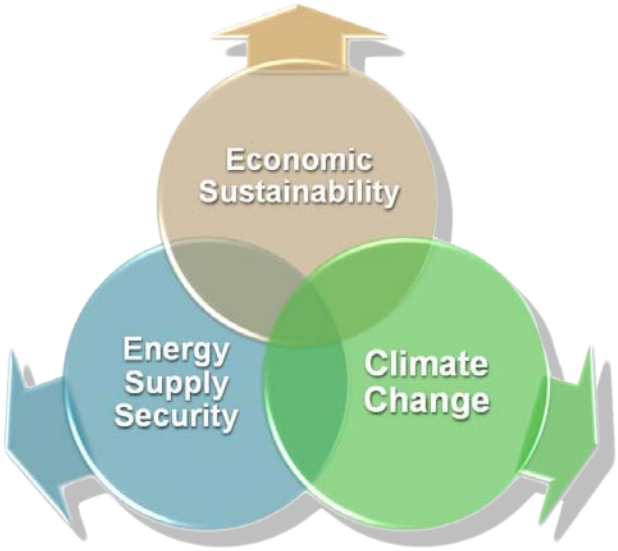
NATIONAL ENERGY TECHNOLOGY LABORATORY

Economic Comparison of IGCC to PC and Oxycombustion



National Rural Electric Cooperative Association

Generation, Fuels and Environment - Membership Advisory Group Meeting

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Disclaimer

Overview

- **Comparison of carbon capture technologies for coal-fired power plants**
  - Pre-combustion (IGCC), Post Combustion (PC with Amine capture), and Oxy-combustion
  - Bituminous coal
  - Today's or near term technology

Information Source for Comparison of Carbon Capture Technologies

- **NETL's "Cost and Performance Baselines for Fossil Energy Plants"**
  - **Bituminous Coal and Natural Gas to Electricity;** Rev 1 August 2007, **Rev 2 to be issued this summer**
  - **Pulverized Coal (Bituminous) Oxycombustion Power Plants; Rev 2, August 2008 (Updated economic parameters for this presentation)**

General Objectives of Baseline Studies

- **What - Determine cost and performance estimates of near-term commercial offerings**
  - Consistent design basis
  - Consistent performance and capital cost estimate methodology
  - Technologies built now and deployed in the near term
- **Why - Provide baseline costs and performance to:**
  - Compare technologies
  - Provide basis for sensitivity analyses
  - Provide basis for screening studies
  - Develop pathway studies to guide R&D for advancing technologies within the FE Program

Design Basis

	Bituminous Baseline
Location	Mid-west
Elevation (ft)	0
Barometric Pres. (psia)	14.7
Temp (F)	59
Coal Type	Illinois #6
Coal HHV (Btu/lb)	11,666
Coal ($/MMBtu)	$1.64
Natural Gas ($/MMBtu)	$6.55
Cooling System	Evaporative

Study Assumptions

- **Capacity Factor assumed to equal Availability**
  - IGCC capacity factor = 80% w/ no spare gasifier
  - PC, Oxycombustion, and NGCC capacity factor = 85%

- **In CO_2 capture cases, CO_2 compressed to 2200 psig, transported 50 miles, sequestered in saline formation at depth of 4,065 feet and monitored for 80 years**

