May 5 - 8, 2003

Greenhouse Gas Emissions Control by Oxygen Firing in Circulating Fluidized Bed Boilers

(US DOE/NETL Cooperative Agreement No. DE-FC26-01NT41146)

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GREENHOUSE GAS EMISSIONS CONTROL BY OXYGEN FIRING IN CIRCULATING FLUIDIZED BED BOILERS

Presented at

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Carbon Sequestration

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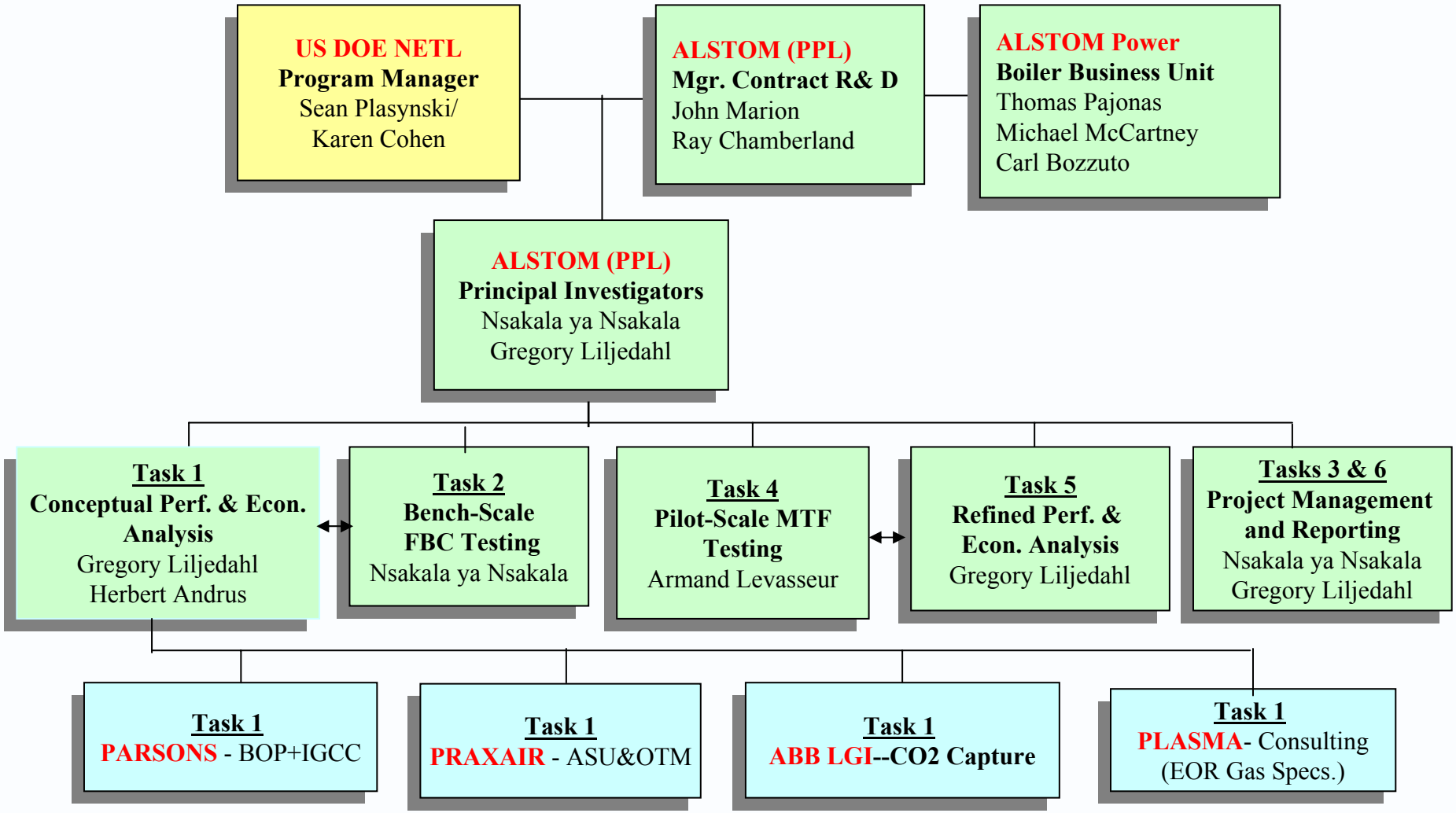
ALSTOM Power Inc.

Summary -- Project Team Members



PROJECT OBJECTIVES AND WORK BREAKDOWN STRUCTURE

Project Objectives

To Determine if Carbon Dioxide Can Be Recovered at an Avoided Cost of $10/Ton (or less) of Carbon Avoided (i.e., $3/Ton of CO_2 Avoided), Using a Newly Constructed CFB While Burning Coal With a Mixture of Oxygen and Recycled Flue Gas, Instead of Air. Specific Objectives:

- **Summarize Performance and Economic Analyses of An Existing Design 210-MWe Air-Fired CFB Plant to Provide Base Case Information**
- **Design an O_2-Fired CFB, for the Same Steam Cycle Parameters as With the Base Case CFB, and Carry Out Performance & Economic Analyses**
- **Design Several Other Advanced CFB-Based Plants for the Same Steam Cycle Parameters, and Carry Out Performance & Economic Analyses**
- **Carry Out Performance & Economic Analyses of IGCC Cases (With and Without CO_2 Capture).**

Project Objectives

- Design an Advanced Chemical Looping IGCC Cases and Carry Out Performance & Economic Analysis
- Compare CFB-Based Technology with IGCC-Based Technologies

Key Outputs Will Include:

- Net Plant Efficiency
- Equipment Configurations & Costs
- Cost of Electricity
- CO_2 Mitigation Costs

- Recommendation of the Case to Evaluate in Phase II (Pilot-Scale Testing) of the Project, Based on Practical, Technical, and Economic Considerations

Work Breakdown Structure

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Phase I

TASK 1
Preliminary Performance & Economic Analysis -- 13 Cases: Baselines, High O_2 Firing, Chemical Looping & IGCC

TASK 2
Bench-Scale Fluidized Bed Combustion (FBC) Experiments -- Bed Agglomeration and SO_2 Capture

TASK 3
Project Period I final Report -- Results/Recommendations

Stop Project

Decision Point (Define the Most Promising Concept)

Implement Budget Project Phase II

Work Breakdown Structure -- Phase II

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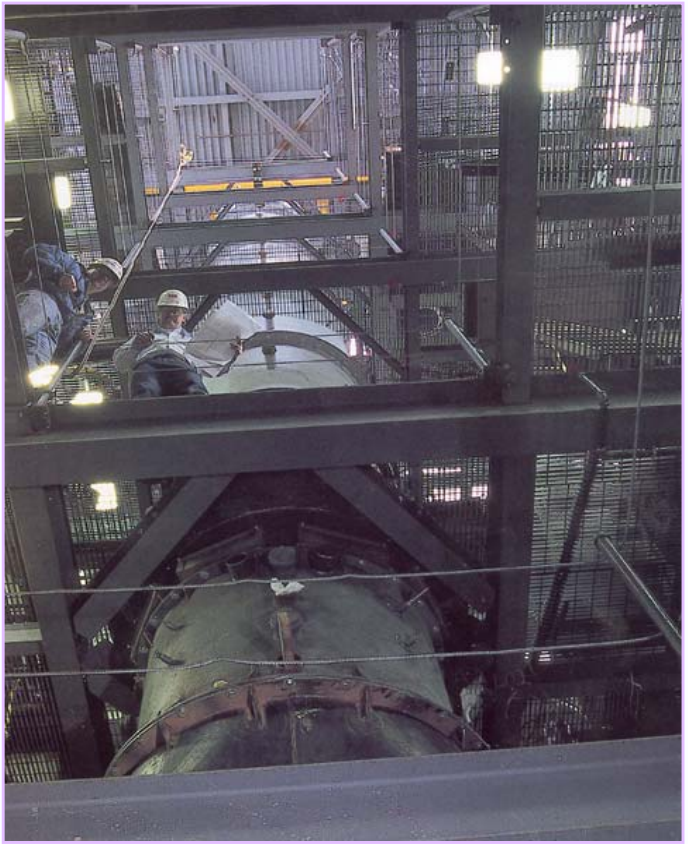
ALSTOM's MTF - Windsor, CT



Phase II

TASK 4
Pilot-Scale Testing (MTF) of Most Promising Concept (s) -- Detailed Combustion/Bed Dynamics Evaluation

TASK 5
Refined Performance & Economic Analysis of Most Promising Concept(s)

TASK 6
Period II Final Report -- Systems Performance & Economics

TECHNICAL AND ECONOMIC ANALYSES OF STUDY CASES

Cases Studied: All ~ 210 MWe Gross)

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Combustion Cases

CASE 1: Base Case, Air-Fired Circulating Fluidized Bed (CFB) Boiler

CASE 2: New Compact Cryogenic O_2-Fired CFB with CO_2 Capture, Purification, Compression and Liquefaction

CASE 3: New Compact Cryogenic O_2-Fired CFB with "Dry" Flue Gas Compression and Liquefaction

CASE 4: O_2-Fired Circulating Moving Bed (CMB) with CO_2 Purification, Compression and Liquefaction

CASE 5: Air-Fired CMB with High Temp. Regenerative Carbonate Process

CASE 6: Case 4, Integrated with Oxygen Transport Membrane (OTM)

CASE 7: Indirect Combustion of Coal and CO_2 Capture via Chemical Looping

Cases Studied: All ~ 300 MW Gross

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Texaco-Based IGCC Cases

CASE 8: Base Case, Built & Operating IGCC w/o CO_2 Capture

CASE 9: Built & Operating IGCC w/ CO_2 Capture, Purification, Compression and Liquefaction

CASE 10: Base Case, Commercially Offered IGCC w/o CO_2 Capture

CASE 11: Built & Operating IGCC w/ CO_2 Capture, Purification, Compression and Liquefaction

Chemical Looping Gasification Cases

CASE 12: Base Case, IGCC w/ Indirect Gasification via Chemical Looping w/o CO_2 Capture

CASE 13: IGCC w/ Indirect Gasification via Chemical Looping w/ CO_2 Capture, Purification, Compression and Liquefaction

Basic Work Steps for Each Study Case

1. Develop Process Design
   - ☞ Material & Energy Balance (Gas and Steam Sides)
   - ☞ Overall Plant Performance and CO_2 Emissions

