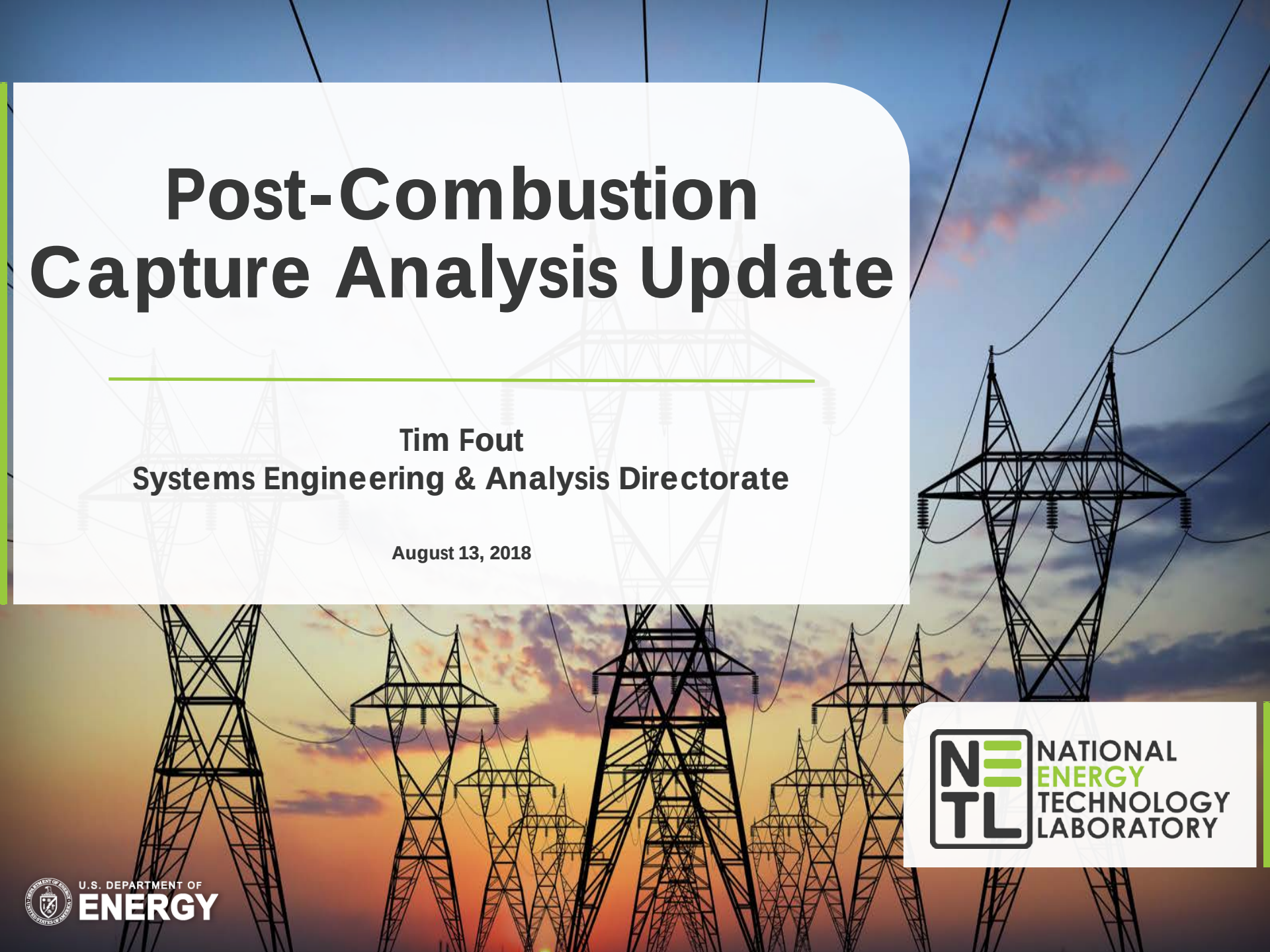
Post-Combustion Capture Analysis Update

Tim Fout
Systems Engineering & Analysis Directorate

August 13, 2018



U.S. DEPARTMENT OF ENERGY

NATIONAL ENERGY TECHNOLOGY LABORATORY

Presentation Outline

- **SEA Background**
- **Progress Reports**
  - Fossil Energy Baseline Update (Revision 4)
    - Case Summary
    - Preliminary Performance Results
  - Carbon Capture Retrofit Database
    - Background
    - Walkthrough

Systems Engineering & Analysis (SEA)

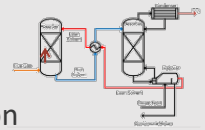
NATIONAL ENERGY TECHNOLOGY LABORATORY

Teams and Scope

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

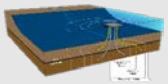


Advanced Technology Design & Cost Estimation

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



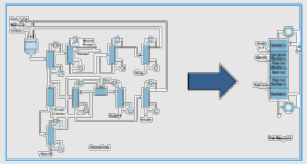
Life Cycle Analysis (LCA)

Process Systems Engineering Research

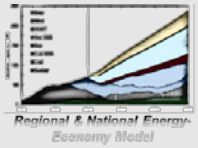
- Process synthesis, design, optimization, intensification
- Steady state and dynamic process model development
- Uncertainty quantification
- Advanced process control

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

Advanced Energy Systems through Process Systems Engineering

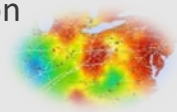


Energy Markets Analysis



Energy Economy Modeling and Impact Assessment

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



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

NETL Cost and Performance Baseline for Fossil Energy Plants Series of Reports

Overview

- **Determine cost and performance estimates of near-term commercial offerings for power plants, both with and without current technology for CO_2 capture**
  - Consistent design basis and analysis methodology
  - Up-to-date performance and capital cost estimates
  - Technologies built and deployed in the near-term
- **Purpose and use**
  - Compare existing technologies
  - **Guide R&D for advancing technologies within the DOE Office of Fossil Energy (FE) Programs**

https://www.netl.doe.gov/research/energy-analysis/baseline-studies

Cost and Performance Baseline for Fossil Energy Plants

Volume	Revision	Date	Fuel Types	Technology	Notes
1a	3	July 2015	Bituminous Coal, Natural Gas	PC, NGCC with and without CO_2 Capture	
1b	2b	July 2015	Bituminous Coal	IGCC with and without CO_2 capture	Year dollar update only
1 Supplement	0	June 2015	Bituminous Coal	PC and IGCC Partial CO_2 Capture	Sensitivity to CO_2 capture levels
3	0	Sept 2011	Sub-bituminous & Lignite Coal, Natural Gas	PC, IGCC, & NGCC with and without CO_2 capture	

Bituminous Baseline Study, Revision 4

Overview

- **Comprehensive update to *NETL Cost and Performance Baseline for Fossil Energy Plants, Volume 1: Bituminous Coal and Natural Gas to Electricity***
  - aka Bituminous Baseline Study
  - Revision 4
- **Current report split into two volumes**
  - PC and NGCC were updated with new technical and cost data – Volume 1a, Revision 3
  - IGCC only received a year $ update (to 2011 $), with no technical or cost estimation updates – Volume 1b, Revision 2b
- **Revision 4 will bring the two volumes into one full report**
  - Incorporates comprehensive technical updates to all cases (PC, IGCC, and NGCC, with and without 90% CCS)
  - Includes updated cost estimates for all technologies, to be reported in 2018 $
- **Performance modeling was developed using Aspen Plus V10.0**
- **Peer Review of performance estimates**
- **Report posting estimated in December 2018**

Bituminous Baseline Study, Revision 4

Technical Updates

- **Updated bituminous coal characteristics, reducing chlorine content to 1,671 ppmw**
- **Implemented Effluent Limitation Guidelines (ELG) regulation compliance systems for PC and IGCC cases**
  - PC – spray dryer evaporator
  - IGCC – brine concentrator and crystallizer
- **PC net plant electrical output updated from 550 MWnet to 650 MWnet**
  - Size selection driven by Black & Veatch (B&V) guidance, and updated NGCC output
- **Updated CO_2 capture system estimate for PC and NGCC capture cases**
- **Revised CO_2 compression process for stable operation**
- **Updated CT and ST performance estimates for NGCC cases**
- **Updates to IGCC cases include:**
  - Water gas shift and COS reactor, ASU, steam turbine, Selexol system

