

Fossil Energy Cost and Performance Western Coal Baseline Study

Jeff Hoffmann

Office of Systems, Analyses and Planning



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Cover Slide Photo – Southwest Regional Partnership (SWP) Paradox Basin, Utah Enhanced Oil Recovery Project. The Aneth oil field is located near Bluff, Utah and is one of the largest oil fields in the nation. Elevation at the site ranges from ~4,450' to ~5,510' above sea level (ASL). Photo courtesy SWP/Resolute National Resources.

Acknowledgements

- **Technology vendor involvement is invaluable to this effort:**
 - Babcock and Wilcox
 - ConocoPhillips
 - Foster Wheeler
 - GE
 - Shell
 - Siemens
 - Southern Company

Objectives

- **Determine cost and performance estimates of near-term commercial offerings for power plants *utilizing low-rank coals*, both with and without current technology for CO₂ capture**
 - *Reasonable*, consistent design requirements
 - Up-to-date performance and capital cost estimates
 - Technologies *available today, deployed by 2015*
- **Provides baseline costs and performance**
 - Compare existing technologies *within appropriate context*
 - Guide R&D for advancing technologies within the FE Program

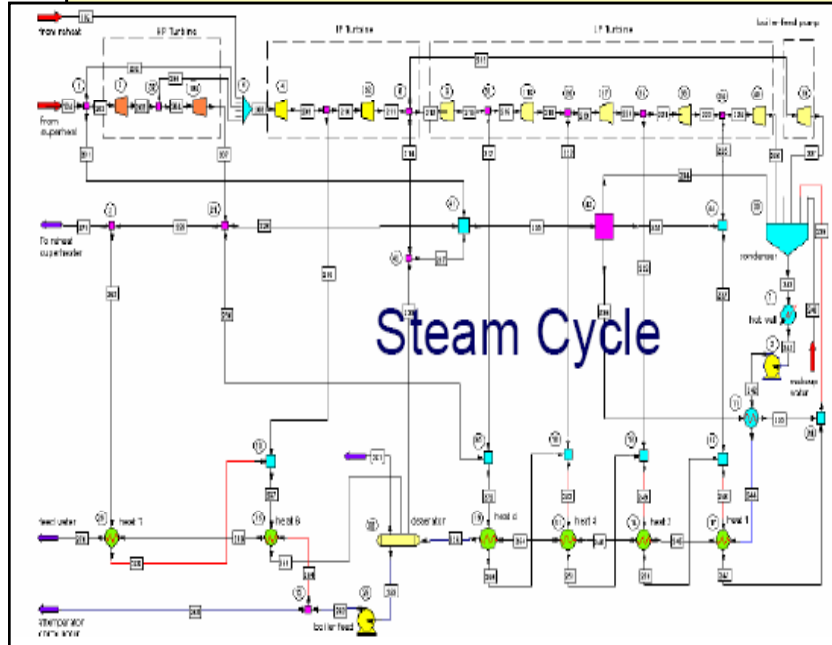
Study Matrix

Plant Type	ST Cond. (psig/°F/°F)	GT	Gasifier/Boiler	PRB	LIG	Acid Gas Removal/CO ₂ Separation / Sulfur Recovery	CO ₂ Capture
IGCC	1800/1050/1050 (non-CO ₂ capture cases)	F Class	CoP E-Gas	√	--	Sulfinol-M / - / Claus	--
						Selexol / Selexol / Claus	90%
			TRIG	√	--	Sulfinol-M / - / Claus	--
						Selexol / Selexol / Claus	90%
	Shell		√	√	Sulfinol-M / - / Claus	--	
					Selexol / Selexol / Claus	90%	
	Siemens		√	√	Sulfinol-M / - / Claus	--	
					Selexol / Selexol / Claus	90%	
PC	3500/1100/1100	N/A	Supercritical	√	√	SDA / - / -	--
						SDA / Econamine / -	90%
	4000/1200/1200		Ultra-Supercritical	√	√	SDA / - / -	--
						SDA / Econamine / -	90%
CFBC	3500/1100/1100	N/A	Supercritical	√	√	In-Bed Limestone / - / -	--
						In-Bed Limestone / Econamine / -	90%

Technical Approach

1. Extensive Process Simulation (ASPEN)

- All major chemical processes and equipment are simulated
- Detailed mass and energy balances
- Performance calculations (auxiliary power, gross/net power output)



2. Cost Estimation

- Inputs from process simulation (Flow Rates/Gas Composition/Pressure/Temp.)
- Sources for cost estimation
 - WorleyParsons
 - Technology Vendors
- Follow DOE Analysis Guidelines

Design Basis: Coal Types

As-Received Ultimate Analysis (weight %)

	Rosebud PRB	ND Lignite
Moisture	25.77	36.08
Carbon	50.07	39.55
Hydrogen	3.38	2.74
Nitrogen	0.71	0.63
Chlorine	0.01	0.00
Sulfur	0.73	0.63
Ash	8.19	9.86
Oxygen (by difference)	11.14	10.51
HHV (Btu/lb)	8,564	6,617

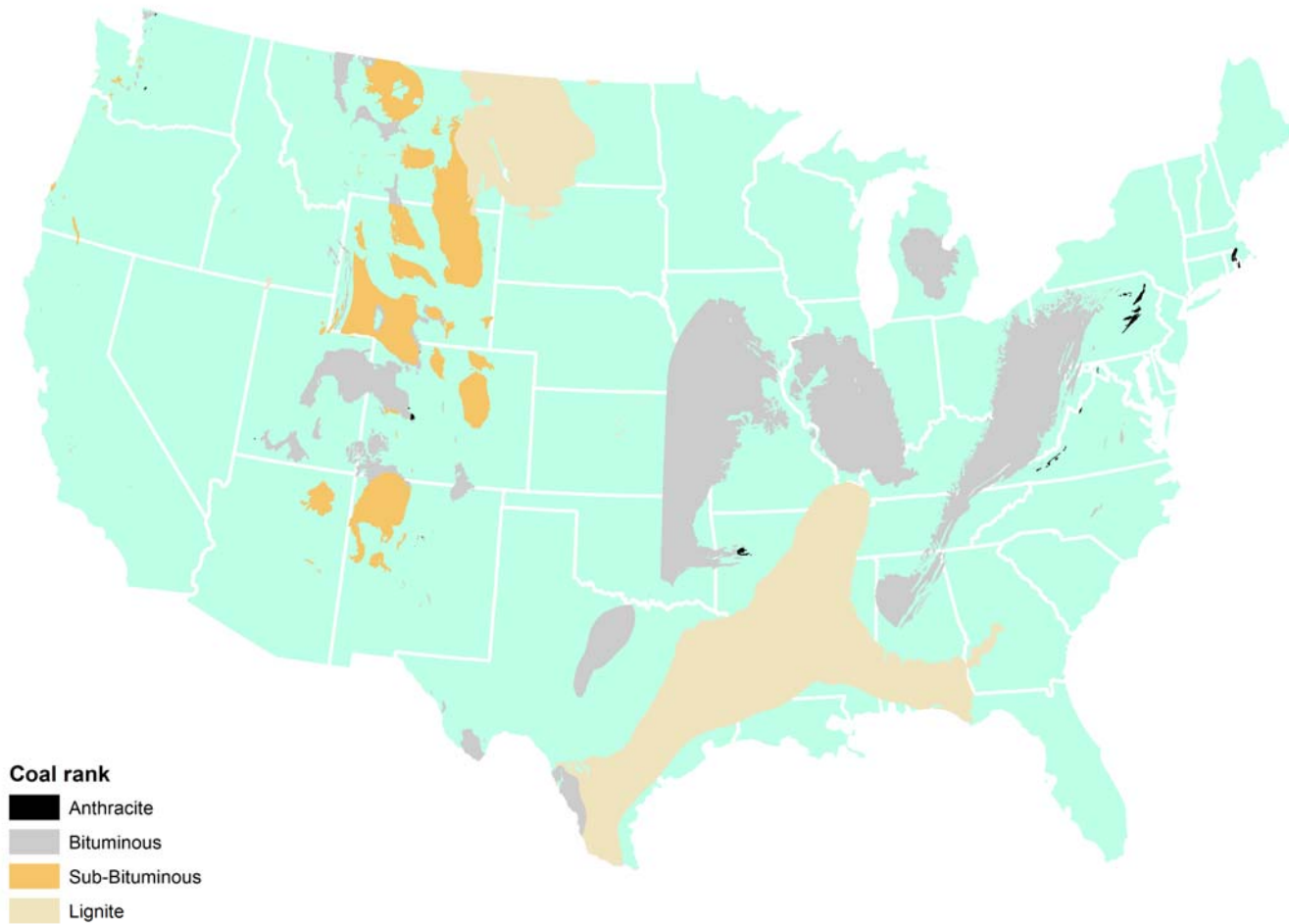
As-Fed Moisture Content (weight %)