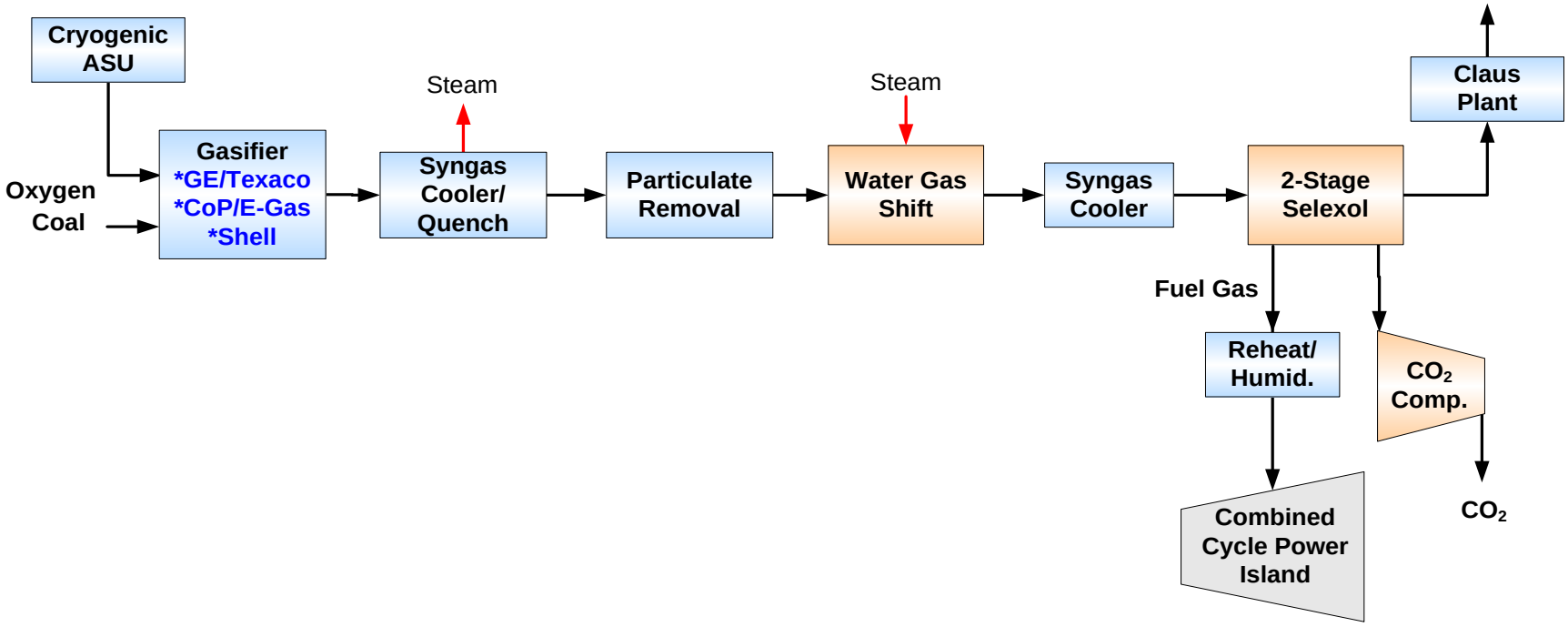
- **Owners costs and CO_2 transport, storage and monitoring (TS&M) costs included in the levelized cost of electricity (LCOE)**

Study Matrix
Bituminous Coal and Natural Gas to Power

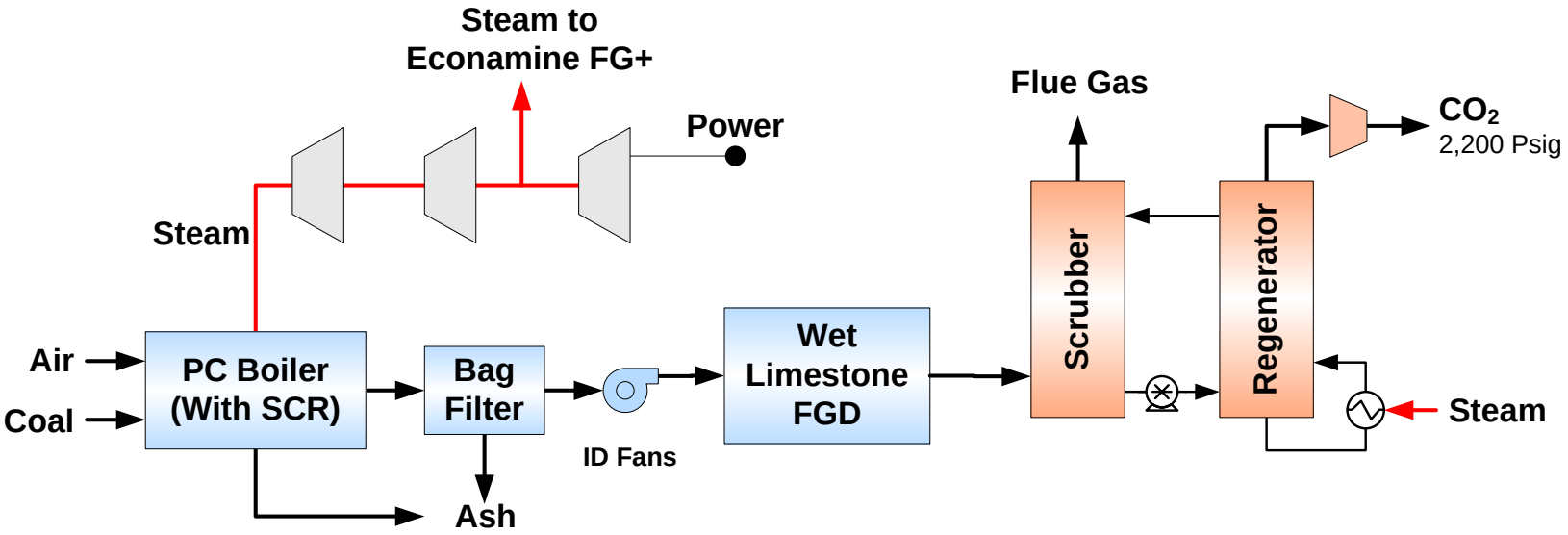
Plant Type	ST Cond. (psig/°F/°F)	GT	Gasifier/ Boiler	Acid Gas Removal/ CO_2 Separation / Sulfur Recovery	CO_2 Cap
IGCC	1800/1050/1050 (non-CO_2 capture cases) 1800/1000/1000 (CO_2 capture cases)	F Class	GEE	Selexol / - / Claus	
				Selexol / Selexol / Claus	90%
			CoP E-Gas	MDEA / - / Claus	
				Selexol / Selexol / Claus	90%
			Shell	Sulfinol-M / - / Claus	
				Selexol / Selexol / Claus	90%
PC	2400/1050/1050		Subcritical	Wet FGD / - / Gypsum	
				Wet FGD / Econamine / Gypsum	90%
	3500/1100/1100		Supercritical	Wet FGD / - / Gypsum	
				Wet FGD / Econamine / Gypsum	90%
NGCC	2400/1050/1050	F Class	HRSG		
				- / Econamine / -	90%

