NATIONAL ENERGY TECHNOLOGY LABORATORY

Current and Future Technologies for Power Generation with Post-Combustion Carbon Capture

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2012 NETL CO_2 Capture Technology Meeting

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Disclaimer

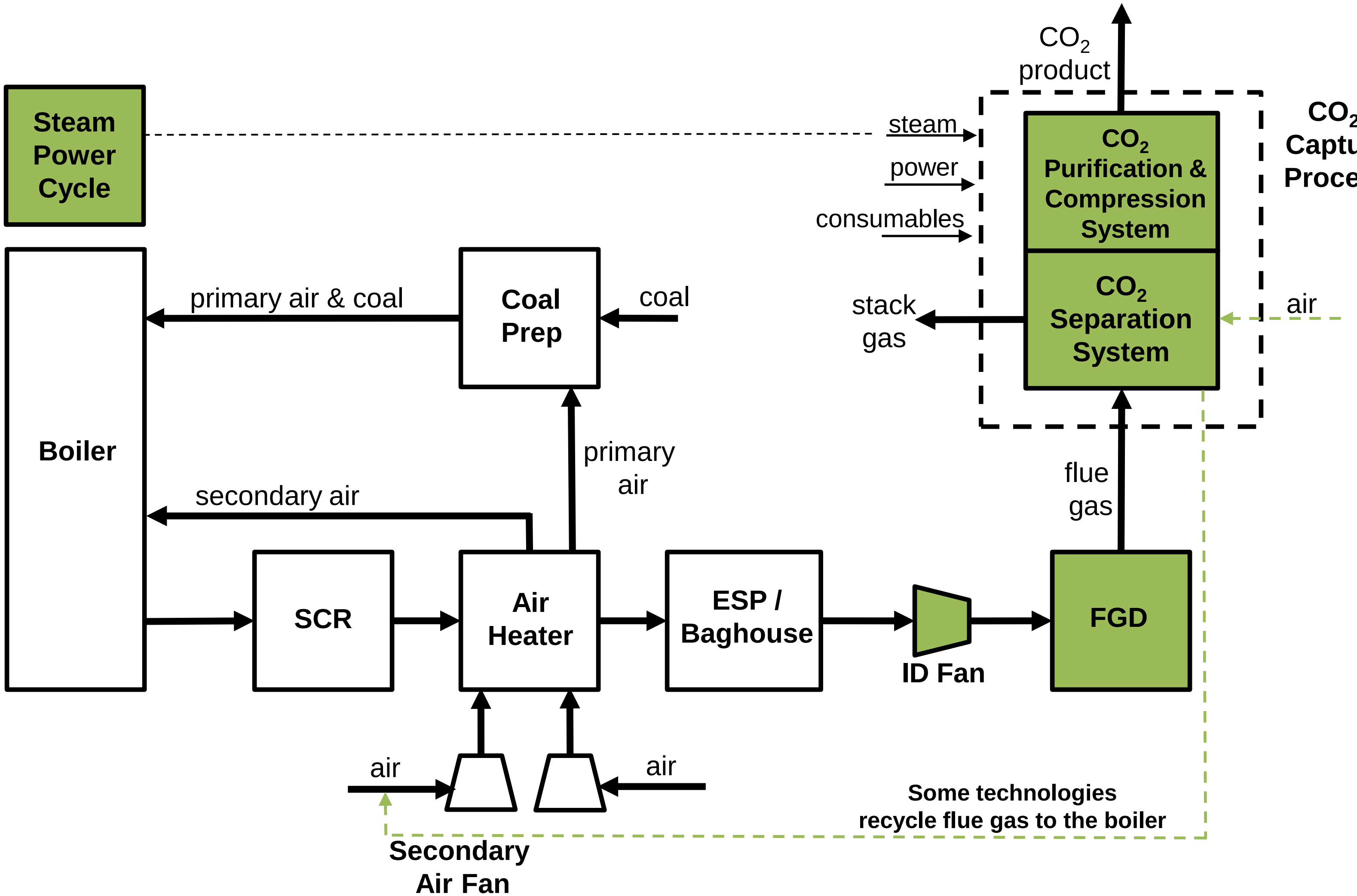
Objectives

- **Support DOE's Carbon Capture and Advanced Combustion R&D Programs**
- **Develop technology pathways that feature post-combustion CCS-enabled PC plants that achieve ≤35% increase in COE relative to today's new supercritical PC plant without CCS.**
- **Utilize the pathway studies to inform technology development though identification of performance and cost targets.**

Scope

- **Technologies included:**
  - Next generation post-combustion CO_2 capture
  - A-USC steam conditions (5000/1350/1400)
  - Advanced CO_2 compression
- **Pathway begins with 1st generation supercritical PC plant with today's post-combustion capture technology**
- **Extend the pathway to include emerging technologies and estimate their performances at a mature stage of development (i.e., 15-20 years), thus simulating "nth-of-a-kind" plant performance (low risk financial structure)**

PC Plant PFD



CO_2 product
Steam Power Cycle
steam
power
consumables
CO_2 Purification & Compression System
CO_2 Capture Process
CO_2 Separation System
stack gas
air
Boiler
primary air & coal
Coal Prep
coal
primary air
secondary air
flue gas
SCR
Air Heater
ESP / Baghouse
ID Fan
FGD
air
air
Some technologies recycle flue gas to the boiler
Secondary Air Fan

PC Plant and Evaluation Basis

Reference Plant Design Basis: NETL Bituminous Baseline report (PC Case 12)

- Bituminous coal (Illinois No. 6)
- Supercritical steam (3500 psig / 1100 F / 1100 F)
- Conventional flue gas cleaning using wet FGD with gypsum product
- Conventional caustic polishing scrubber to reduce SO_2 below 10 ppmv
- Flue gas ID fan boosts pressure 1.2 psi -- **changes with advanced CO_2 separation technology**
- 90% carbon capture using Conventional CO_2 separation system based on amine absorber technology -- **replaced with advanced CO_2 separation technology**
- Steam extracted for solvent stripper (1,931,497 lb/hr; 73.5 psia; 565 F) – **changes with advanced CO_2 separation technology**
- Conventional water inter-cooled CO_2 compression incorporating a triethylene glycol dehydration system – **may change with advanced CO_2 separation technology**

PC Plant Performance and Cost Parameters

- PC plant performance and cost determined by CO_2 Capture Process power and cost parameters
- Power Parameters
  - CO_2 separation system auxiliary power
  - fuel recovery and compression system auxiliary power
  - CO_2 separation system net steam power loss
  - CO_2 separation system impact on the ID-fan power consumption
- Cost Parameters
  - capital cost of the CO_2 separation system
  - capital cost of the fuel recovery and compression system
  - variable operating cost of the CO_2 separation system
  - Delta cost of steam cycle
  - Delta cost of ID fan