Slurry Gasifier, PC, CFBC	N/A	N/A
Transport Gasifier	18%	N/A
Dry Feed Gasifier	6%	12%

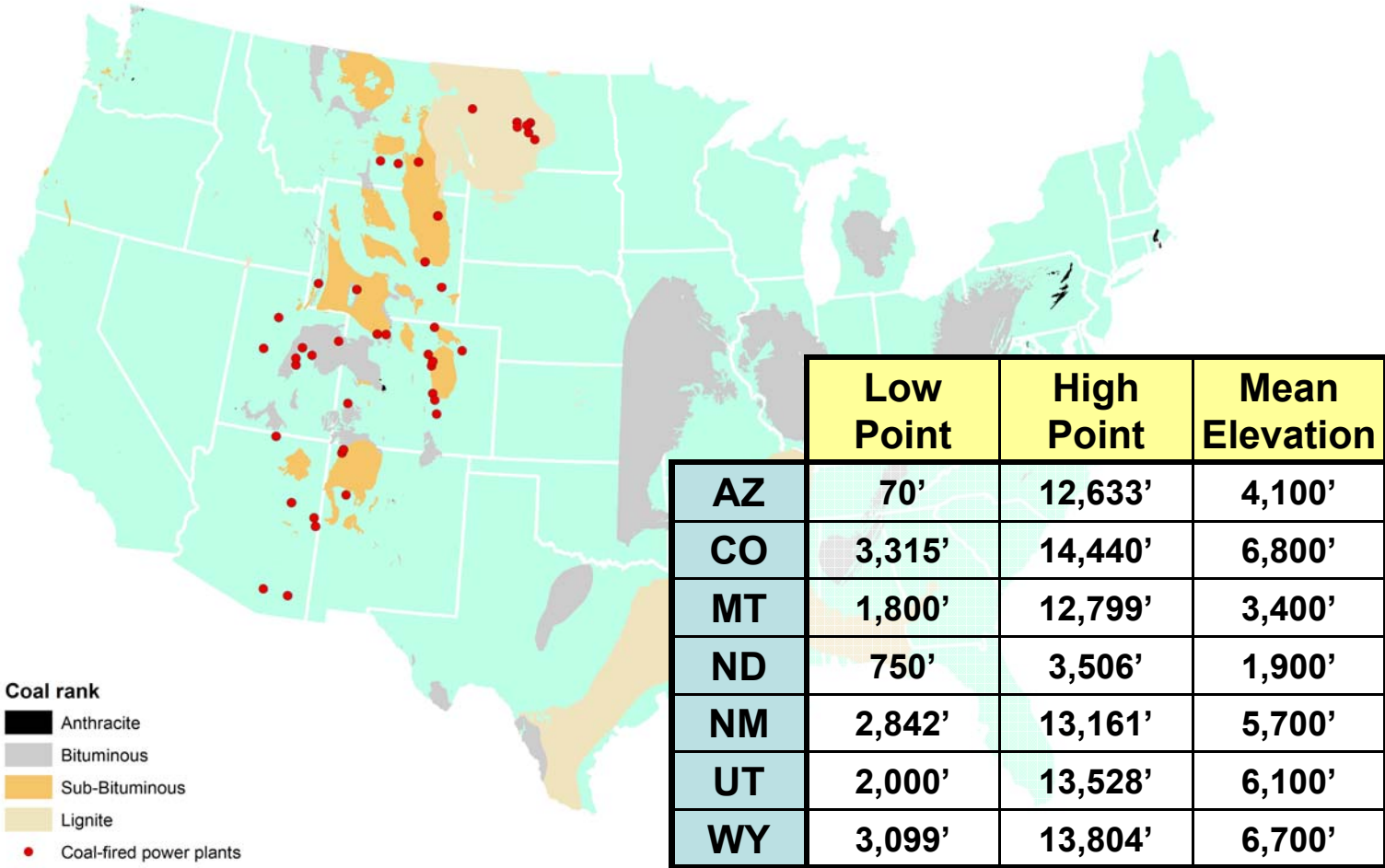
Design Basis: Ambient Conditions

	Rosebud PRB	ND Lignite
Elevation, m (ft)	1,036 (3,400)	579 (1,900)
Barometric Pressure, MPa, (psia)	0.09 (13.0)	0.10 (13.8)
Design Temperature, Dry Bulb, °C (°F)	5.6 (42)	4.4 (40)
Design Temperature, Wet Bulb, °C (°F)	2.8 (37)	2.2 (36)
Design Relative Humidity, %	62	68
Cooling/Make-up Water Source	Assume limited water availability, 50% condenser cooling load to air cooled condenser, 50% and all auxiliary cooling to wet cooling tower (municipal/ground water mix).	

Coal Fields/Power Plants



Coal Fields/Power Plants

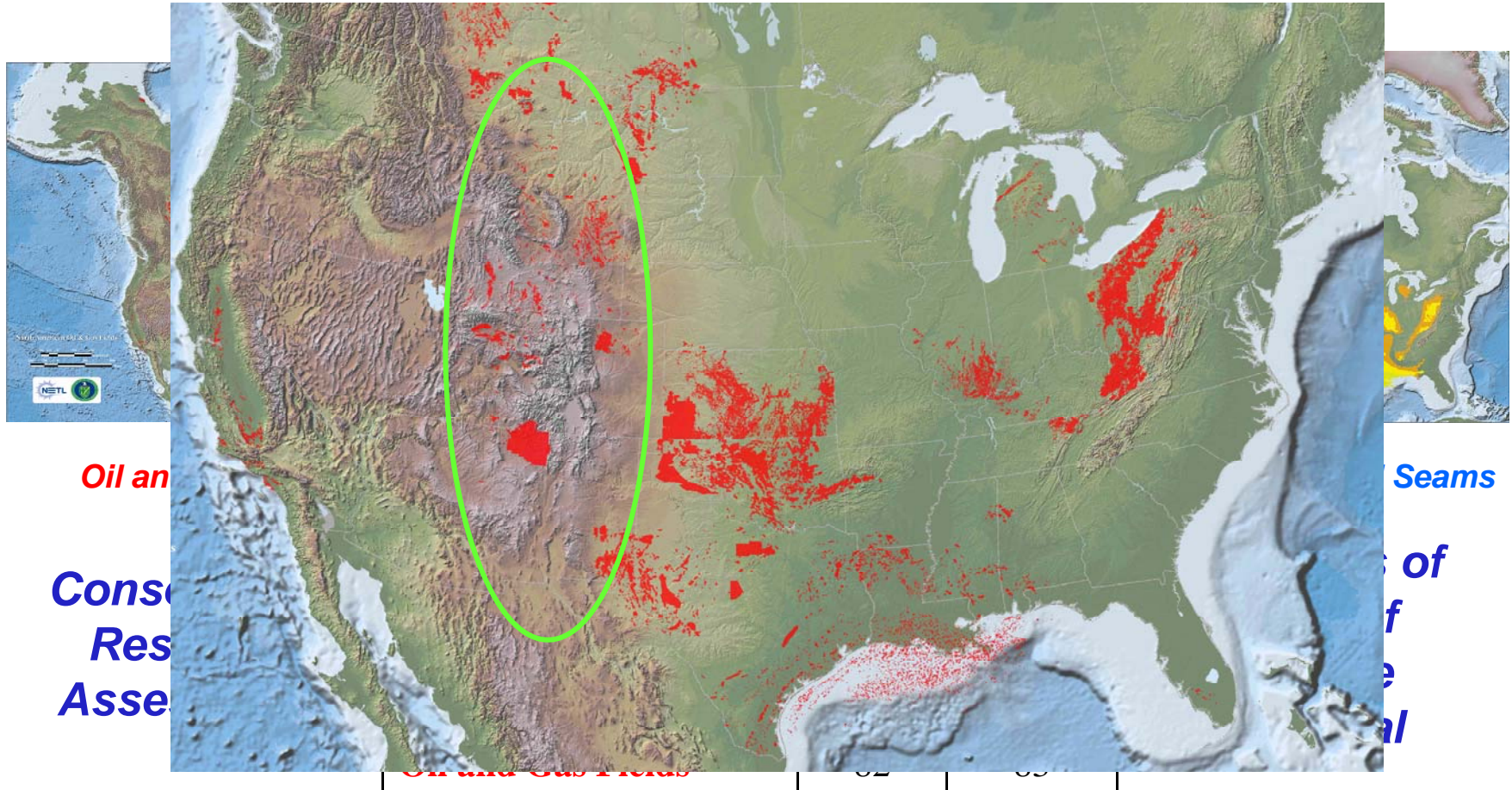


Coal rank
 Anthracite
 Bituminous
 Sub-Bituminous
 Lignite
 Coal-fired power plants