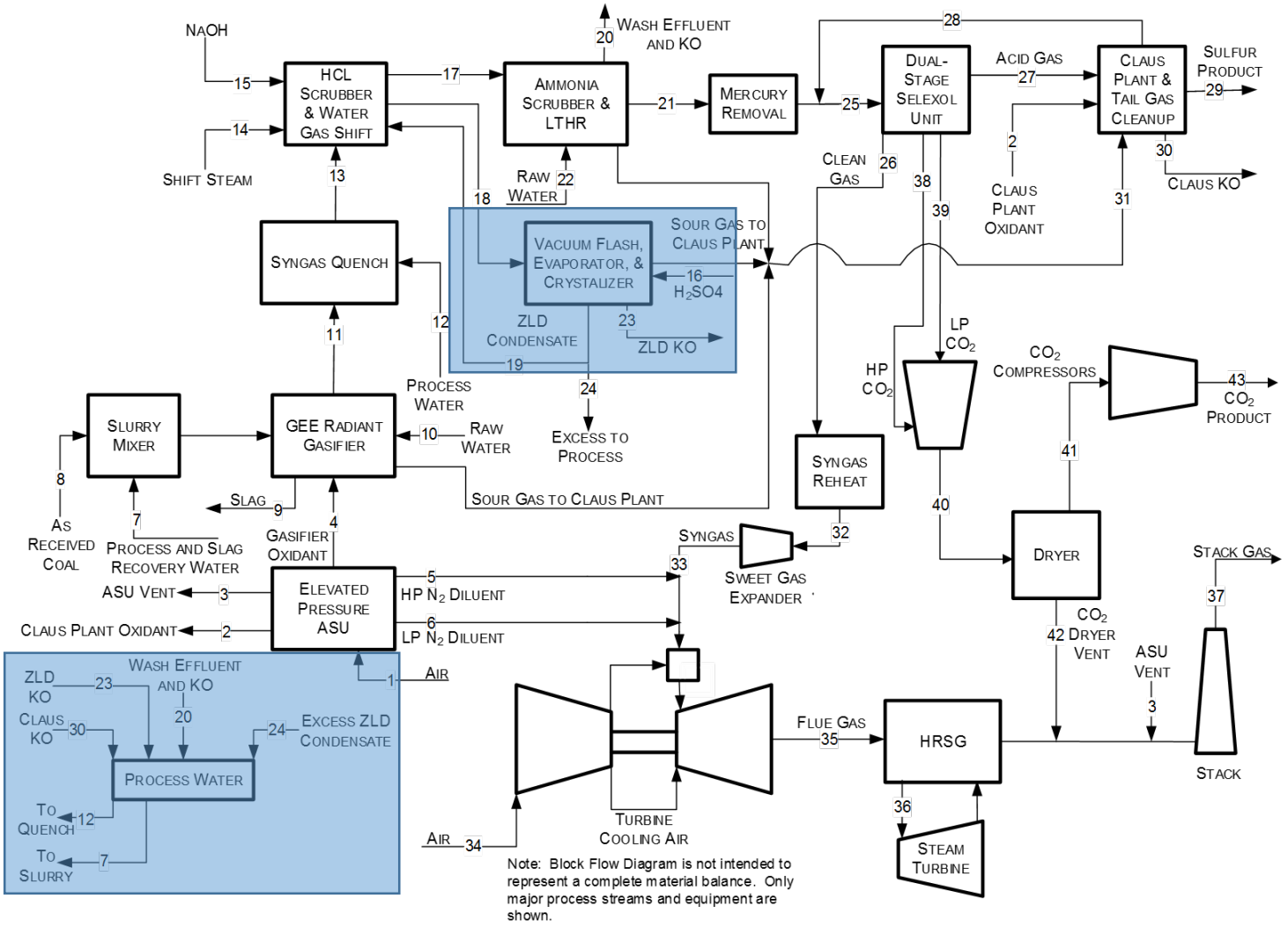
Bituminous Baseline Study, Revision 4

Case Configuration

Case	Unit Cycle	Steam Cycle, psig/°F/°F	Combustion Turbine	Gasifier/Boiler Technology	H_2S Separation	Sulfur Removal	PM Control	CO_2 Separation[A]	Process Water Treatment
B1A	IGCC	1800/1050/1050	2 x State-of-the-art 2008 F-Class	Shell	Sulfinol-M	Claus Plant/Sulfur	Cyclone, candle filter, and water scrubber	N/A	Vacuum flash. brine concentrator, crystallizer
B1B		1800/1000/1000			Selexol			Selexol 2nd stage	
B4A		1800/1050/1050		CB&I E-Gas™	Refrigerated MDEA		Cyclone, candle filter, and water scrubber	N/A	Vacuum flash. brine concentrator, crystallizer
B4B		1800/1000/1000			Selexol			Selexol 2nd stage	
B5A		1800/1050/1050		GEE Radiant	Selexol		Quench, water scrubber, and AGR adsorber	N/A	Vacuum flash. brine concentrator, crystallizer
B5B		1800/1000/1000						Selexol 2nd stage	
B5B-Q		1800/1000/1000		GEE Quench	Selexol		Quench, water scrubber, and AGR adsorber	Selexol 2nd stage	Vacuum flash. brine concentrator, crystallizer
B11A	PC	2400/1050/1050	N/A	Subcritical PC	N/A	Wet FGD/ Gypsum	Baghouse	N/A	Spray dryer evaporator
B11B							Baghouse	Cansolv	
B12A		3500/1100/1100		SC PC	N/A	Wet FGD/ Gypsum	Baghouse	N/A	Spray dryer evaporator
B12B							Baghouse	Cansolv	
B31A	NGCC	2400/1085/1085	2 x State-of-the-art 2017 F-Class	HRSG	N/A	N/A	N/A	N/A	N/A
B31B								Cansolv	

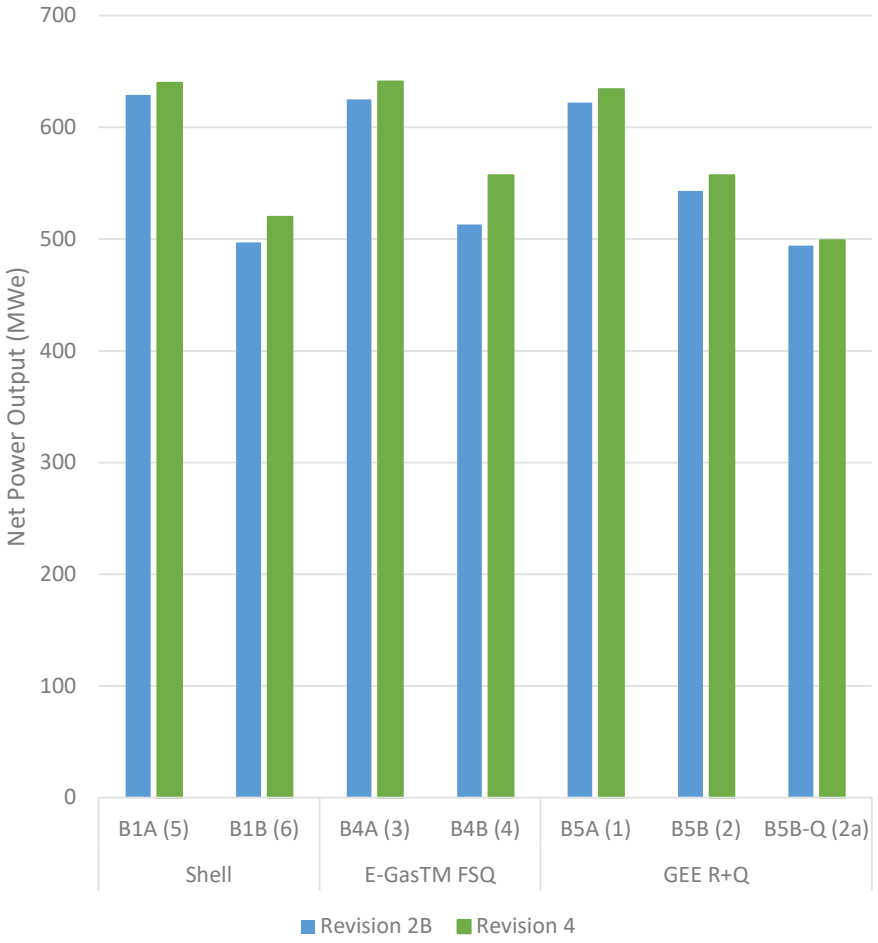
B5B (GEE Radiant Capture)

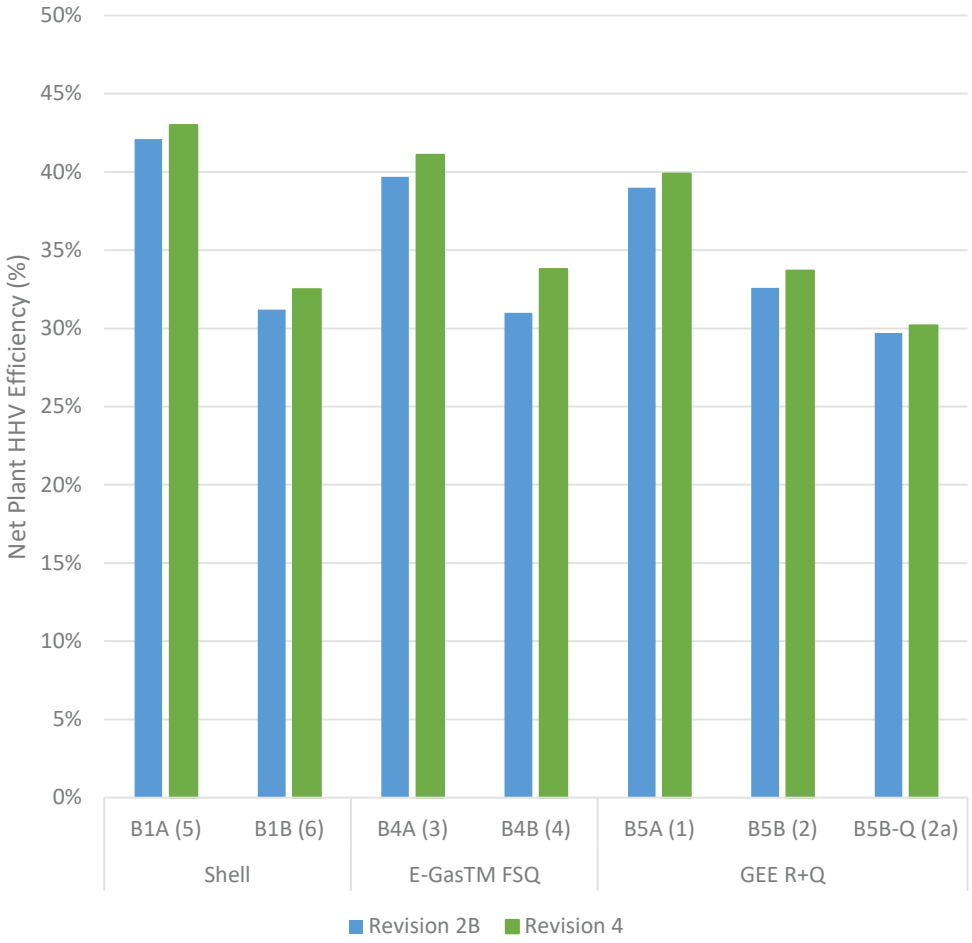
Block Flow Diagram



Bituminous Baseline Study, Revision 4

Rev2B Versus Rev4 – IGCC Net Power & Efficiency





Bituminous Baseline Study, Revision 4

NATIONAL ENERGY TECHNOLOGY LABORATORY

Performance Summary

	Integrated Gasification Combined Cycle						
	Shell		E-Gas™ FSQ		GEE R+Q		
	B1A	B1B	B4A	B4B	B5A	B5B	B5B-Q
PERFORMANCE							
Gross Power Output (MWe)	765	696	763	741	765	741	685
Auxiliary Power Requirement (MWe)	126	176	122	185	131	185	185
Net Power Output (MWe)	640	520	641	557	634	557	499
Coal Flow rate (lb/hr)	435,459	467,340	456,329	482,197	464,732	482,580	482,918
Natural Gas Flow rate (lb/hr)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
HHV Thermal Input (kW_t)	1,488,819	1,597,818	1,560,173	1,648,615	1,588,902	1,649,926	1,651,082
Net Plant HHV Efficiency (%)	43.00%	32.50%	41.10%	33.80%	39.90%	33.70%	30.20%
Net Plant HHV Heat Rate (Btu/kWh)	7,942	10,491	8,308	10,095	8,554	10,113	11,282
Raw Water Withdrawal, gpm	4,128	4,927	4,357	5,039	4,798	5,355	6,128
Process Water Discharge, gpm	922	1,040	944	1,068	1,033	1,087	1,182
Raw Water Consumption, gpm	3,206	3,887	3,413	3,971	3,766	4,267	4,946