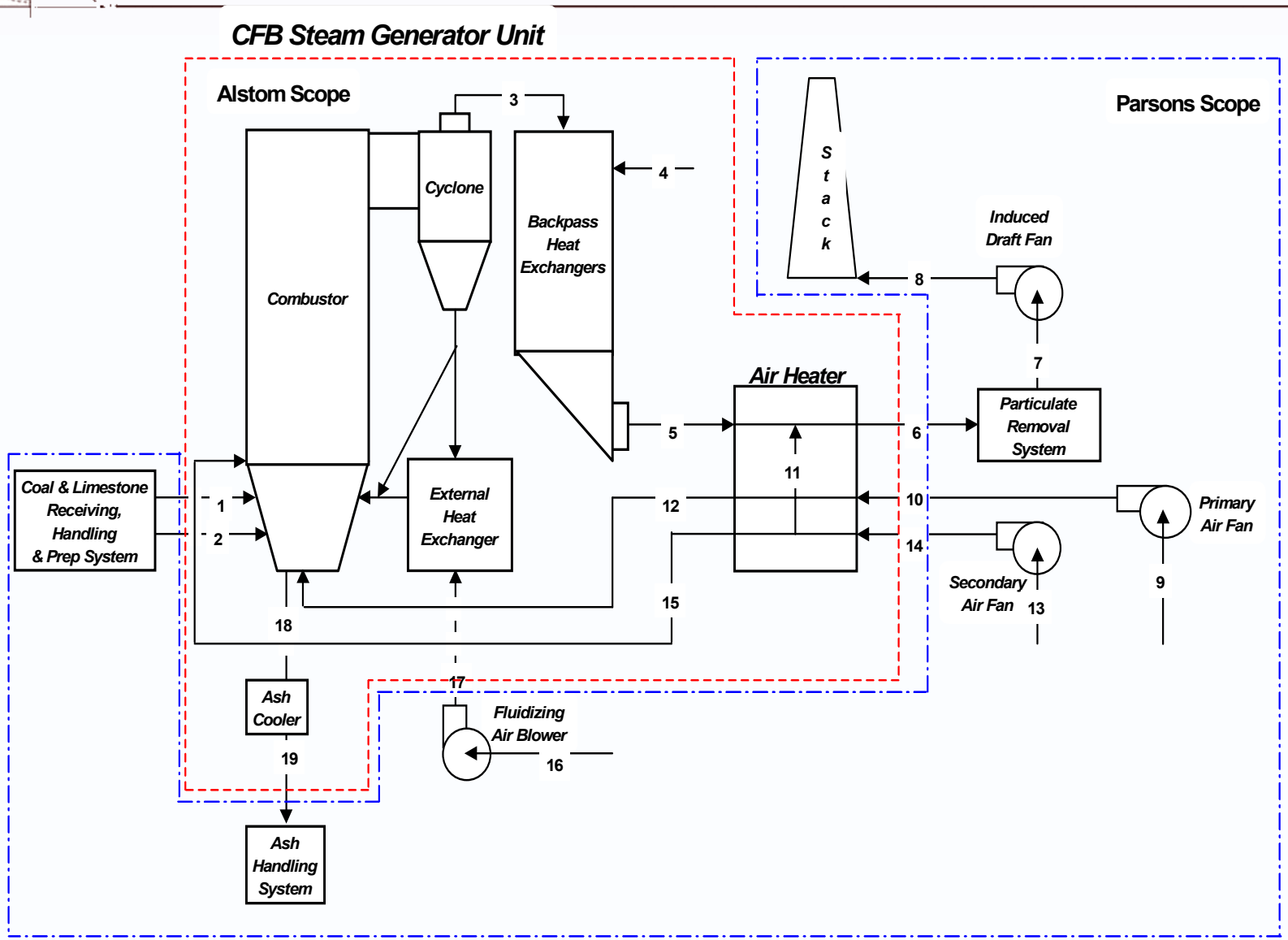
2. Develop System/Component Specifications & Designs

3. Develop Boiler/Gasifier Plant Drawings

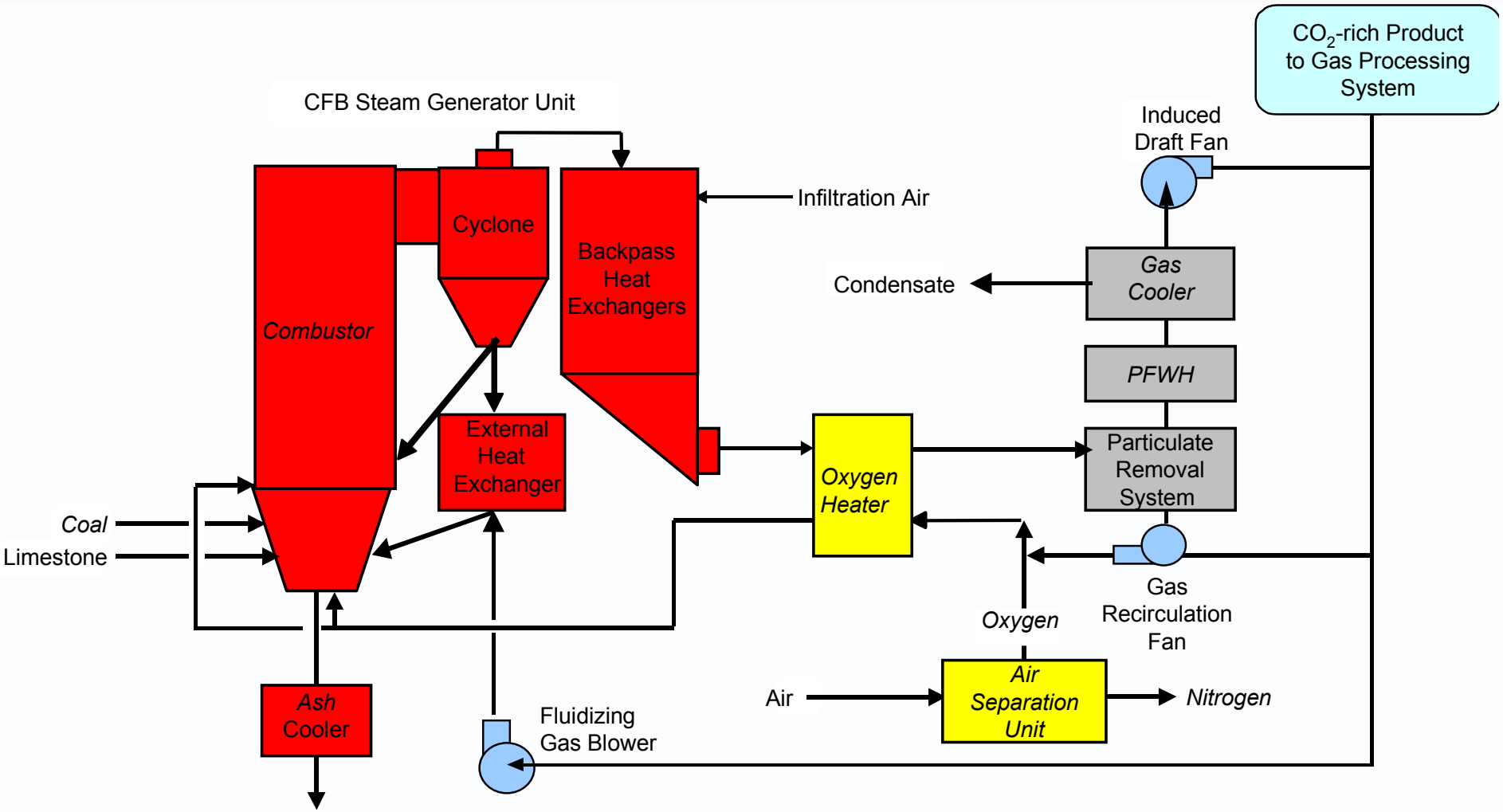
4. Develop Equipment Costs
   - ☞ Capital Costs
   - ☞ O & M Costs

5. Economic Evaluation
   - ☞ Levelized Cost of Electricity (COE)
   - ☞ CO_2 Mitigation Costs

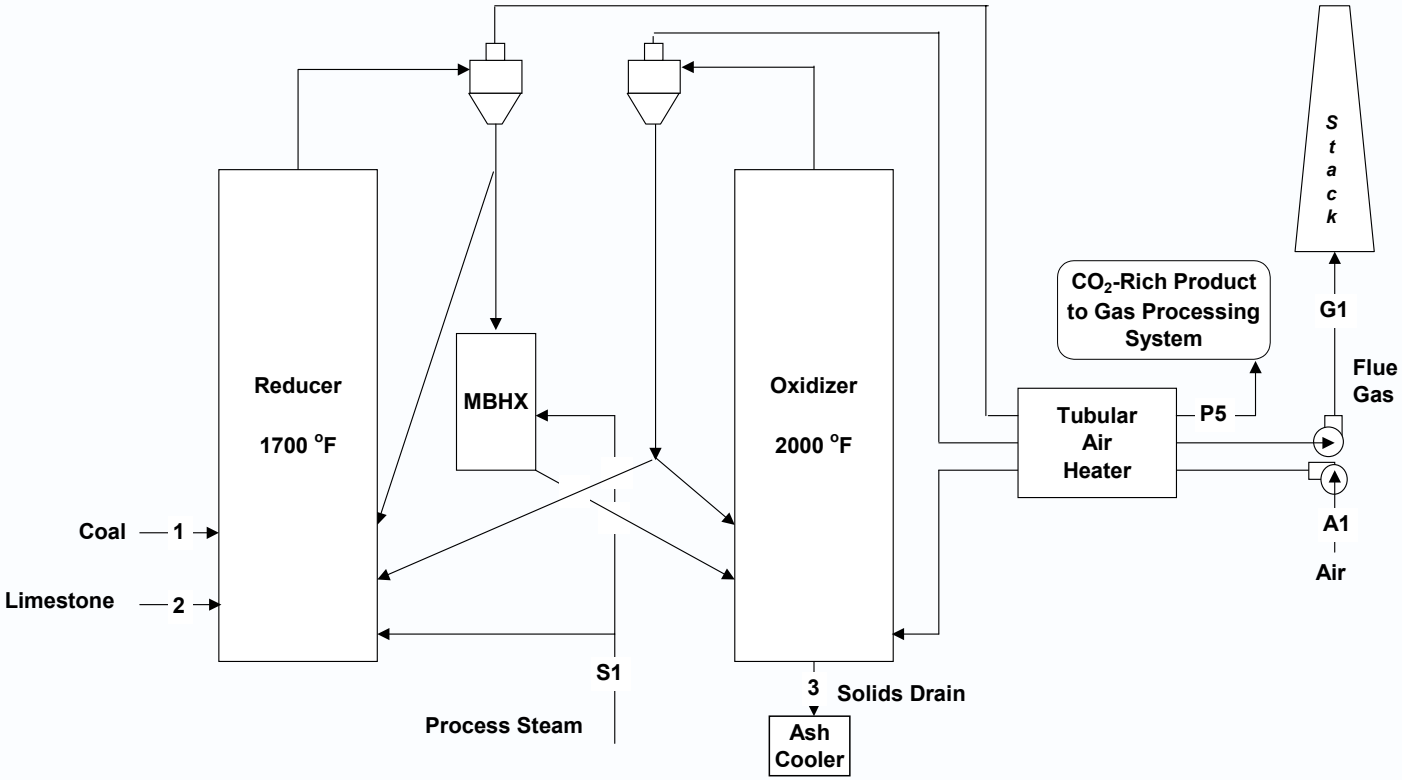
Case 1: Air-Fired CFB -- Boiler Island Equipment Scope Definition