Technical Approach

1. Process Simulation - ASPEN

- *All major chemical processes and equipment were simulated*
- *Mass and energy balances*
- *Performance calculations including auxiliary power*

2. Selection of 2nd Generation Capture Technology

- *Two pathway studies initially selected:*
  - *Membrane (based on MTR technology)*
  - *Sorbent (based on TDA Research technology)*
- *Design basis information developed based largely on information available in literature*

Design Basis

- **Coal: IL #6**
- **Mid-Western site – Baseline Study**
- **Environmental Requirements**
  - NO_X: 0.07 lb/MMBtu
  - SO_2: 0.085 lb/MMBtu
  - Particulate: 0.013 lb/MMBtu
  - Mercury: 1.14lb/Tbtu
- **90% CO_2 Capture**
- **Cooling System: Evaporative Cooling Tower**
- **Plant capacity: 550 MW**

Cost Estimation

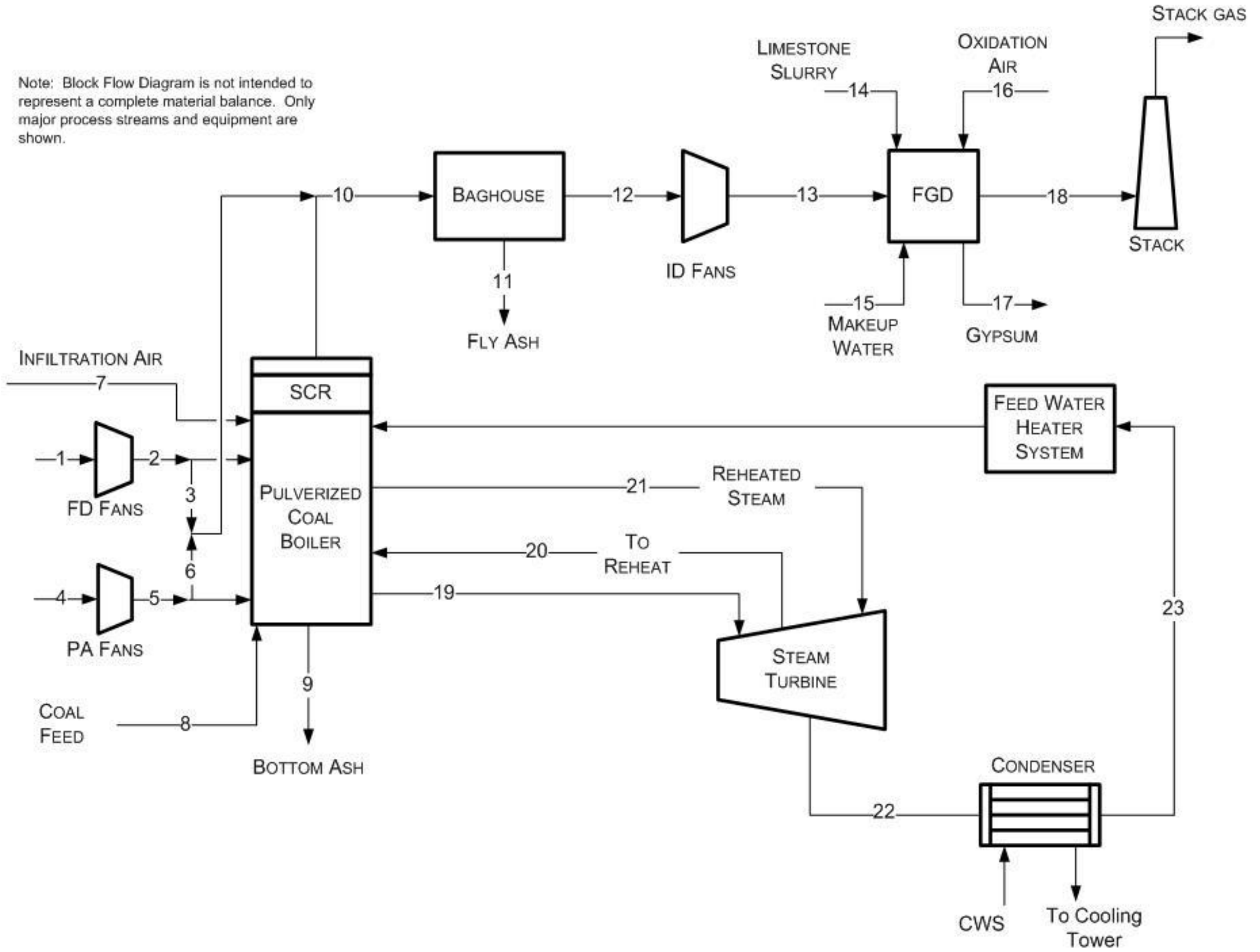
- **Consistent with Baseline Study**
- **June 2007 $**
- **Project contingency**
  - Commercial technologies: 10-15%
  - Next generation technology: 24% for capture technologies; 20% for CO_2 compression
- **Process contingency**
  - Zero for all plant components except A-USC boiler and turbines at 10% and 15%, respectively
- **CO_2 transport, storage and monitoring costs are not included**

Pathway Case Summary – Membrane based

Case	Capture Technology	Steam Conditions	CO_2 Compression Technology	Financial Structure
1A	None	SC	None	Low risk
1B	None	AUSC	None	High risk
2	Fluor Econamine	SC	Conventional	High risk
3	Enhanced Fluor Econamine	SC	Conventional	High risk
4	MHI KS-1 Solvent	SC	Conventional	High risk
5A	MTR Membrane	SC	Conventional	High risk
5B	MTR Membrane	USC	Conventional	High risk
5C	MTR Membrane	AUSC	Conventional	High risk
5D	MTR Membrane	AUSC	Adv. Shockwave	High risk
5E	MTR Membrane	AUSC	Adv. Shockwave	Low risk

Notes: • Fluor-based cases are consistent with NETL Bituminous Baseline Report (2010)
• MTR-based cases utilize enhanced performance and cost parameters