Bituminous Baseline Study, Revision 4

NATIONAL ENERGY TECHNOLOGY LABORATORY

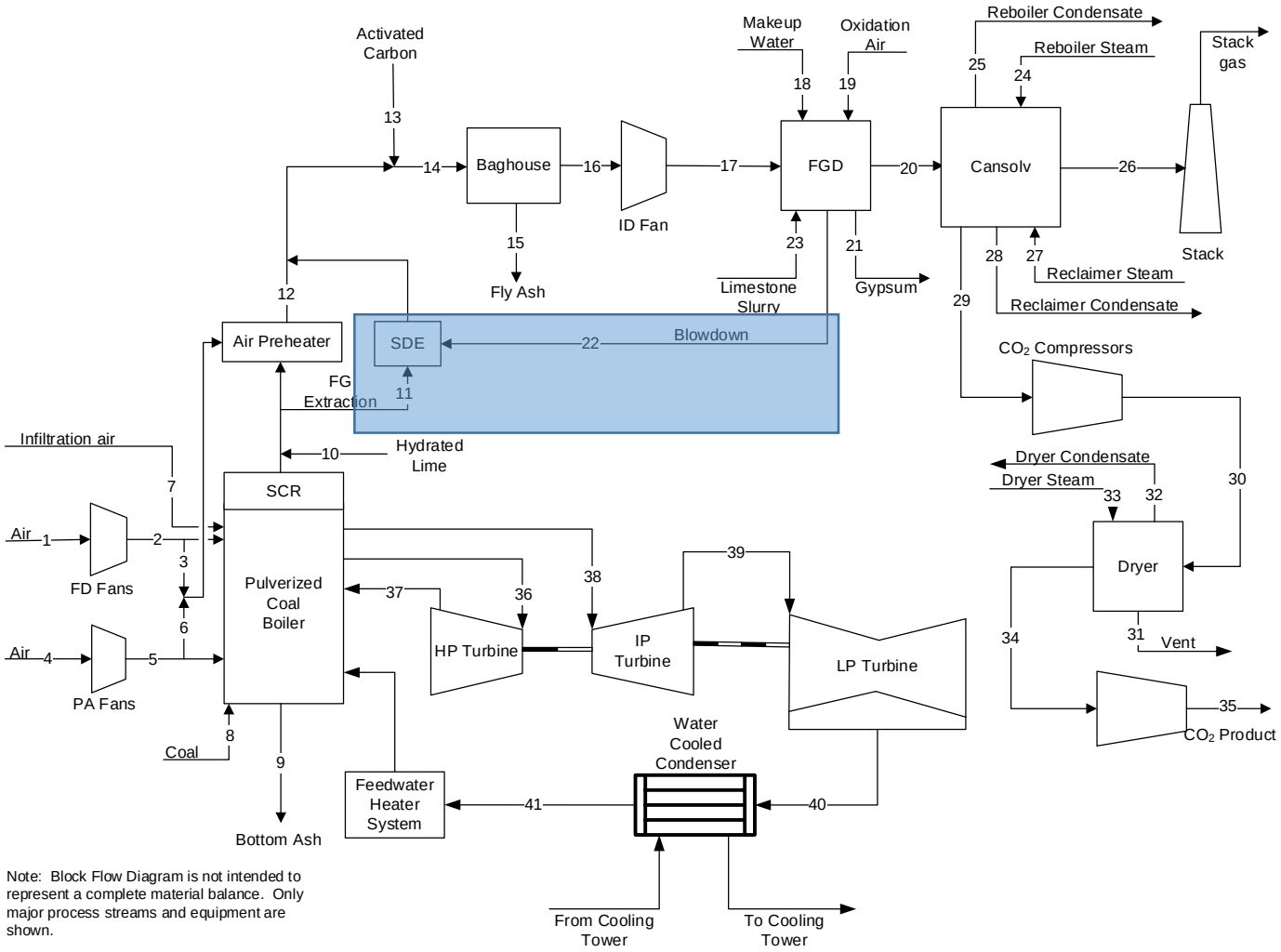
Performance Summary

	Integrated Gasification Combined Cycle						
	Shell		E-Gas™ FSQ		GEE R+Q		
	B1A	B1B	B4A	B4B	B5A	B5B	B5B-Q
PERFORMANCE							
Gross Power Output (MWe)	765	696	763	741	765	741	685
Auxiliary Power Requirement (MWe)	126	176	122	1			
Net Power Output (MWe)	640	520	641	5			
Coal Flow rate (lb/hr)	435,459	467,340	456,329	48			
Natural Gas Flow rate (lb/hr)	N/A	N/A	N/A	N			
HHV Thermal Input (kW_t)	1,488,819	1,597,818	1,560,173	1,64			
Net Plant HHV Efficiency (%)	43.00%	32.50%	41.10%	33			
Net Plant HHV Heat Rate (Btu/kWh)	7,942	10,491	8,308	10			
Raw Water Withdrawal, gpm	4,128	4,927	4,357	5,			
Process Water Discharge, gpm	922	1,040	944	1,			
Raw Water Consumption, gpm	3,206	3,887	3,413	3,			

Emissions Summary

	Shell		E-Gas™ FSQ		GEE R+Q		
	B1A	B1B	B4A	B4B	B5A	B5B	B5B-Q
EMISSIONS							
CO2 Capture Rate, %	0	90	0	90	0	90	90
CO_2 Emissions (lb/MMBtu)	200	21	199	20	197	20	20
CO_2 Emissions (lb/MWh-gross)	1,328	161	1,391	153	1,396	151	163
CO_2 Emissions (lb/MWh-net)	1,589	215	1,657	203	1,685	201	224
SO_2 Emissions (lb/MMBtu)[B]	0.02	0	0.028	0	0.002	0	0
SO_2 Emissions (lb/MWh-gross)	0.13	0	0.192	0	0.015	0	0
NOx Emissions (lb/MMBtu)	0.023	0.019	0.022	0.019	0.021	0.019	0.019
NOx Emissions (lb/MWh-gross)	0.39	0.382	0.393	0.371	0.376	0.364	0.394
PM Emissions (lb/MMBtu)	0.007	0.007	0.007	0.007	0.007	0.007	0.007
PM Emissions (lb/MWh-gross)	0.047	0.056	0.05	0.054	0.05	0.054	0.058
Hg Emissions (lb/TBtu)	0.452	0.383	0.43	0.396	0.423	0.395	0.365
Hg Emissions (lb/MWh-gross)[C]	3.00E-06	3.00E-06	3.00E-06	3.00E-06	3.00E-06	3.00E-06	3.00E-06

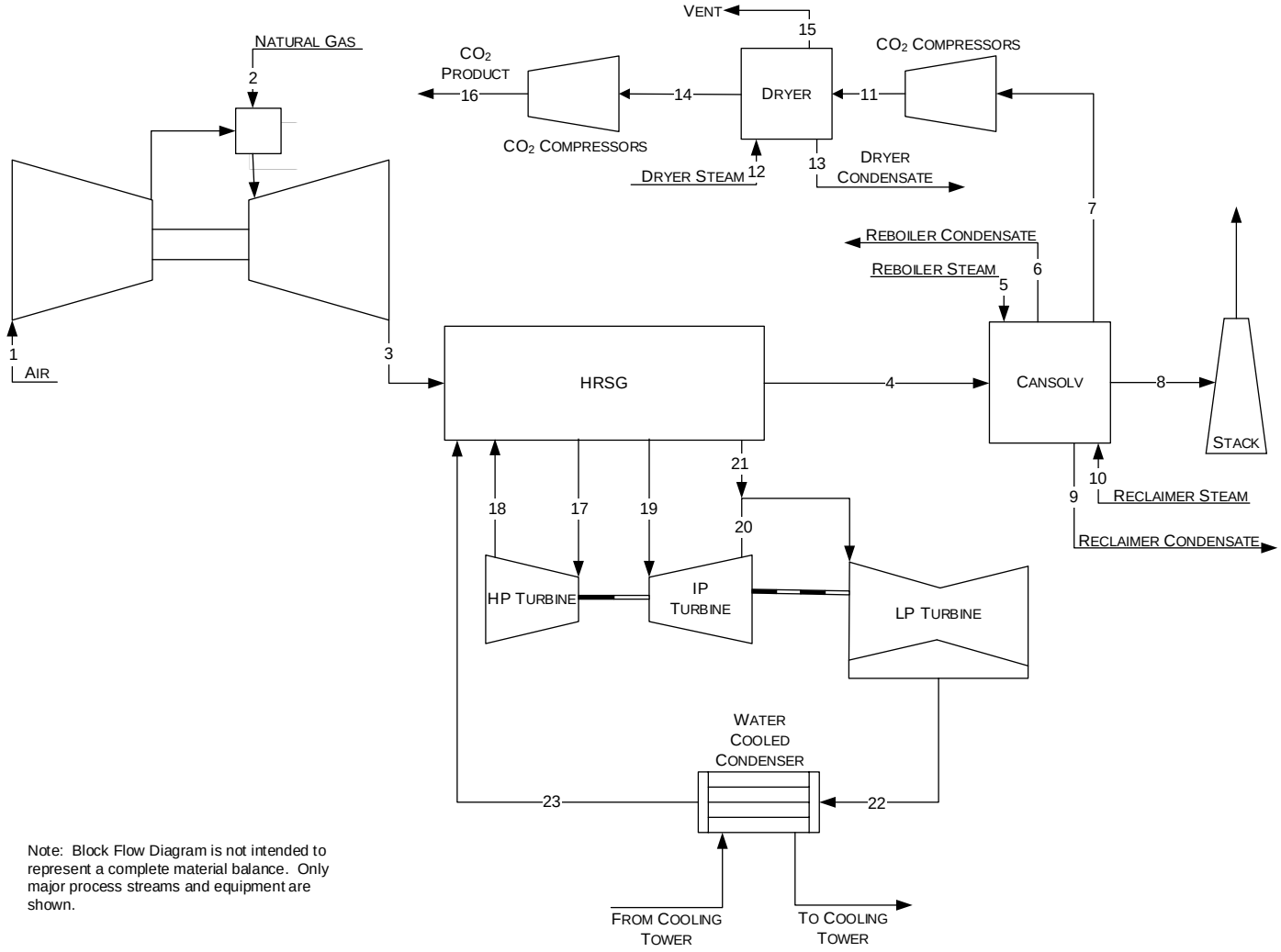
Final Block Flow Diagram – B12B



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

B31B (NGCC Capture)