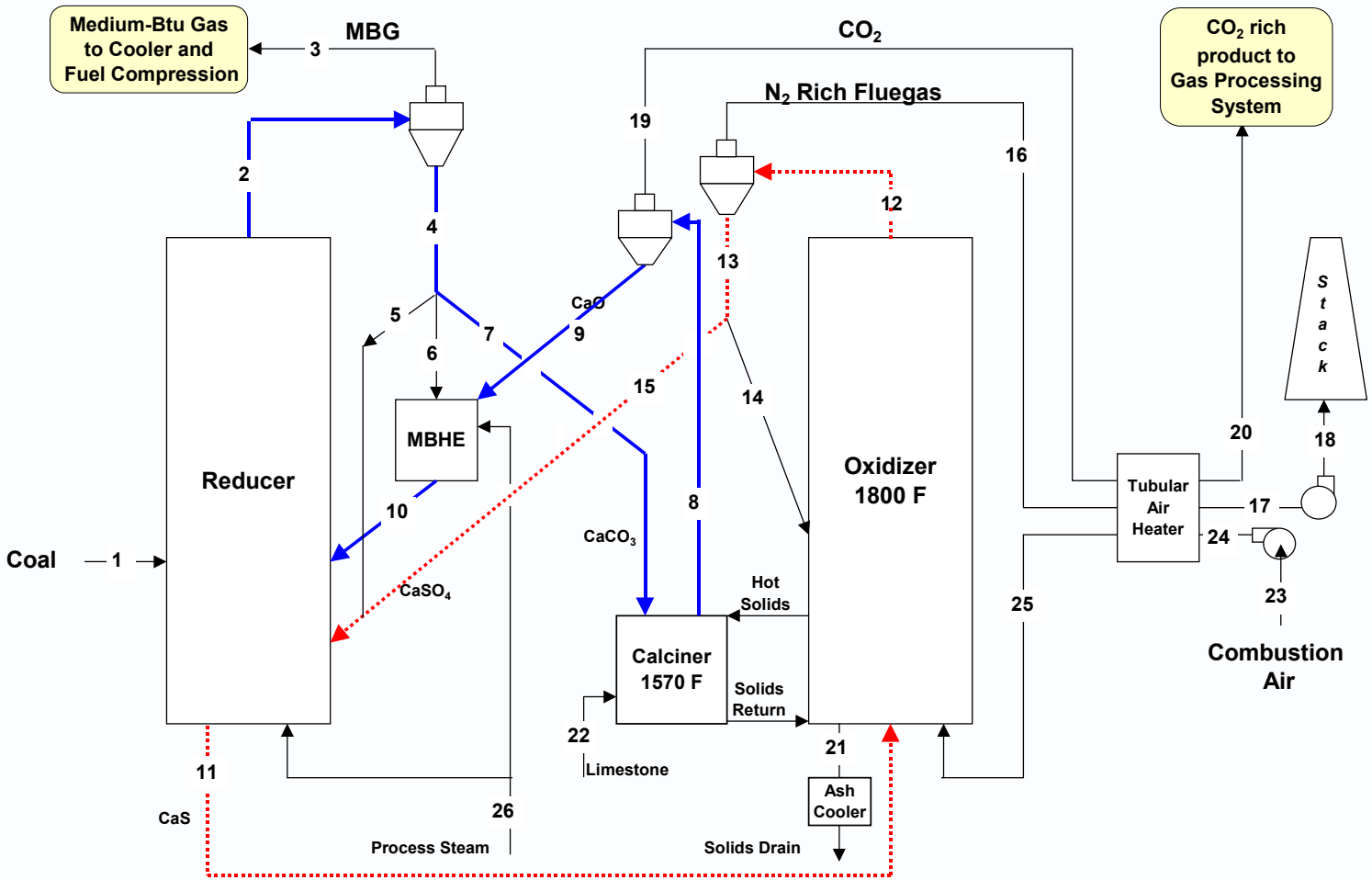
Case 2/3: Oxygen-Fired CFB -- Boiler Island Equipment Scope Definition



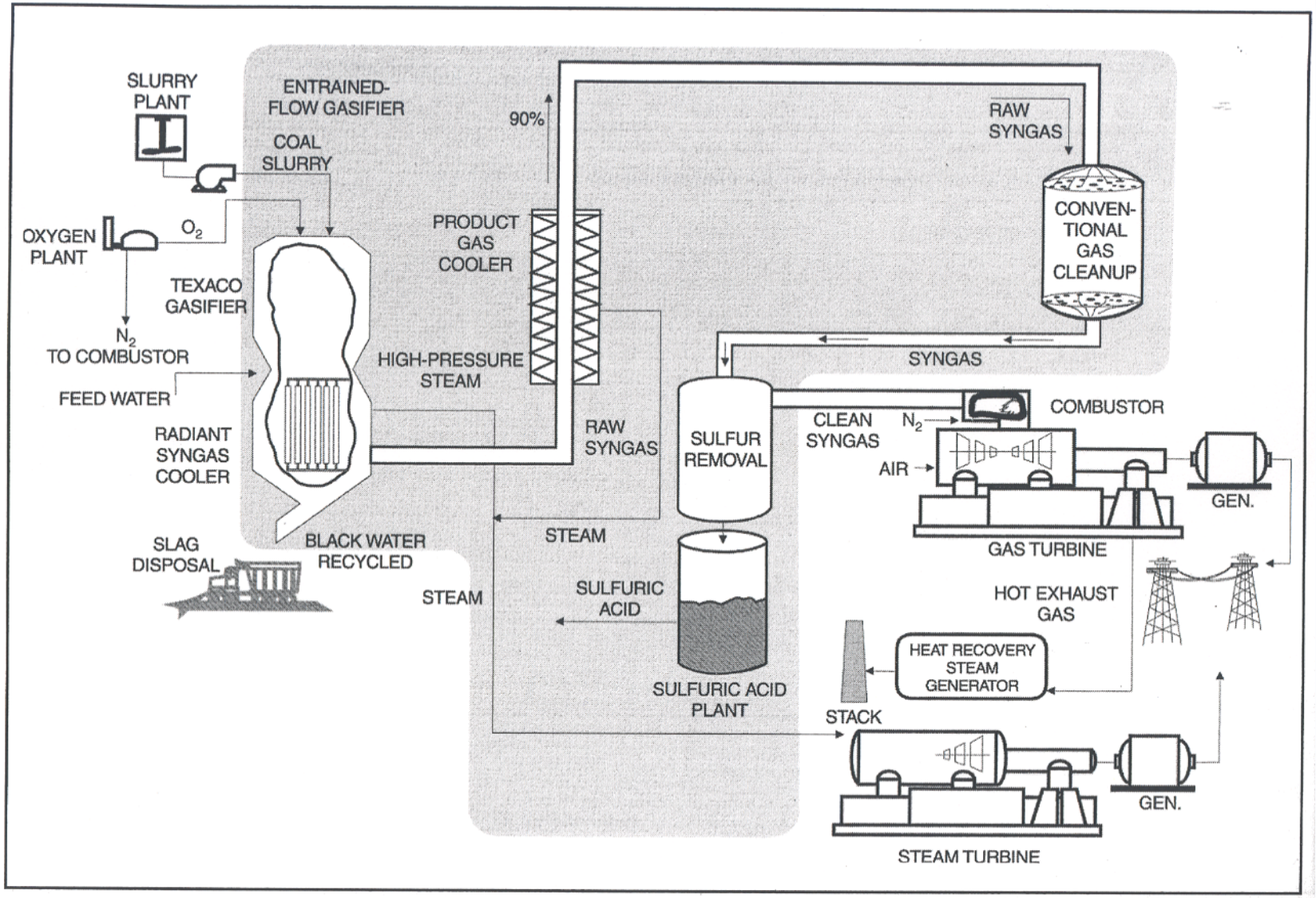
Case 7: Chemical Looping Combustion, Boiler Island Equipment Scope Definition