Cases 1A & 1B: PC w/o CCS



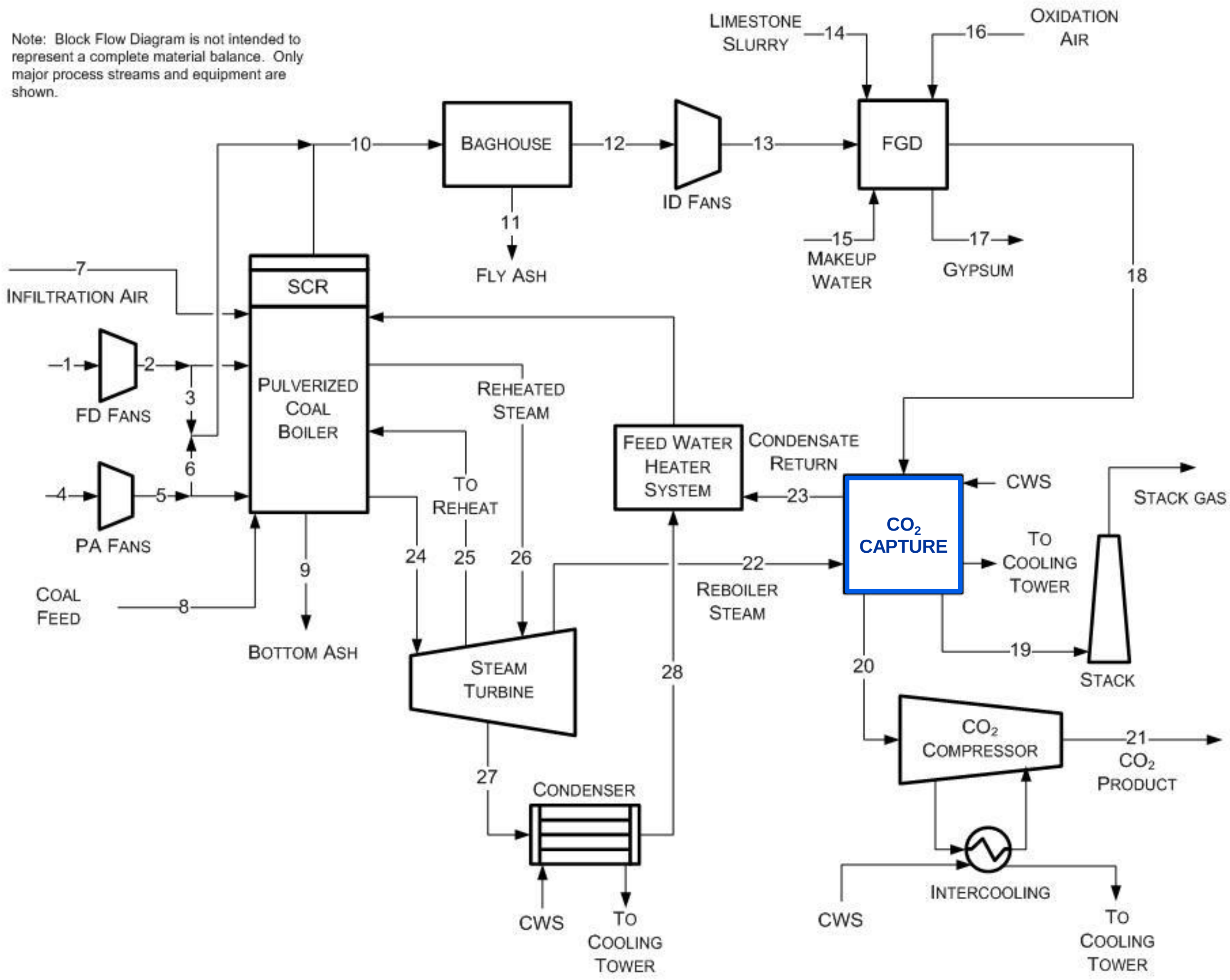
Power Summary – Case 1A (SC)

CASE 1A POWER SUMMARY (kWe)	
TOTAL (STEAM TURBINE) POWER, kWe	**580,400**
AUXILIARY LOAD SUMMARY, kWe	
Coal Handling and Conveying	440
Pulverizers	2,780
Sorbent Handling & Reagent Preparation	890
Ash Handling	530
Primary Air Fans	1,300
Forced Draft Fans	1,660
Induced Draft Fans	7,050
SCR	50
Baghouse	70
Wet FGD	2,970
Condensate Pumps	800
Circulating Water Pumps	4,730
Cooling Tower Fans	2,440
Transformer Losses	1,820
TOTAL AUXILIARIES, kWe	**30,410**
NET POWER, kWe	**549,990**
Net Plant Efficiency (HHV)	39.3%

Power Summary – Case 1B (A-USC)

CASE 1B POWER SUMMARY (kWe)	
TOTAL (STEAM TURBINE) POWER, kWe	**577,800**
AUXILIARY LOAD SUMMARY, kWe	
Coal Handling and Conveying	420
Pulverizers	2,570
Sorbent Handling & Reagent Preparation	820
Ash Handling	490
Primary Air Fans	1,200
Forced Draft Fans	1,540
Induced Draft Fans	6,500
SCR	40
Baghouse	60
Wet FGD	2,750
Condensate Pumps	620
Circulating Water Pumps	4,080
Cooling Tower Fans	2,110
Transformer Losses	1,800
TOTAL AUXILIARIES, kWe	**27,820**
NET POWER, kWe	**549,980**
Net Plant Efficiency (HHV)	42.5%

