Post-Combustion Capture Retrofit: Eliminating the Derate

Presented at NETL CO_2 Capture Technology Project Review Meeting

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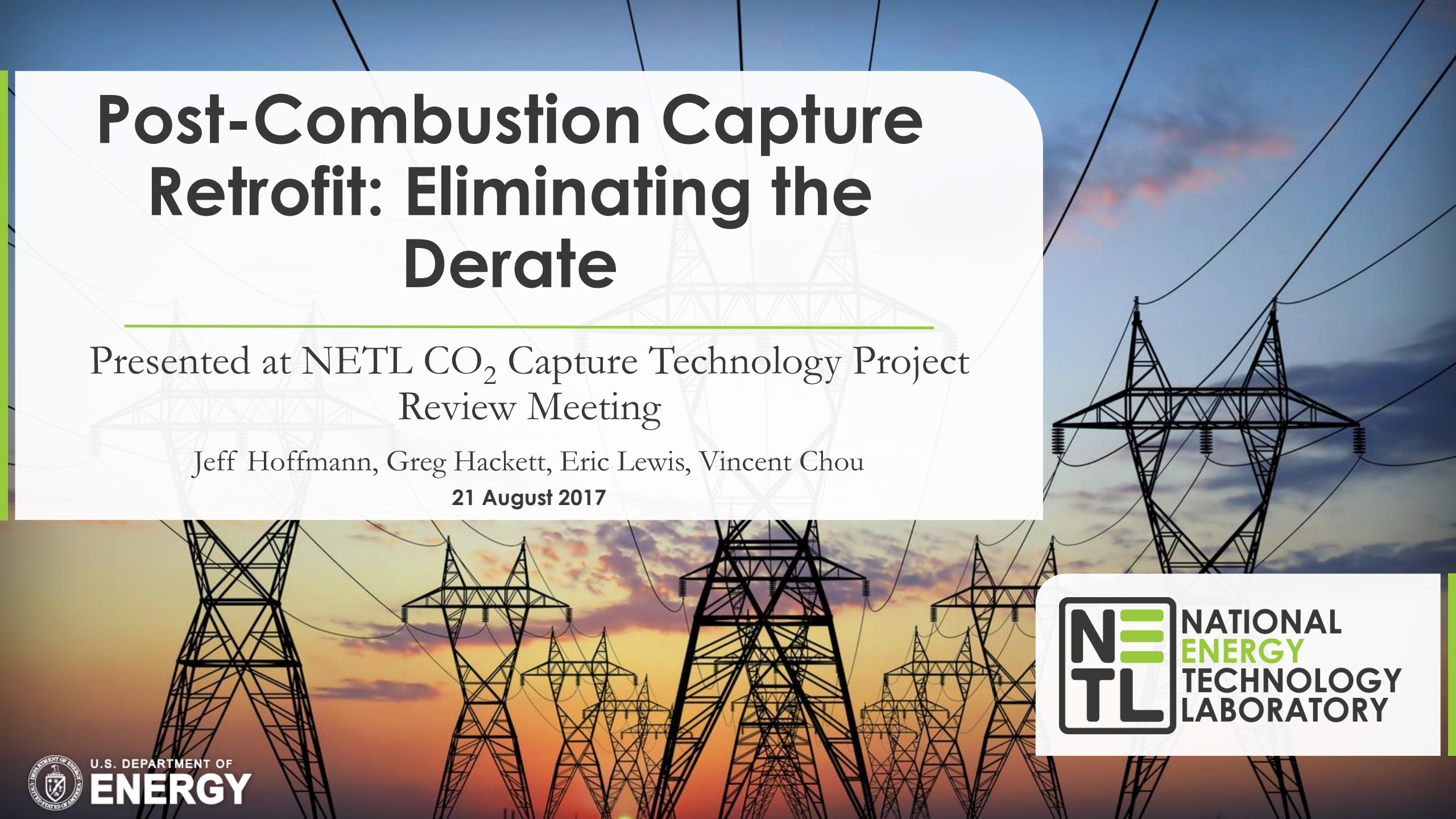

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Retrofit to Existing Subcritical Coal Plant

- Existing subcritical coal plants are a significant component of existing US coal-fueled electricity generating infrastructure
- Solvent based post combustion capture system most likely near-term option if CO_2 capture necessary
- Retrofit into existing plant considered technically feasible, but carries significant impact to existing plant economic business case
  - New capital expenditures
  - Decreased revenue due to lower plant net output (i.e., derate)

Basis for Study Comparison

NETL Cost and Performance Baseline Studies

Volume	Title	Description
1	**Bituminous Coal and Natural Gas to Electricity (aka Bituminous Baseline)**	Establishes performance and cost data for SOA fossil energy power systems for integrated gasification combined cycle (IGCC), pulverized coal (PC), and natural gas combined cycle (NGCC) plants with and without capture
3	**Low-Rank Coal and Natural Gas to Electricity (aka Low Rank Baseline)**	Establishes performance and cost data for SOA fossil energy power systems for IGCC, PC, and NGCC plants using low rank coals