GEE – GE Energy
CoP – Conoco Phillips

IGCC Power Plant with CO_2 Capture



Pulverized Coal Power Plant with CO_2 Capture



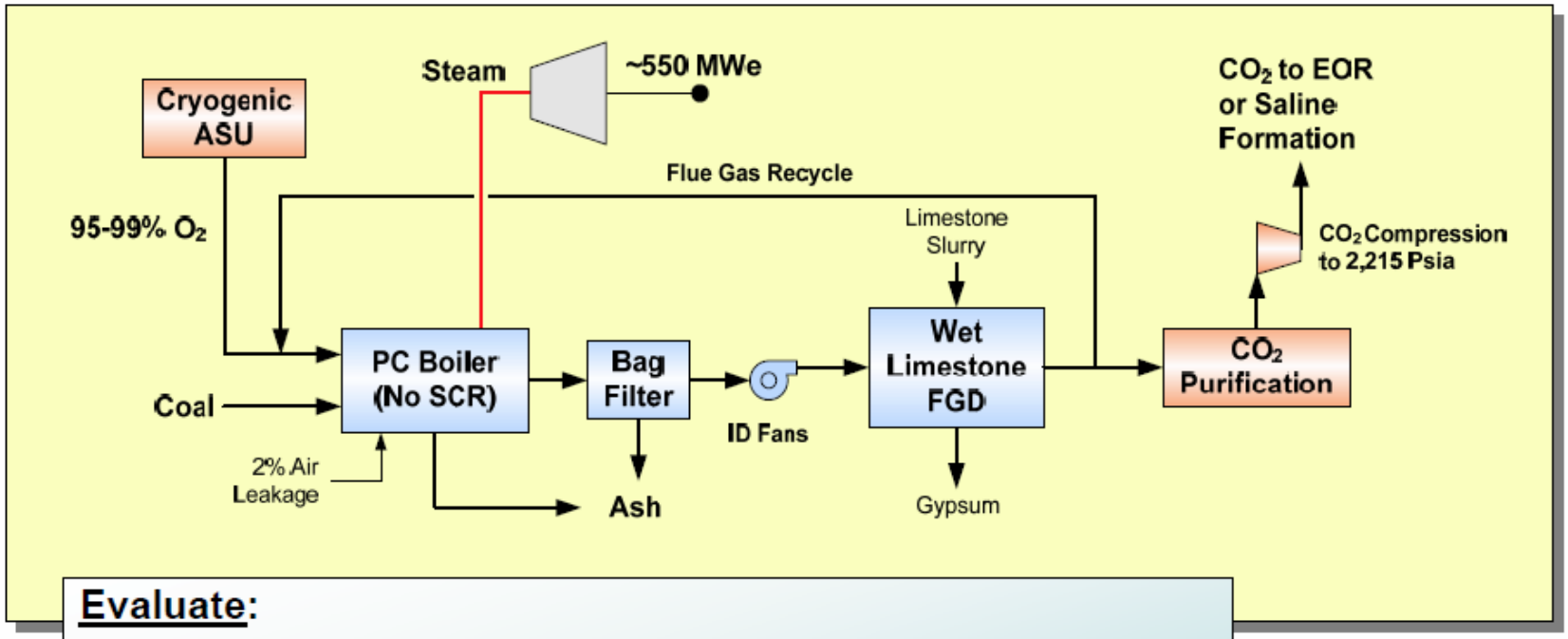
Study Matrix
Bituminous Oxycombustion

Case	Plant Design	Steam Cycle	Oxidant	Pipeline Specification
1	Air Fired No CO_2 Capture	SC	Air	N/A
2		USC		N/A
3	Air Fired MEA CO_2 Capture	SC		UR Saline Formation
4		USC		UR Saline Formation
5	Oxycombustion	SC	95%	UR Saline Formation
5A			99%	UR Saline Formation
