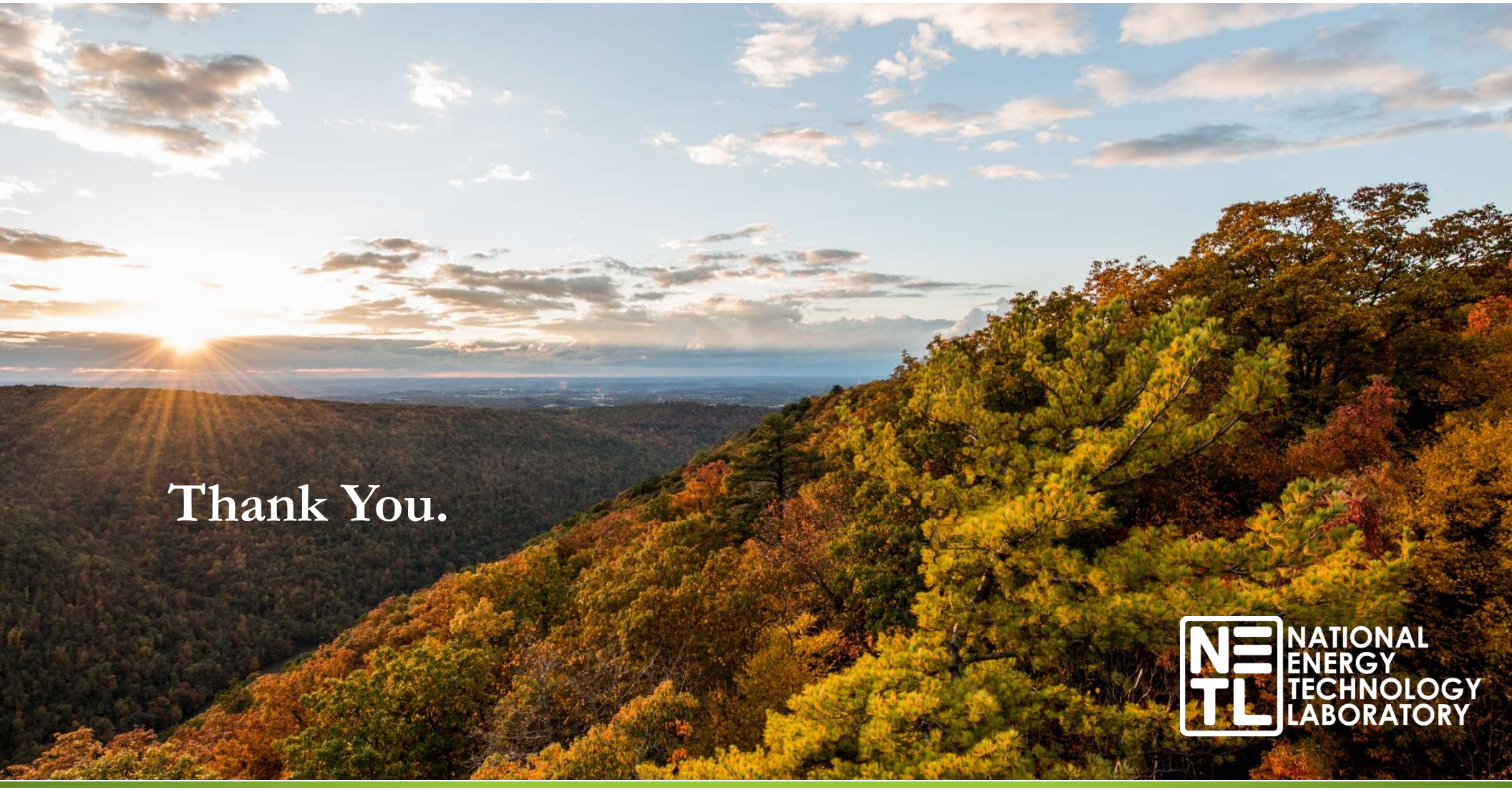
Thanks to everyone involved in the development of this effort!!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