BFD for PC with CO_2 Capture

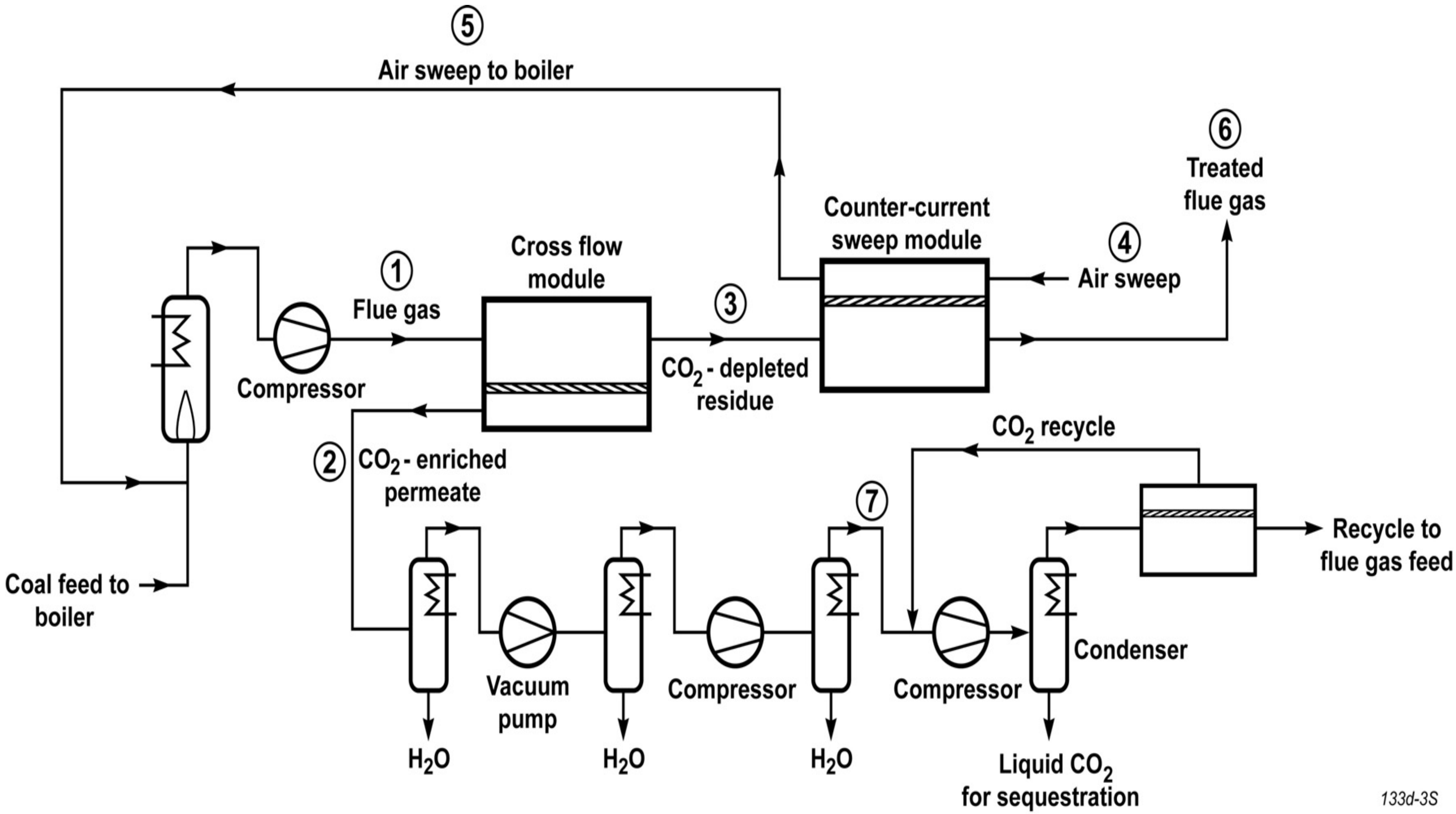


Power Summary – Case 2

(representative of current capture technology)

CASE 2 POWER SUMMARY (kWe)	
TOTAL (STEAM TURBINE) POWER, kWe	**662,800**
AUXILIARY LOAD SUMMARY, kWe	
Coal Handling and Conveying	510
Pulverizers	3,850
Sorbent Handling & Reagent Preparation	1,250
Ash Handling	740
Primary Air Fans	1,800
Forced Draft Fans	2,300
Induced Draft Fans	11,120
SCR	70
Baghouse	100
Wet FGD	4,110
Econamine FG Plus Auxiliaries	20,600
CO_2 Compression	44,890
Condensate Pumps	560
Circulating Water Pumps	10,100
Ground Water Pumps	910
Cooling Tower Fans	5,230
Transformer Losses	2,290
TOTAL AUXILIARIES, kWe	**112,830**
NET POWER, kWe	**549,970**
Net Plant Efficiency (HHV)	28.4%

MTR CO_2 Capture Membrane Process (Case 5)