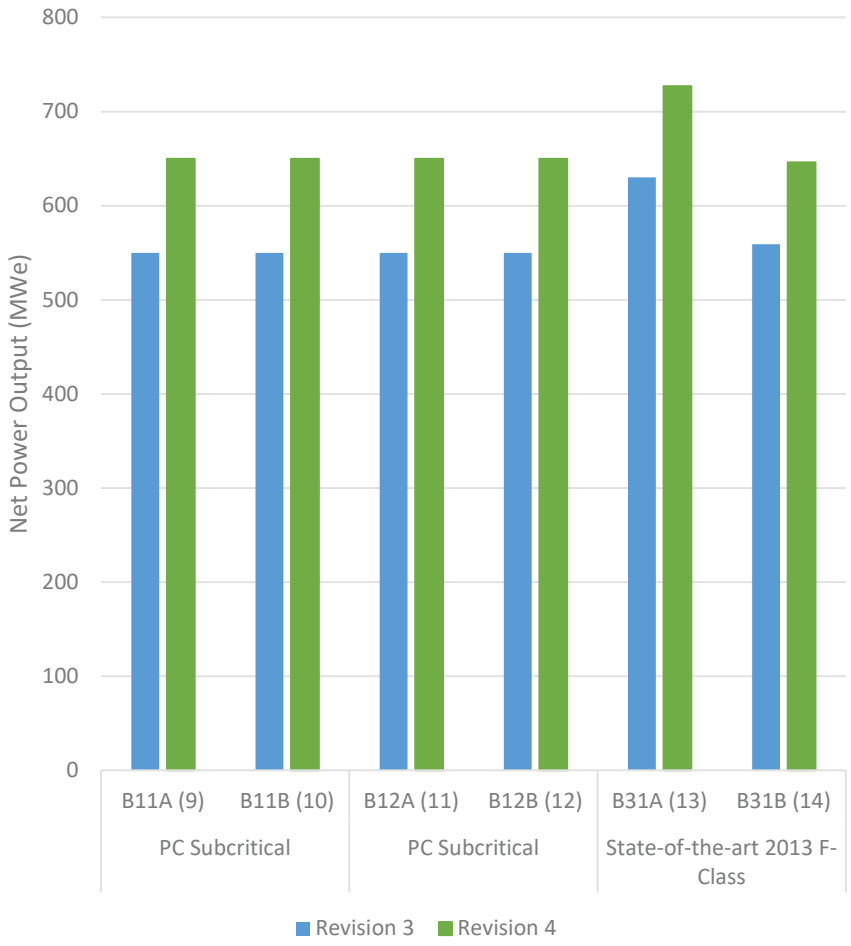
Block Flow Diagram

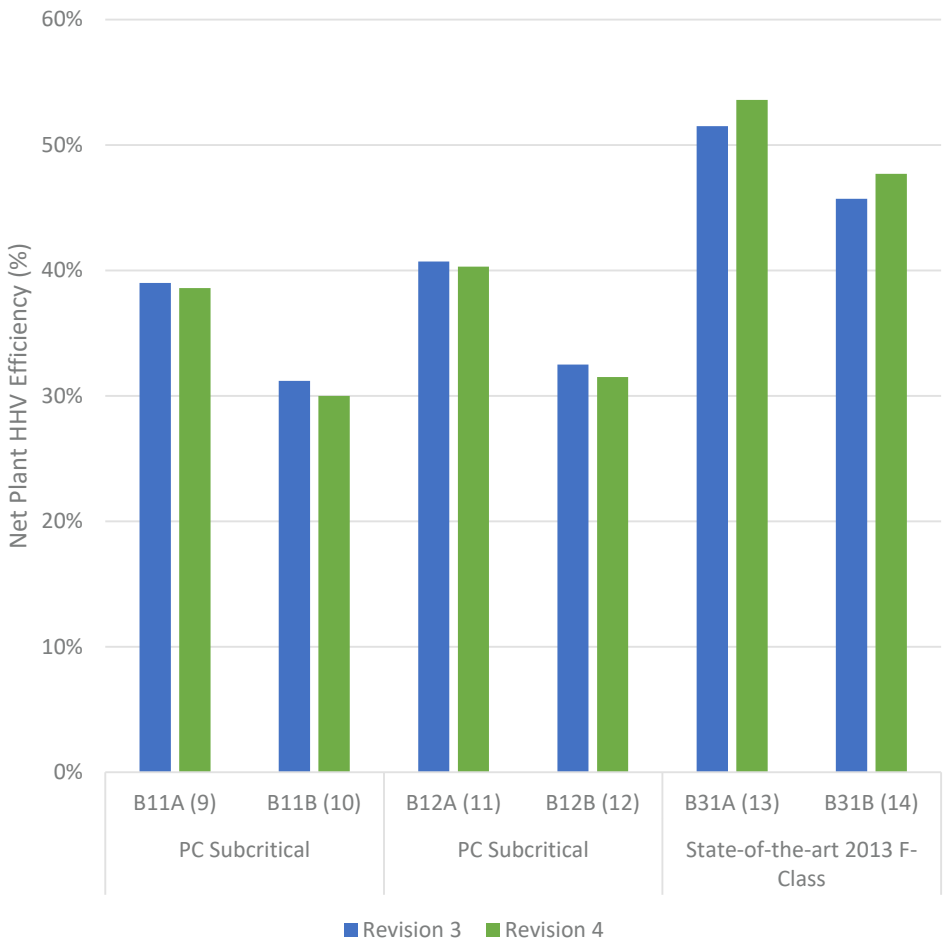


Note: Block Flow Diagram is not intended to represent a complete material balance. Only major process streams and equipment are shown.

Bituminous Baseline Study, Revision 4

Rev3 Versus Rev4 – PC/NGCC Net Power & Efficiency





Bituminous Baseline Study, Revision 4

NATIONAL ENERGY TECHNOLOGY LABORATORY

Performance Summary

	Pulverized Coal Boiler				NGCC	
	PC Subcritical		PC Supercritical		State-of-the-art 2017 F-Class	
	B11A	B11B	B12A	B12B	B31A	B31B
PERFORMANCE						
Gross Power Output (MWe)	687	776	685	770	740	690
Auxiliary Power Requirement (MWe)	37	126	35	120	14	44
Net Power Output (MWe)	650	650	650	650	727	646
Coal Flow rate (lb/hr)	492,047	634,448	472,037	603,246	N/A	N/A
Natural Gas Flow rate (lb/hr)	N/A	N/A	N/A	N/A	205,630	205,630
HHV Thermal Input (kW_t)	1,682,291	2,169,156	1,613,879	2,062,478	1,354,905	1,354,905
Net Plant HHV Efficiency (%)	38.60%	30.00%	40.30%	31.50%	53.60%	47.70%
Net Plant HHV Heat Rate (Btu/kWh)	8,832	11,387	8,473	10,828	6,363	7,158
Raw Water Withdrawal, gpm	6,480	10.427	6,053	9,719	2,902	4,704
Process Water Discharge, gpm	1,333	3,044	1,242	2,850	657	1,655
Raw Water Consumption, gpm	5,147	7,383	4,811	6,869	2,245	3,050

Bituminous Baseline Study, Revision 4

NATIONAL ENERGY TECHNOLOGY LABORATORY

Performance Summary

	Pulverized Coal Boiler				NGCC	
	PC Subcritical		PC Supercritical		State-of-the-art 2017 F-Class	
	B11A	B11B	B12A	B12B	B31A	B31B
PERFORMANCE						
Gross Power Output (MWe)	687	776	685	770	740	690
Auxiliary Power Requirement (MWe)	37	126	35	120		
Net Power Output (MWe)	650	650	650	650		
Coal Flow rate (lb/hr)	492,047	634,448	472,037	603,246		
Natural Gas Flow rate (lb/hr)	N/A	N/A	N/A	N/A	20	
HHV Thermal Input (kW_t)	1,682,291	2,169,156	1,613,879	2,062,478	1,3	
Net Plant HHV Efficiency (%)	38.60%	30.00%	40.30%	31.50%	53	
Net Plant HHV Heat Rate (Btu/kWh)	8,832	11,387	8,473	10,828	6	
Raw Water Withdrawal, gpm	6,480	10.427	6,053	9,719	2	
Process Water Discharge, gpm	1,333	3,044	1,242	2,850		
Raw Water Consumption, gpm	5,147	7,383	4,811	6,869	2	

Emissions Summary

	PC Subcritical		PC Supercritical		State-of-the-art 2017 F-Class	
	B11A	B11B	B12A	B12B	B31A	B31B
EMISSIONS						
CO2 Capture Rate, %	0	90	0	90	0	90
CO_2 Emissions (lb/MMBtu)	202	20	202	20	119	12
CO_2 Emissions (lb/MWh-gross)	1,691	193	1,627	185	741	80
CO_2 Emissions (lb/MWh-net)	1,787	230	1,714	219	755	85
SO_2 Emissions (lb/MMBtu)[B]	0.081	0	0.081	0	0.001	0
SO_2 Emissions (lb/MWh-gross)	0.674	0	0.648	0	0.006	0
NOx Emissions (lb/MMBtu)	0.084	0.073	0.087	0.077	0.004	0.003
NOx Emissions (lb/MWh-gross)	0.7	0.7	0.7	0.7	0.022	0.022
PM Emissions (lb/MMBtu)	0.011	0.009	0.011	0.01	0.002	0
PM Emissions (lb/MWh-gross)	0.09	0.09	0.09	0.09	0.012	0
Hg Emissions (lb/TBtu)	0.359	0.314	0.373	0.328	0	0
Hg Emissions (lb/MWh-gross)[C]	3.00E-06	3.00E-06	3.00E-06	3.00E-06	0	0

NETL CCS Retrofit Analysis and Modeling

SOA Post-Combustion Capture System Quotes

2nd Generation Post-Combustion Capture System Cost/Perf

1
8

NETL CCS Retrofit Analysis and Modeling

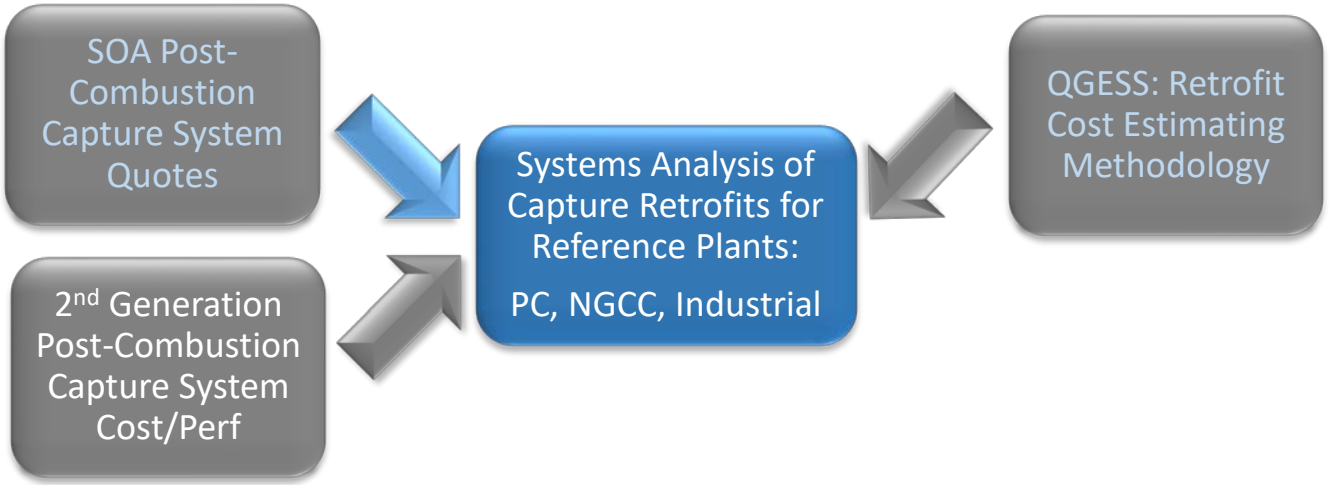
SOA Post-Combustion Capture System Quotes