Case13: Chem. Looping Gasification, Gasif. Island Equipment Scope Definition

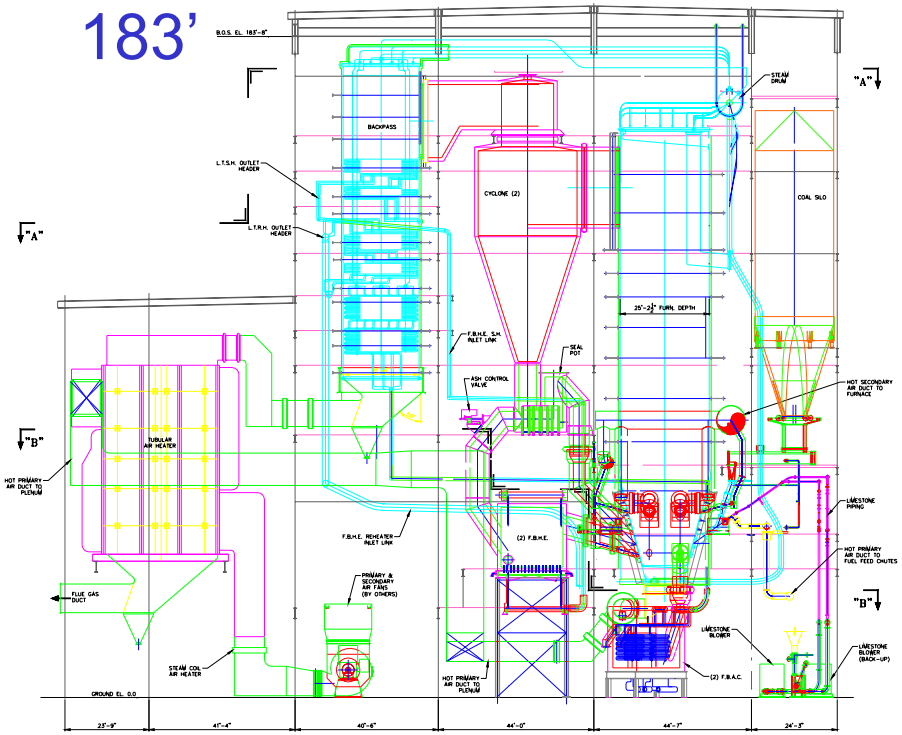


Case 8: Tampa Electric's IGCC Demo Plant -- Equipment Scope Definition



Side View: Case 1 vs. Case 2

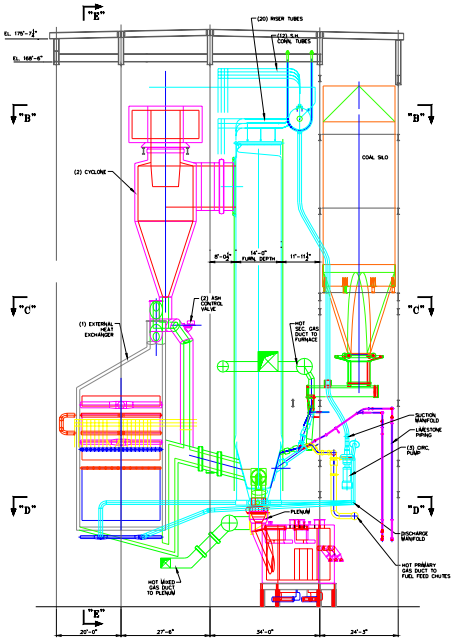
183’



← 220’ →

Air Fired CFB

156’

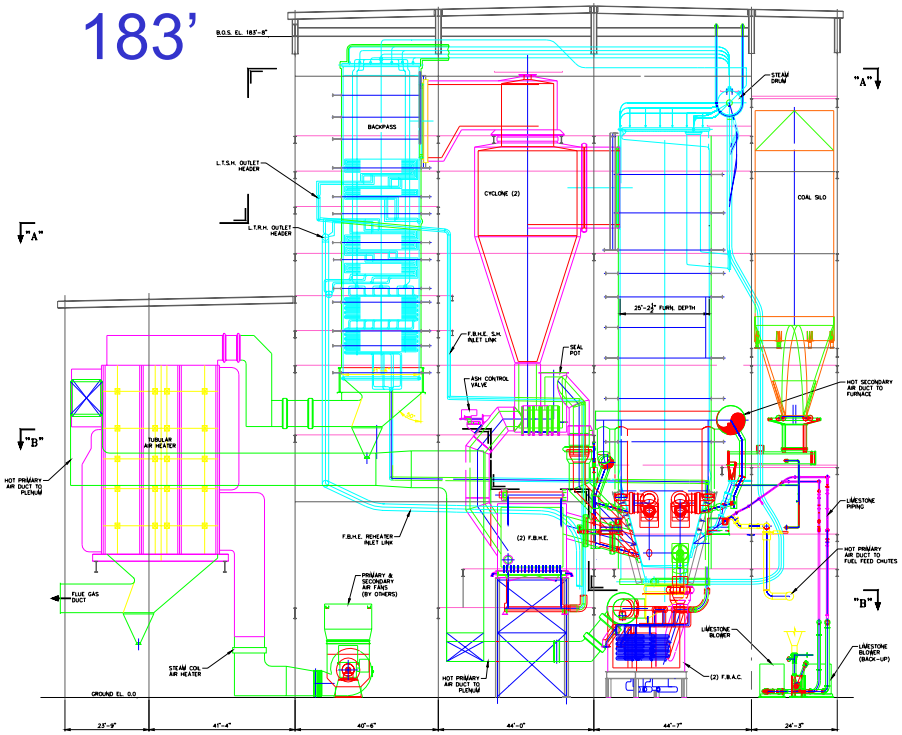


← 106’ →

Oxygen Fired CFB

Side View: Case 1 vs. Case 13

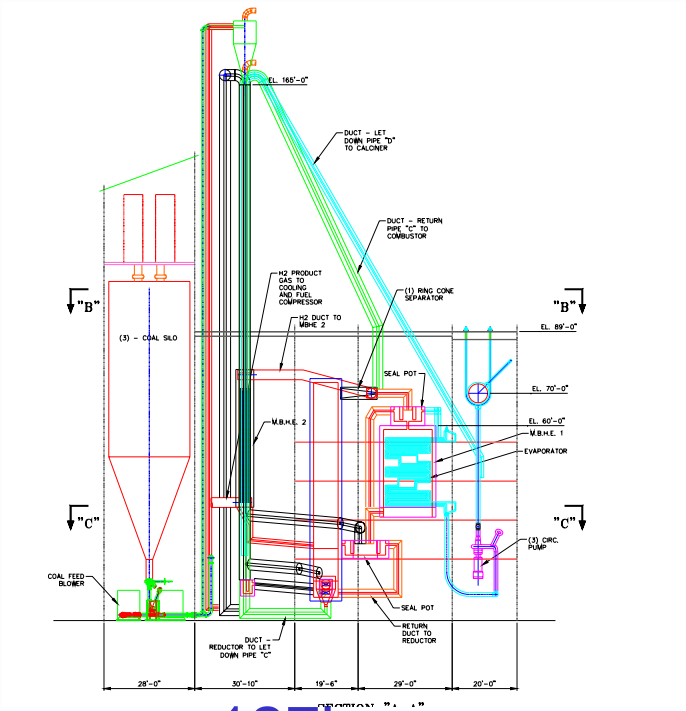
183’



← 220’ →

Air Fired CFB

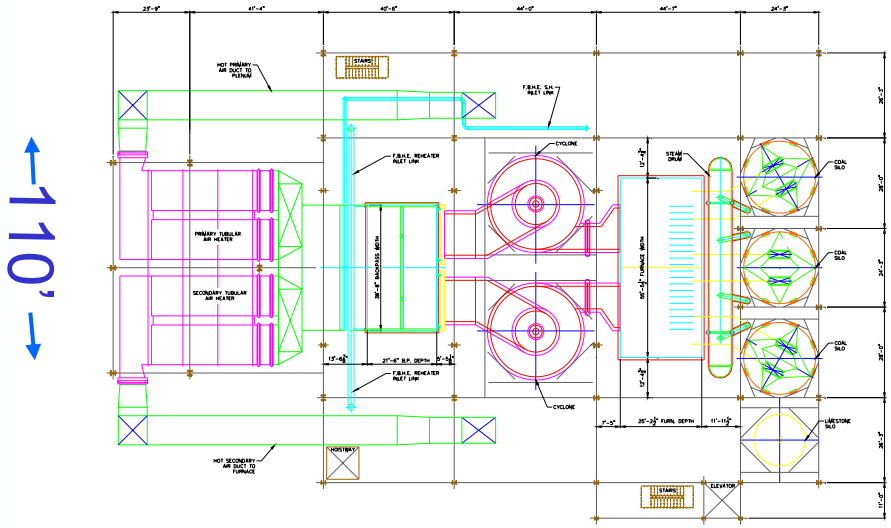
140’