5B			95%	Match 5A
5C			95%	URSF and >95% CO_2
6		USC	95%	UR Saline Formation
6A			95%	URSF and >95% CO_2
7		SC	~100% ITM	UR Saline Formation
7A			~100% ITM	URSF and >95% CO_2

URSF: Unrestricted Saline Formation Specification

Supercritical (SC): 3,500 psig/1,100 F/1,150 F – Current state-of-art
Ultra-supercritical (USC): 4,000 psig/1,350 F/1,400 F – Advanced material program

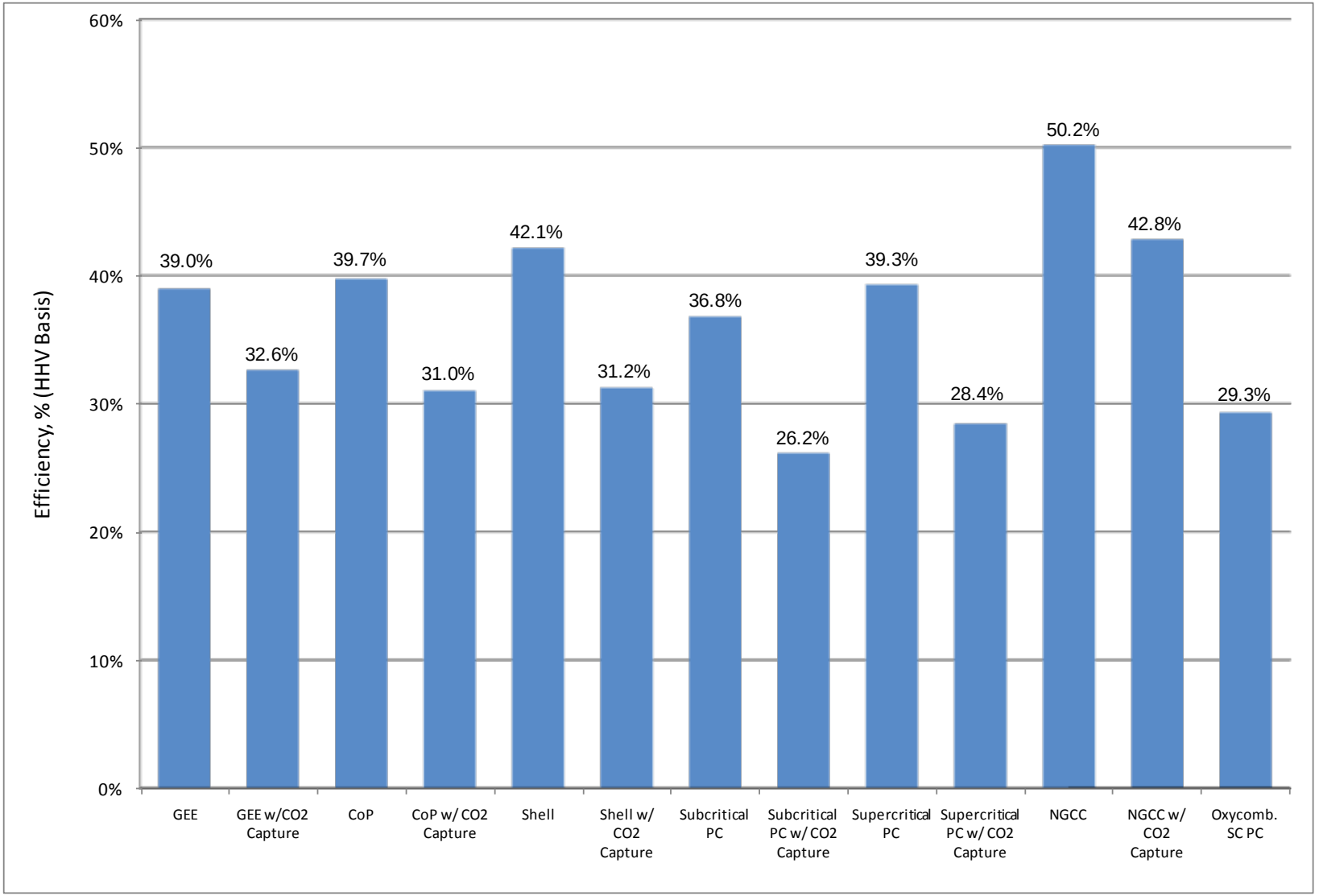
Oxycombustion Pulverized Coal Power Plant