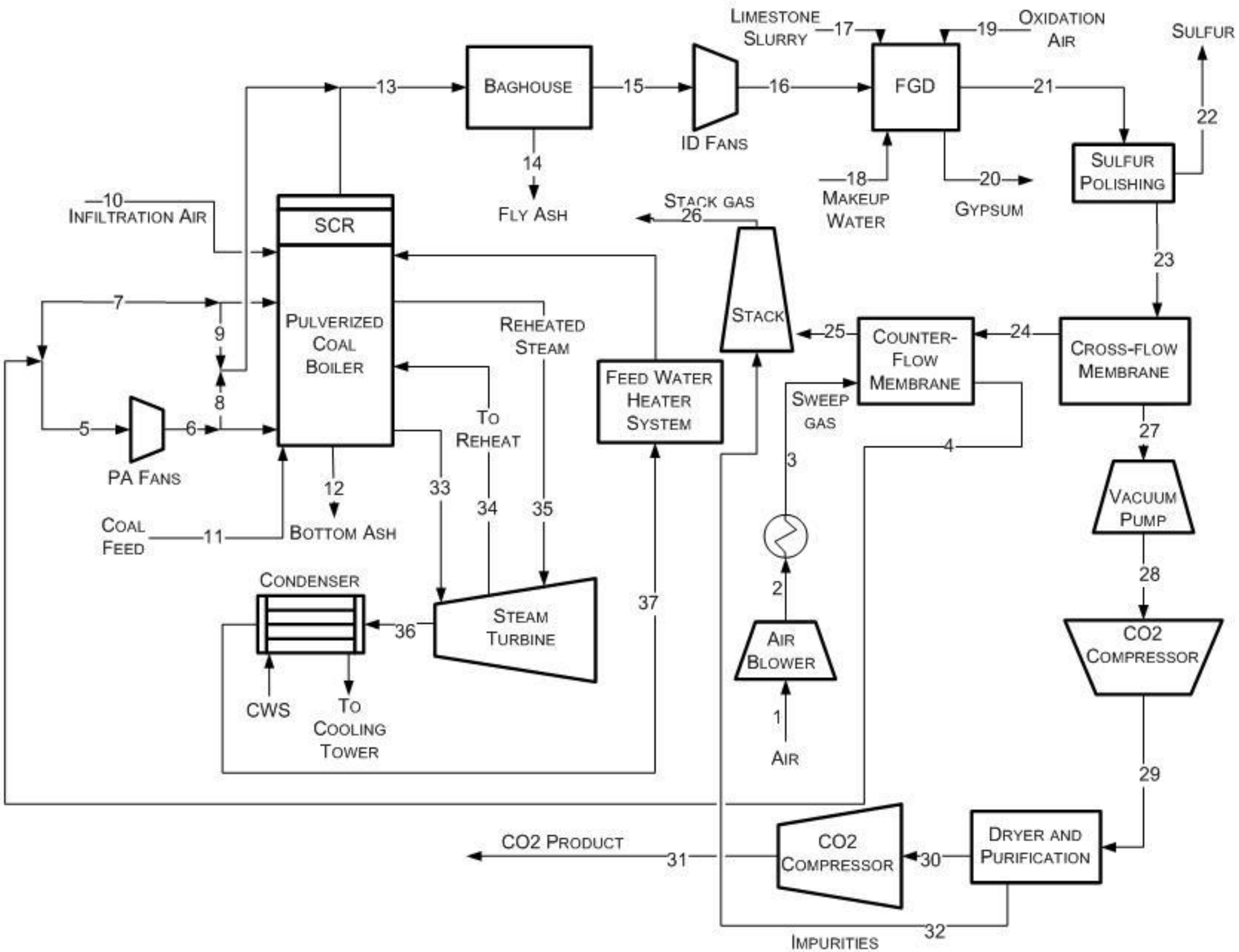


Design Basis: Case 5 MTR Membrane Process

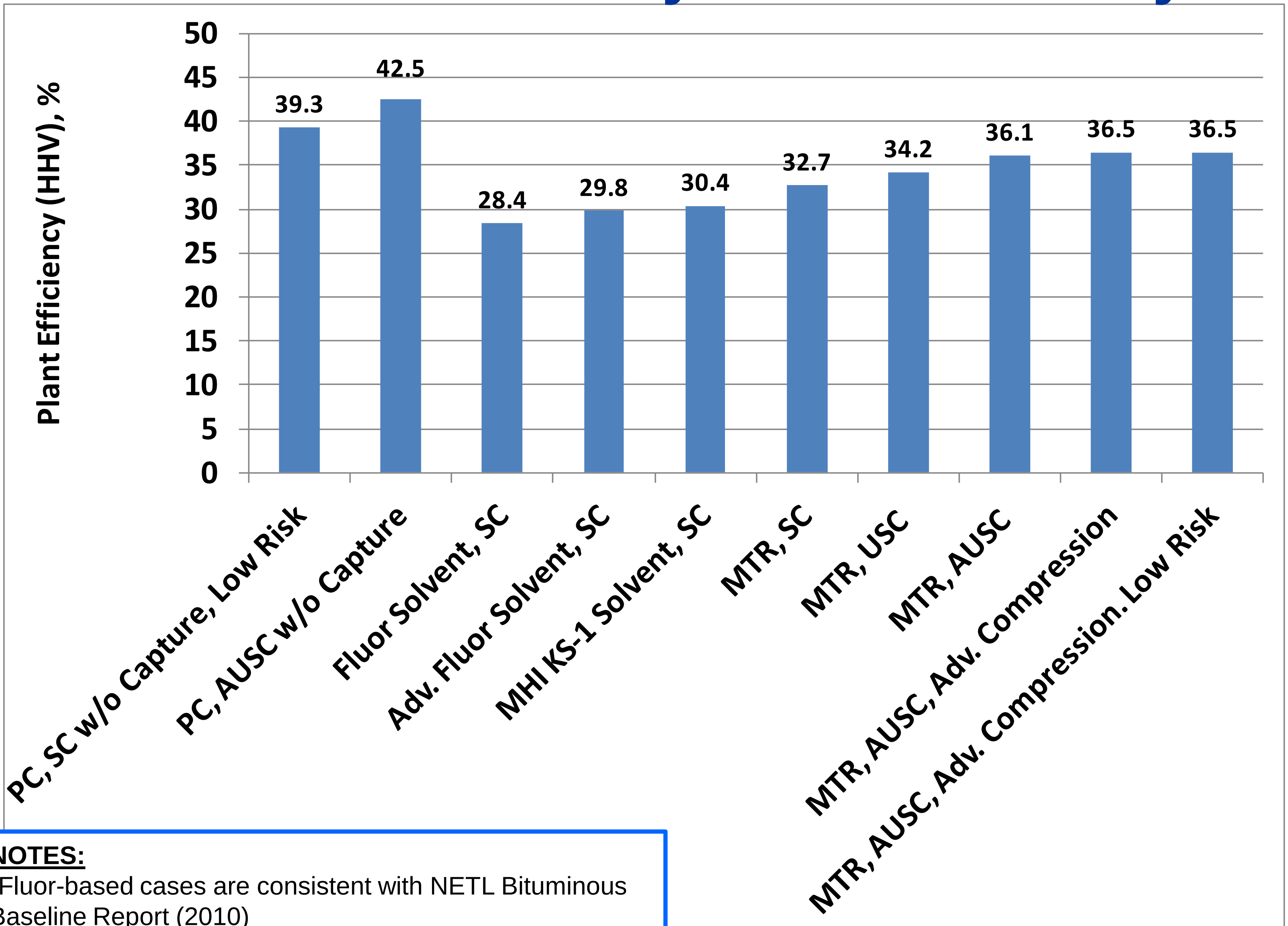
Enhanced Performance Relative to Literature
Key Parameter Assumptions

- **Membrane Process**
  - **CO_2 and SO_2 Permeance: 3,500 gpu**
  - N_2, O_2, Ar Permeance: 100 gpu
  - H_2O Permeance: 5,000 gpu
  - **Pressure drop: 1.0 psi (flue gas and sweep sides)**
  - Vacuum pump achieves 0.2 bar pressure
  - Membrane replacement time 5 years
  - Membrane surface area: 1,500,000 m^2
  - **Membrane installed cost \$80/m^2**
  - Membrane replacement cost \$15/m^2
- **CO_2 Shockwave Compressor (Cases 5D & 5E)**
  - **Increased polytropic efficiency: 93%**