2nd Generation Post-Combustion Capture System Cost/Perf

QGESS: Retrofit Cost Estimating Methodology

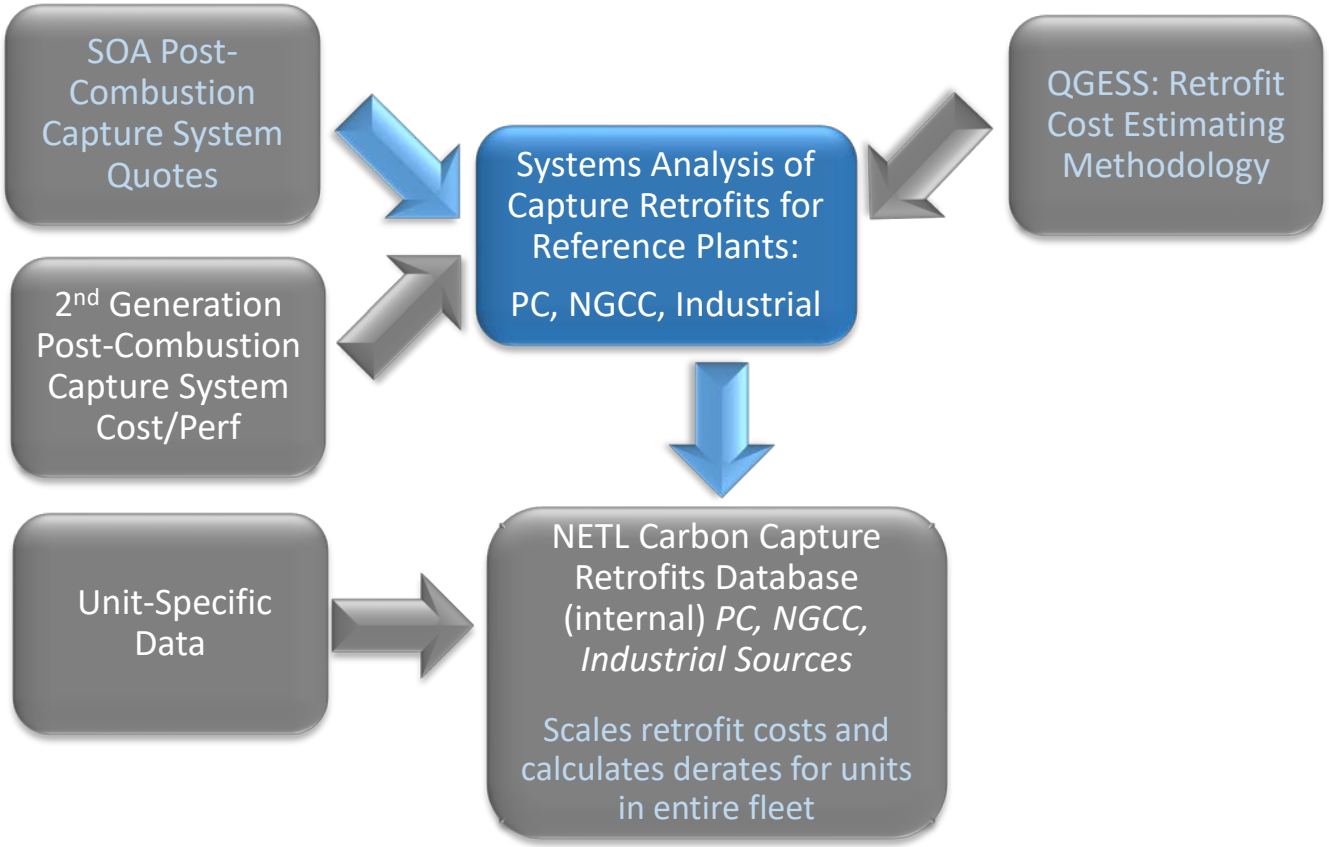
1
9

NETL CCS Retrofit Analysis and Modeling



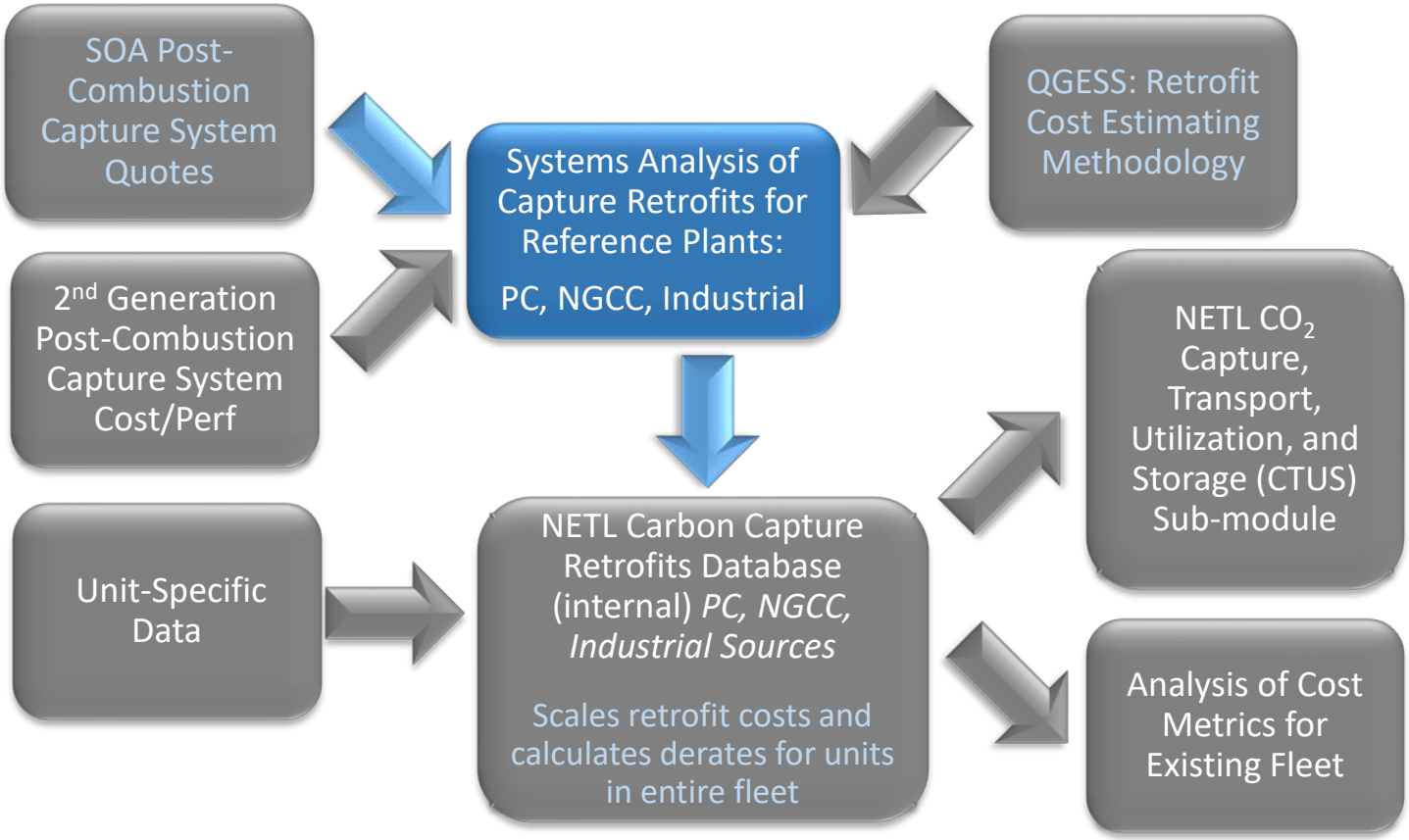
2
0

NETL CCS Retrofit Analysis and Modeling



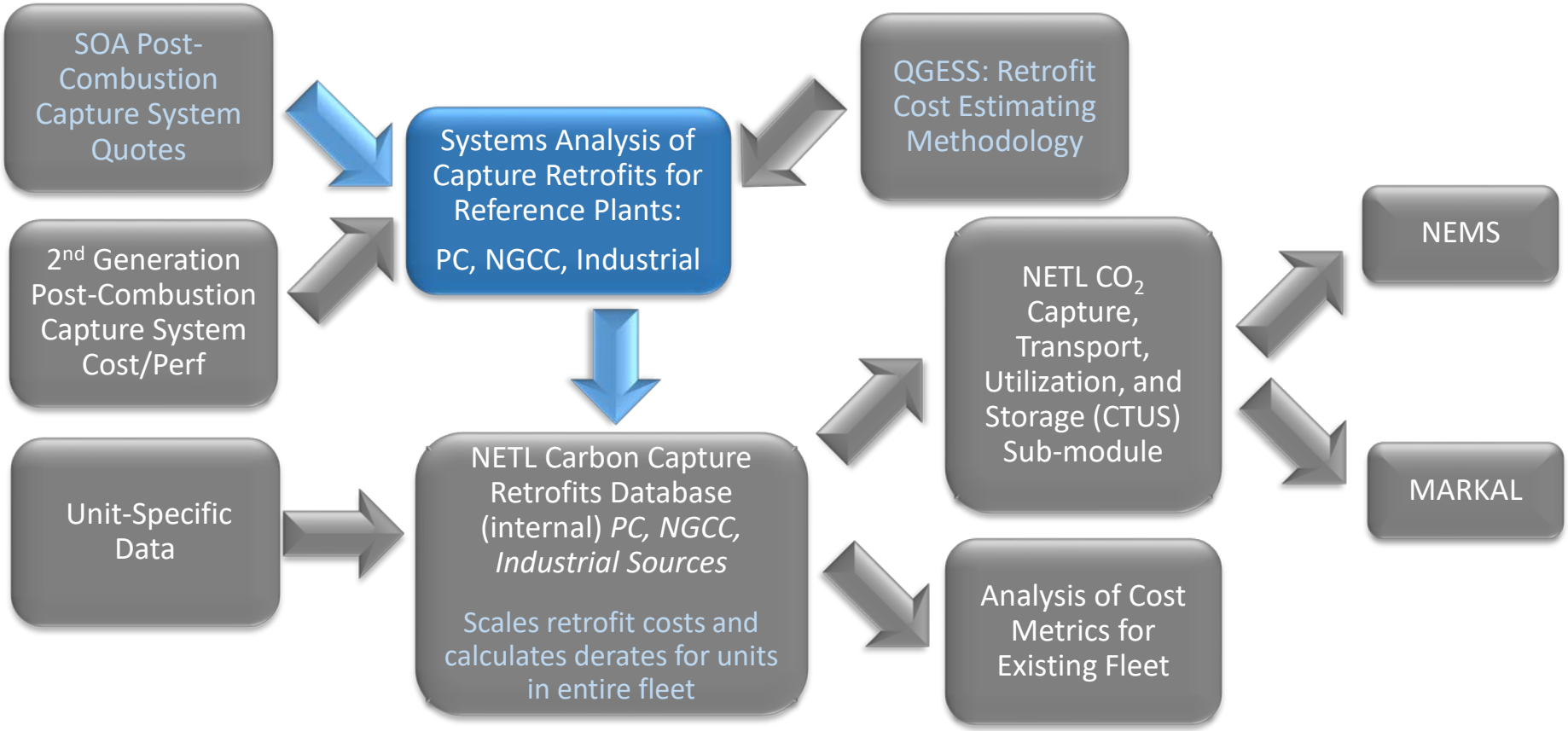
2
1

NETL CCS Retrofit Analysis and Modeling



2
2

NETL CCS Retrofit Analysis and Modeling

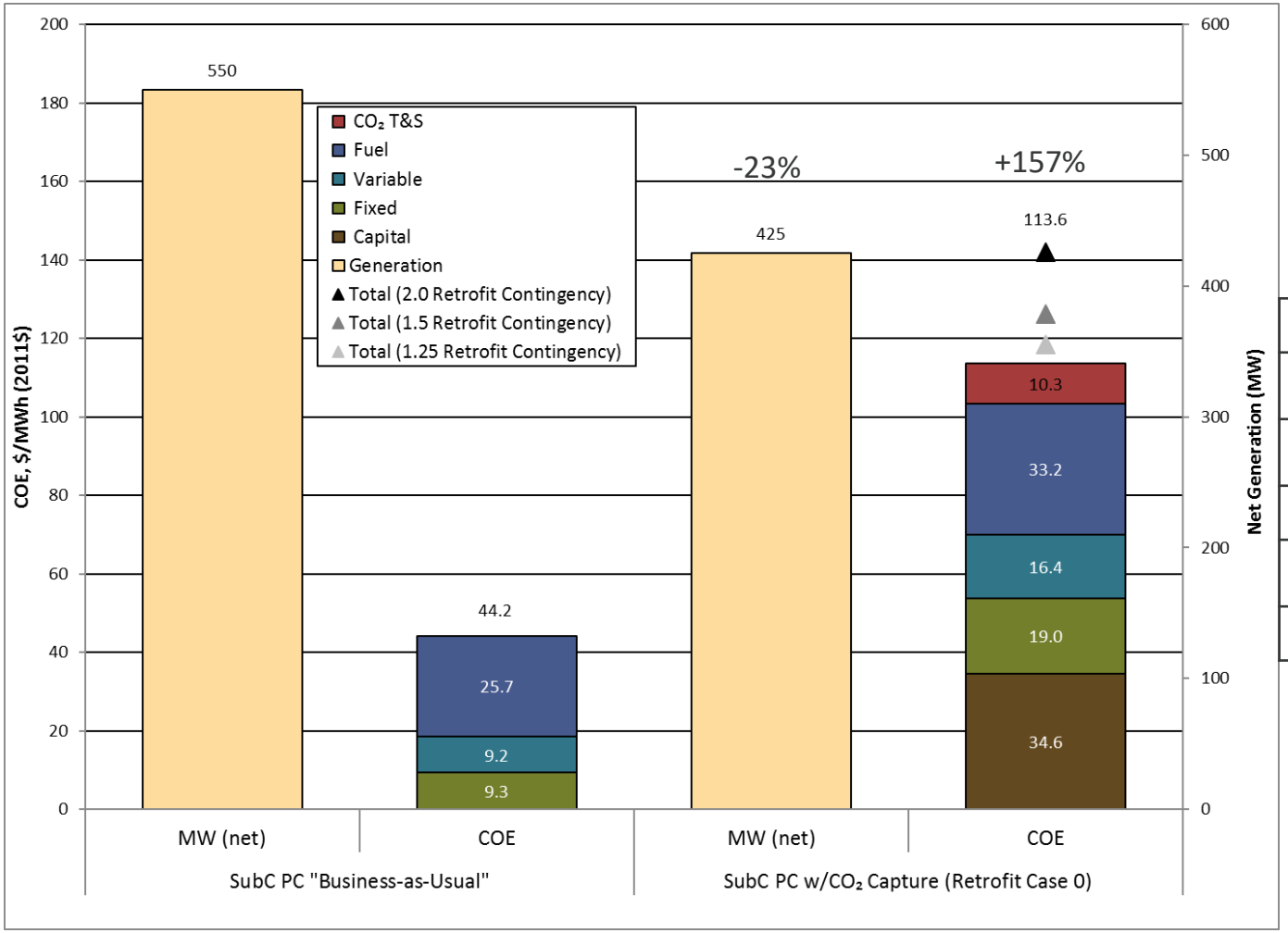


2
3

Supporting Reports

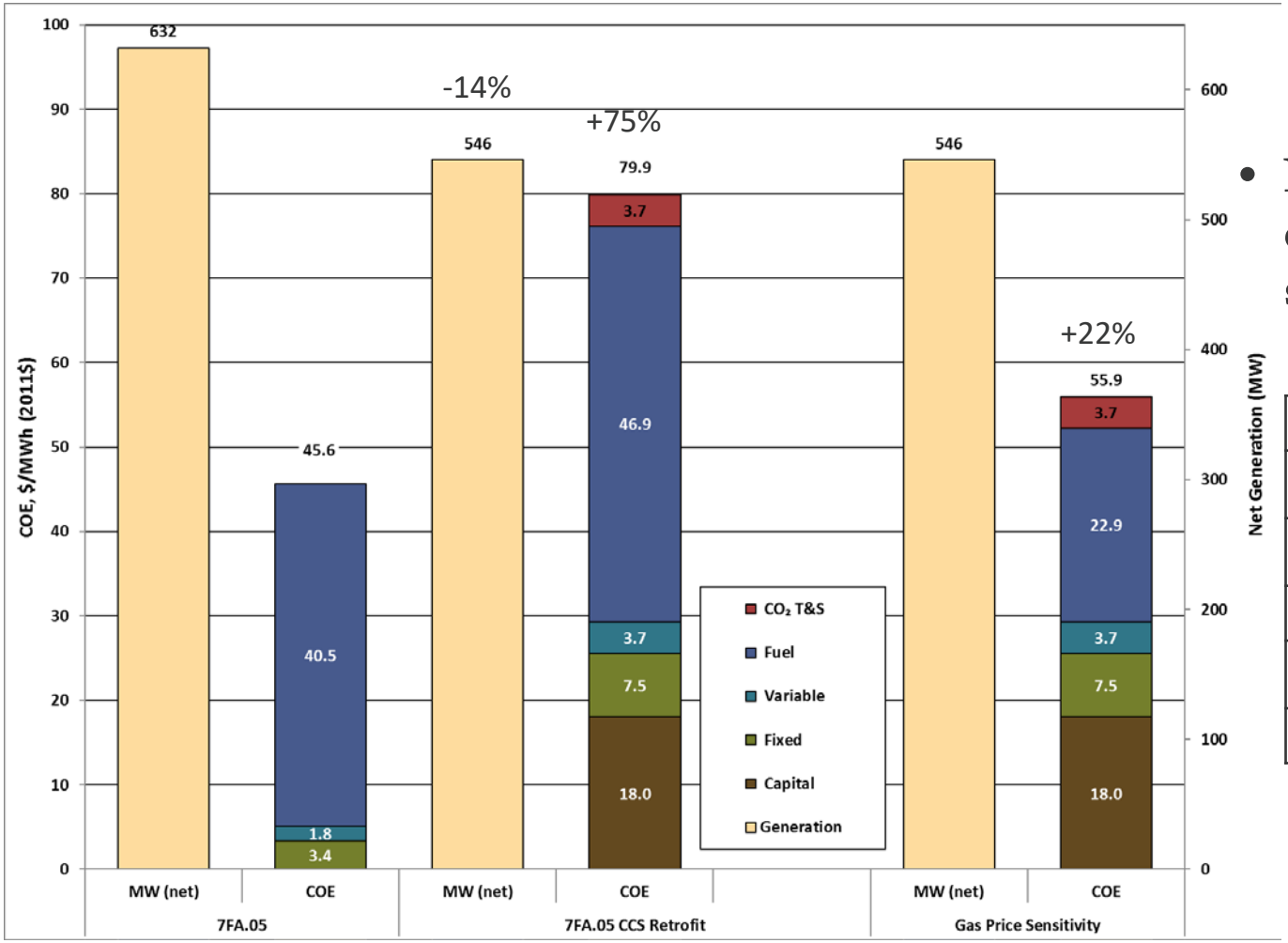
- **PC**
  - "Eliminating the Derate of Carbon Capture Retrofits Study Update," Late 2017
- **NGCC**
  - "Cost and Performance of Retrofitting NGCC Units for Carbon Capture," Late 2017
- **Industrial**