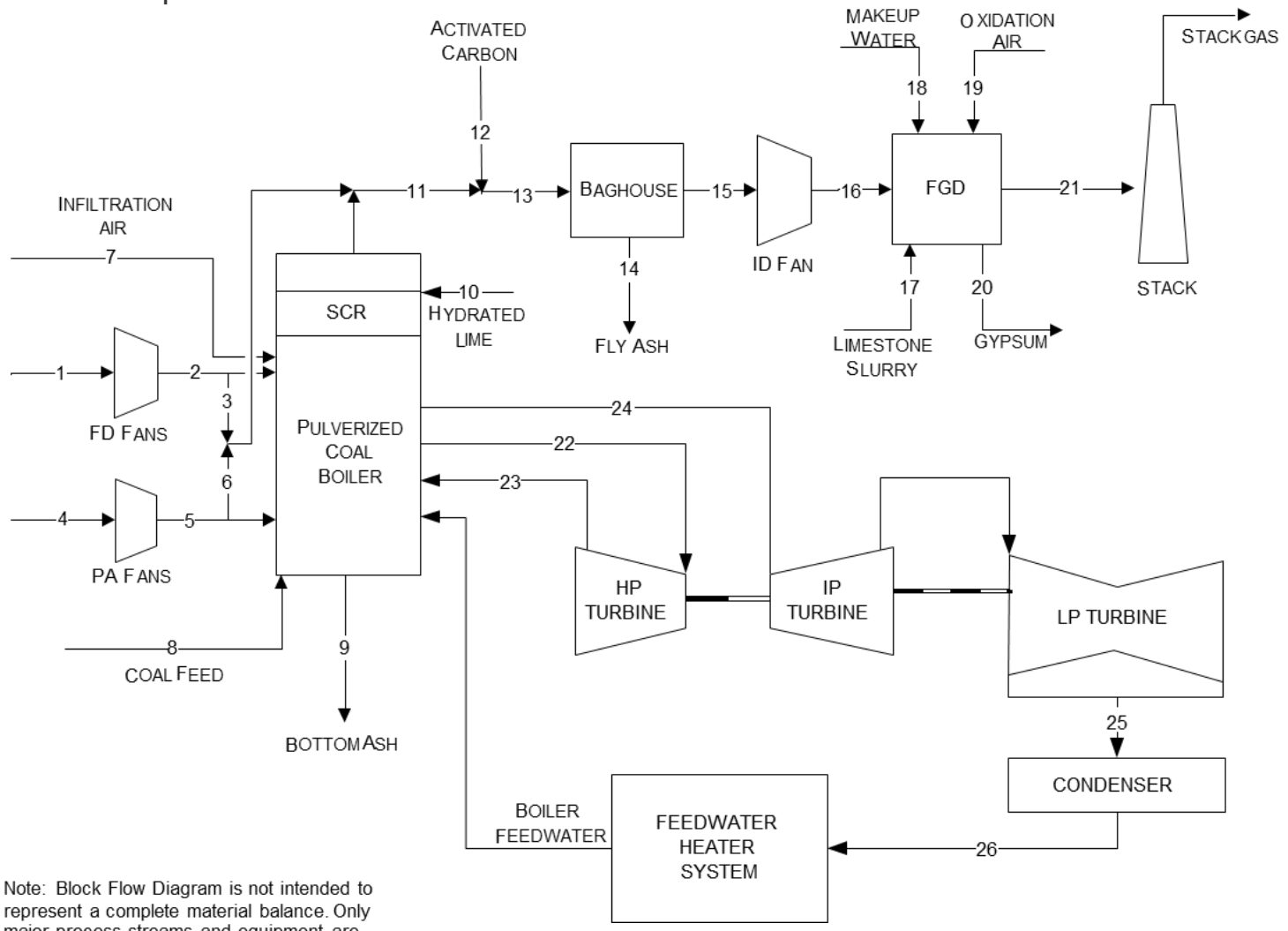
These documents provide:

1. A starting point for modeling design basis
2. An outline for TEA reporting format (stream tables, auxiliary load tables, etc.)

Available online at *http://www.netl.doe.gov/research/energy-analysis/baseline-studies*