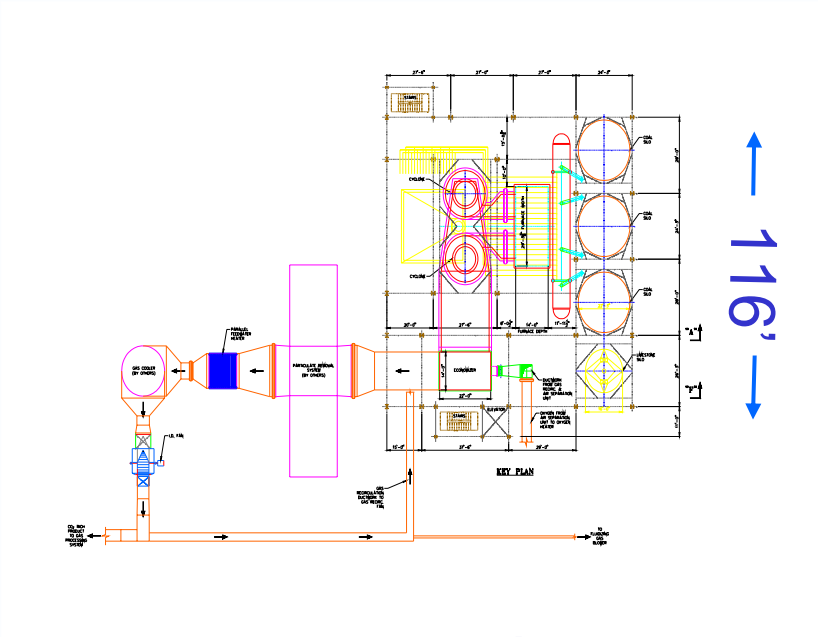


←127’ →

Chem. Looping Gasification

Plan View: Case 1 vs. Case 2

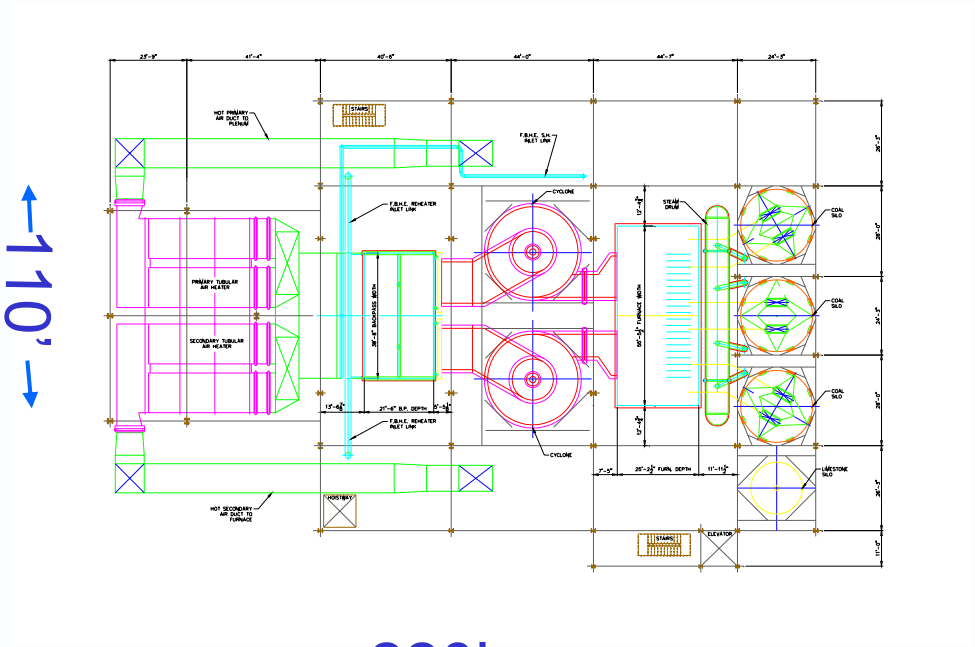


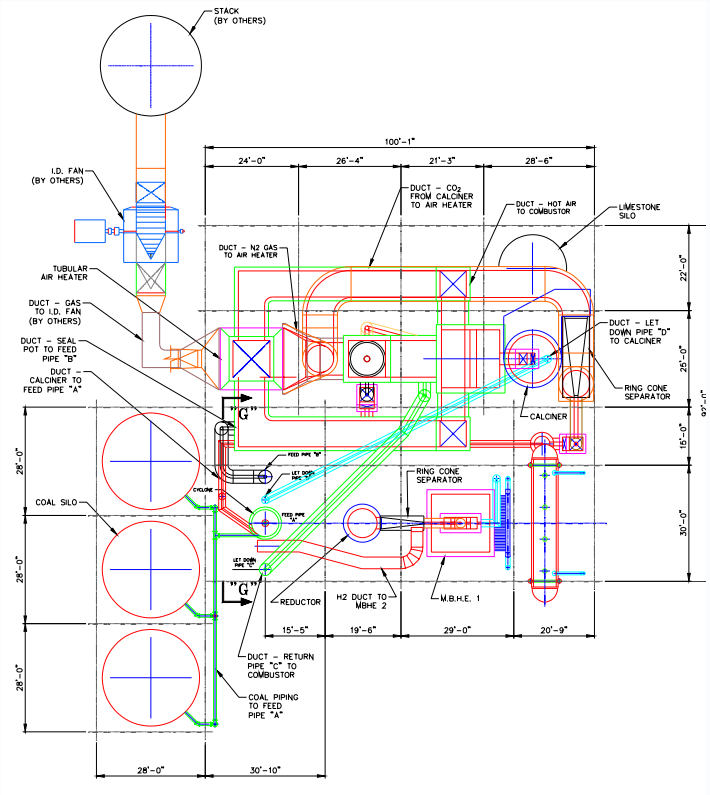


Air Fired CFB

Oxygen Fired CFB

Plan View: Case 1 vs. Case 13





Air Fired CFB

Chem. Looping Gasification

SUMMARY OF RESULTS

NET PLANT EFFICIENCIES, % HHV

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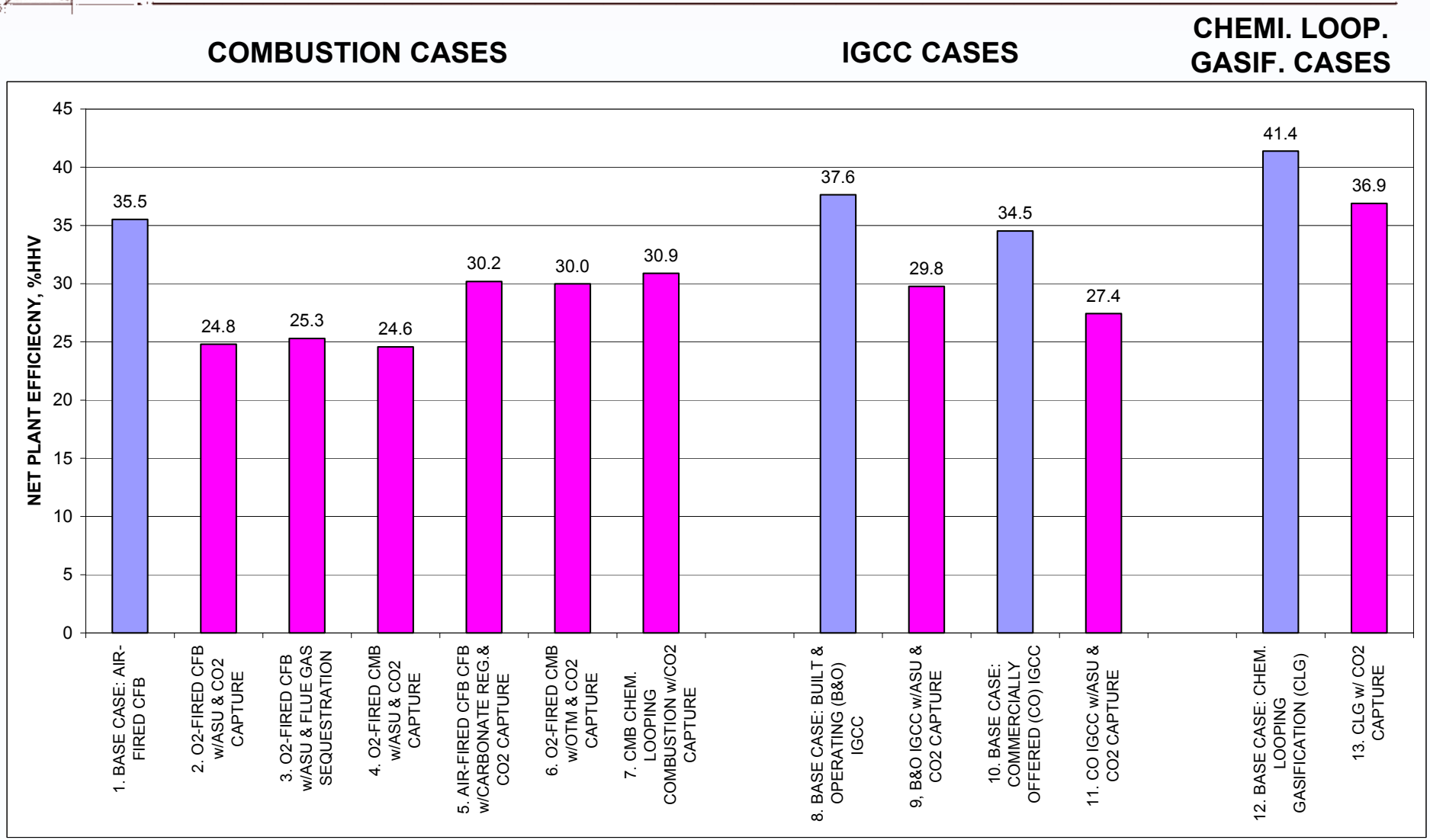
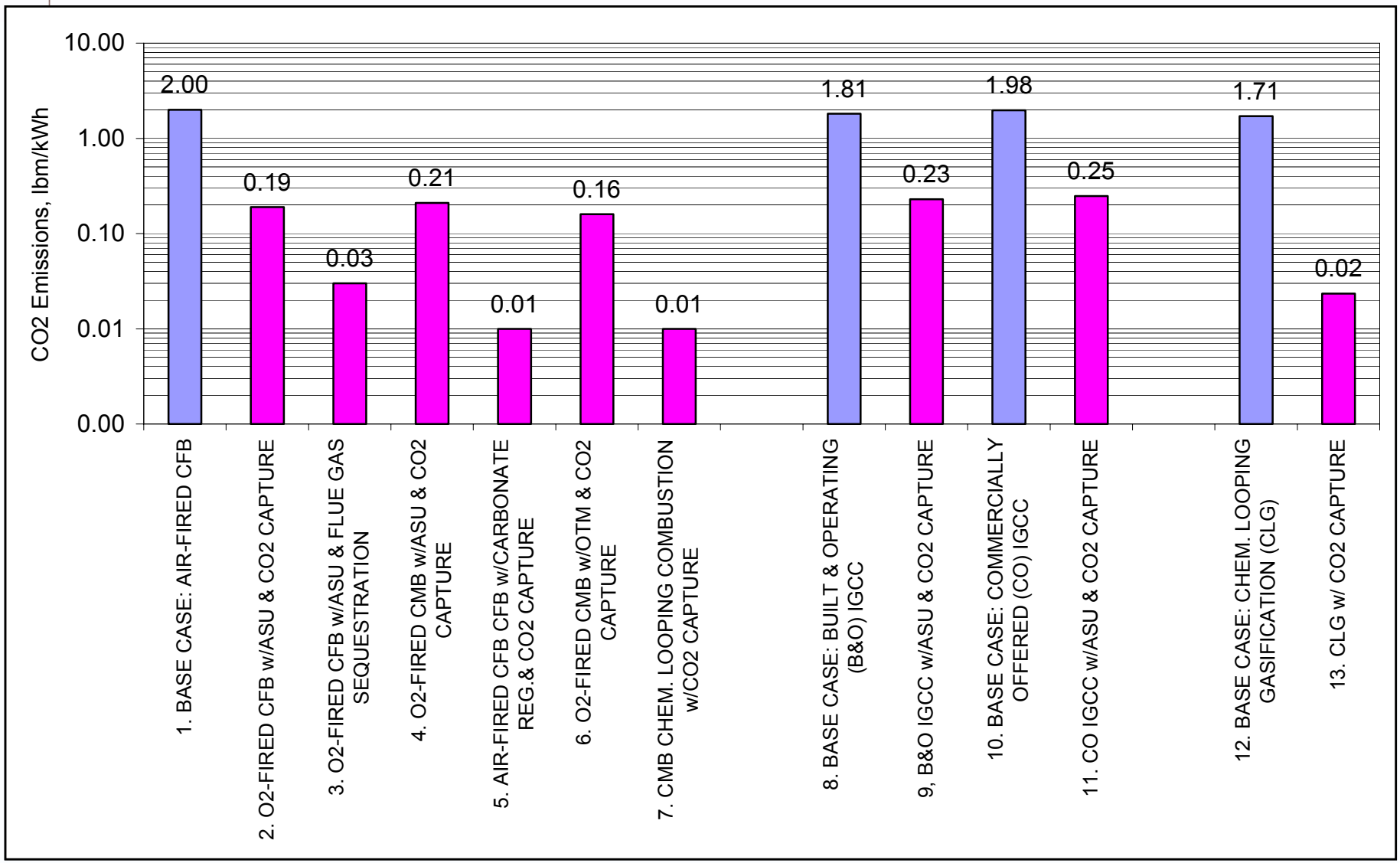


