Guidance for NETL's Carbon Capture R&D Program

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NETL CO_2 Capture Technology Meeting
July 11, 2013

Acknowledgements

- **Booz Allen Hamilton**
  - Richard Newby
  - Mark Woods
- **NETL**
  - Jim Black
  - Kristin Gerdes
  - Mike Matuszewski
  - Bob Stevens
  - Capture and Adv. Combustion Technology Program Leadership

Objectives

- **Devise a methodology to estimate power plant performance and cost using specific developer-provided characteristics of advanced CO_2 capture technology**
  - Ensure results on a consistent basis
  - Include diverse capture technologies: solvents, sorbents, adsorbents, membranes, phase change, cryogenic concepts
  - Reduce time and cost to assess advanced technology development status and guide development
- **Develop 'COE' and 'cost of CO_2' metrics for an advanced capture technology that relate to the NETL advanced power plant R&D goals**

Example
PC plant with 2nd gen post-comb. capture → COE contributions from
• **Capture technology**
• Steam conditions
• Compression technology → Plant COE Goal: 20% reduction in SOA IGCC with capture ($106/MWh)

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Approach

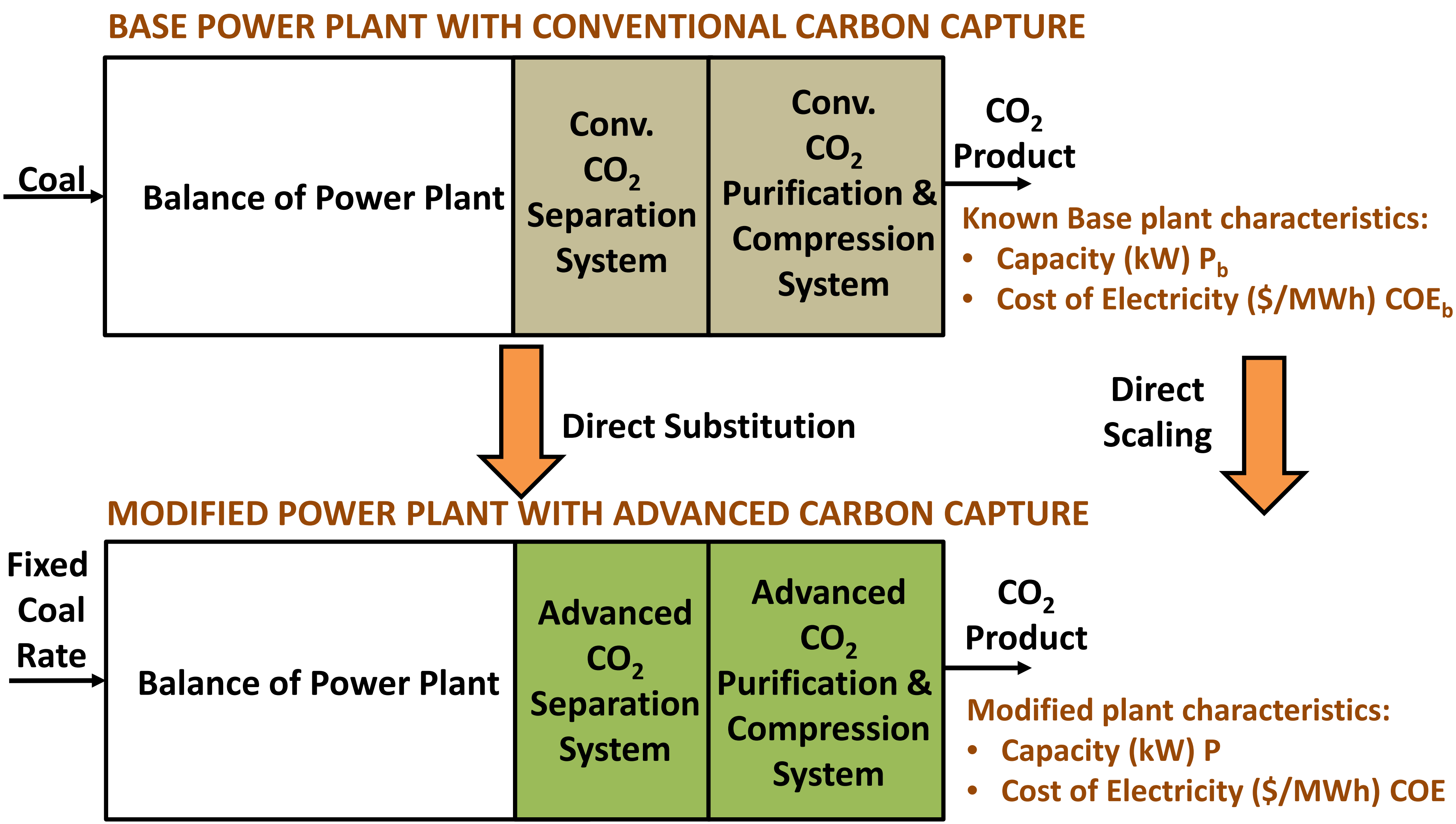
NETL Baseline Study Reference Plants
(PC post-combustion, PC oxy-combustion, IGCC pre-combustion)
with Representation of Today's Capture Technology