Source: Carpenter, A. and Provorse, C., *The World Almanac of the USA*, World Almanac Books, 1996

Geologic Sequestration Opportunities

U.S. Emissions ~ 6 GT CO₂/yr all sources



Available at http://www.netl.doe.gov/publications/carbon_seq/refshelf.html

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Impact of Altitude on GT Output

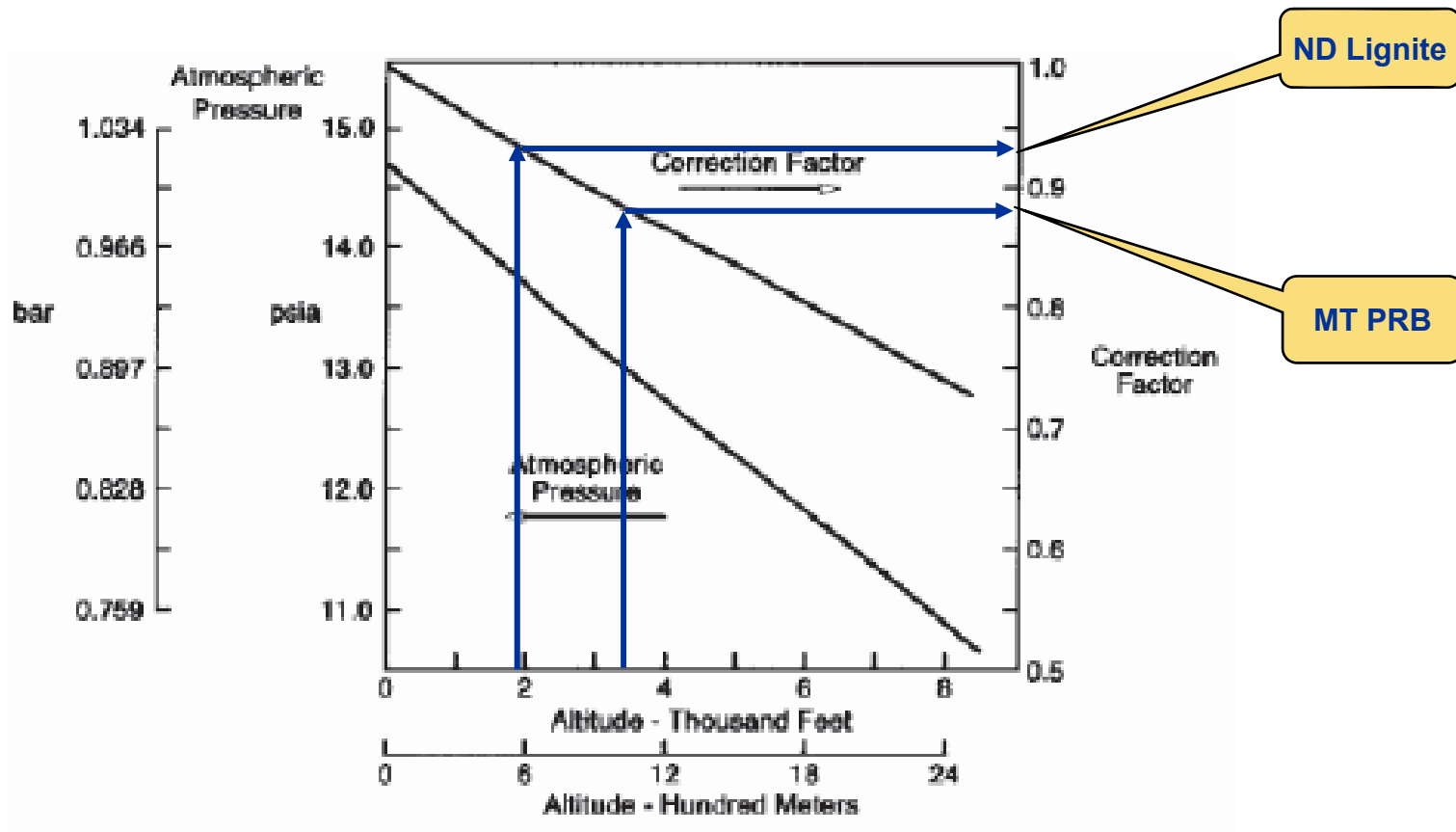


Figure 10. Altitude correction curve

However, the GT heat rate is largely unaffected.

Source: GE Power Systems, *GE Gas Turbine Performance Characteristics*, GER-3567H (10/00)

Design Basis: Environmental Targets

	IGCC	PC		CFBC	
SO ₂	0.013 lb/MMBtu	0.119 lb/MMBtu		0.113 lb/MMBtu	
NO _x	15 ppmv (dry) @ 15% O ₂	0.07 lb/MMBtu		0.07 lb/MMBtu	
PM	0.007 lb/MMBtu	0.013 lb/MMBtu		0.013 lb/MMBtu	
Hg	> 90% capture	PRB	LIG	PRB	LIG
		0.6 lb/TBtu	1.1 lb/TBtu	3.0 lb/TBtu	4.8 lb/TBtu

Design Basis: Sequestration Assumptions

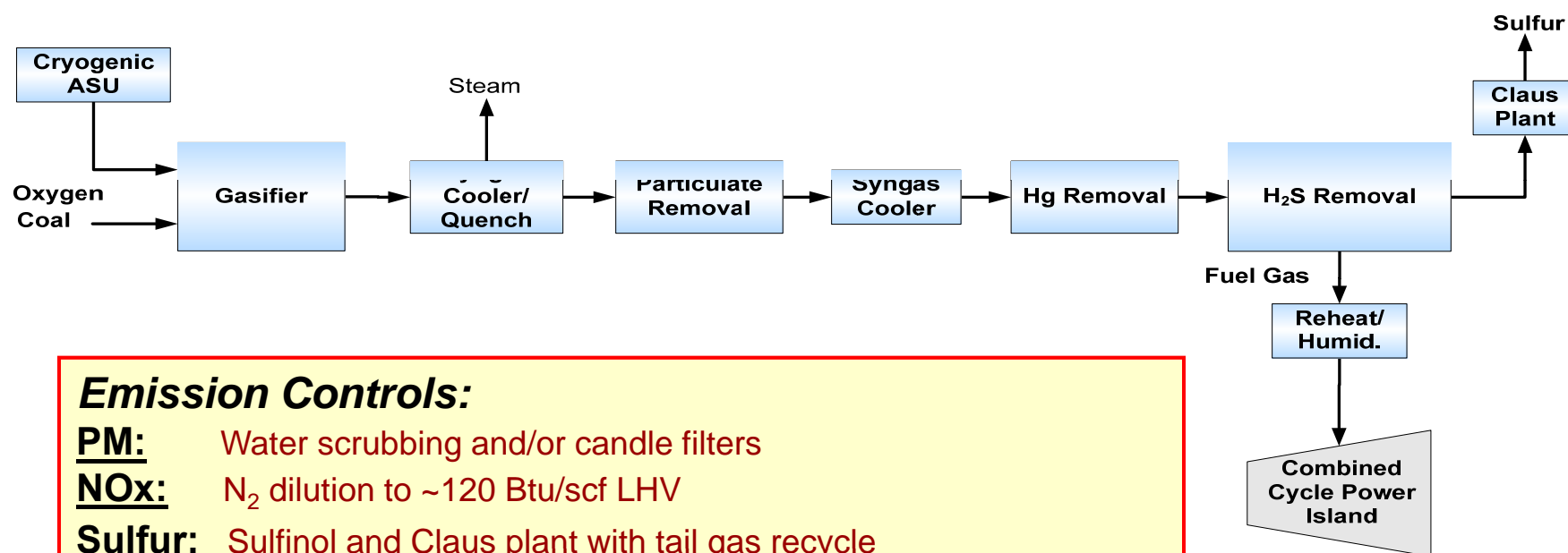
Plant Gate CO₂ Pressure (psia)	2,215
Wellhead CO₂ Pressure (psia)	1,515
Inlet Temp (oF)	79
Maximum N₂ Concentration (ppmv)	<300
Maximum O₂ Concentration (ppmv)	<40
Maximum Ar Concentration (ppmv)	<10
Pipeline Length (miles)	50
Formation Depth (ft)	4,055
Formation Permeability (millidarcy)	22
Formation Pressure (psig)	1,220