CO_2 EMISSIONS



TOTAL EPC INVESTMENT COSTS, JULY 2003 $/kW

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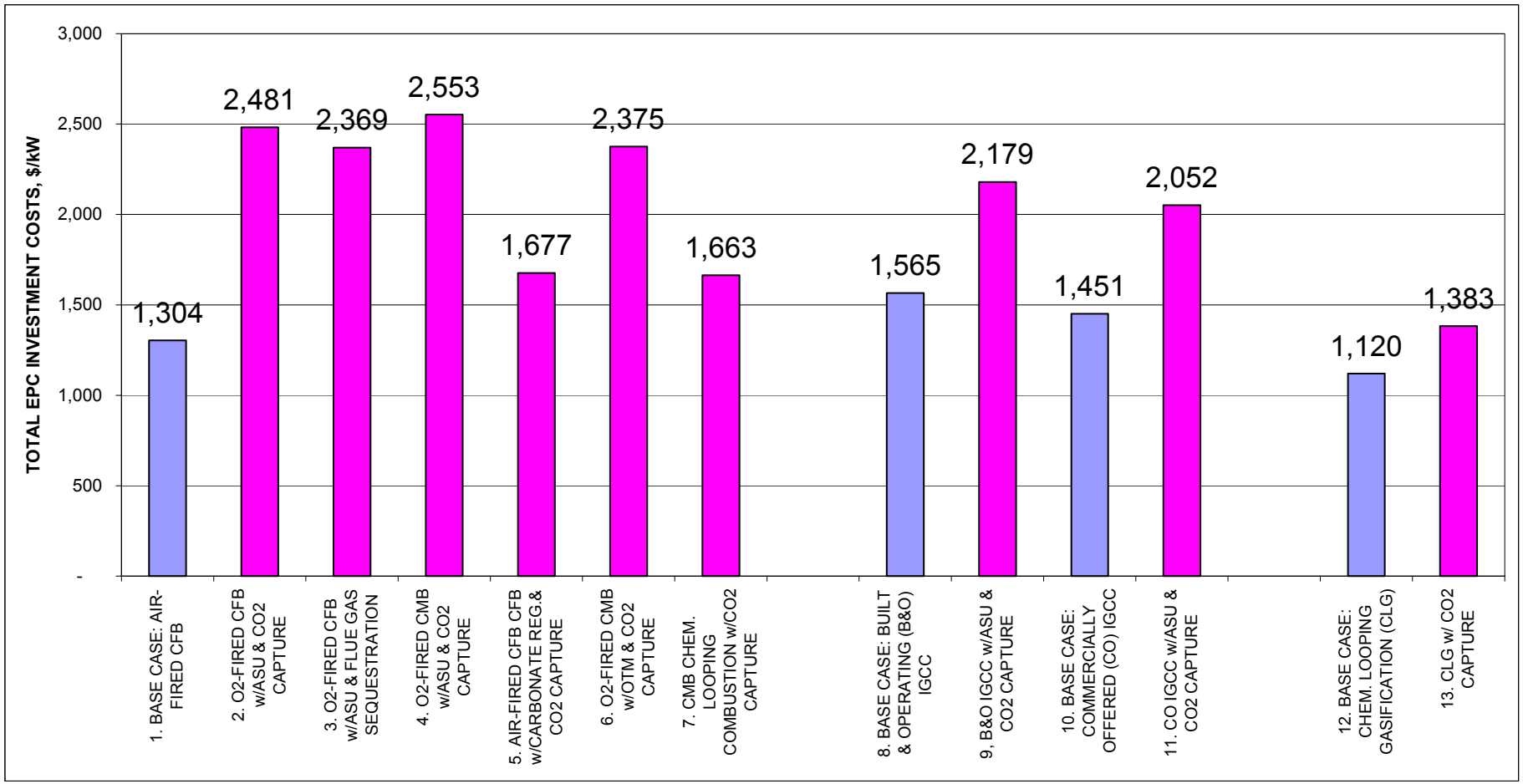
COMBUSTION CASES

IGCC CASES

CHEMI. LOOP. GASIF. CASES



ECONOMIC ASSUMPTIONS

ITEM		Technology Type		
		CFB and CMB Systems - Cases 1, 2, 3, 4, 6	Chemical Looping Systems - Cases 5, 7	IGCC Systems - Cases 8, 9, 10, 11, 12 , 13
POWER GENERATION				
	Net output (MW)	Case Sensitive	Case Sensitive	Case Sensitive
	Availability factor (%)	80%	80%	80%
	Net plant heat rate, HHV (Btu per kWh)	Case Sensitive	Case Sensitive	Case Sensitive
TIME FRAME				
	Construction period (months)	30	36	48
	Analysis Horizon (years)	30	30	30
PROJECT COSTS				
	Fixed O&M costs ($ per kW)	Case Sensitive	Case Sensitive	Case Sensitive
	Variable O&M costs (cents per kWh)	Case Sensitive	Case Sensitive	Case Sensitive
	Total Initial Project Costs (% of EPC)	17.0%	17.0%	19.0%
FUEL COST				
	Coal Price ($ per MMBtu)	1.25	1.25	1.25
	Natural Gas Price ($ per MMBtu)	4.00	4.00	4.00
FINANCING ASSUMPTIONS				
	Equity	50.0%	50.0%	50.0%
	Debt	50.0%	50.0%	50.0%
DEBT PORTFOLIO				
	Interest Rates (Financed) [1]			
	During Construction	5.60%	5.60%	5.60%
	During Operation	5.10%	5.10%	5.10%
	Up-front Fee (Financed)	2.0%	2.0%	2.0%
	Commitment Fee	1.0%	1.0%	1.0%
	Loan Tenor (years after construction)	30	30	30
TAXES				
	Corporate Tax	20.0%	20.0%	20.0%
COST OF CAPITAL ASSUMPTIONS				
	Discount Factor	10.0%	10.0%	10.0%

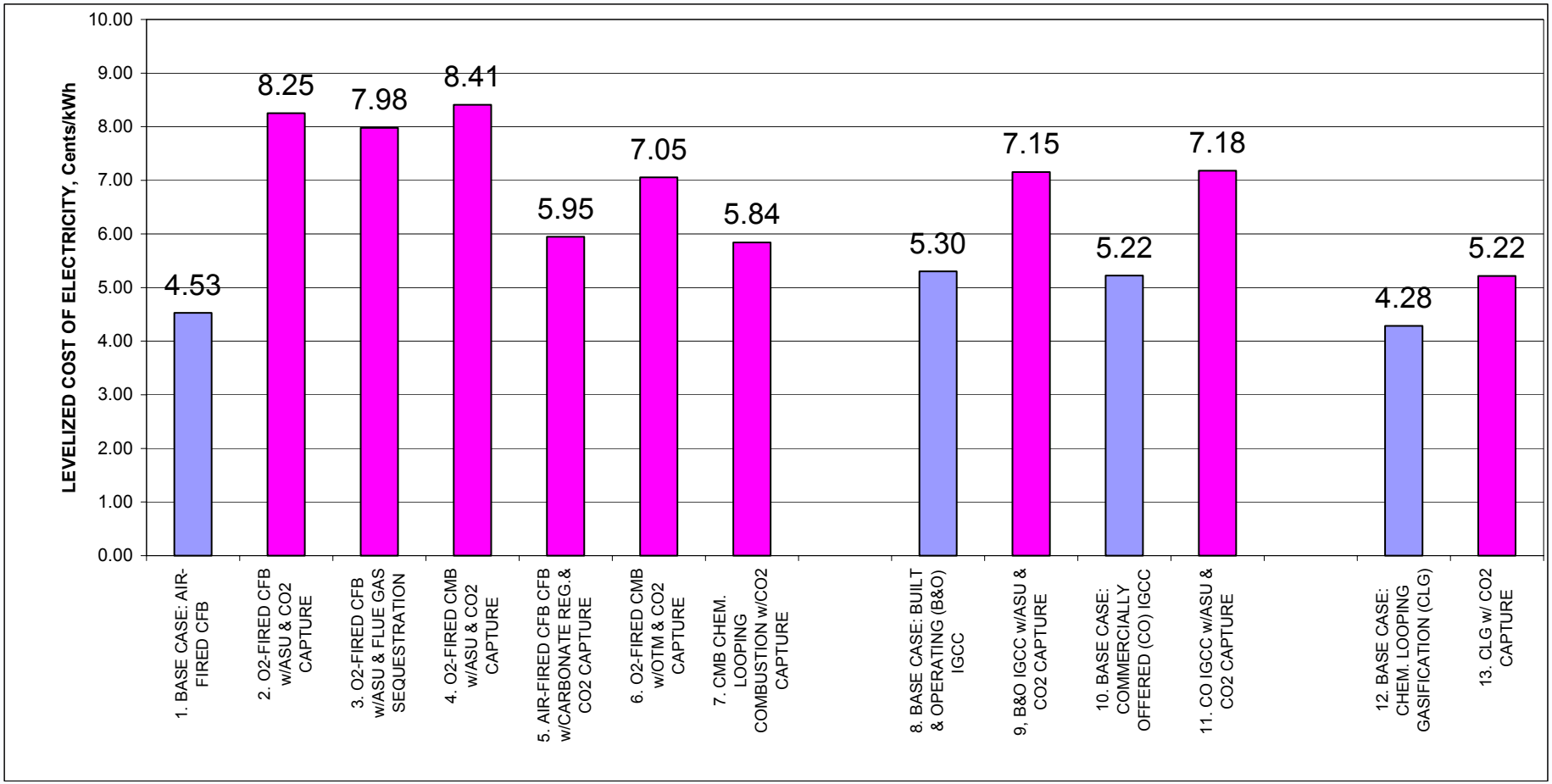
[1] **Wall Street Journal, 4/23/03, London Interbank Offered Rate (LIBOR) Swap Curve**