Baseline Subcritical Pulverized Coal Plant

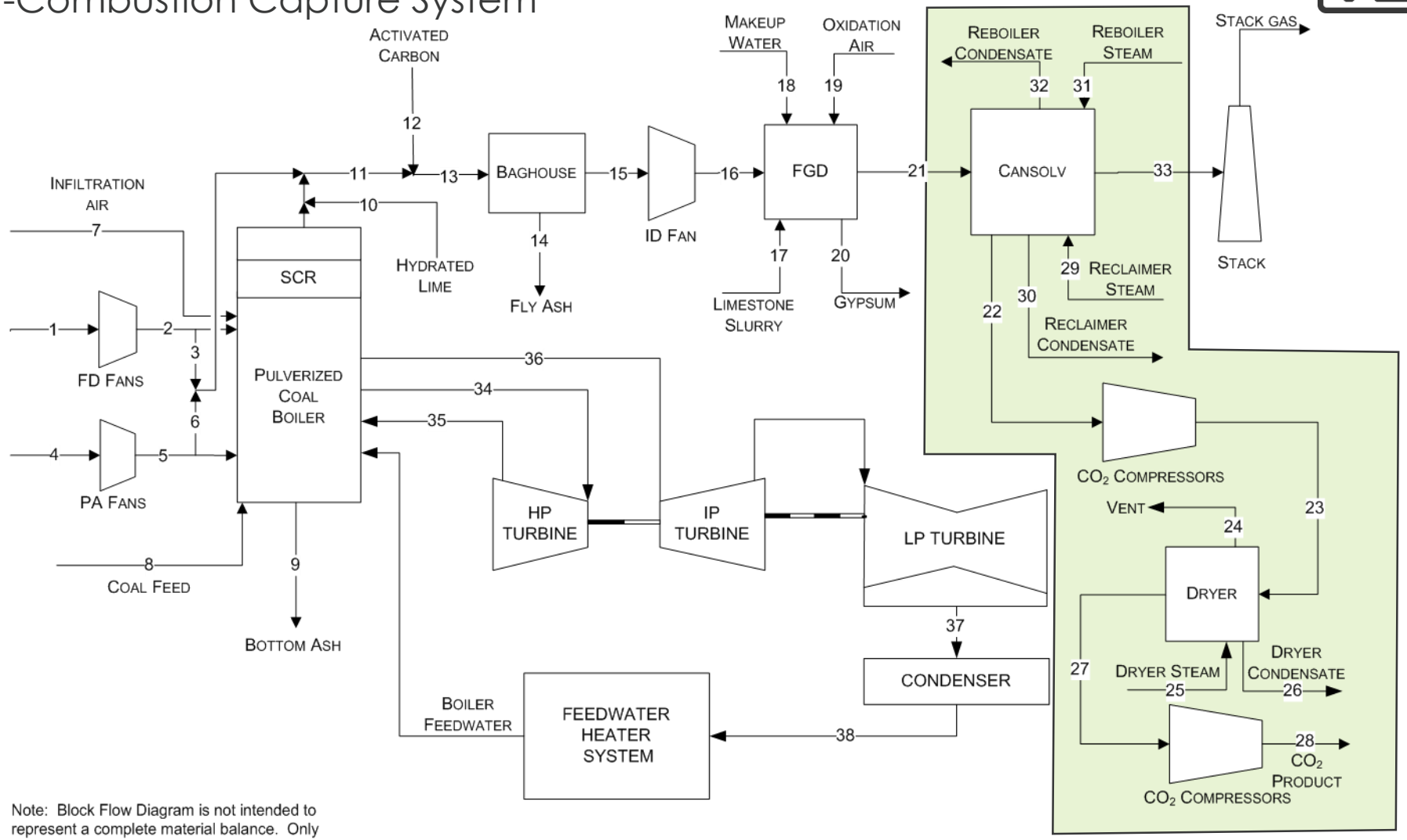
Plant with no Carbon Capture



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

Baseline Plant with CO_2 Capture

Plant with Post-Combustion Capture System

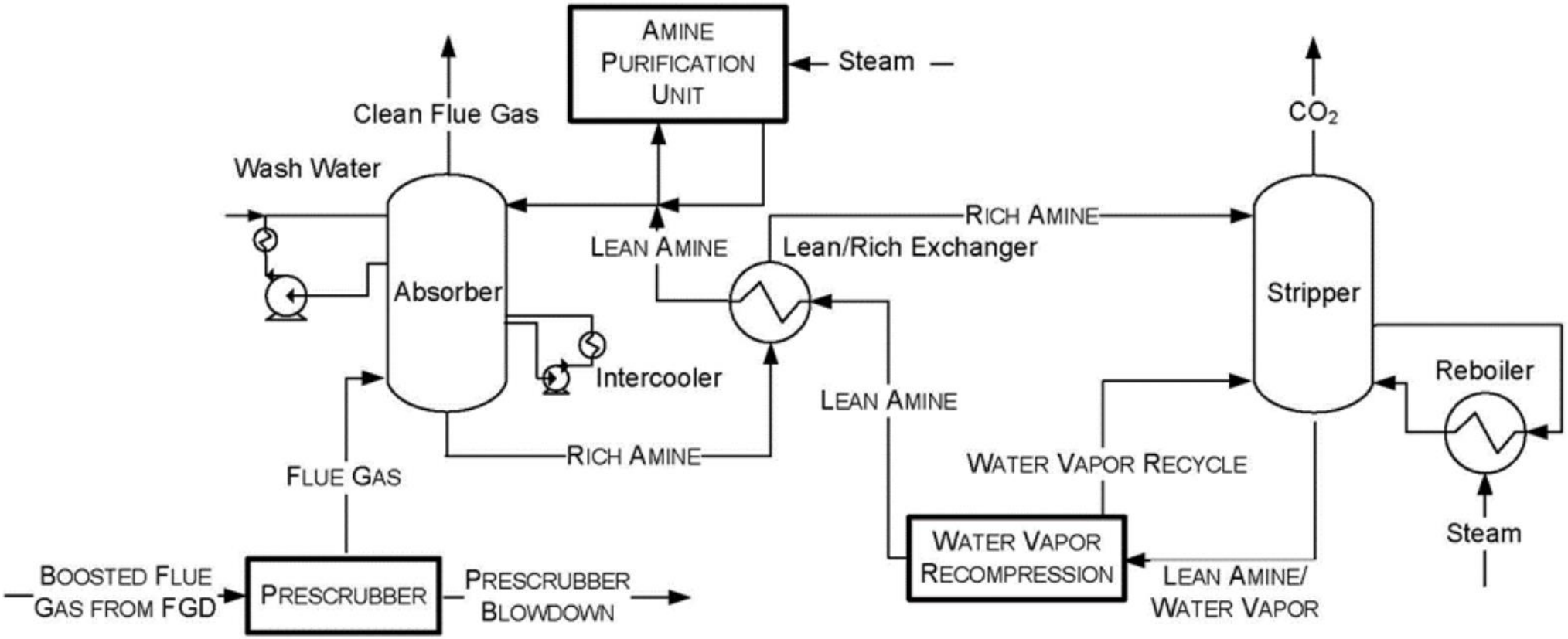


Note: Block Flow Diagram is not intended to represent a complete material balance. Only major process streams and equipment are shown.

Source: National Energy Technology Laboratory, "Cost and Performance Baseline for Fossil Energy Plants, Volume 1a: Bituminous Coal (PC) and Natural Gas to Electricity, Revision 3," U.S. Department of Energy, Pittsburgh, PA, 2015

CO_2 Capture System Block Flow Diagram

Based on Shell Cansolv System



Source: National Energy Technology Laboratory, "Cost and Performance Baseline for Fossil Energy Plants, Volume 1a: Bituminous Coal (PC) and Natural Gas to Electricity, Revision 3," U.S. Department of Energy, Pittsburgh, PA, 2015

Derate Resulting from Capture Retrofit

Substantial Impact to Net Power Output of Retrofitted Coal Plant[1]