Design Basis: Other Assumptions

- **Coal drying processes**
 - Dry-feed entrained flow gasifiers – WTA process
 - Transport gasifier – indirect heated fluidized bed
 - Slurry-feed gasifier, PC & CFBC – no drying
- **Nitrogen dilution was used to the maximum extent possible in all IGCC cases and syngas humidification/steam injection were used only if necessary to achieve approximately ~120 Btu/scf syngas LHV**
- **Capacity Factor assumed to equal Availability**
 - IGCC capacity factor = 80% w/ no spare gasifier
 - PC and CFBC capacity factor = 85%

Technology Configurations

Current Technology IGCC without CCS



Emission Controls:

PM: Water scrubbing and/or candle filters

NOx: N₂ dilution to ~120 Btu/scf LHV

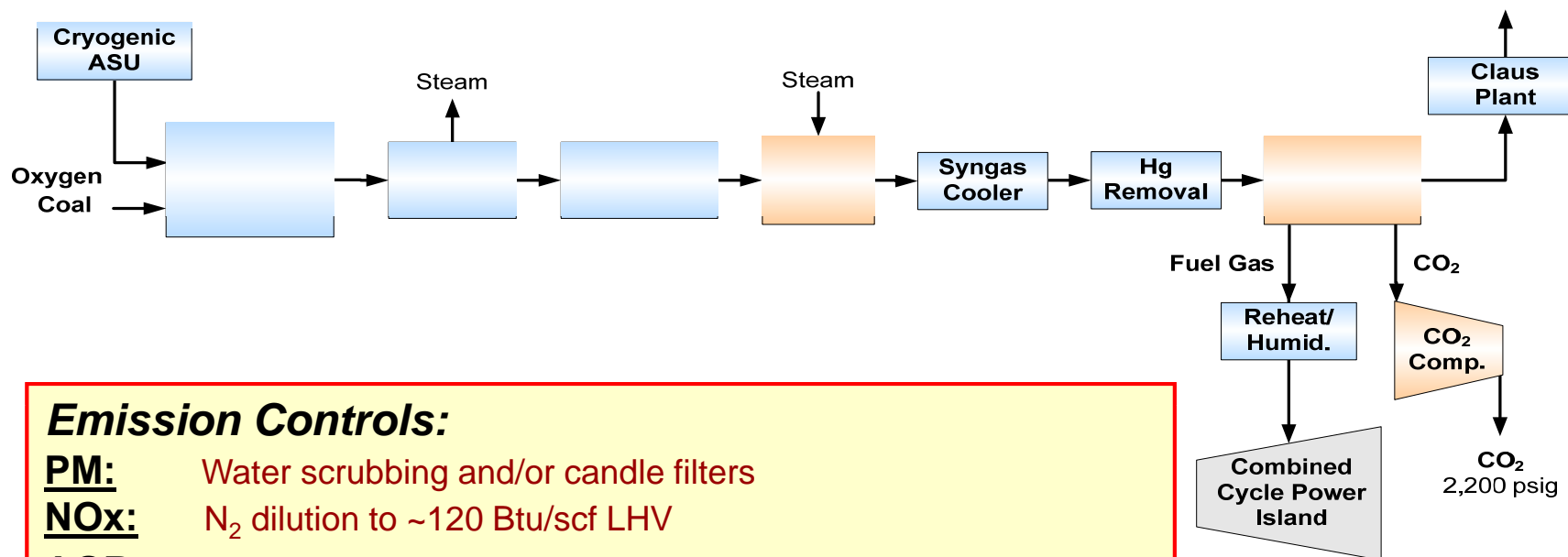
Sulfur: Sulfinol and Claus plant with tail gas recycle

Hg: Activated carbon beds

Advanced F-Class Turbine: 232 MWe – ISO conditions

Steam Conditions: 1800 psig/1050°F/1050°F

Current Technology IGCC with CCS



Emission Controls:

PM: Water scrubbing and/or candle filters

NO_x: N₂ dilution to ~120 Btu/scf LHV

AGR: Selexol and Claus plant with tail gas recycle

Hg: Activated carbon beds

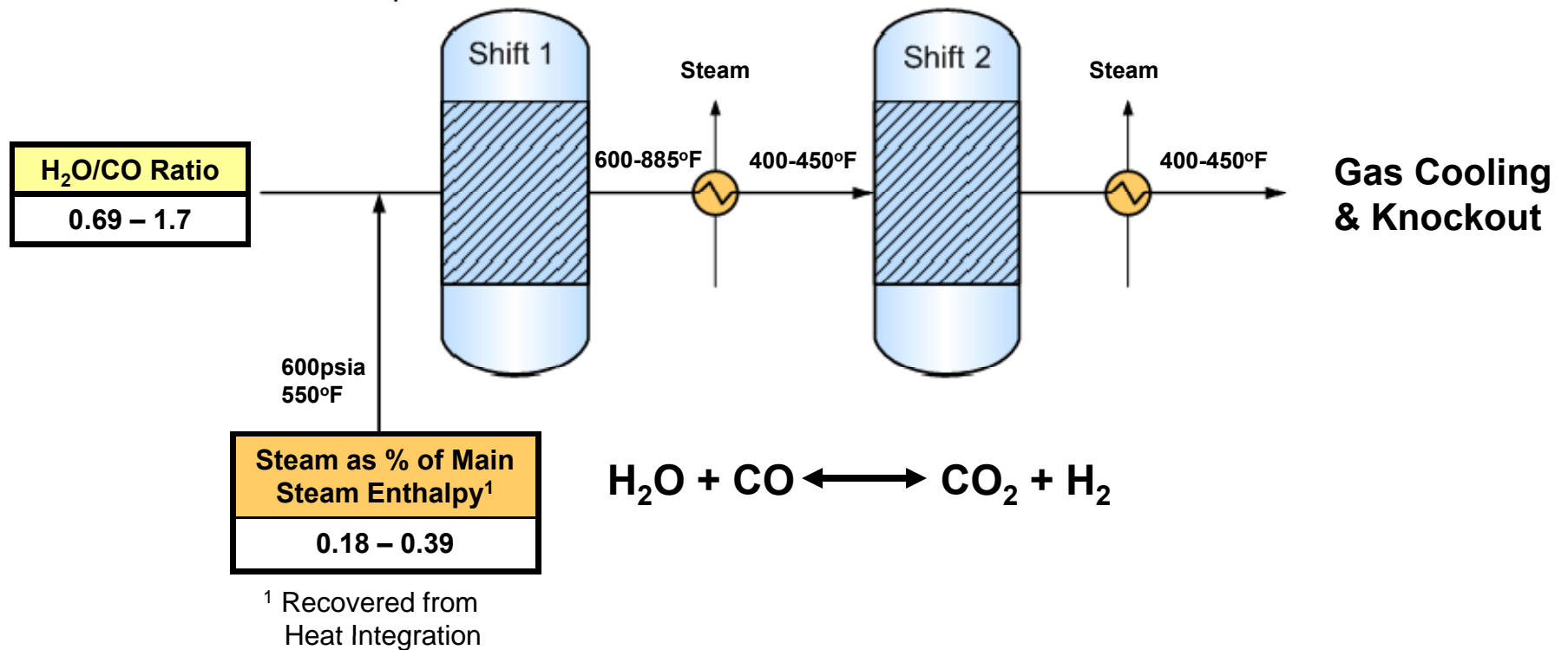
Advanced F-Class Turbine: 232 MWe – ISO Conditions