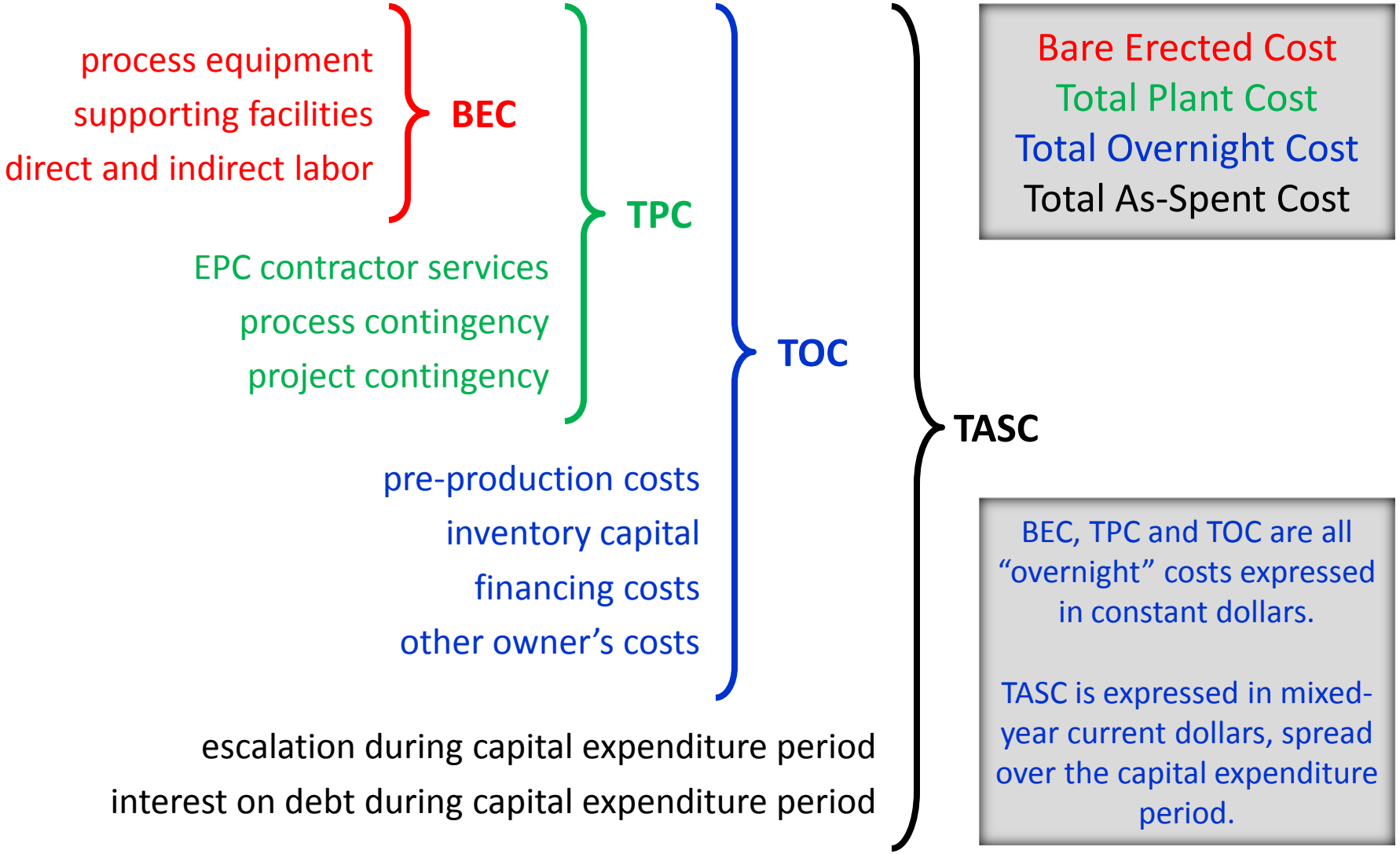
Evaluate:

1. Impact 95 versus 99% oxygen purity has on the CO_2 purification/compression process
2. Minimum CO_2 recycle rate
3. Co-sequestration (CO_2/NOx/SOx) feasibility