  - "Cost of Capturing CO_2 from Industrial Sources," DOE/NETL-2013/1602, January 2014

Subcritical PC Retrofit Results



Retrofit Capex	$741,400,000
Heat Rate (pre retrofit)	8,740 Btu/kWh
Heat Rate (post retrofit)	11,300 Btu/kWh
CO_2 Capture Rate	880,451 Lb CO_2/hr
Energy Penalty	≈0.14 kWh/Lb CO_2 captured
Incremental O&M	$16.9/MWh

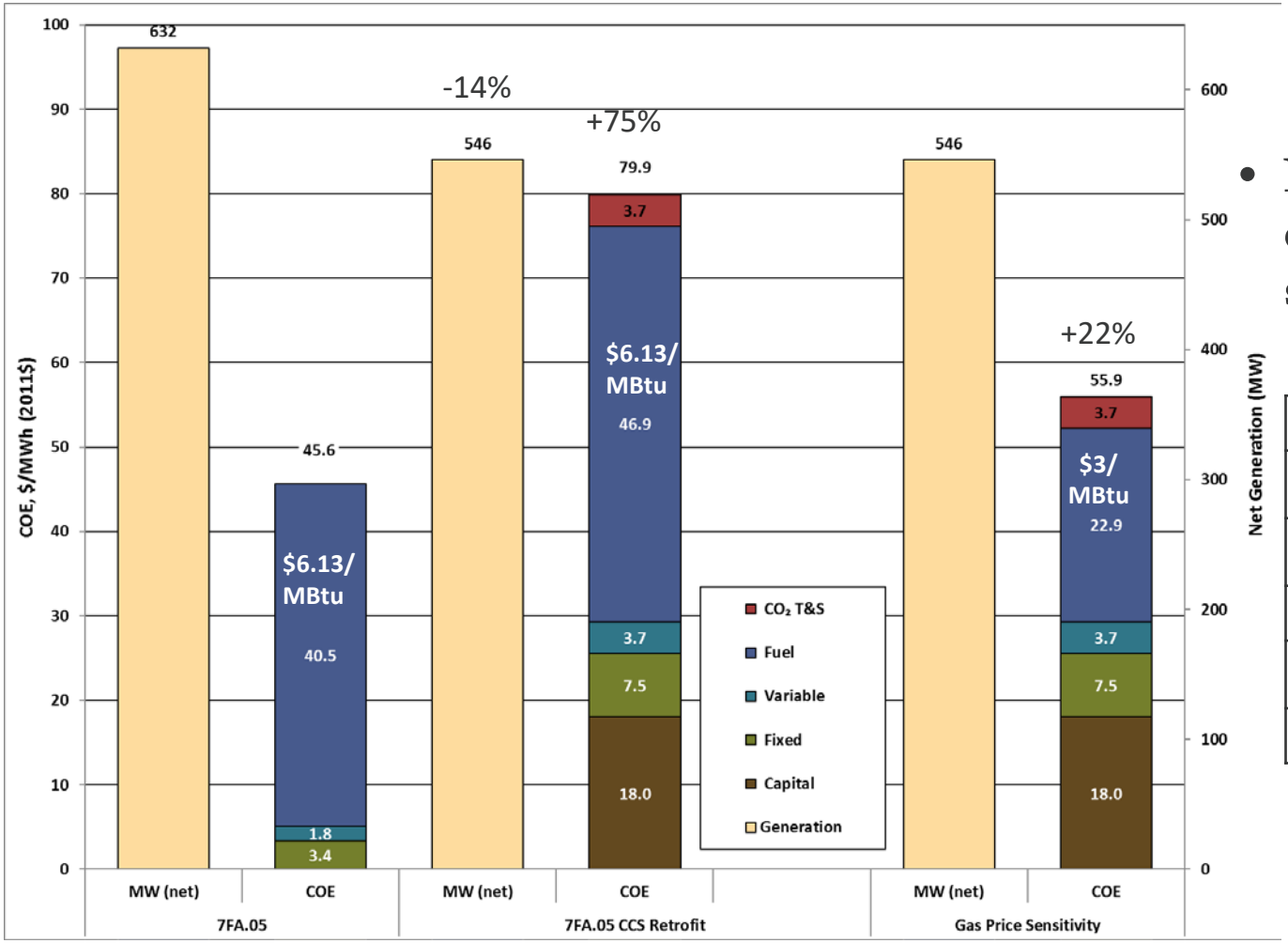
NGCC Retrofit Results



- NGCC cost of electricity highly sensitive to gas price!

Retrofit Capex	$647,300,000
Heat Rate (pre retrofit) HHV	6,607 Btu/kWh
Heat Rate (post retrofit) HHV	7,583 Btu/kWh
CO_2 Capture Rate	445,333 Lb CO_2/hr
Energy Penalty	≈0.19 kWh/Lb CO_2 captured
Incremental O&M	$6.15/MWh

NGCC Retrofit Results



- NGCC cost of electricity highly sensitive to gas price!