- **Decreased steam flow to steam turbine**
  - Auxiliary steam demand "robbed" from existing steam cycle
    - Reboiler steam (>99% of thermal energy) extracted from IP/LP crossover
    - Reclaimer steam (<0.5% of thermal energy) extracted from HP exhaust
    - CO_2 dryer steam (<0.5% of thermal energy) extracted from IP turbine
  - Approximately 14% decrease in steam turbine gross power output for reference plant
- **Increased parasitic load for base plant**
  - Auxiliary power demand "diverted" from grid
    - Compression system (~65% of total "new" parasitic load)
    - Capture system (~30% of total "new" parasitic load)
    - Miscellaneous BoP (~5% of total "new" parasitic load)
  - Approximately 145% increase in total plant parasitic load for reference plant
- **Net impact equates to loss of ~23% of reference plant pre-retrofit net output available for sale to the grid**

1. Based on an existing (pre-retrofit) subcritical pulverized coal plant with a heat rate of 8,740 BTU/kWh. See Case B11A, Bituminous Baseline Volume 1a Revision 3 (National Energy Technology Laboratory, "Cost and Performance Baseline for Fossil Energy Plants, Volume 1a: Bituminous Coal (PC) and Natural Gas to Electricity, Revision 3," U.S. Department of Energy, Pittsburgh, PA, 2015)

Opportunities to Reduce Retrofit Impact

Scope of Derate Mitigation Options Study

- Consider alternative approaches for power and steam generation that avoids integration complexities and reduction of power output from the existing coal-fueled power plant

Case	Description	Capture Plant Steam Supply	Utility Power Supply	Aux Plant Design Considerations
0	Fully Integrated with Existing Plant	Extraction from existing plant steam cycle	Deduct from plant export power	N/A – Retrofit baseline for comparison
1	Simple Cycle CHP	Aux plant heat recovery steam generator (HRSG)	Aux plant combustion turbine (CT)	Capture plant steam demand drives CT sizing (sized to provide sufficient exhaust flow to HRSG)
2	Combined Cycle CHP	Aux plant steam turbine (ST) bottom cycle	Aux plant combined cycle	Capture plant steam demand drives new ST sizing designed for steam extraction

Concept Graphics of Cases Considered

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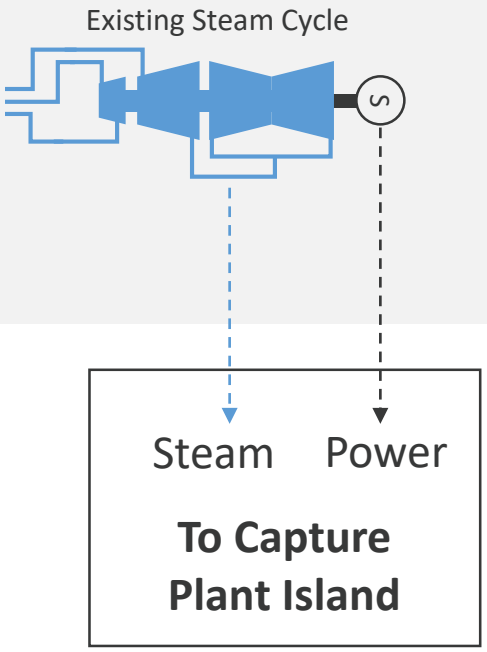
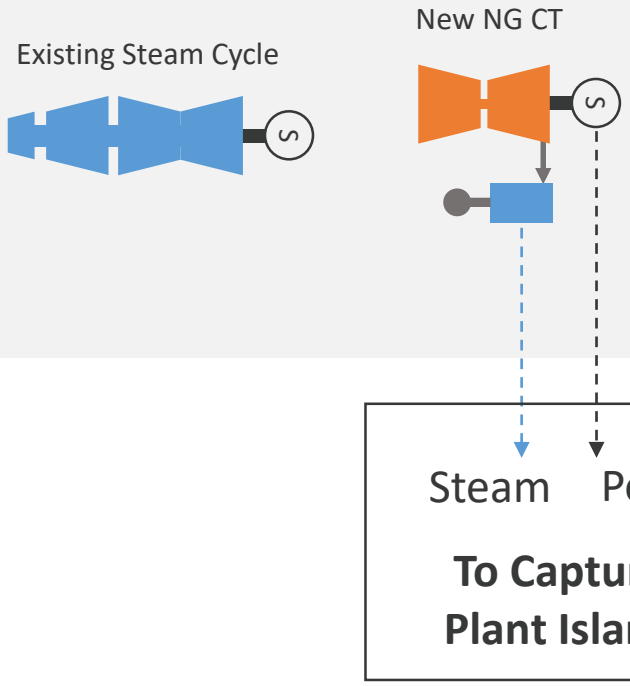
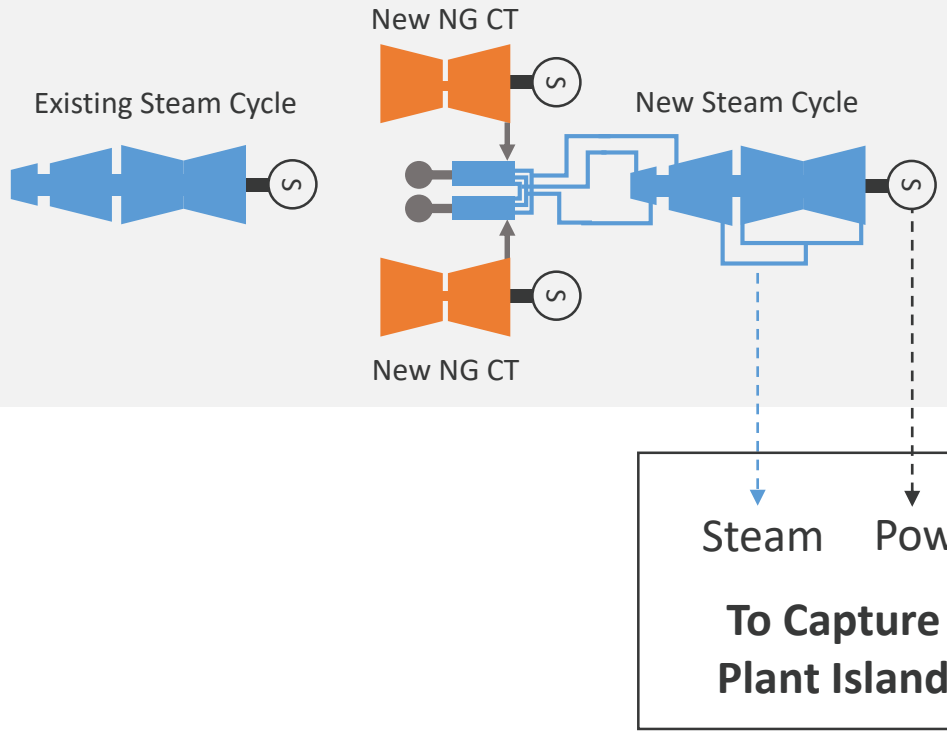
Case 0 – Full Integration