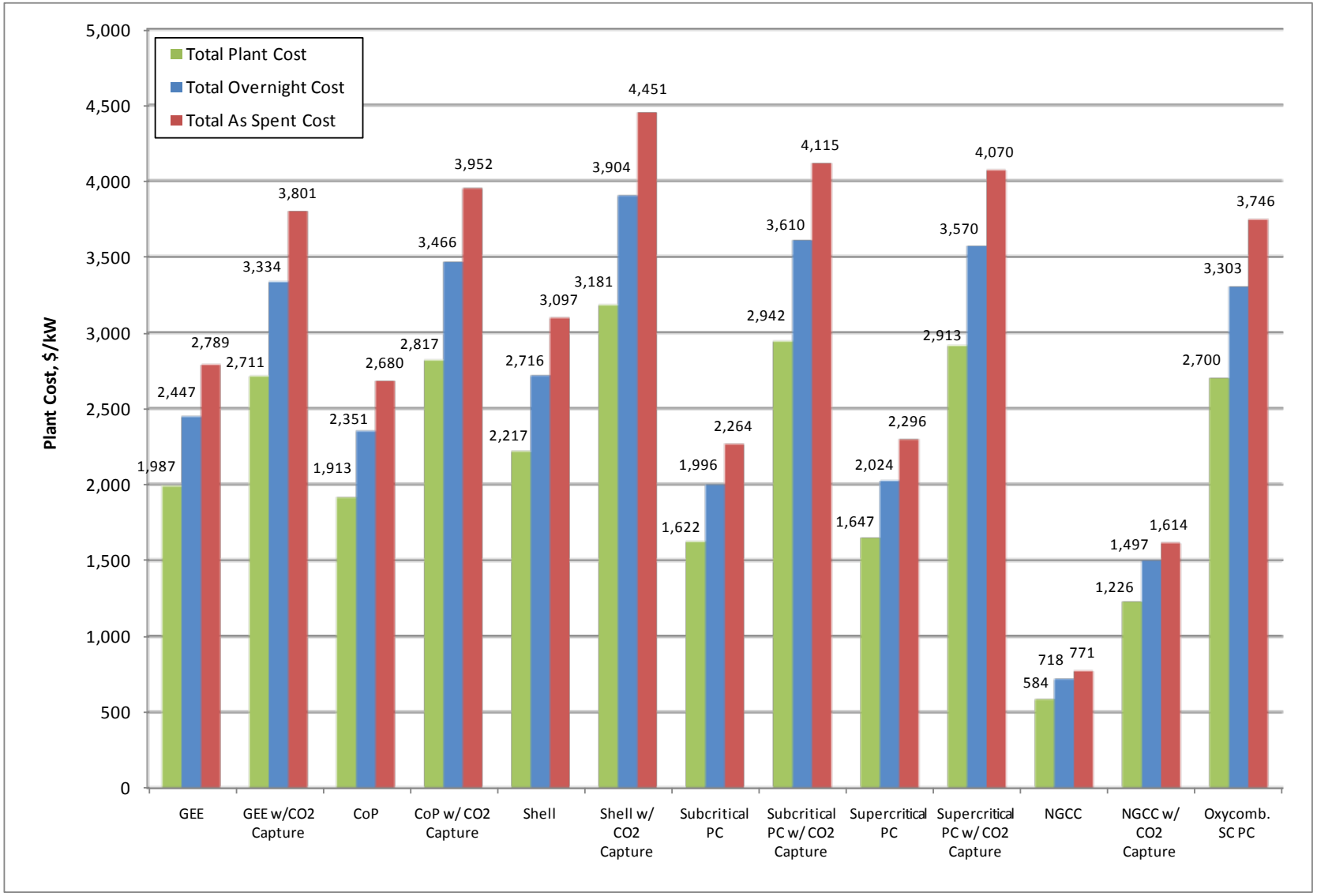
Plant Efficiency



Levels of Capital Cost



Plant Costs


Total Plant Cost
Total Overnight Cost
Total As Spent Cost
Plant Cost, $/kW
5,000
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
1,987
2,447
2,789
2,711
3,334
3,801
1,913
2,351
2,680
2,817
3,466
3,952
2,217
2,716
3,097
3,181
3,904
4,451
1,622
1,996
2,264
2,942
3,610
4,115
1,647
2,024
2,296
2,913
3,570
4,070
584
718
771
1,226
1,497
1,614
2,700
3,303
3,746
GEE
GEE w/CO2 Capture
CoP
CoP w/ CO2 Capture
Shell
Shell w/ CO2 Capture
Subcritical PC
Subcritical PC w/ CO2 Capture
Supercritical PC
Supercritical PC w/ CO2 Capture
NGCC
NGCC w/ CO2 Capture
Oxycomb. SC PC