Remove 'Conventional' CO_2 Capture Process;
Insert Advanced Capture Technology

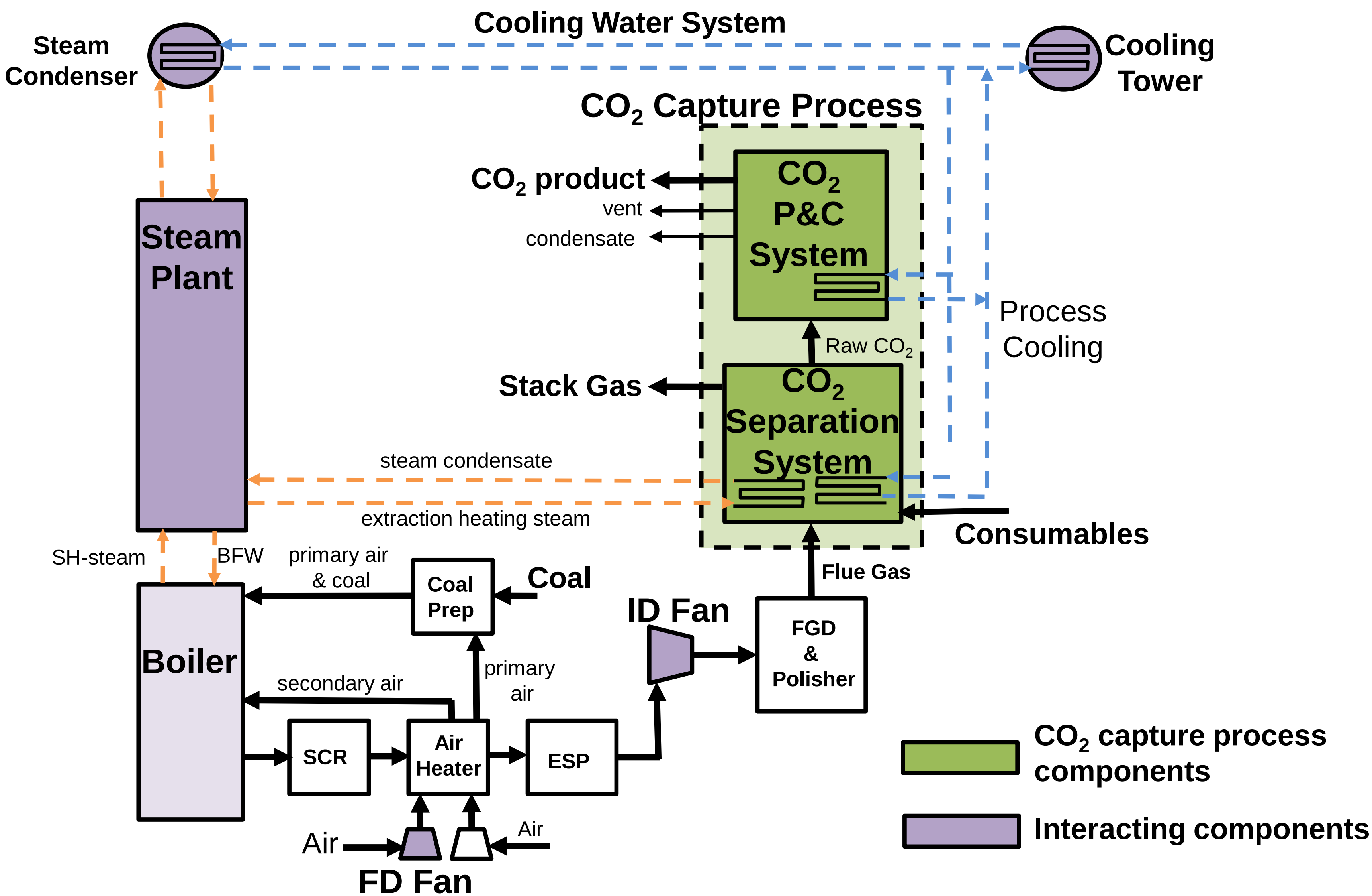
- Developer given plant design basis and boundary conditions
- Developer provides specific set of performance and cost estimate parameters for their process

Methodology Utilizes Adv. Technology Inputs to Project Integrated Plant Performance and Cost