LEVELIZED COST OF ELECTRICITY, Cents/kWh

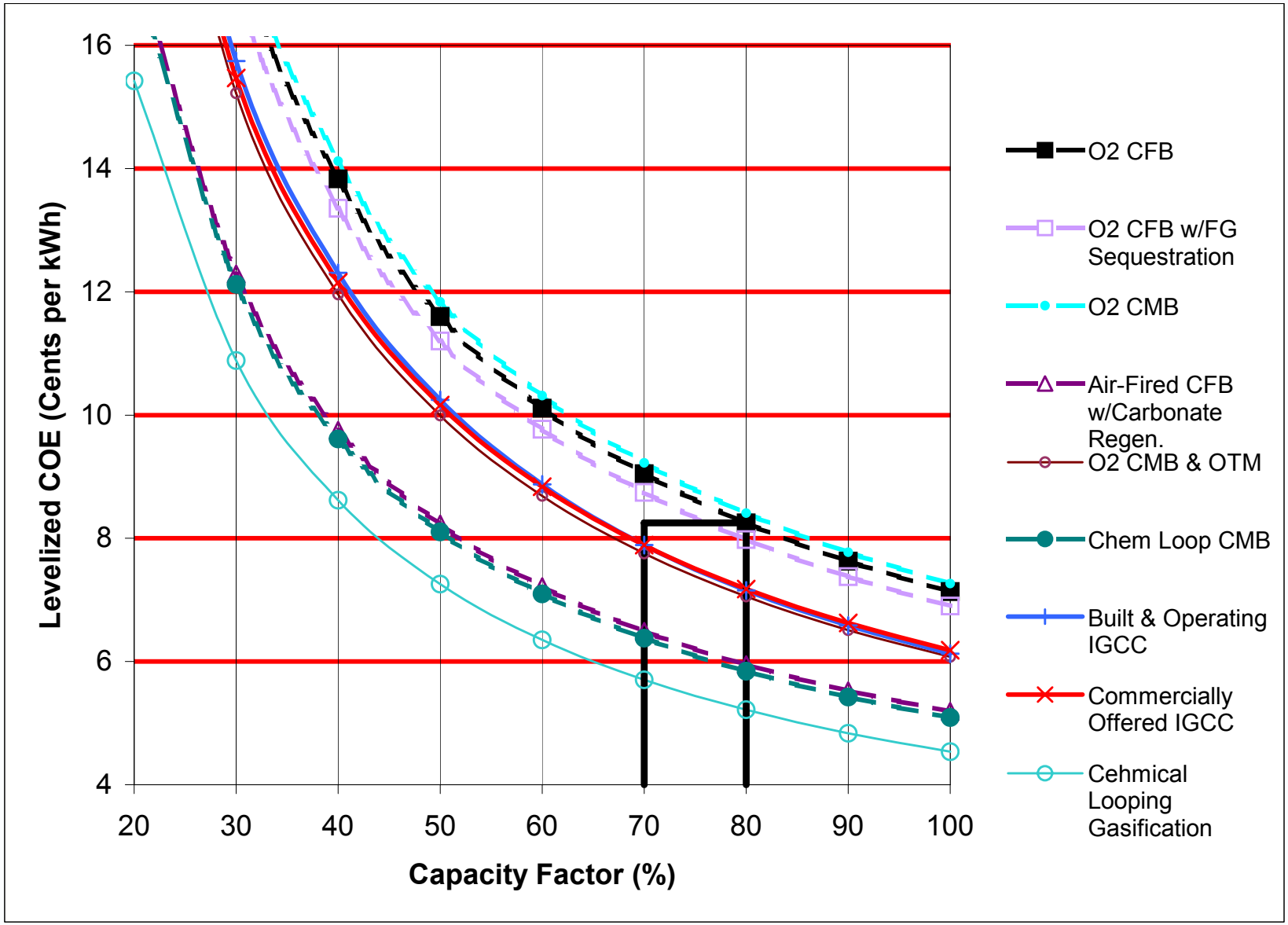
COMBUSTION CASES

IGCC CASES

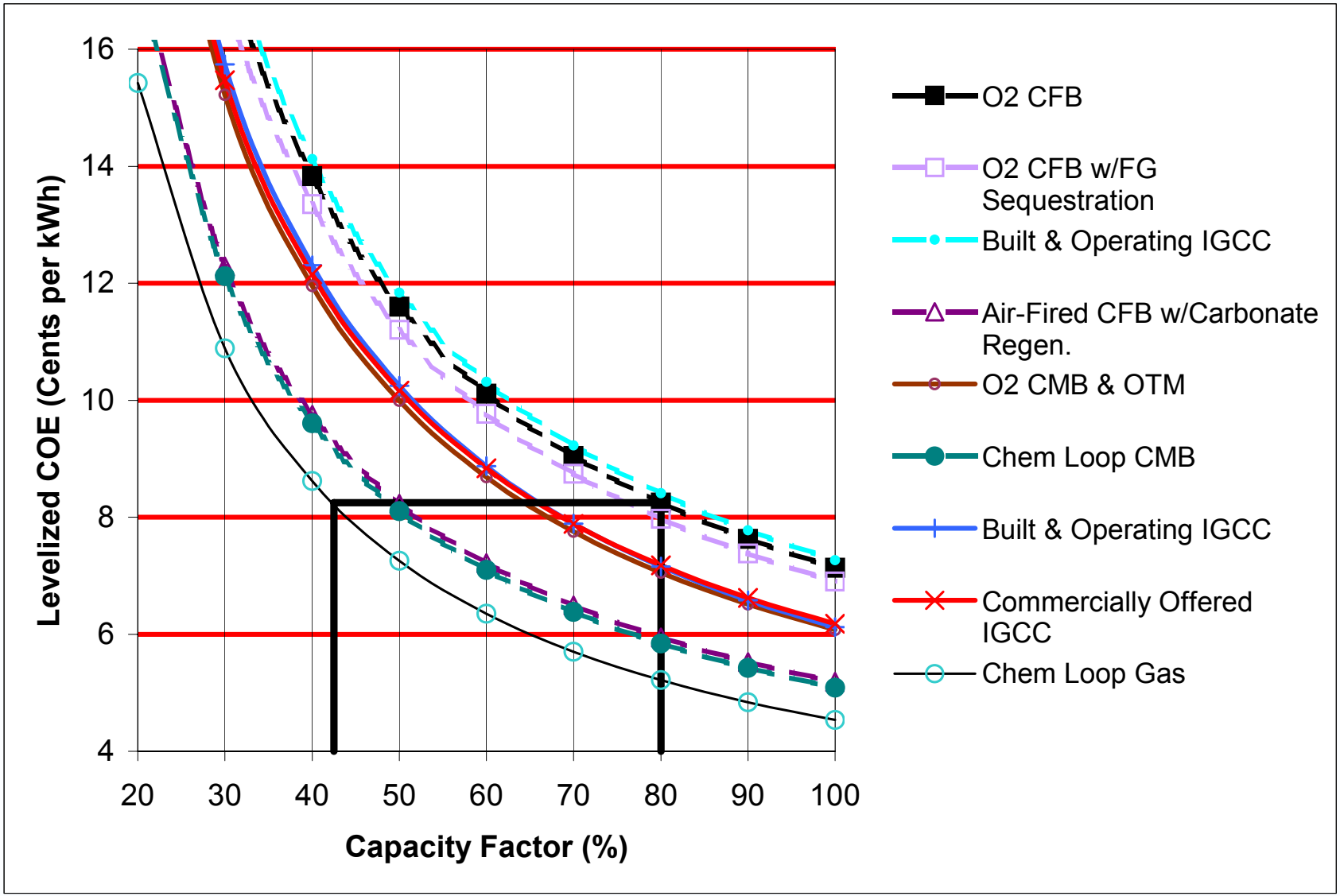
CHEMI. LOOP. GASIF. CASES



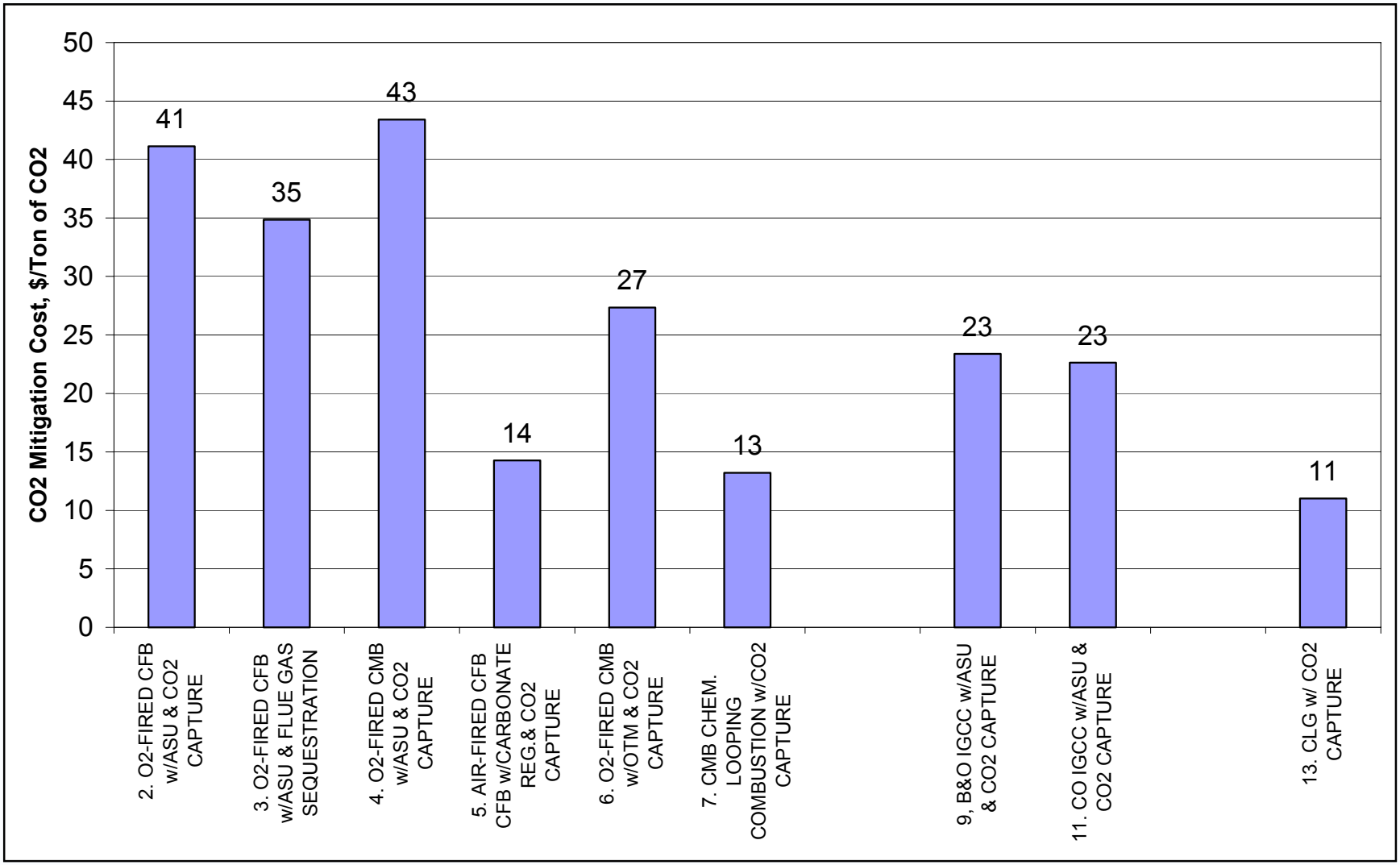
LEVELIZED COST OF ELECTRICITY, Cents/kWh