Finance Structure

		Investor Owned Utility (IOU)		Independent Power Projects (IPP)	
		Low-Risk	High-Risk	Low-Risk	High-Risk
Capital Structure	*Percent Debt*	50%	45%	70%	60%
	Percent Equity	50%	55%	30%	40%
Interest Rate		4.5% (LIBOR plus 1%)	5.5% (LIBOR plus 2%)	6.5% (LIBOR plus 3%)	8.5% (LIBOR plus 5%)
IRROE		12%	12%	20%	20%
Before Tax Weighted Cost of Capital		8.25%	9.08%	10.55%	13.10%
After Tax Weighted Cost of Capital (ATWCC)		7.39%	8.13%	8.82%	11.16%

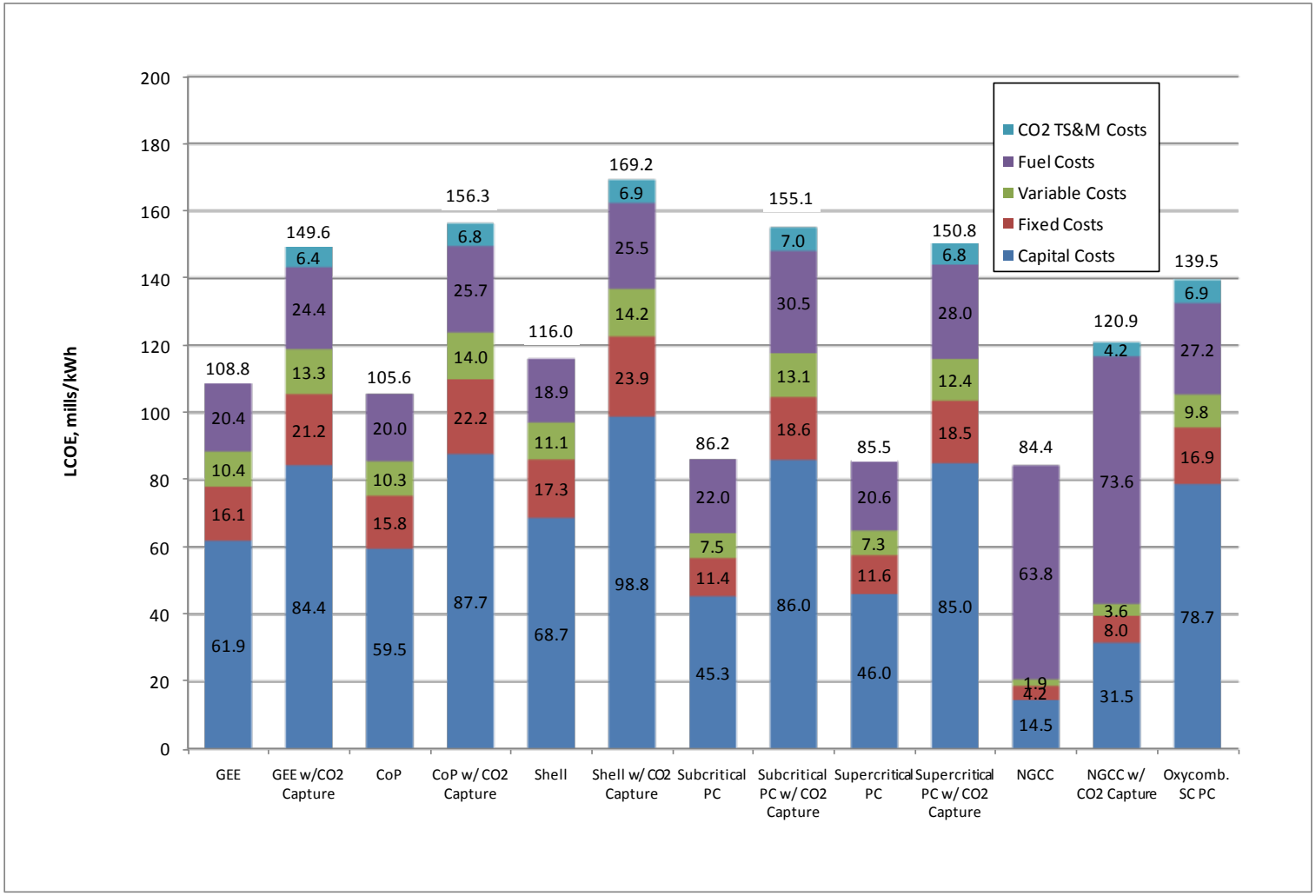
Assumptions for DCF Analysis
(resulting CCF is dependent on these assumptions)