Methodology for
Power Plant Performance and Cost Scaling

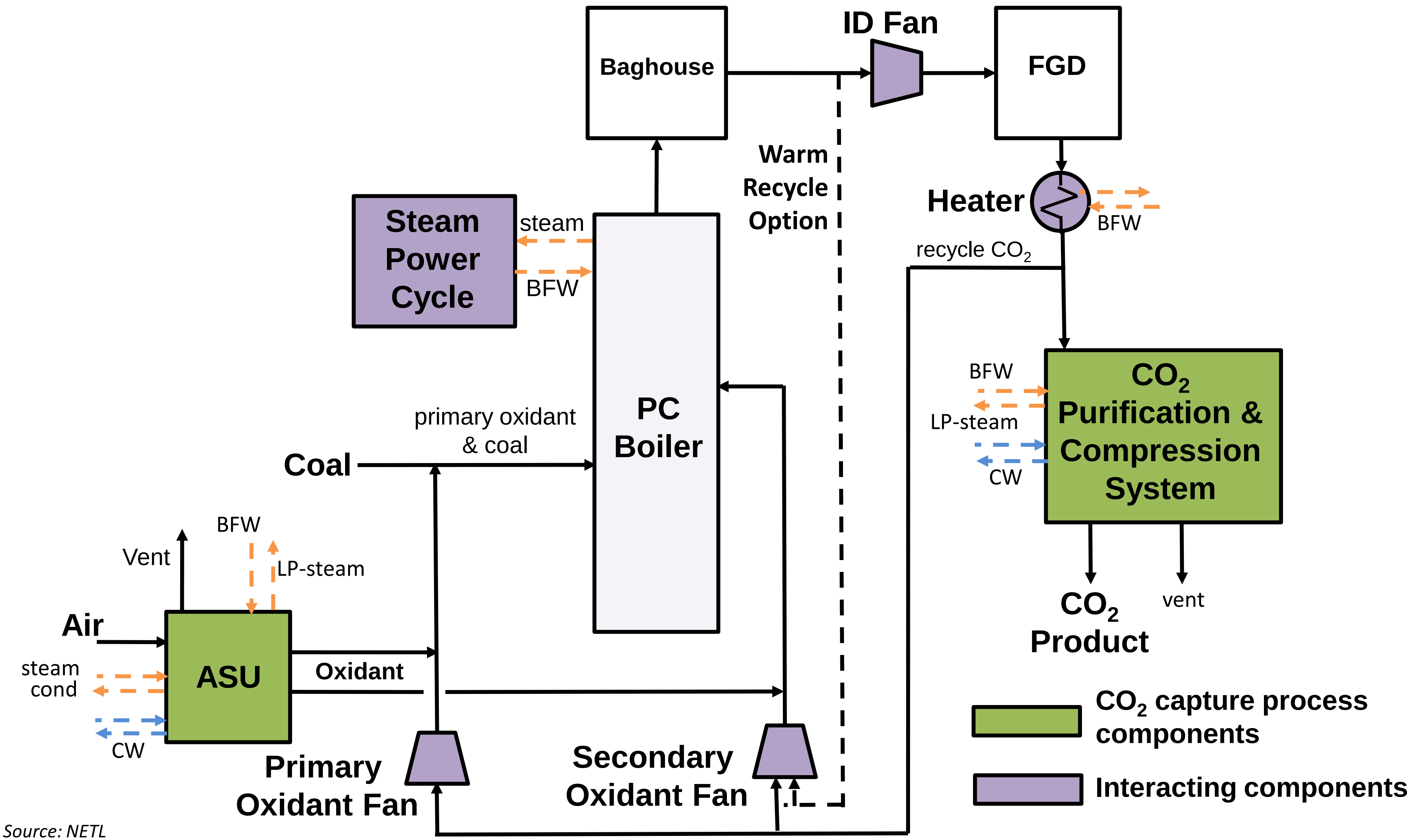


PC Post-Combustion



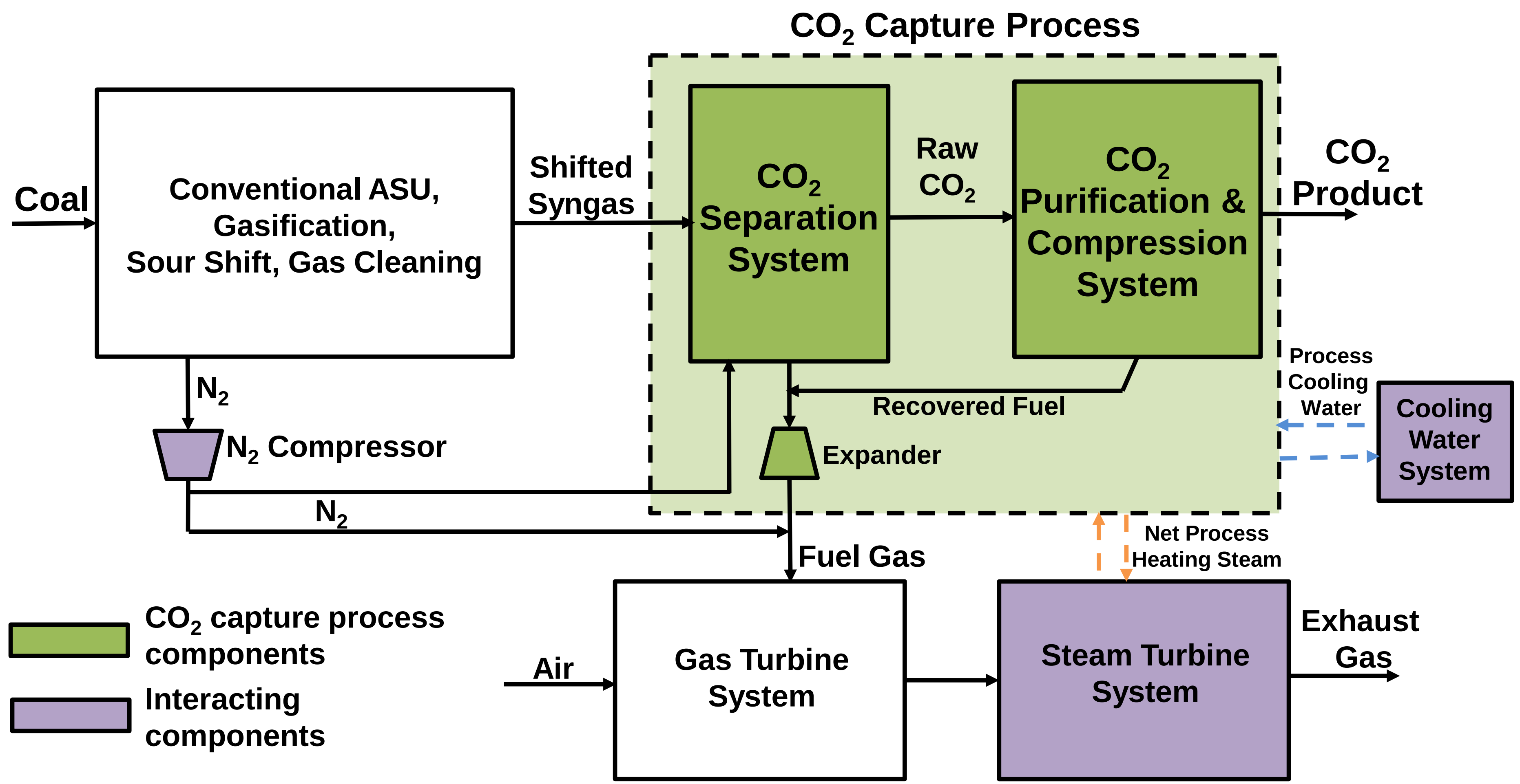
Source: NETL

PC Oxy-Combustion



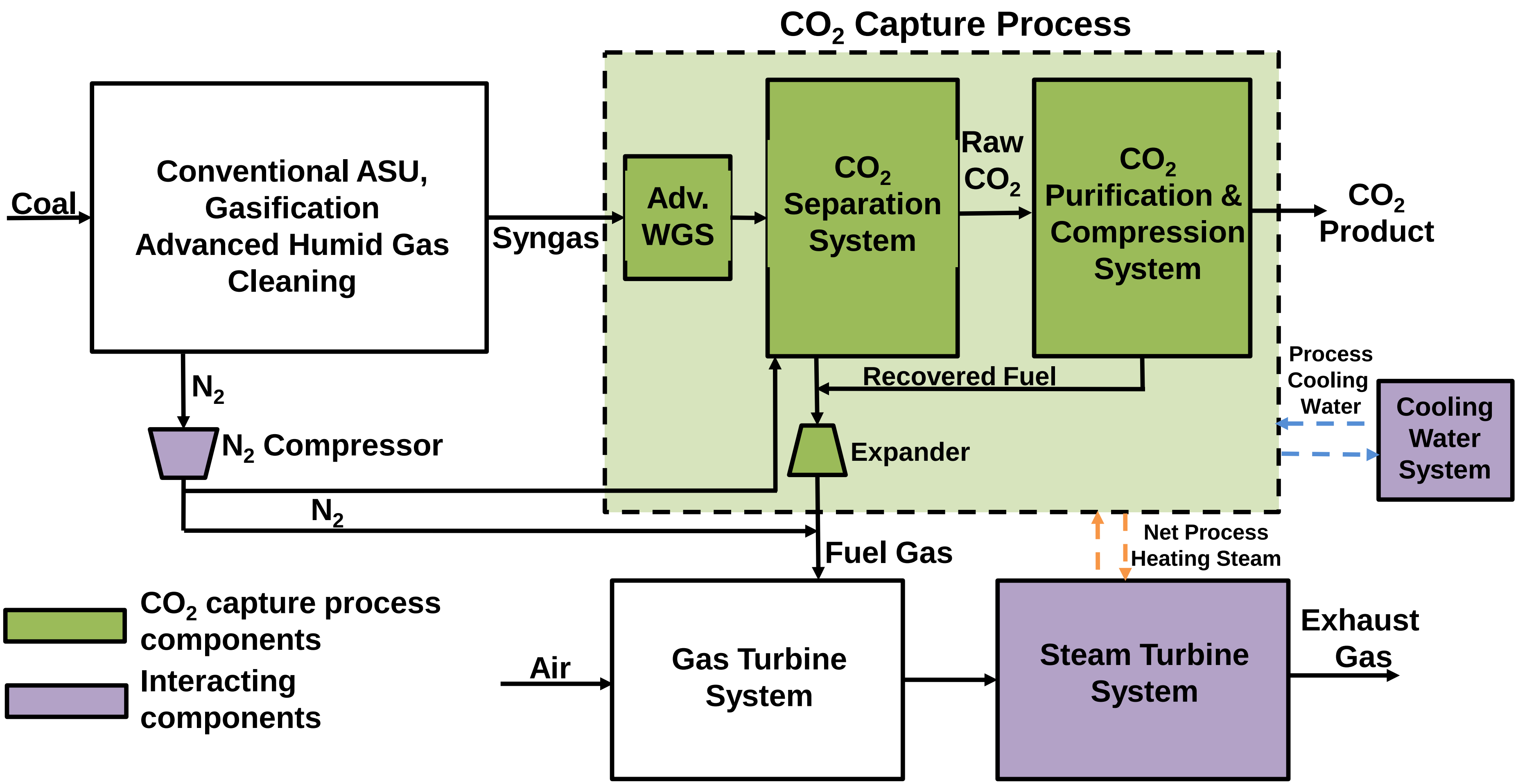
Source: NETL

IGCC Pre-Combustion Conventional Gas Cleaning



Source: NETL

IGCC Pre-Combustion
Advanced Humid Gas Cleaning



Source: NETL

Power Factor (PF)
Associated with Advanced Capture Technology

- **Represents the sum of the impacts of the advanced CO_2 capture process on the power plant generating capacity**
- **Form of the Power Factor (kW per tonne/hr CO_2) is:**

$$\mathbf{PF} = \underline{A}_{CO2} + \underline{A}_{P\&C} + (\underline{P}_{bST} - \underline{P}_{ST}) + \Sigma\,(\underline{A}_i - \underline{A}_{bi})$$

- $\underline{A}_{CO2}$: Advanced CO_2 separation system auxiliary power, kW/tonne/hr CO_2
- $\underline{A}_{P\&C}$: Purification & compression system auxiliary power, kW/tonne/hr CO_2
- Interaction terms:
  - $(\underline{P}_{bST} - \underline{P}_{ST})$: Difference between steam cycle power in advanced and base plant