Cases 5A-5E: PC with MTR Membrane

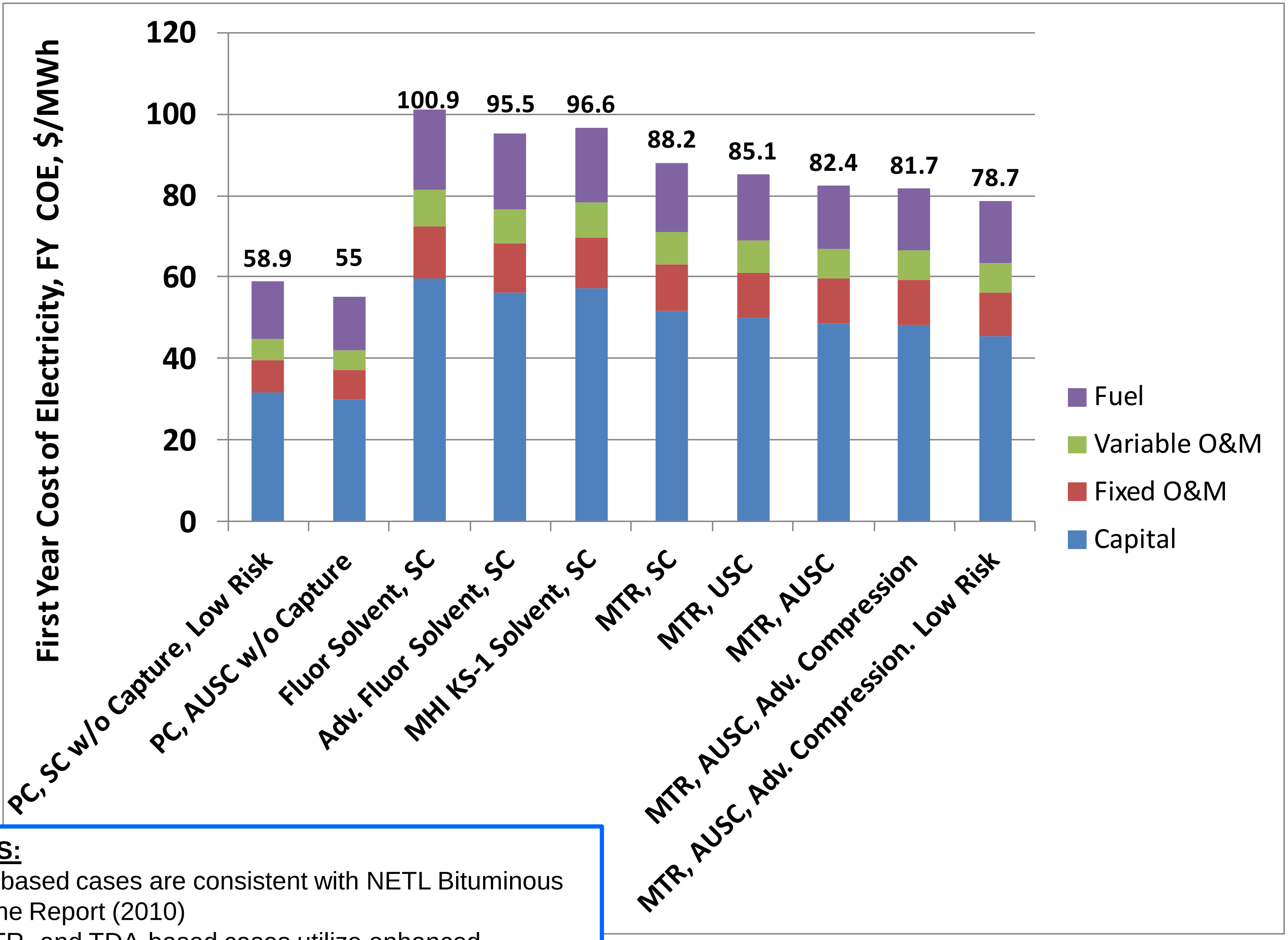


Membrane Pathway Plant Efficiency



NOTES:
•Fluor-based cases are consistent with NETL Bituminous Baseline Report (2010)
•All MTR- and TDA-based cases utilize enhanced performance and cost parameters

First-Year Cost of Electricity – Membrane



NOTES:
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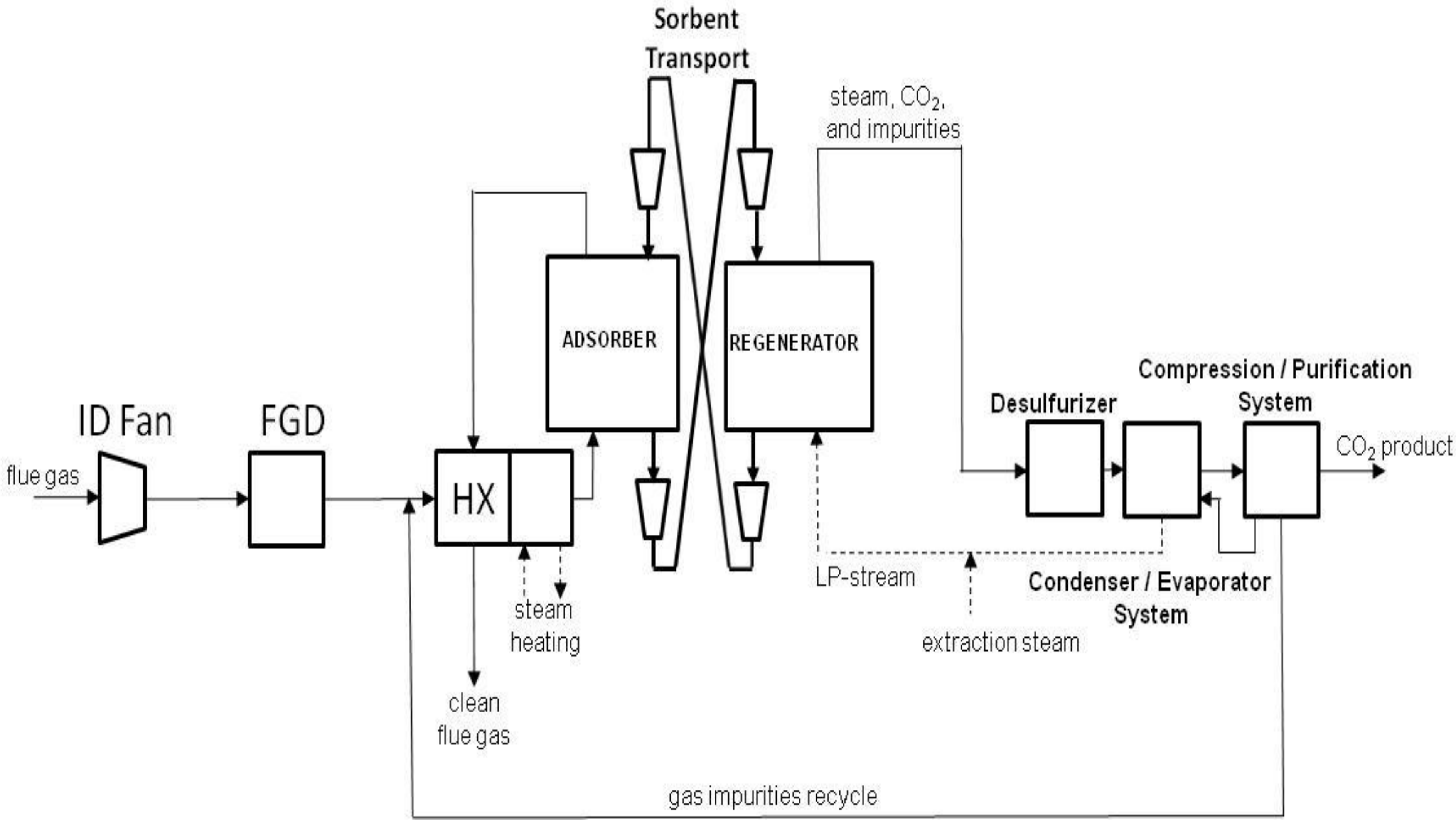
Pathway Case Summary – Sorbent based