Steam Conditions: 1800 psig/1000°F/1000°F

Water-Gas Shift Reactor System

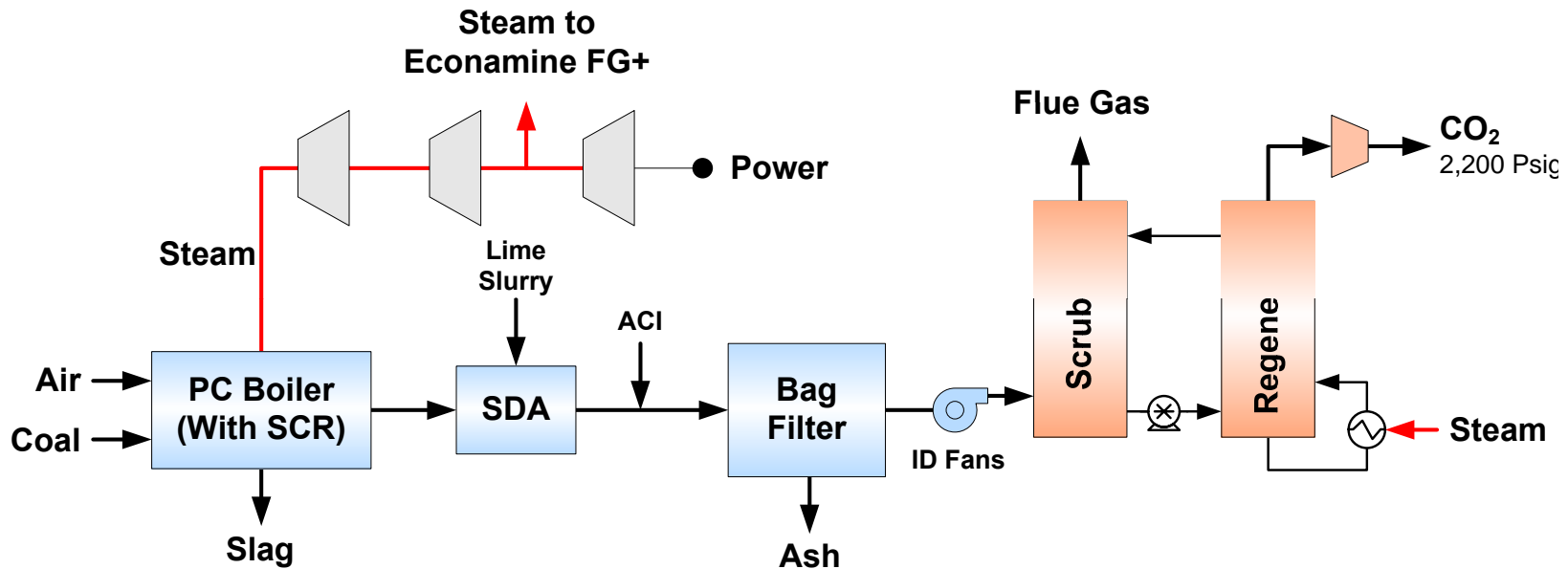
Design:

- Haldor Topsoe SSK Sulfur Tolerant Catalyst
- Up to 99% CO Conversion
- 2 Shift Stages
- $H_2O/CO = 2.0$ (Project Assumption)
- Overall $\Delta P = \sim 30$ psia



Current Technology Pulverized Coal Power Plant

Orange Blocks Indicate Unit Operations Added for CO₂ Capture Case



PM Control: Baghouse

NO_x Control: LNB + OFA + SCR

Sulfur Control: SDA

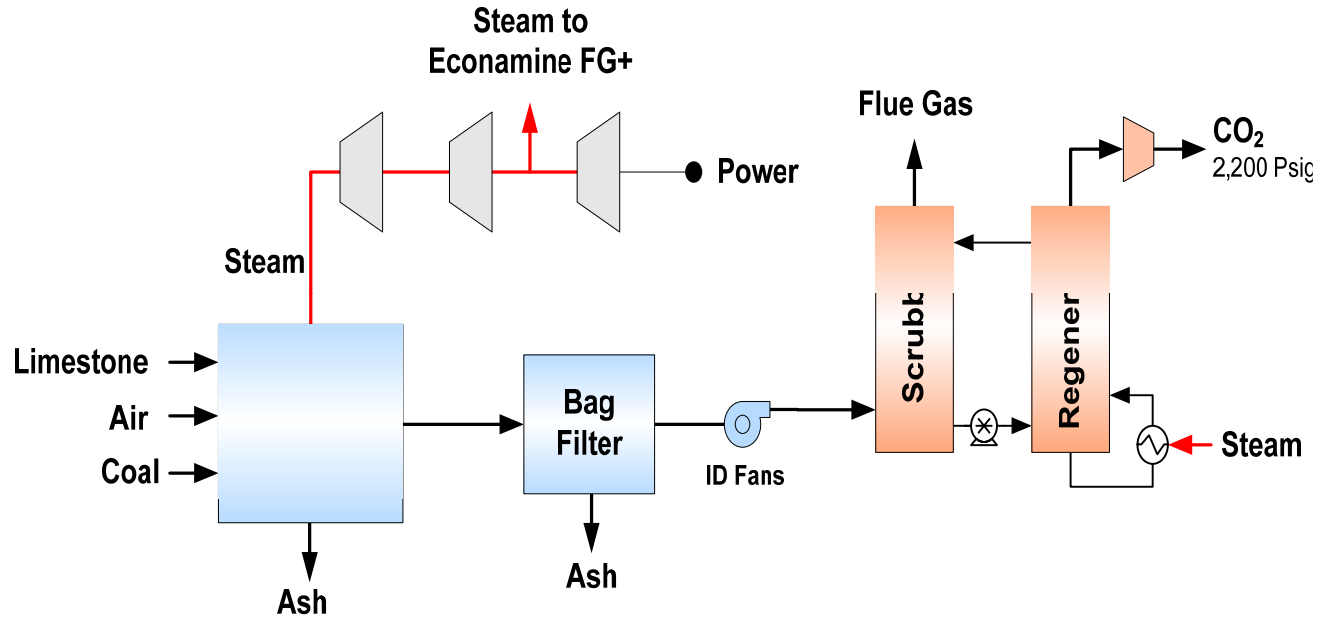
Mercury Control: Co-benefit capture + ACI trim