Case 1 – New NG CHP



Case 2 – New 2x1 NGCC CHP



Key Assumptions

- **90% CO_2 capture from treated stream**
- **No CO_2 capture required for the CHP plant exhaust**
  - Considered reasonable on the basis that entire facility (combined existing plant + CHP) emissions rate (mass per unit output) lower than new stand-alone natural gas-fueled plant
- **Existing T&D grid infrastructure capable of accommodating increased net plant output**
- **Retrofit economics only considers costs for capture system retrofit and required modifications to the base plant**
  - Existing plant is fully "paid down", remaining life consistent with new capital for capture plant
- **CO_2 transport and storage (T&S) logistics are achievable**
  - Costs estimated consistent with NETL systems studies, applied as a \$11/tonne CO_2 "delivered" to plant battery limits (NETL standard for US Midwest plant location)

Scope of Modifications

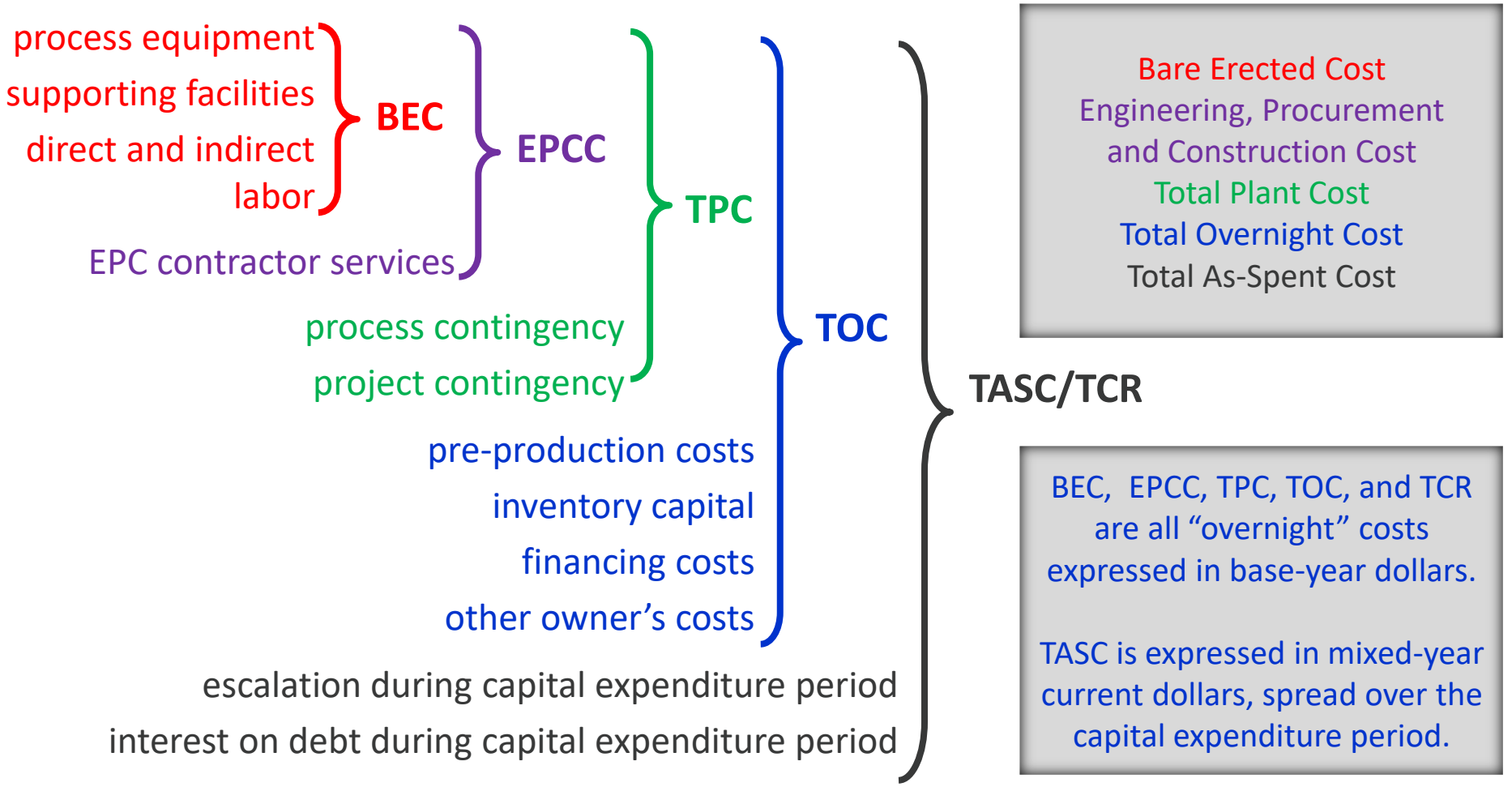
Plant Area	Case 0	Case 1	Case 2
Feedwater & Misc. BOP Systems			
FW, makeup, etc. systems for HRSG		•	•
CO_2 Removal & Compression			
Cansolv process	•	•	•
CO_2 compression/drying train	•	•	•
Letdown turbine addition	•		
Combustion Turbine & Accessories			
Combustion turbine(s) generator		•	•
HRSG, Ducting & Stack			
PC plant ducting and stack	•	•	•
HRSG with SCR		•	•
Steam Turbine Generator			
Steam bottoming cycle			•
Existing ST extraction piping	•		
HRSG steam piping		•	•
Cooling Water System			
Auxiliary wet cooling tower	•	•	•
Accessory Electric Plant			
Addition for CCS auxiliary loads	•	•	•
Addition for CT auxiliary loads		•	•
Instrumentation & Control (I&C)			
CHP plant I&C additions		•	•
Misc. I&C	•	•	•
Site Improvements			
Site prep, facilities & improvements	•	•	•
Buildings & Structures			
Water treatment, waste & circ. buildings	•	•	•
CT building		•	•
ST building			•