Case	Capture Technology	Steam Conditions	CO_2 Compression Technology	Financial Structure
1A	None	SC	None	Low risk
1B	None	AUSC	None	High risk
2	Fluor Econamine	SC	Conventional	High risk
3	Enhanced Fluor Econamine	SC	Conventional	High risk
4	MHI KS-1 Solvent	SC	Conventional	High risk
6A	TDA Adsorbent	SC	Conventional	High risk
6B	TDA Adsorbent	USC	Conventional	High risk
6C	TDA Adsorbent	AUSC	Conventional	High risk
6D	TDA Adsorbent	AUSC	Adv. Shockwave	High risk
6E	TDA Adsorbent	AUSC	Adv. Shockwave	Low risk

Notes:
- Fluor-based cases are consistent with NETL Bituminous Baseline Report (2010)
- TDA-based cases utilize enhanced performance and cost parameters

TDA Sorbent CO_2 Capture Process

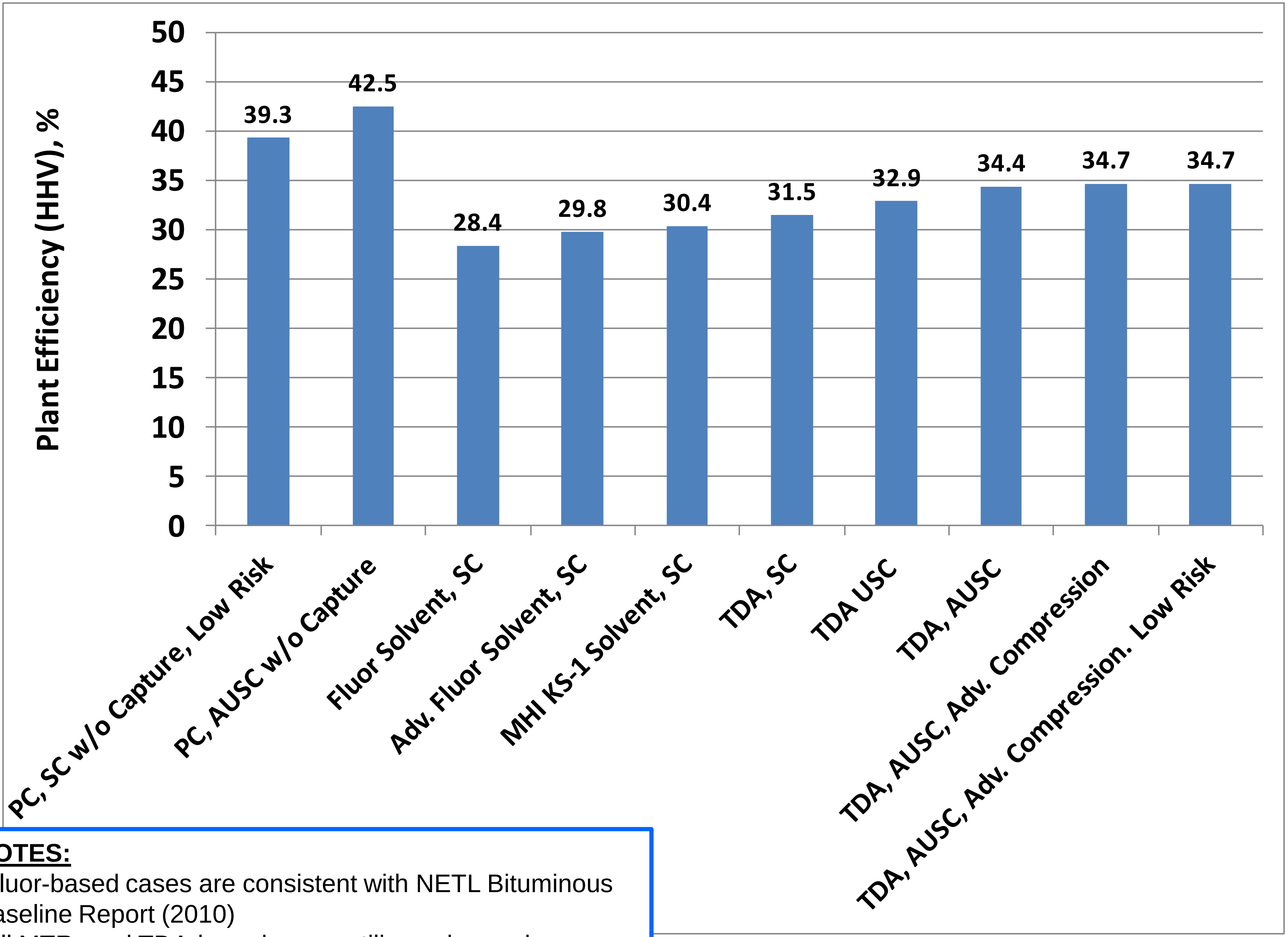


Design Basis: Case 6 TDA Sorbent Process

Enhanced Performance Relative to Literature
Key Parameter Assumptions

- **TDA Sorbent Process**
  - Adsorbent: alkalized alumina; 3/8 inch diameter spheres
  - Adsorbent cost: $5/lb
  - **Sorbent CO_2 loading: 3.0%**
  - Adsorber and regenerator temperature: 140°C
  - Adsorber and regenerator pressure drop: 0.4 psi
  - Adsorbent entrains 1.0 wt% of inlet N_2, O_2 and water vapor to the regenerator
  - **Regenerator off-gas: 50 mole % CO_2**
  - Adsorber-regenerator type: Moving bed
  - Adsorbent transport: Bucket conveyor-elevators
- **CO_2 Shockwave Compressor**
  - **Increased polytropic efficiency: 93%**