Steam Conditions (SC): 3500 psig/1100°F/1100°F

Steam Conditions (USC): 4200 psig/1200°F/1200°F

Current Technology Circulating Fluidized Bed

Orange Blocks Indicate Unit Operations Added for CO₂ Capture Case



PM Control: Baghouse

NO_x Control: SNCR

Sulfur Control: In-bed Limestone Injection

Mercury Control: Co-benefit capture

Steam Conditions (SC): 3500 psig/1100°F/1100°F

Performance Comparisons

Performance Results

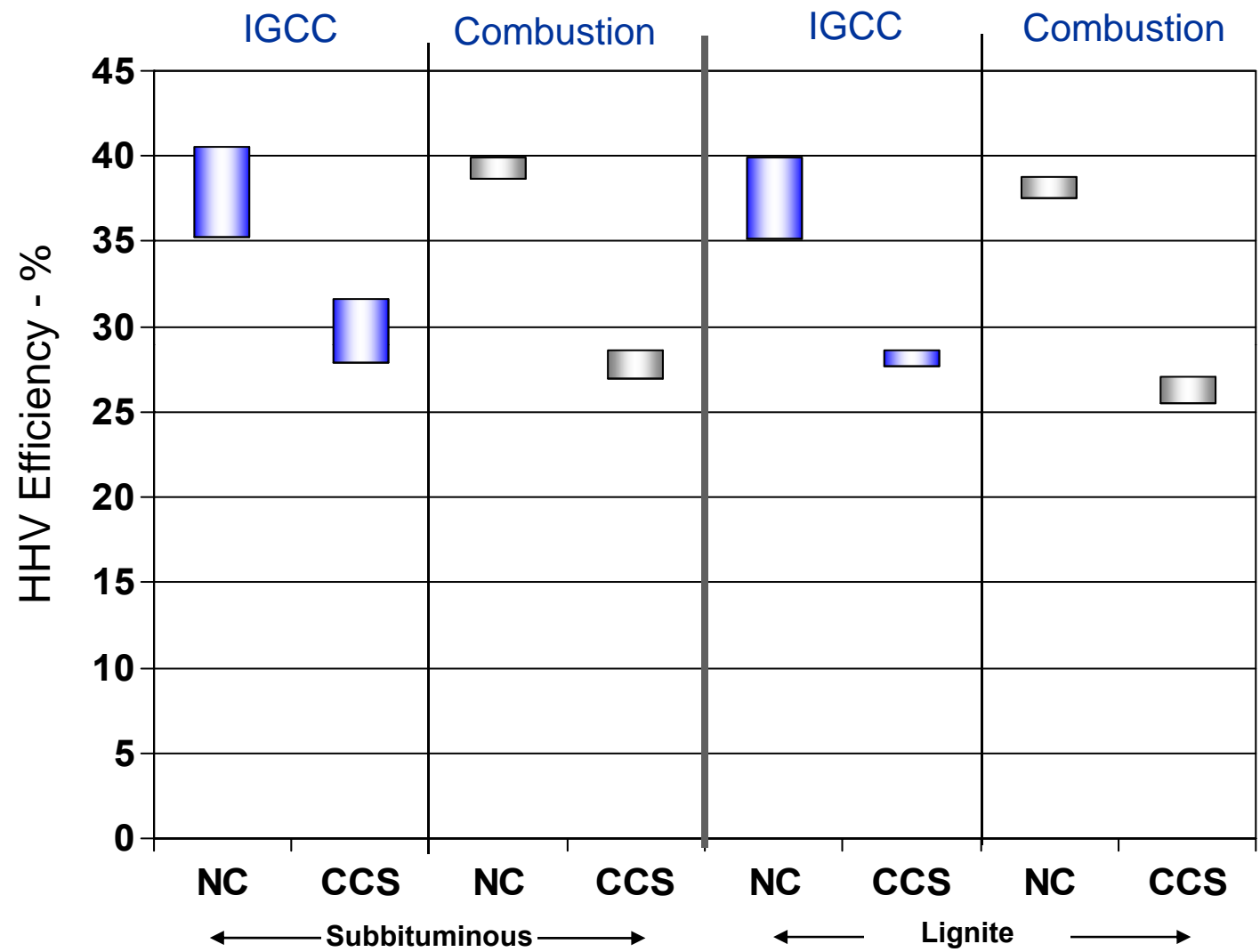
Subbituminous Coal

	IGCC		Supercritical		Ultra-Supercritical		CFBC	
CO ₂ Capture	NO	Yes	NO	YES	NO	YES	NO	YES
Gross Power (MW)	635 – 700	657 – 716	583	673	582	666	578	664
Net Power (MW)	540 – 570	444 – 506	550	550	550	550	550	550
Efficiency (HHV)	35.3 – 40.5	27.9 – 31.6	38.7	27.0	39.9	28.6	39.4	27.8

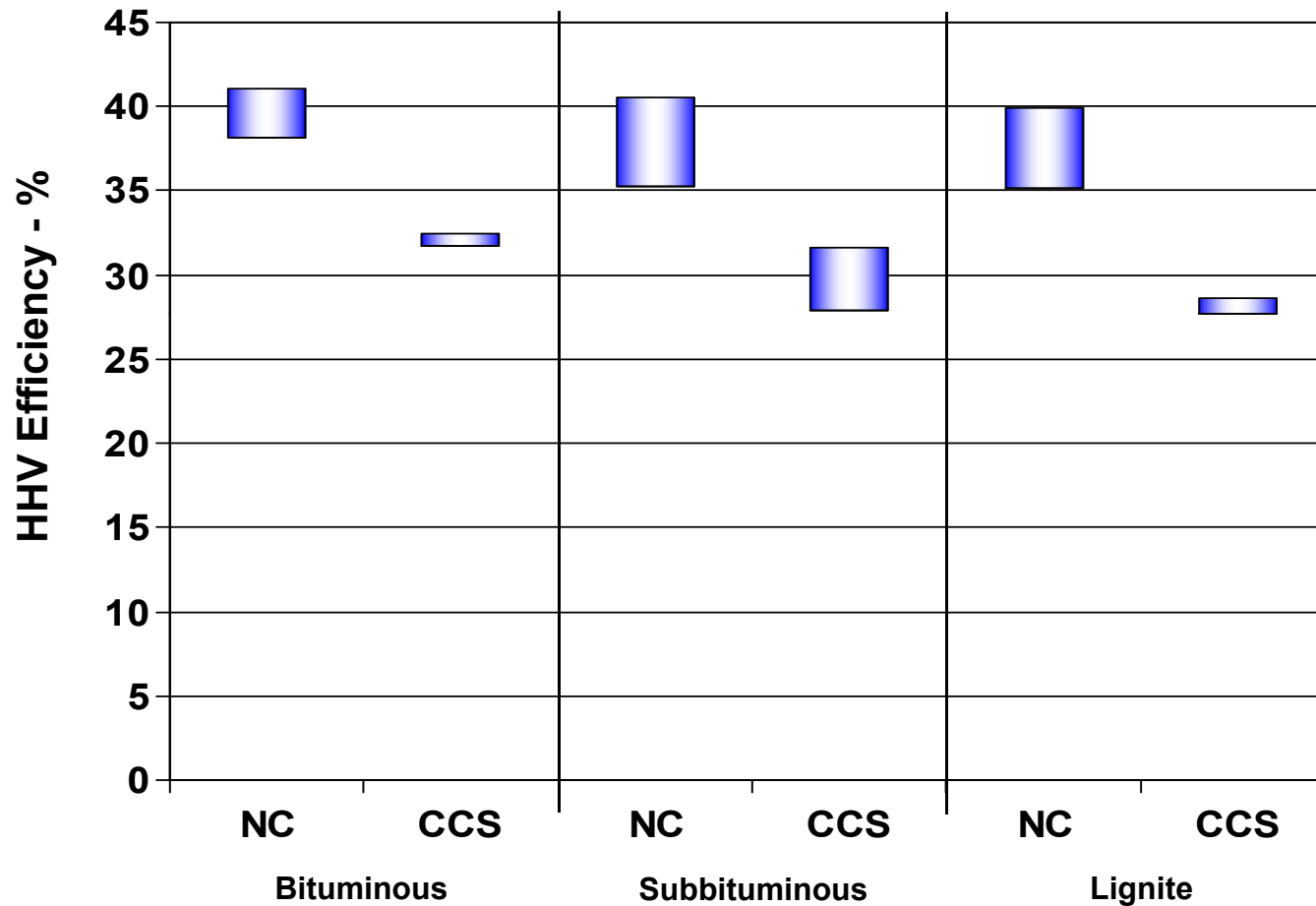
Lignite

	IGCC		Supercritical		Ultra-Supercritical		CFBC	
CO ₂ Capture	NO	Yes	NO	YES	NO	YES	NO	YES
Gross Power (MW)	707 – 778	706 – 712	585	684	583	676	579	672
Net Power (MW)	555 – 629	471 – 483	550	550	550	550	550	550
Efficiency (HHV)	35.1 – 39.9	27.7 – 28.6	37.5	25.5	38.8	27.1	38.6	26.3

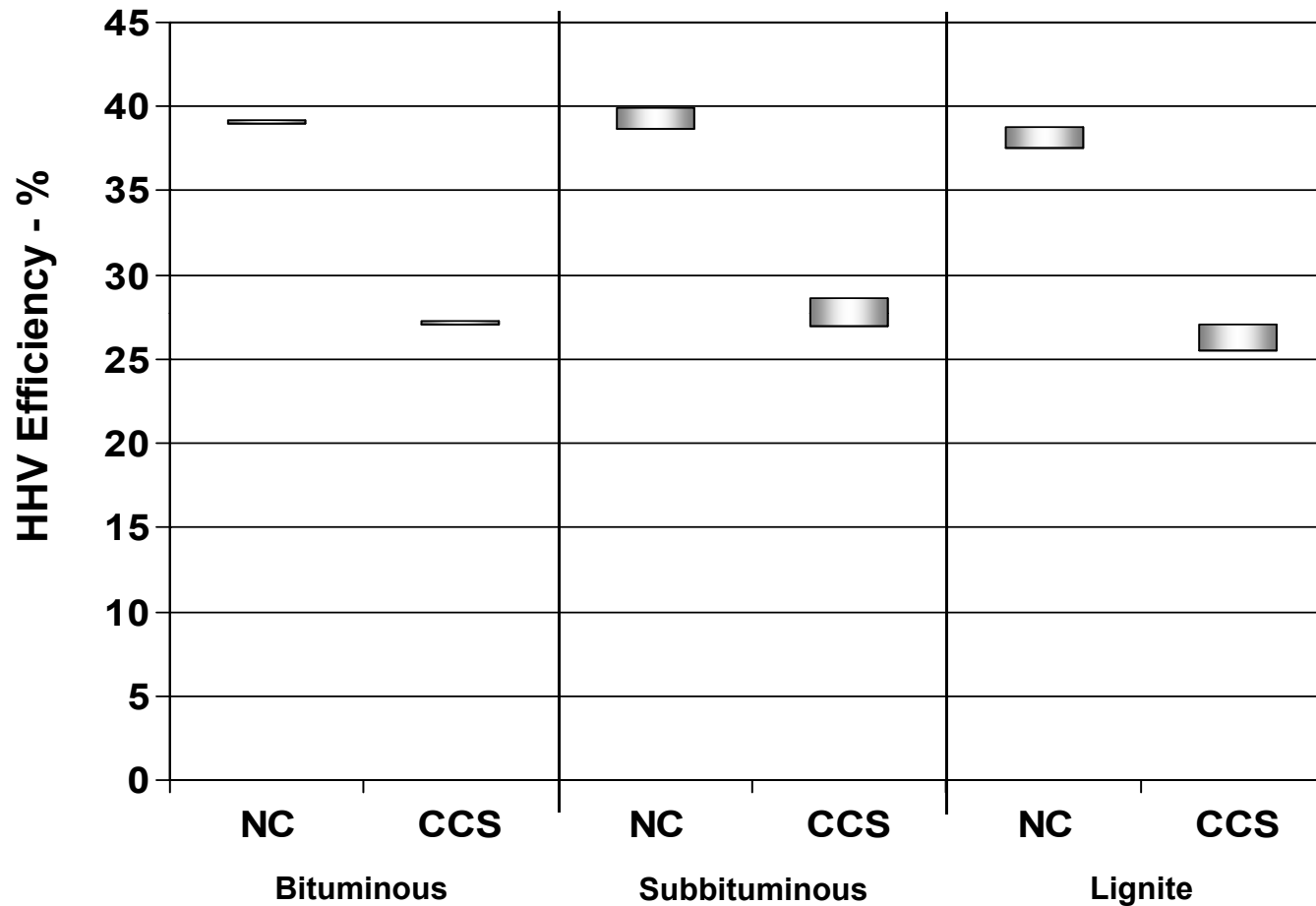
Comparative Efficiencies – Low Rank Cases