Preliminary Performance Results

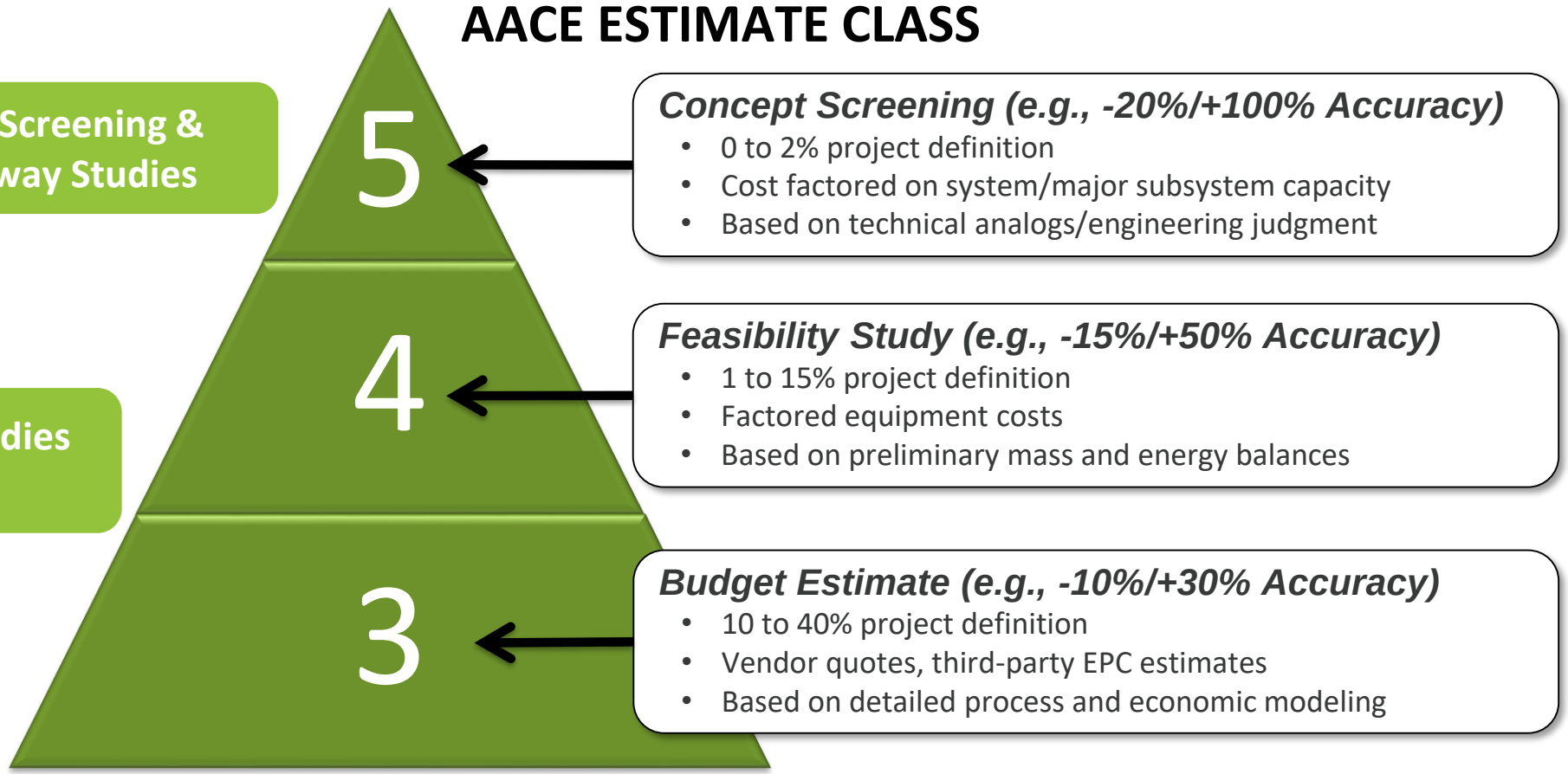
	Pre-Retrofit[1]	Case 0	Case 1	Case 2	New SCPC w/CCS[1]	New NGCC[1]
Gross Power Output (MWe)	**581**	**501**	**811**	**1,148**	**642**	**641**
Pre-Retrofit	N/A	581	581	581	N/A	N/A
Auxiliary Power Requirement (MWe)	**31**	**76**	**81**	**88**	**91**	**11**
Net Power Output (MWe)	**550**	**425**	**730**	**1,060**	**550**	**630**
Pre-Retrofit	*N/A*	*550*	*550*	*550*	*N/A*	*N/A*
HHV Thermal Input (kWt)	**1,408,630**	**1,408,440**	**2,074,494**	**2,631,664**	**1,694,366**	**1,223,032**
Net Plant HHV Efficiency (%)	**39%**	**30.2%**	**35.2%**	**40.3%**	**32.5%**	**51.5%**
Net Plant HHV Heat Rate (Btu/kWh)	**8,740**	**11,301**	**9,700**	**8,468**	**10,508**	**6,629**
Plant-level CO_2 Emissions - *Retrofit cases are aggregate of existing unit plus new CHP*						
(lb/MMBtu)	204	20	52	66	20	119
(lb/MWh-gross)	1,683	195	453	516	190	773
(lb/MWh-net)	1,779	230	503	559	223	786
Overall CO_2 Capture (% of unabated potential at full load)	N/A	90%	71%	60%	90%	N/A