  - $(\underline{A}_i - \underline{A}_{bi})$: Difference between system “i” auxiliary power in advanced and base plant

COE Factor (COEF)

- **Represents all contributions of the advanced CO_2 Capture Process components to the power plant COE**
- **The form of the COE Factor (\$ per tonne/hr CO_2) is:**

$$\mathrm{COEF} = \underline{C}_{CO2} + \underline{C}_{P\&C} + (\underline{C}_{ST} - \underline{C}_{bST}) + \Sigma\, (\underline{C}_{i} - \underline{C}_{bi}) + K_c \bullet \underline{OC}_{VarCO2}$$

- $\underline{C}_{CO2}$: Capital cost of the CO_2 separation system, \$/tonne/hr CO_2
- $\underline{C}_{P\&C}$: Capital cost of the CO_2 purification and compression system, \$/tonne/hr CO_2
- $\underline{OC}_{VarCO2}$: Variable operating cost of the
  CO_2 separation and CPU systems, \$/yr per tonne/hr CO_2
- K_c is a constant based on financial assumptions
- Interaction terms:
  - $\underline{C}_{ST} - \underline{C}_{bST}$: Change in capital cost of the steam turbine system, \$/tonne/hr CO_2
  - $\underline{C}_{i} - \underline{C}_{bi}$: Change in capital cost of the “I” system, \$/tonne/hr CO_2

Methodology for Power Plant Performance and Cost Scaling

- **Net power (P) and first-year COE (w/o T&S) Scaling Relationships:**

$$P = B_1 - B_2 \bullet \text{Power Factor}$$

$$COE = [B_3 + B_4 \bullet \text{COE Factor}] \;/\; P$$

- **The "B" terms are constants derived from the base plant performance and cost**
- **Power Factor and COE Factor are based on characteristics of the advanced CO_2 capture process**

Fixed Coal Feed Rate for Reference Plant and Advanced Capture Plant

PC Post-Combustion Example
Inputs for Membrane-Based CO_2 Capture Process

Required CO_2 Capture Process Input Data	
CO_2 process steam heating duty (MMBtu/hr)	0
Extracted steam heating temperature (F)	N/A
CO_2 process cooling duty (MMBtu/hr)	0
CO_2 separator pressure drop (psi)	2
FD fan boost pressure (psi)	1.5
CO_2 separation process auxiliary power (kW)	34,897
CO_2 purification & compression power (kW)	57,404
CO_2 separation process cost ($1000)	307,311
CO_2 purification & compression cost ($1000)	67,184
CO_2 capture process annual variable operating cost ($1000)	5,215

These input data are based on a hypothetical membrane system concept with design, operating and performance parameters* selected to meet the DOE goal.