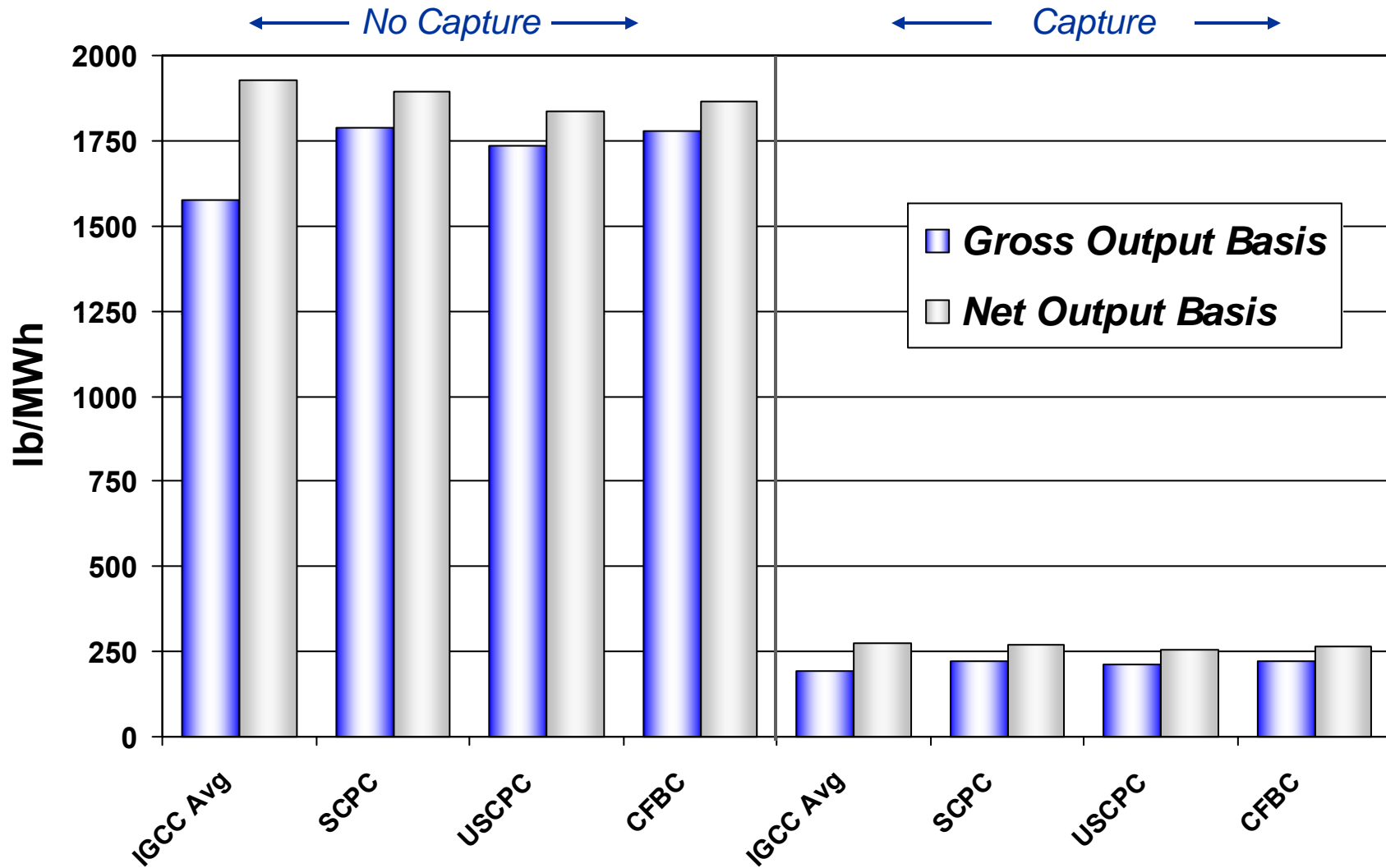
Comparative IGCC Efficiencies



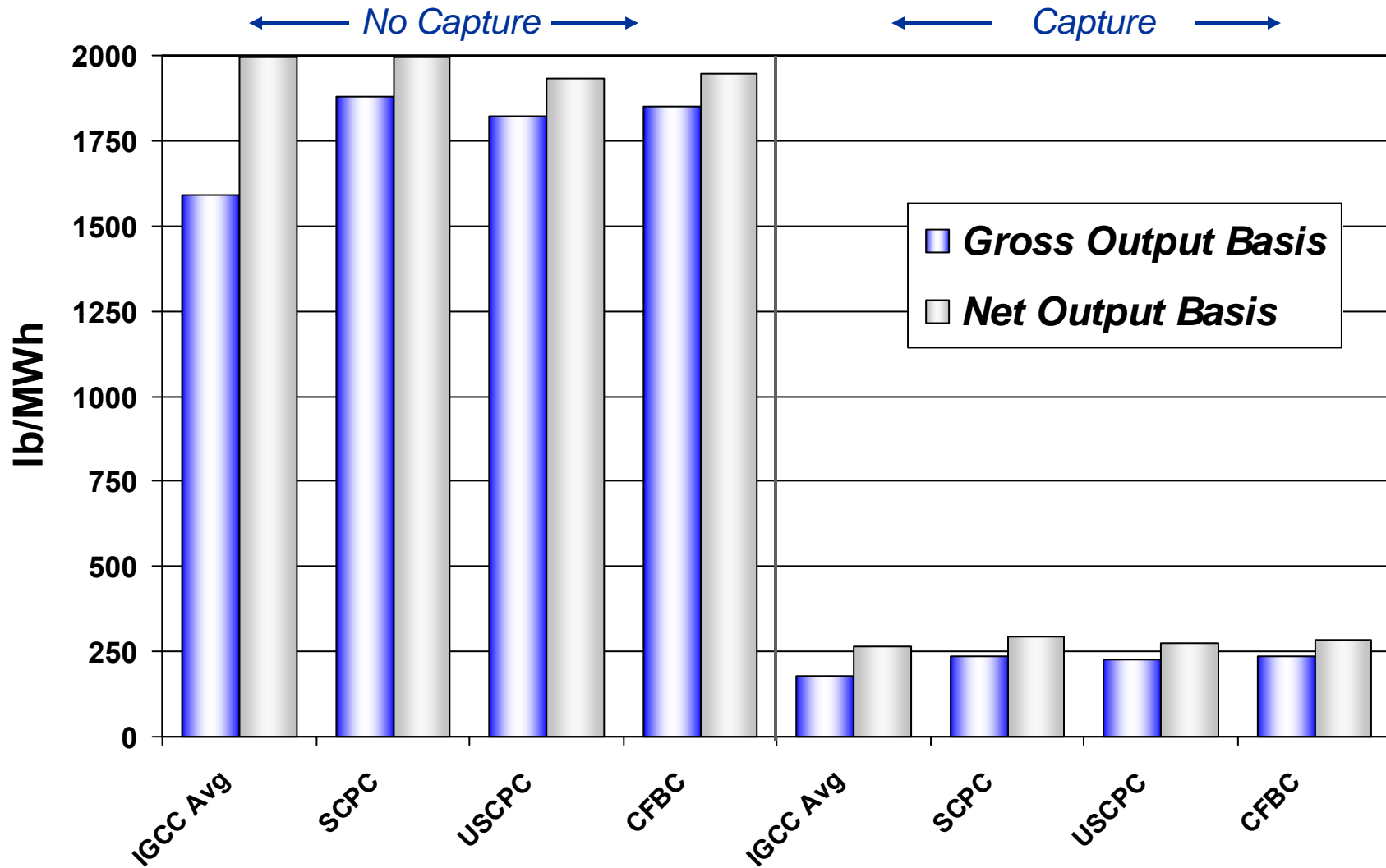
Comparative Combustion Efficiencies



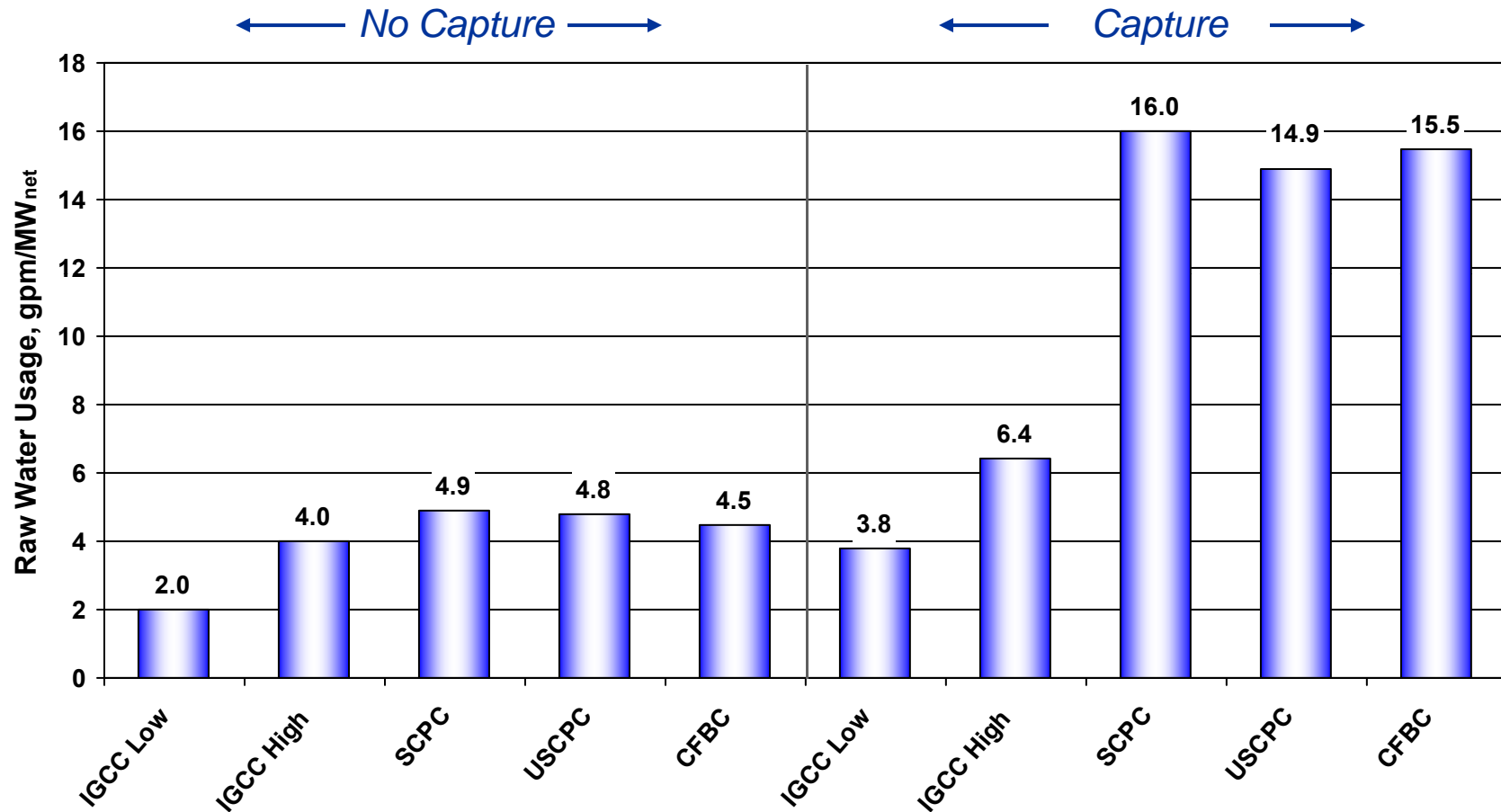
CO₂ Emissions – Subbituminous Cases



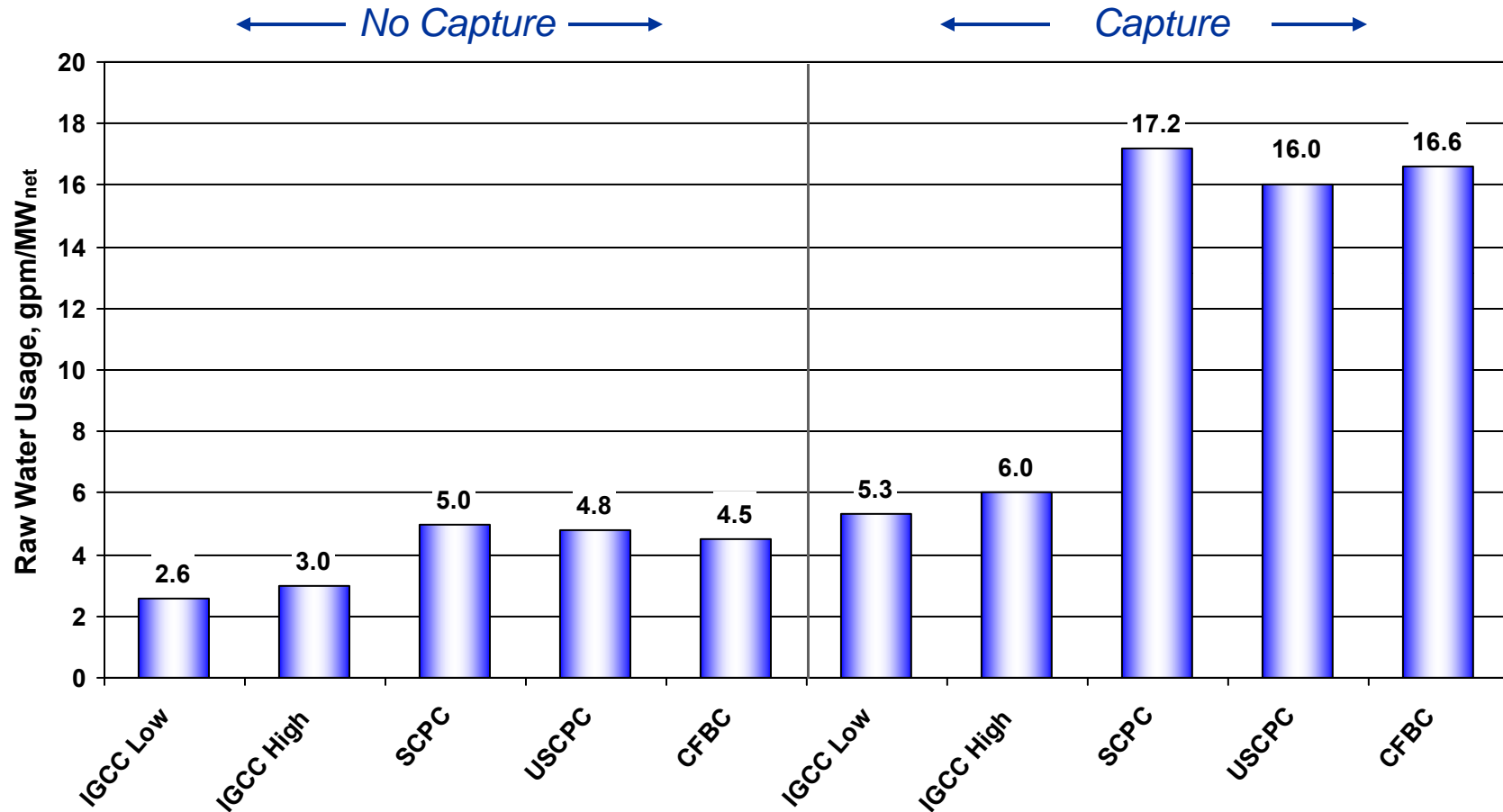
CO₂ Emissions – Lignite Cases



Raw Water Usage Subbituminous Plants



Raw Water Usage Lignite Plants



Next Steps

- **PC & CFBC**

- Report for Peer Review in Mid- to Late-November

- **Oxygen-Blown IGCC**

- Report for Peer Review in Late Winter, Early Spring 2009

- **Air-Blown IGCC, NGCC at Elevation**

- Report for Peer Review in Mid- to Late Summer 2009

- **Sensitivity Analyses Under Consideration**

- Various degrees of GT/ASU Integration
 - Alternate Combustion Turbine
 - Intermediate levels of CO₂ Capture
 - Cooling System
 - PRB at ISO Conditions
 - Economies of Scale

- **FE R&D Advanced Technologies**

Efficiency Timeline