1. All comparison cases from Bituminous Baseline Volume 1a Revision 3 (National Energy Technology Laboratory, "Cost and Performance Baseline for Fossil Energy Plants, Volume 1a: Bituminous Coal (PC) and Natural Gas to Electricity, Revision 3," U.S. Department of Energy, Pittsburgh, PA, 2015). Pre-Retrofit (Case B11A), New SCPC w/CCS (Case B12B), New NGCC (Case B31A)

Economic Analysis – Capital Costs



Classes of NETL Cost Estimates



Process flow diagrams (PFDs) and piping and instrument diagrams (P&IDs) are the primary documents that define estimate class. AACE Recommended Practice No. 18R-97 describes the AACE cost estimate classification system.

Economic Analysis – Figure of Merit

Cost of Electricity (COE)

$$COE = \frac{\begin{matrix}First\ year \\ capital\ charge\end{matrix} + \begin{matrix}first\ year \\ fixed\ operating \\ costs\end{matrix} + \begin{matrix}first\ year \\ variable\ operating \\ costs\end{matrix}}{\begin{matrix}annual\ net\ megawatt\ hours \\ of\ power\ generation\end{matrix}}$$

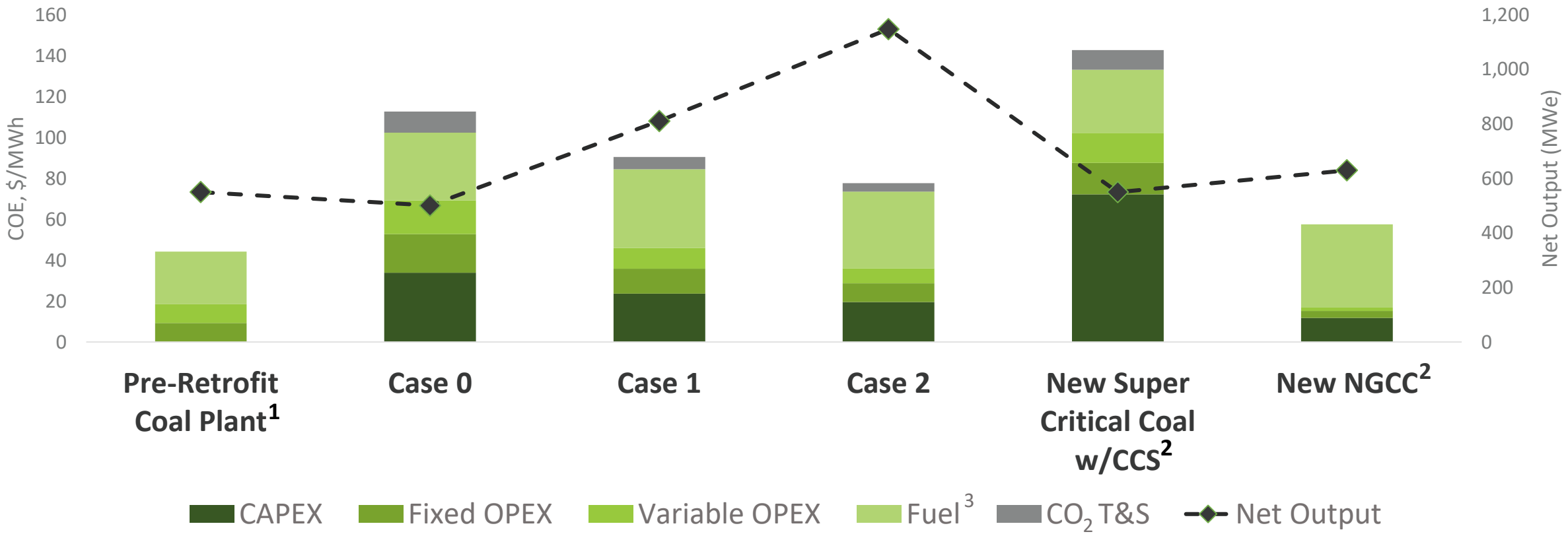
- **COE is the minimum revenue a power plant must receive for the electricity generated to cover cost and stated internal rate of return on equity (IRROE)**
  - Determining the COE involves a complex set of financial assumptions
  - To simplify the COE calculation, a capital charge factor (CCF) has been developed
    - Simplifies and unifies common financial terms and assumptions
    - Annualizes the capital cost over the life of the plant

Preliminary Cost Results

	Pre-Retrofit[1]	Case 0	Case 1	Case 2	New SCPC w/CCS[1]	New NGCC[1]
Total Plant Cost (2011$/kW)	**N/A**	**1,709**	**1,191**	**983**	**3,524**	**685**
Bare Erected Cost	*N/A*	*1,214*	*833*	*735*	*2,716*	*561*
Home Office Expenses	*N/A*	*111*	*79*	*66*	*263*	*51*
Project Contingency	*N/A*	*251*	*77*	*53*	*430*	*73*
Process Contingency	*N/A*	*132*	*164*	*129*	*115*	*0*
Total Overnight Cost (2011$MM)	**N/A**	**880**	**1,056**	**1,268**	**2,384**	**528**
Total Overnight Cost (2011$/kW)	**N/A**	**2,069**	**1,447**	**1,195**	**4,333**	**838**
Owners Costs	*N/A*	*360*	*256*	*213*	*809*	*154*
Total As-Spent Cost (2011$/kW)	**N/A**	**2,231**	**1,560**	**1,289**	**4,940**	**901**
COE ($/MWh)	**44.2**	**112.8**	**90.6**	**77.7**	**142.8**	**57.6**
Capital Costs	*N/A*	*33.9*	*23.7*	*19.6*	*72.2*	*11.8*
Fixed O&M	*9.3*	*18.9*	*12.2*	*9.1*	*15.4*	*3.4*
Variable O&M	*9.2*	*16.4*	*10.1*	*7.4*	*14.7*	*1.7*
Fuel	*25.7*	*33.2*	*38.5*	*37.5*	*30.9*	*40.7*
CO_2 T&S	*N/A*	*10.3*	*6.0*	*4.1*	*9.6*	*N/A*