* Includes design concept, permeances (e.g. CO_2, H_2O, SO_2, N_2, O_2), operating temperature, operating pressures, membrane surface area, pressure drop, membrane life, membrane cost, and module cost

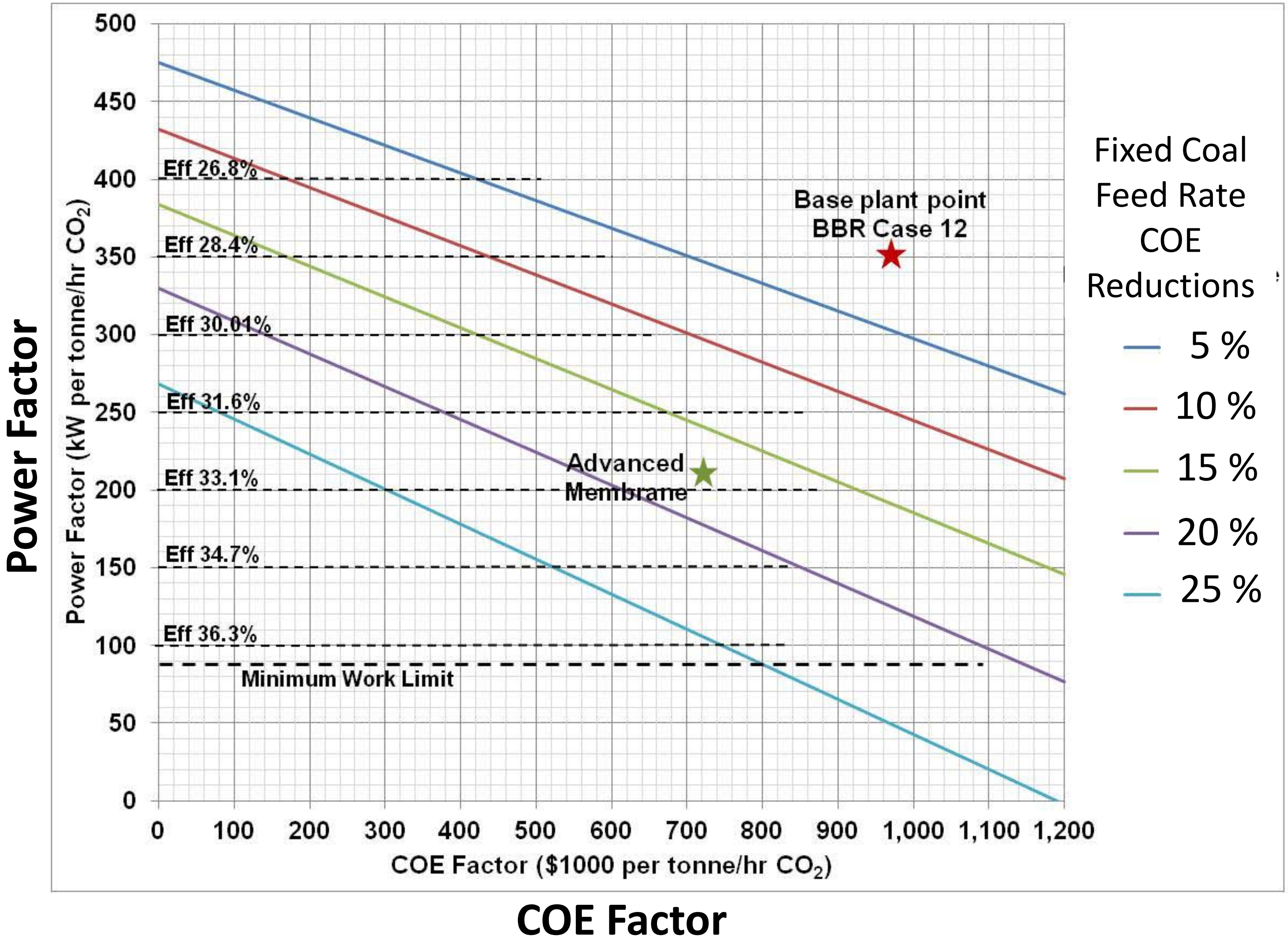
Example Results for PC Post-Combustion Membrane-Based CO_2 Capture Process

PC Power Plant Results	
Power Factor (kW per tonne/hr flue gas CO_2)	**210.06**
Plant net efficiency (%, HHV)	**32.81**
COE Factor ($ per tonne/hr flue gas CO_2)	**721,849**
COE ($/MWh)	**113.3**
COE Reduction (%)	**17.5**

These input data are based on a hypothetical membrane system concept with design, operating and performance parameters* selected to meet the DOE goal.