Pathway Plant Efficiency – Sorbent pathway



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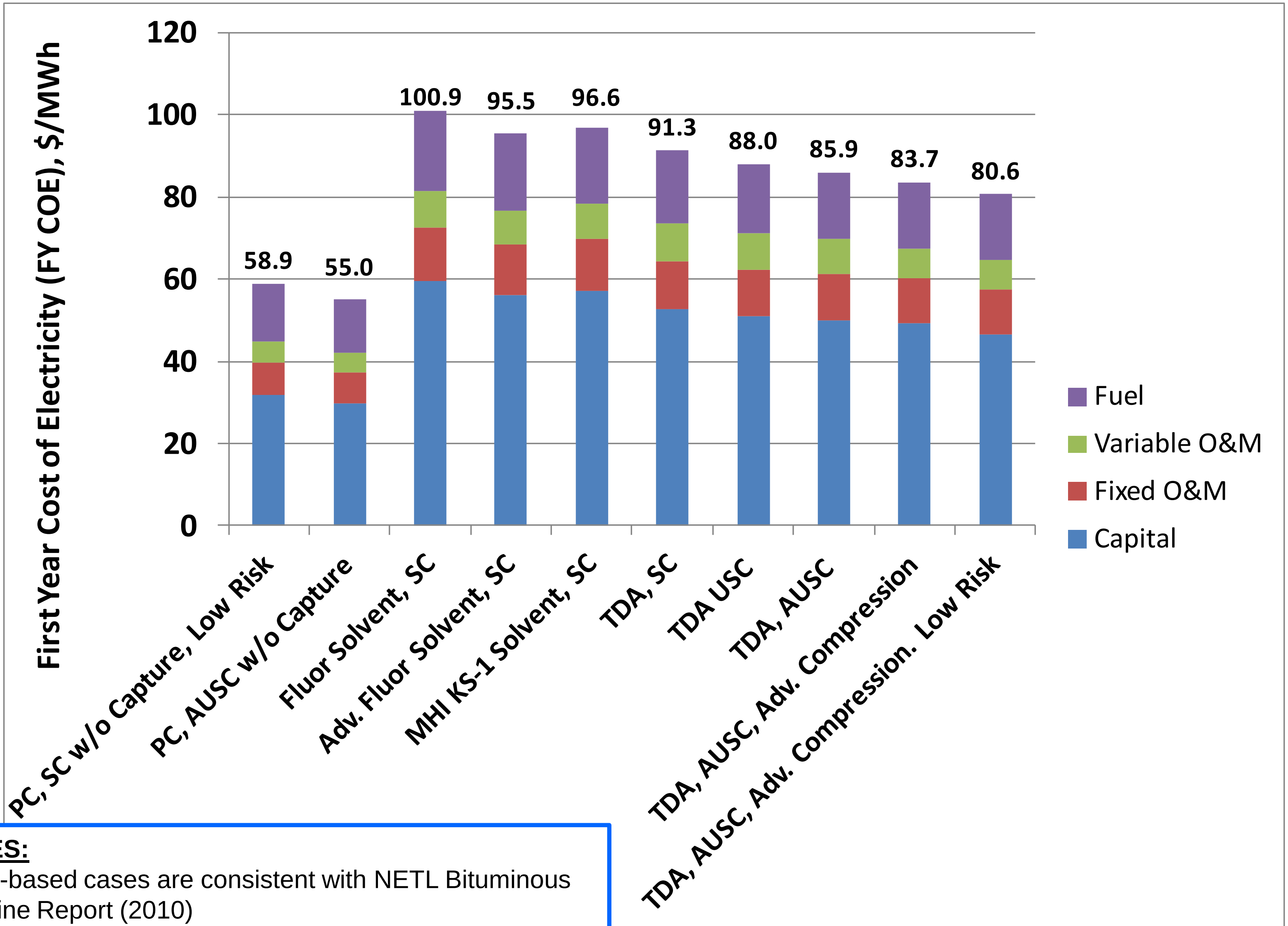
First-Year Cost of Electricity – Sorbent



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Conclusions

- The pathway study provides perspective on design and operating parameters, capital cost and operating cost that will be required to achieve the ≤ 35% increase in COE for advanced post-combustion carbon capture, CO_2 compression, and advanced steam cycles.
- This work illustrates the challenge in meeting the DOE COE target, suggesting that it will be difficult to achieve with only a single technology but rather through the combination of several technologies.
- Future work includes evaluating the effects of 2011$ and simulating a 2nd generation carbon capture technology in a retrofit application.

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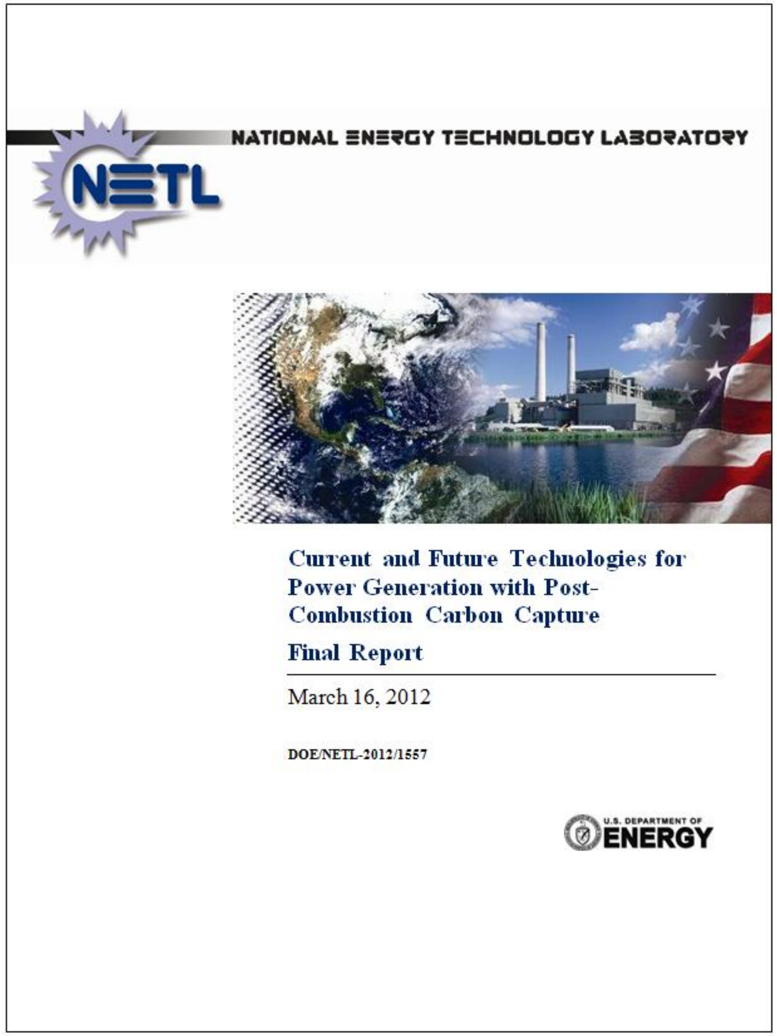
Further Information



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Current and Future Technologies for Power Generation with Post-Combustion Carbon Capture

Final Report

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