Retrofit Capex	$647,300,000
Heat Rate (pre retrofit) HHV	6,607 Btu/kWh
Heat Rate (post retrofit) HHV	7,583 Btu/kWh
CO_2 Capture Rate	445,333 Lb CO_2/hr
Energy Penalty	≈0.19 kWh/Lb CO_2 captured
Incremental O&M	$6.15/MWh

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[56]*

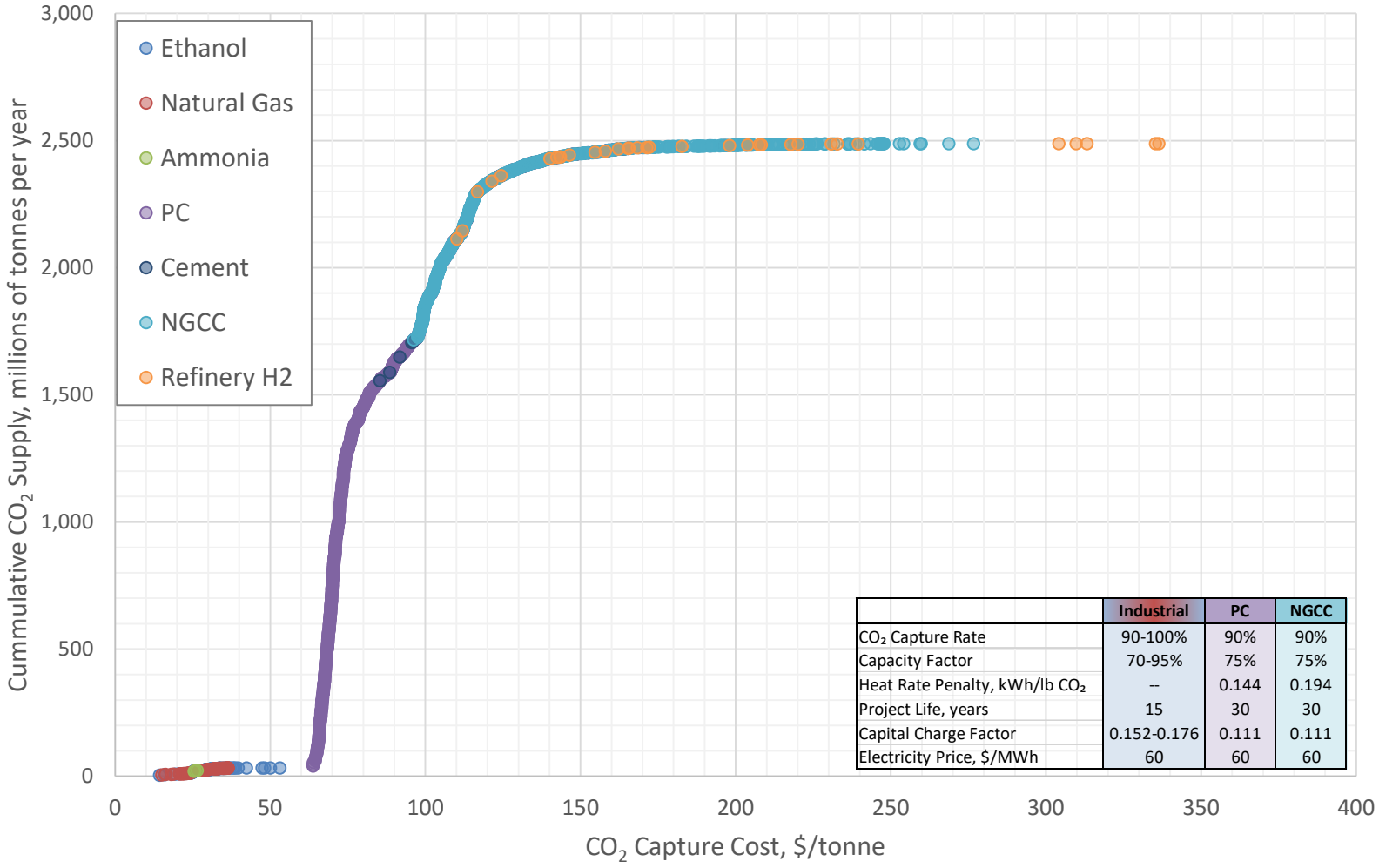
Industrial Source Retrofit Methodology

- 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

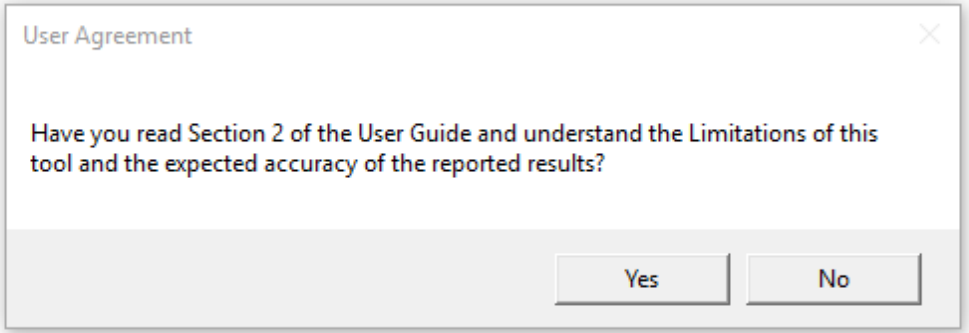
PC CCRD Walkthrough

NATIONAL ENERGY TECHNOLOGY LABORATORY

MACROS MUST BE ENABLED TO UTILIZE THIS TOOL

Note: A copy of the User Guide can be viewed by clicking the icon to the right.
The User Guide provides a general walkthrough of the CCRDs. Section 2 of the User Guide explans the limitations and expected accuracy of the reported results and must be read prior to using this tool.

Start Program



PC CCRD Walkthrough (con't)

- **Plant Inputs**
  - Pre-filled with baseline NETL cases as guides
  - Input parameters include:
    - Plant Name
    - Plant State
    - Plant NERC Region
    - Gross to Net Factor (MWnet/MWgross)
    - Nameplate Capacity
    - Net Summer Capacity
    - Net Winter Capacity
    - Heat Rate
    - CO_2 Annual Rate
    - NOx Summer Rate
    - NOx Control Equipment
    - SO_2 Annual Rate
    - SO_2 Control Equipment
    - Weighted Average Variable O&M
    - Fuel Costs (12 month weighted average)
    - Cooling System Type
    - Capacity Factor (2016, 2015, 2014)

PC CCRD Walkthrough (con't)

Plant Information - User Data Entry

Unit ID	Plant ID	Plant Name	Plant State	Plant NERC Region	Gross to Net Factor (MW_{net}/MW_{gross})	Nameplate Capacity, MW	Net Summer Capacity, MW	Net Winter Capacity, MW	Heat Rate, Btu/kWh	CO2 Annual Rate, lbs/MMBtu	NOx Summer Rate, lbs/MMBtu	NOx Control Equipment
1	B11A	SubCritical PC NETL bituminous baseline no capture	MO	SERC	95	550	550	550	8,740	204	0.083	Low NOx Burners; Selective Catalytic Reduction
2	B12A	SuperCritical PC NETL bituminous baseline no capture	MO	SERC	95	550	550	550	8,379	204	0.088	Low NOx Burners; Selective Catalytic Reduction
3	S12A	SuperCritical PC NETL subbituminous baseline no capture	MT	WECC	94	550	550	550	8,813	215	0.070	Low NOx Burners; Selective Catalytic Reduction
4	S13A	UltraSuperCritical PC NETL subbituminous baseline no captu	MT	WECC	95	550	550	550	8,552	215	0.070	Low NOx Burners; Selective Catalytic Reduction
5	L12A	SuperCritical PC NETL ND Lignite baseline no capture	ND	MRO	94	550	550	550	9,093	220	0.070	Low NOx Burners; Selective Catalytic Reduction
6	L13A	UltraSuperCritical PC NETL ND Lignite baseline no capture	ND	MRO	94	550	550	550	8,795	220	0.070	Low NOx Burners; Selective Catalytic Reduction
7	S22A	SuperCritical CFB NETL subbituminous baseline no capture	MT	WECC	95	550	550	550	8,770	213	0.070	Selective Non-catalytic Reduction
8	L22A	SuperCritical CFB NETL ND Lignite baseline no capture	ND	MRO	95	550	550	550	8,975	219	0.070	Selective Non-catalytic Reduction

SO_2 Annual Rate, lbs/MMBtu	SO_2 Control Equipment	Weighted Average Variable O&M Costs, $/MWh	Weighted Average Fixed O&M Costs, $/MWh	Fuel Costs (12 month weighted average), $/MWh	Cooling System Type	Capacity Factor 2016, %	Capacity Factor 2015, %	Capacity Factor 2014, %
0.085	Wet Limestone FGD	9.23	9.30	25.67	Recirculating with induced draft cooling tower(s)	85.0	85.0	85.0
0.085	Wet Limestone FGD	9.05	9.60	24.61	Recirculating with induced draft cooling tower(s)	85.0	85.0	85.0
0.119	Lime Spray Dryer FGD	5.10	9.00	7.80	Recirculating with induced draft cooling tower(s) -a parallel wet/dry	85.0	85.0	85.0
0.119	Lime Spray Dryer FGD	5.10	9.30	7.60	Recirculating with induced draft cooling tower(s) -a parallel wet/dry	85.0	85.0	85.0
0.132	Lime Spray Dryer FGD	6.10	9.70	7.50	Recirculating with induced draft cooling tower(s) -a parallel wet/dry	85.0	85.0	85.0
0.132	Lime Spray Dryer FGD	6.10	10.10	7.30	Recirculating with induced draft cooling tower(s) -a parallel wet/dry	85.0	85.0	85.0
0.102	Fluidized Bed Limestone Injection	5.30	9.10	7.80	Recirculating with induced draft cooling tower(s) -a parallel wet/dry	85.0	85.0	85.0
0.113	Fluidized Bed Limestone Injection	6.10	9.50	7.40	Recirculating with induced draft cooling tower(s) -a parallel wet/dry	85.0	85.0	85.0

PC CCRD Walkthrough (con't)