* Includes design concept, permeances (e.g. CO_2, H_2O, SO_2, N_2, O_2), operating temperature, operating pressures, membrane surface area, pressure drop, membrane life, membrane cost, and module cost

COE Reduction Plot for PC Post-Combustion Membrane Technology Example



This plot represents the COE reduction contribution for a plant with

- Adv. capture tech.
- SC steam
- Conv. compression
- High-risk financial

Source: NETL

Methodology for Power Plant Cost Metrics and Goals

- **The PC Plant with the advanced CO_2 capture process is related to the NETL advanced power generation R&D goal of 20% reduction in the COE ($106/MWh)**

PC Plant with advanced CO_2 capture, SC steam, conventional compression, high-risk financial

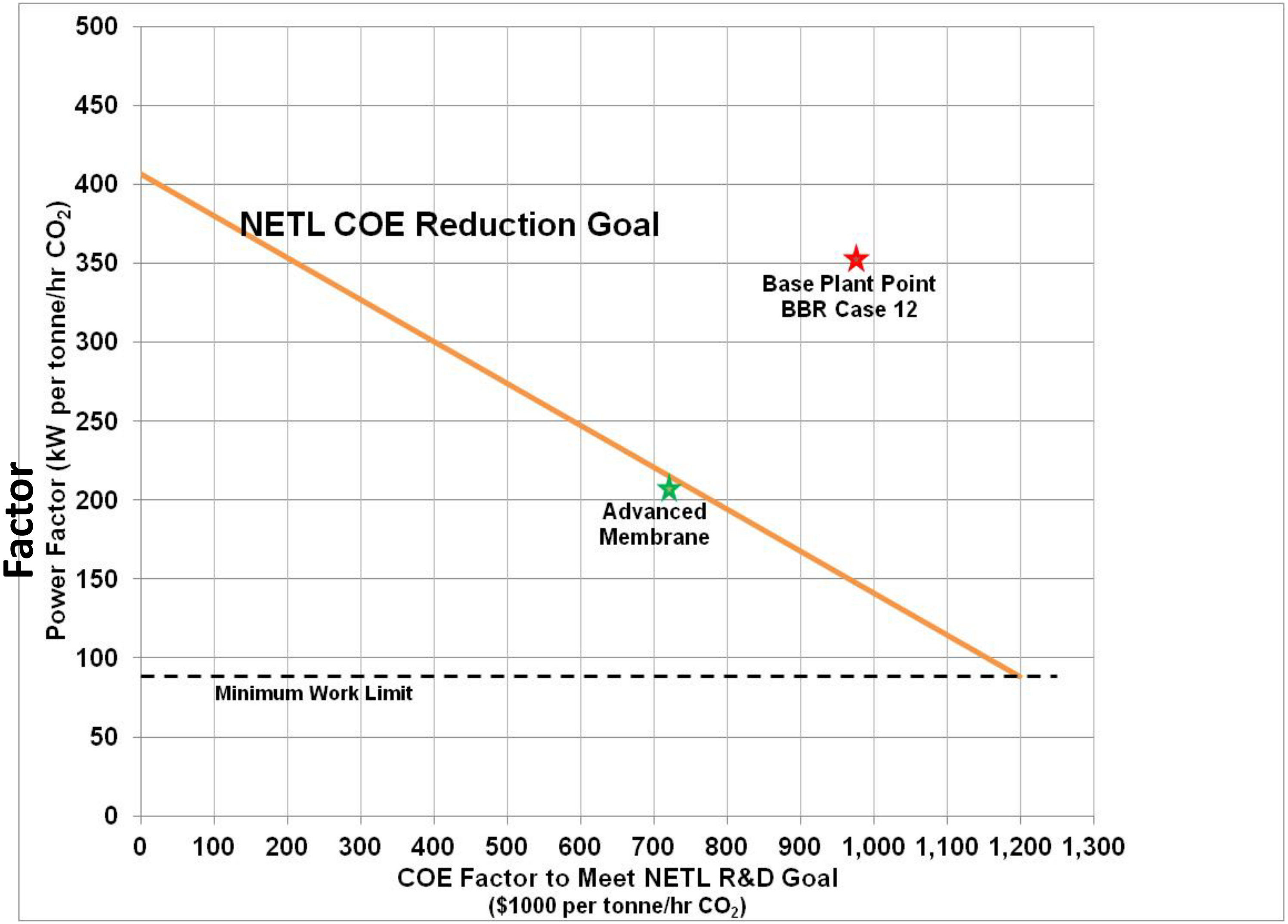
→

PC Plant with advanced CO_2 capture, AUSC steam, conventional compression, low-risk financial

The methodology for an IGCC plant with advanced capture would include options for an advanced gas turbine, ASU, gas cleaning, gasification.