Parameter	Value
TAXES	
Income Tax Rate	38% (Effective 34% Federal, 6% State)
Capital Depreciation	20 years, 150% declining balance
Investment Tax Credit	0%
Tax Holiday	0 years
FINANCING TERMS	
Repayment Term of Debt	15 years
Grace Period on Debt Repayment	0 years
Debt Reserve Fund	None
TREATMENT OF CAPITAL COSTS	
Capital Cost Escalation During Construction (nominal annual rate)	3.6%
Distribution of Total Overnight Capital over the Capital Expenditure Period (before escalation)	3-Year Period: 10%, 60%, 30% 5-Year Period: 10%, 30%, 25%, 20%, 15%
Working Capital	zero for all parameters
% of Total Overnight Capital that is Depreciated	100% (t*his assumption introduces a very small error even if a substantial amount of TOC is actually non-depreciable*)
INFLATION	
LCOE, O&M, Fuel Escalation (nominal annual rate) Escalation rates must be the same for LCOE approximation to be valid	3.0%COE, O&M, Fuel

[1] A nominal average annual rate of 3.6% is assumed for escalation of capital costs during construction. This rate is equivalent to the nominal average annual escalation rate for process plant construction costs between 1941 and 2008 according to the *Chemical Engineering* Plant Cost Index.
[2] An average annual escalation rate of 3.0% is assumed. This rate is equivalent to the average annual escalation rate between 1947 and 2008 for the U.S. Department of Labor's Producer Price Index for Finished Goods, the so-called "headline" index of the various Producer Price Indices. (The Producer Price Index for the Electric Power Generation Industry may be more applicable, but that data does not provide a long-term historical perspective since it only dates back to December 2003.)

Levelized Cost of Electricity

30-Year, Current-Dollar



Coal cost $1.64/MMBtu, Gas cost $6.55/MMBtu

Highlights
Efficiency & Capital Cost

- **Using today's technology, coal-based plants are efficient and clean**
  - PC and IGCC: 39-42%, HHV (without CCS)
  - Emissions meet or exceed current environmental requirements
  - 90% of CO_2 can be removed, but at significant increase in COE

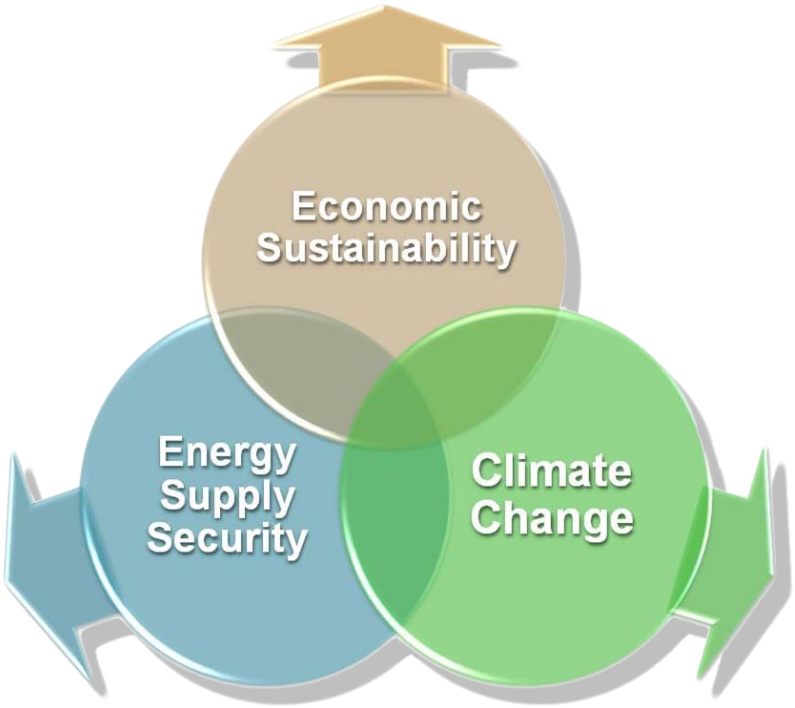
Total Overnight Cost, $/kW June-2007 (equiv. to Jan-2010)		
No CCS	NGCC	718
	Supercritical PC	2,024
	CoP IGCC	2,351
With CCS	NGCC	1,497
	Supercritical PC	3,570
	GE IGCC	3,334
	SC PC Oxycombustion	3,303

~ ⅔ to ¾ more than PC w/o CCS

Highlights
LCOE

LCOE, $/MWh		
No CCS	NGCC	84
	Supercritical PC	86
	CoP IGCC	106
With CCS	NGCC	121
	Supercritical PC	151
	GE IGCC	150
	SC PC Oxycombustion	140

~ ⅔ to ¾ more than PC w/o CCS



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