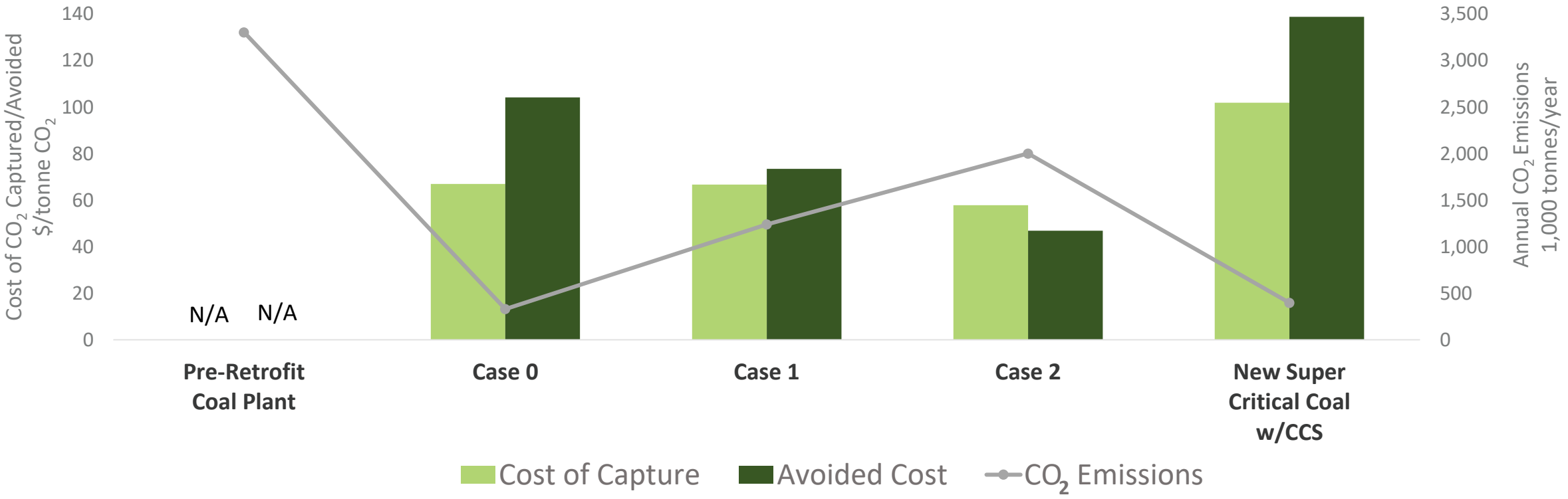
1. All comparison cases from Bituminous Baseline Volume 1a Revision 3 (National Energy Technology Laboratory, "Cost and Performance Baseline for Fossil Energy Plants, Volume 1a: Bituminous Coal (PC) and Natural Gas to Electricity, Revision 3," U.S. Department of Energy, Pittsburgh, PA, 2015). Pre-Retrofit (Case B11A excluding CAPEX), New SCPC w/CCS (Case B12B), New NGCC (Case B31A)
2. Assumed delivered fuel prices: coal $2.94/MMBtu, NG $6.13/MMBtu

Retrofit Comparison with New Plant Options



1. Bituminous Baseline Volume 1a Revision 3 (National Energy Technology Laboratory, "Cost and Performance Baseline for Fossil Energy Plants, Volume 1a: Bituminous Coal (PC) and Natural Gas to Electricity, Revision 3," U.S. Department of Energy, Pittsburgh, PA, 2015) - Case B11A excluding CAPEX component
2. Bituminous Baseline Volume 1a Cases B12B (new supercritical coal w/CCS) and B31A (new F-Class 2x1 NGCC w/o CCS)
3. Assumed delivered fuel prices: coal $2.94/MMBtu, NG $6.13/MMBtu

Comparison of Capture Metrics[1]



1. Cost of Capture and Avoided Cost calculations include incremental CAPEX, OPEX and fuel, and account for loss/gain of revenue for post-retrofit power sales. Assumed delivered fuel prices: coal $2.94/MMBtu, NG $6.13/MMBtu, market selling price of electricity at $60/MWh
2. All comparison cases from Bituminous Baseline Volume 1a Revision 3 (National Energy Technology Laboratory, "Cost and Performance Baseline for Fossil Energy Plants, Volume 1a: Bituminous Coal (PC) and Natural Gas to Electricity, Revision 3," U.S. Department of Energy, Pittsburgh, PA, 2015). Pre-Retrofit (Case B11A), New SCPC w/CCS (Case B12B)

Conclusions

- An auxiliary CHP plant can provide a feasible means to mitigate the economic impact for a post-combustion retrofit
- Using the cost metric of COE, the NGCC-CHP auxiliary plant (Case 2) approaches that of a new NGCC plant and is well below that of a new SCPC plant equipped with CCS
- Process flexibility and short-term fuel price stability may provide additional plant-level economic benefits not captured here
- Wide scale CCS deployment would require the build out of significant CO_2 T&S infrastructure

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Thank You

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