NATIONAL ENERGY TECHNOLOGY LABORATORY

User Inputs and Constants Used in Calculations

Input Desired Scenarios to be Analyzed Here

Parameter	Units	Value			Comments
		SCENARIO #1	SCENARIO #2	SCENARIO #3	
CO_2 Capture Rate	Choose option	Default	Default	Default	
	%	90%	90%	90%	
CO_2 Capture Technology	Choose Option	Amine Based	Amine Based	Amine Based	
Pre-Retrofit Capacity Factor	Choose Option	User Input	User Input	User Input	Unit Actual uses plant level reported CFs. Average value is the average reported capacity factor
	%	85%	75%	65%	
Post-Retrofit Capacity Factor	Choose Option	Delta	Delta	Delta	Use Absolute or delta from pre-retrofit CF. If the delta entered is lower than the unit's actual CF
	% or Reduction Delta	0%	10%	10%	calculations.
Retrofit Unit Capacity Applicability Limit	Choose Option	Default	Default	Default	All units with a nameplate capacity below the limit are excluded from all calculations.
	MW	25	25	25	
Retrofit Cost Factor	Choose Option	Default	Default	Default	Multiplier applied to Total Plant Capital Cost.
		1.10	1.10	1.10	
Capital Charge Factor	Choose Option	High Risk	High Risk	High Risk	Default values are for a 3-year construction period with either a 10-, 20-, or 30-year economic li
	Choose Option	30-year	30-year	30-year	
		0.111	0.111	0.111	
Advanced Options					
CO_2 Emissions Rate	Choose option	Unit Actual	Unit Actual	Unit Actual	
	lb/MMBtu	N/A	N/A	N/A	
Maximum CO_2 Capture Rate Per Train	Choose option	Default	Default	Default	If the CO_2 production rate exceeds the maximum, multiple trains will be used.
	TPD	15,772	15,772	15,772	
Plant Capacity Metric	Choose Option	Nameplate	Nameplate	Nameplate	
Cost Year Basis	Choose Option	Default	Default	Default	
	Year	2011	2011	2011	Scaled based on Chemical Engineering Cost Index (CEPCI). Only 2011 or 2017 can be selected
Cooling preference?	Choose Option	Existing	Existing	Existing	Select cooling system (dry or wet) based on either type of existing cooling system or location's (
Projected Sales Price of Electricity	Choose Option	Default	State	State	Cost for lost revenue/price to purchase make-up power. State uses annual average retail price
	$/MWh	60	N/A	N/A	sectors from EIA. Only used in breakeven CO_2 metric calculations.
Include SCR with retrofit?	Choose Option	Yes	Yes	Yes	
Include FGD with retrofit?	Choose Option	Yes	Yes	Yes	
Additional Heat Rate Penalty	Choose Option	None	None	None	This value is a user specified penalty in addition to the calculated values for CO2 capture and s
	Btu/kWh	N/A	N/A	N/A	
CO_2 Transport and Storage Costs	Choose Option	Default	Default	Default	COE and Breakeven CO_2 Emissions Penalty include T&S.
	$/tonne captured	11.00	11.00	11.00	Breakeven CO_2 Sales Price never includes T&S.

PC CCRD Walkthrough (con't)

- **Scenario Results**
  - CAPEX
    - Additional SCR, FGD
    - CO_2 Removal and Compression
    - Letdown turbine
    - Cooling Water
    - BOP
    - Total Retrofit Cost TPC and TOC
  - Incremental OPEX
    - Fixed (Labor, Taxes & Insurance)
    - Variable (Chemicals/Waste, Maintenance)
    - Total Fixed and Total Variable
  - Parasitic Load
    - SCR Load, FGD Load (if additional removal required)
    - Parasitic Cooling and Electrical Load
    - Parasitic Steam Turbine Derate
  - Overall Summary
    - Makeup/Excess Power Costs/Credits
    - Total Incremental Cost
    - Existing Fixed O&M in COE Change
    - CO_2 T&S Cost
    - Total Incremental COE
    - Breakeven CO_2 Sales Price
    - Breakeven CO_2 Emissions Penalty

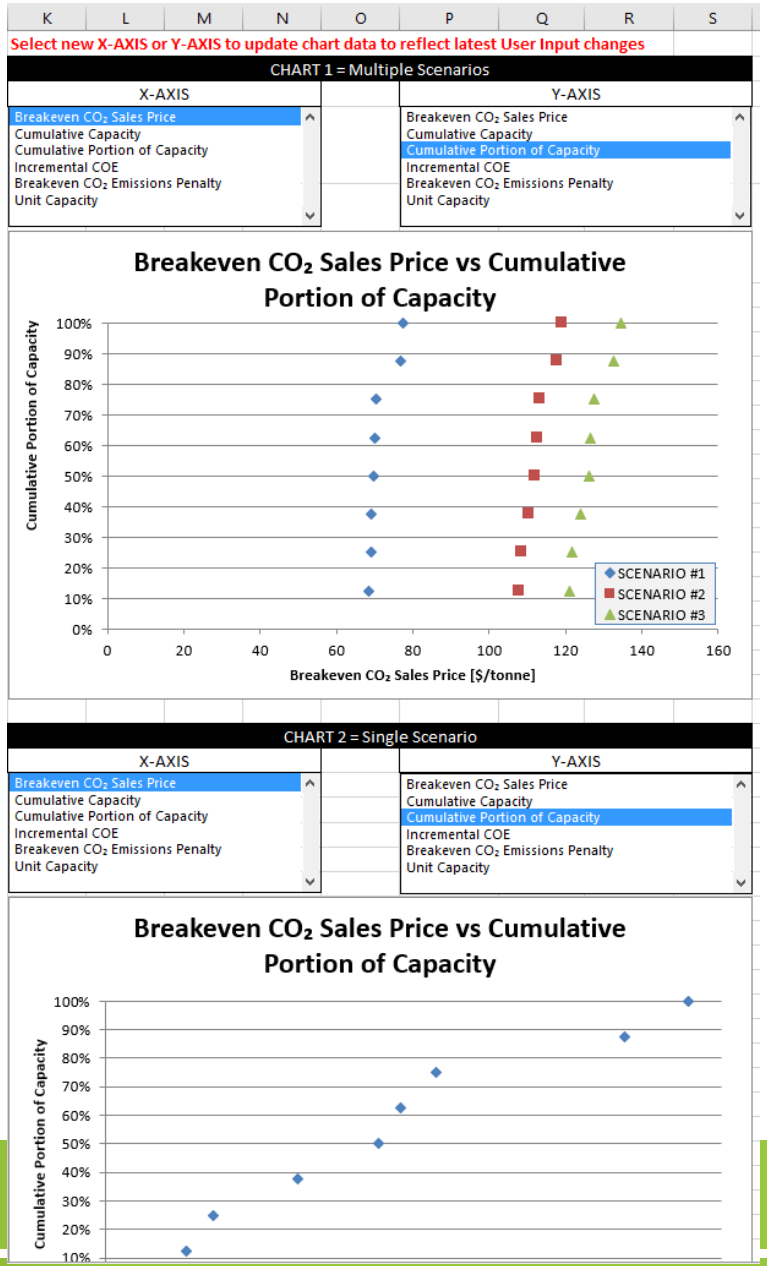
PC CCRD Walkthrough (con't)

- Results Tab

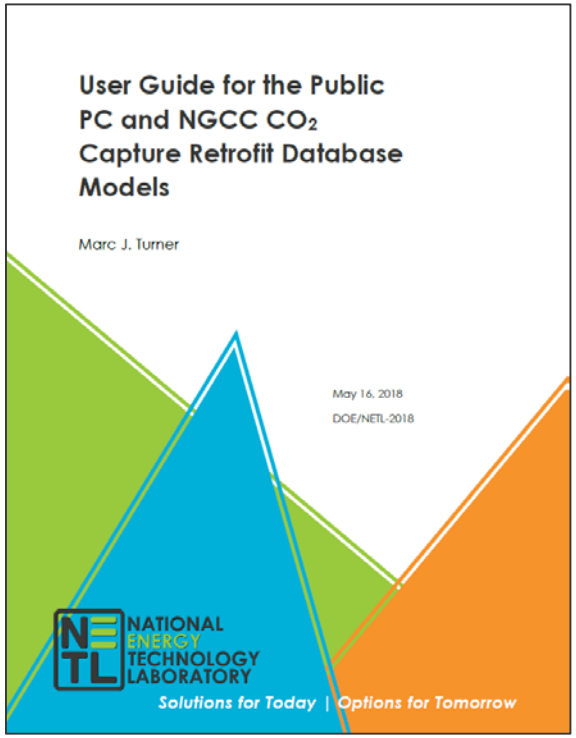
	A	B	C	D	E	F	G	H	I	J	K
1	1) Filter Column 'E' for CCS Retrofit Applicability. 2) Filter appropriate data for charts, if necessary				SCENARIO #1						
2					CCS retrofit applicability	Pre-Retrofit Total Capacity	CO2 Captured	Total Incremental COE	Breakeven CO_2 Sales Price	Breakeven CO_2 Emissions Penalty	Cumulative Capacity
3	Plant Name	Unit ID	State	Plant ID	Yes/No	MW	10^3 TPY	$/MWh	$/tonne	$/tonne	MW
4	SubCritical PC NETL bituminous baseline no cap	1	MO	B11A	Y	550	3,286	59.9	68.4	79.4	550
5	SuperCritical PC NETL bituminous baseline no c	2	MO	B12A	Y	550	3,150	57.5	69.2	80.2	1,100
6	SuperCritical PC NETL subbituminous baseline	3	MT	S12A	Y	550	3,487	66.0	69.7	80.7	1,650
7	UltraSuperCritical PC NETL subbituminous base	4	MT	S13A	Y	550	3,384	64.1	70.3	81.3	2,200
8	SuperCritical PC NETL ND Lignite baseline no ca	5	ND	L12A	Y	550	3,679	79.3	76.9	87.9	2,750
9	UltraSuperCritical PC NETL ND Lignite baseline	6	ND	L13A	Y	550	3,558	76.7	77.6	88.6	3,300
10	SuperCritical CFB NETL subbituminous baseline	7	MT	S22A	Y	550	3,443	65.2	69.9	80.9	3,850
11	SuperCritical CFB NETL ND Lignite baseline no c	8	ND	L22A	Y	550	3,622	68.9	69.0	80.0	4,400

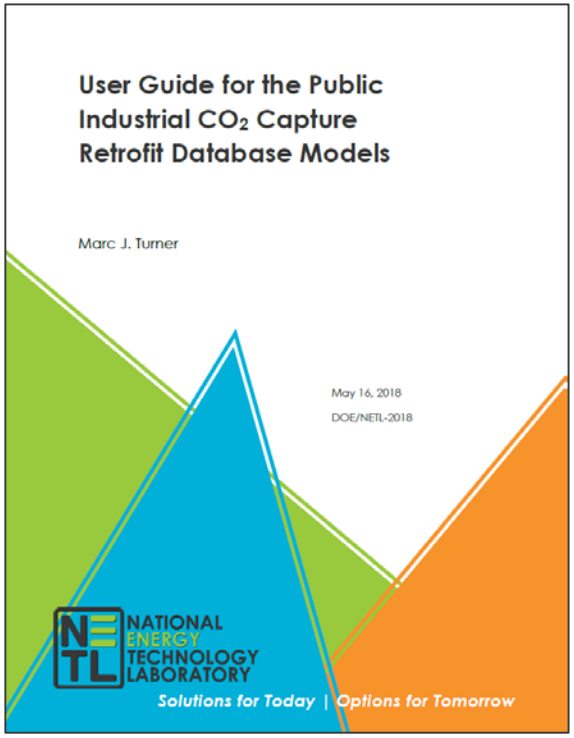
PC CCRD Walkthrough (con't)

- Charts Tab



User Manuals





Acknowledgements

NETL

Robert James
Travis Shultz
Eric Grol
Jeff Hoffmann
Kristin Gerdes
Greg Hackett
Walter Shelton
Michael Matuszewski*

Leidos

Norma Kuehn
Marc Turner
Alexander Zoelle

Key Logic

Mark Woods

Deloitte Consulting

Dale Keairns
Eric Lewis

Questions?

Timothy Fout

Engineering Process Analysis Team

Timothy.Fout@netl.doe.gov

304-285-1341