LEVELIZED COST OF ELECTRICITY, Cents/kWh



CO_2 MITIGATION COSTS, $/Ton Of CO_2 Avoided



OXYFUEL CFB TECHNOLOGY FOR “EOR” APPLICATION

Oxygen Fired CFB

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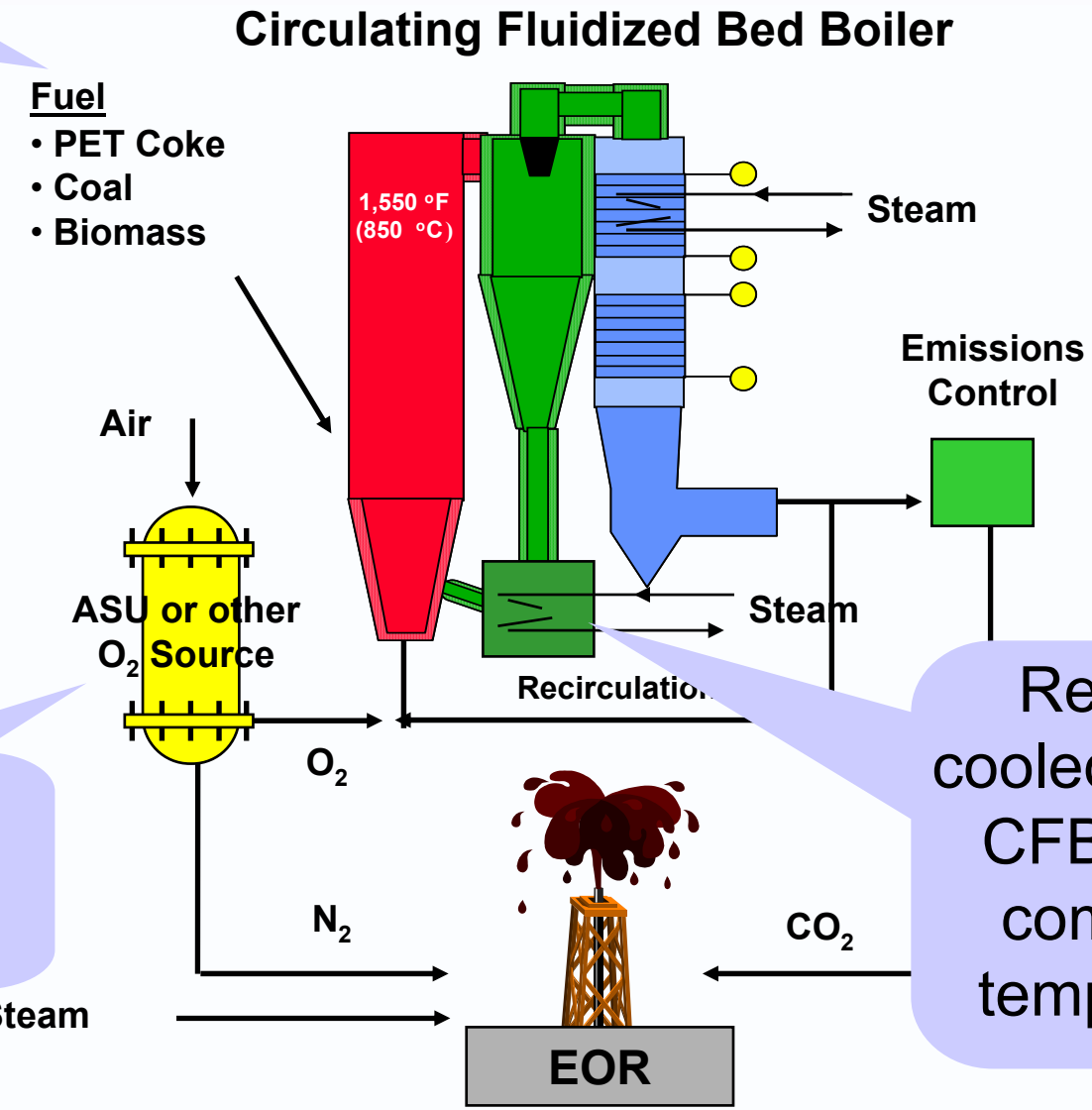
Fuel Flexible



Future - O_2 Membranes

Recycled cooled solids in CFB control combustor temperature

COST OF ELECTRICITY OF OXYFUEL CFB (EOR APPLICATION)

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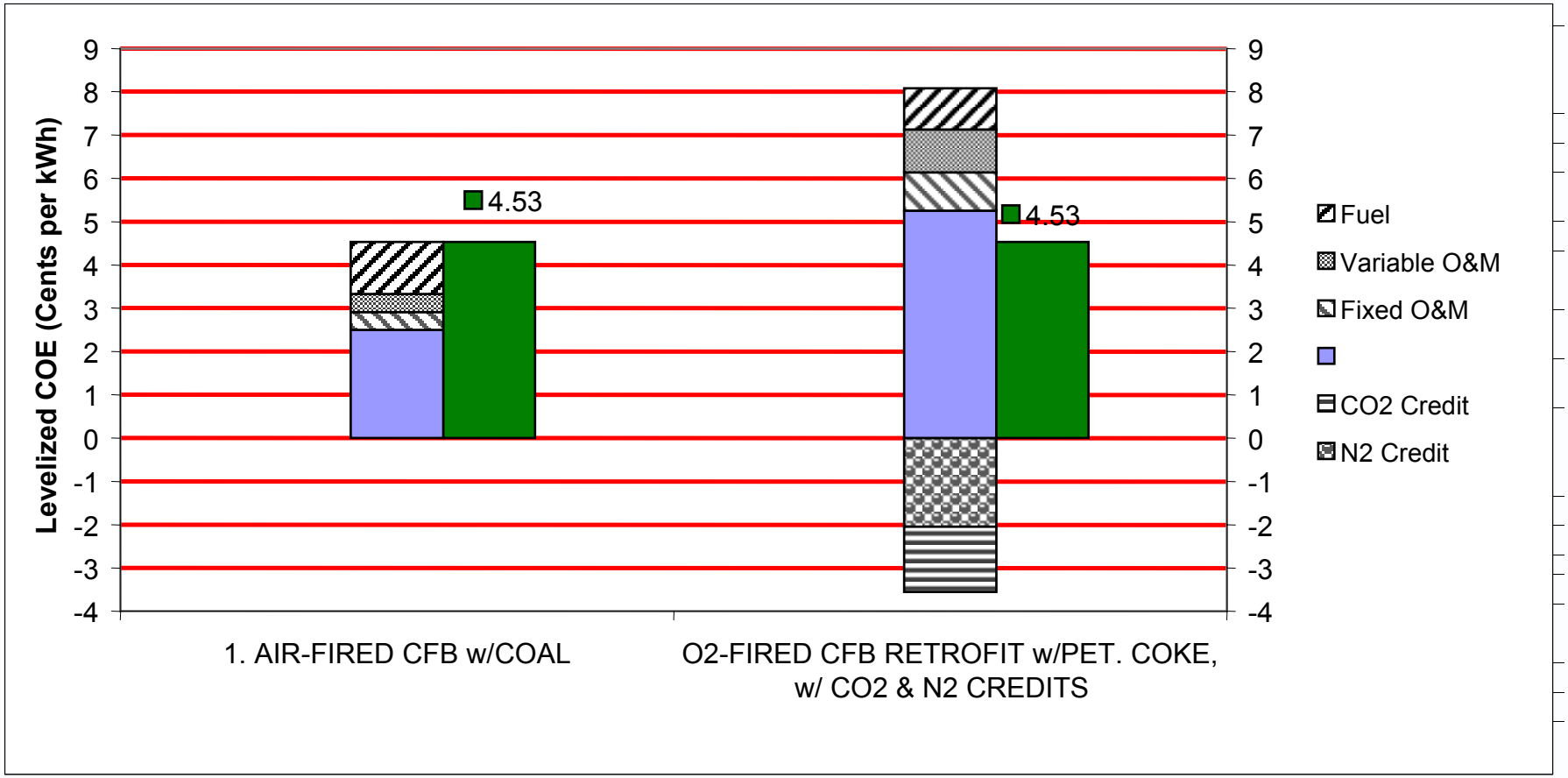
Assumptions :

1. Pet Coke Cost: $0.65/MMBtu
2. Revenues: CO_2 = $17/Ton; N_2 Revenue: $8/Ton



CONCLUDING REMARKS

CONCLUSIONS

- There Are a Number of Potential Alternatives Approaches to CO_2 Capture For Sequestration in Solid Fuel-Fired Power Plants

- The Long Run Potential for Advanced Chemical Looping Appears to Come Closest to Approaching The Target Economic Values (COE vs. Today's COE and Avoided Cost of CO_2 ($11/Ton of CO_2 vs. $3.0/Ton of Carbon (or $10/Ton of Carbon)

- Nearer Term Chemical Looping Alternatives Appear to Be Economically Competitive with IGCC for CO_2 Capture

CONCLUSIONS (CONTINUED)

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- Oxygen-Fired CFB/CMB Alternatives Can Be Competitive Under Appropriate Niche Conditions (EOR) and Are Available in The Near Term

- Oxygen-Fired CFB/CMB With Flue Gas Sequestration Provides The Only True “Zero Emissions” Power Plant

- Oxygen-Fired CFB/CMB Can Provide for The Near Term Demonstration of The Circulating Moving Bed Technology, Which Is An Enabling Technology for Chemical Looping

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