COEF and PF to Meet
NETL Advanced Power Generation R&D Goal

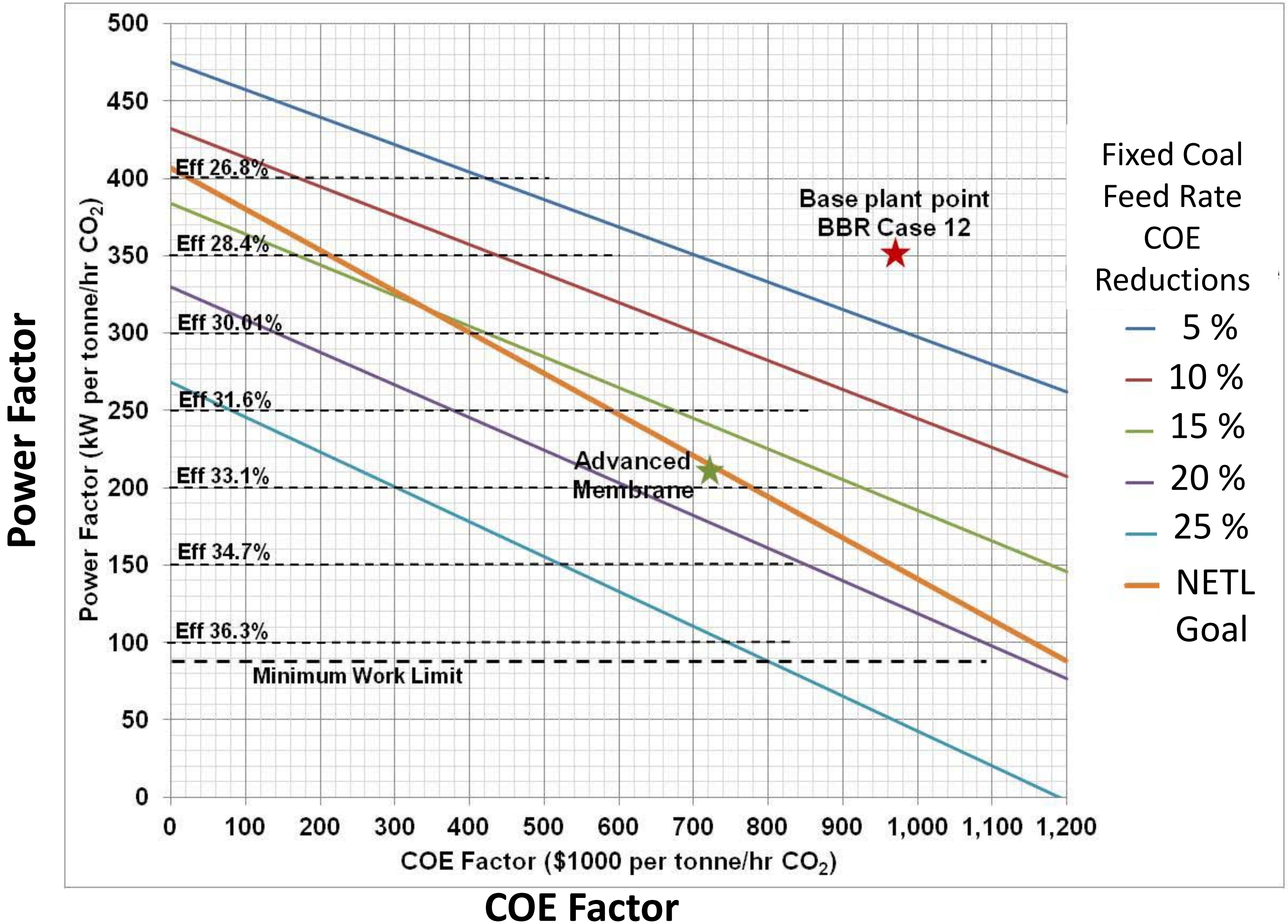
Power Factor



COE Factor to Meet NETL R&D Goal

Source: NETL

Relationship of Capture Technology Metrics to NETL R&D Program Goal for COE



Methodology Tool Application

- **A technology developer or evaluator can apply the methodology relationships to assess the feasibility, sensitivity, development requirements, and development progress of CO_2 separation technologies**
- **If the technology developer can estimate the PF for the CO_2 Capture Process, the COEF required to meet any given COE goal can be determined and assessed**
- **If the technology developer can estimate the PF and COEF for the CO_2 capture process, the COE for the resulting plant can be determined and assessed**