Cost and Performance Baseline for Fossil Energy Plants

CMU Seminar

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Fossil Energy Plant Baseline Study

-Report Contains-

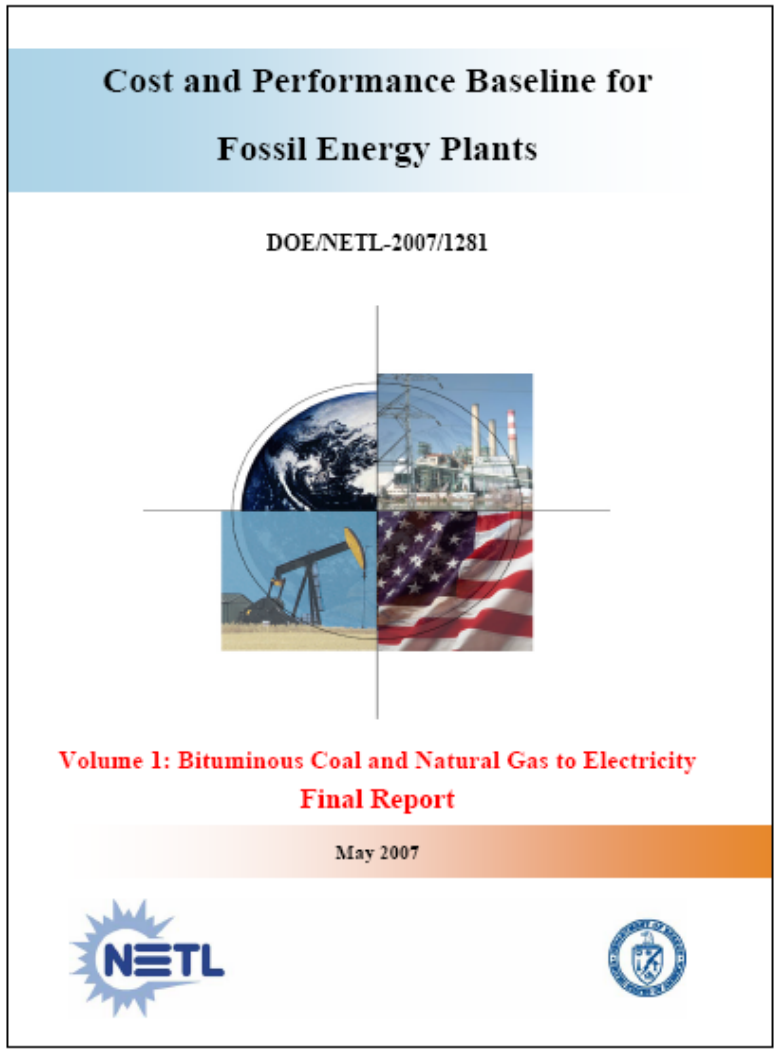
Subcritical PC

Supercritical PC

IGCC

NGCC

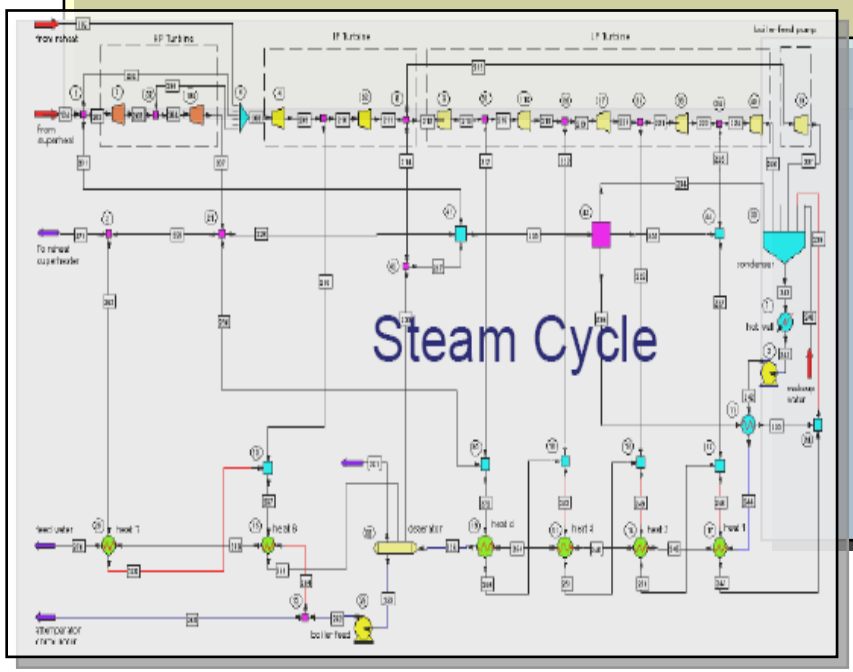
- Consistent design requirements
- Up-to-date performance and capital cost estimates
- Technologies built now and deployed by 2010



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**
  - Parsons
  - Vendor sources where available
- **Follow DOE Analysis Guidelines**

Study Matrix

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	GE	Selexol / - / Claus	
				Selexol / Selexol / Claus	90%
			CoP E-Gas	MDEA / - / Claus	
				Selexol / Selexol / Claus	88%[1]
			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	2400/1050/950	F Class	HRSG		
				- / Econamine / -	90%

[1] CO_2 capture is limited to 88% by syngas CH_4 content

GEE – GE Energy
CoP – Conoco Phillips

Design Basis: Coal Type

Illinois #6 Coal Ultimate Analysis (weight %)

	As Rec'd	Dry
Moisture	11.12	0
Carbon	63.75	71.72
Hydrogen	4.50	5.06
Nitrogen	1.25	1.41
Chlorine	0.29	0.33
Sulfur	2.51	2.82
Ash	9.70	10.91
Oxygen (by difference)	6.88	7.75
	100.0	100.0
HHV (Btu/lb)	11,666	13,126

Environmental Targets

Pollutant	IGCC[1]	PC[2]	NGCC[3]
SO_2	0.0128 lb/MMBtu	0.085 lb/MMBtu	< 0.6 gr S /100 scf
NOx	15 ppmv (dry) @ 15% O_2	0.07 lb/MMBtu	2.5 ppmv @ 15% O_2
PM	0.0071 lb/MMBtu	0.017 lb/MMBtu	Negligible
Hg	> 90% capture	1.14 lb/TBtu	Negligible

[1] Based on EPRI's CoalFleet User Design Basis Specification for Coal-Based IGCC Power Plants
[2] Based on BACT analysis, exceeding new NSPS requirements
[3] Based on EPA pipeline natural gas specification and 40 CFR Part 60, Subpart KKKK

Economic Assumptions

Startup	**2010**
Plant Life (Years)	**20**
Capital Charge Factor, %	
High Risk	
(All IGCC, PC/NGCC with CO_2 capture)	**17.5**
Low Risk	
(PC/NGCC without CO_2 capture)	**16.4**
Dollars (Constant)	**2007**
Coal ($/MM Btu)	**1.80**
Natural Gas ($/MM Btu)	**6.75**
Capacity Factor	
IGCC	**80**
PC/NGCC	**85**

Total Plant Cost

- **Includes**
  - Equipment
    - Initial chemicals and catalyst loadings
  - Materials
  - Labor
    - Direct and Indirect
  - Engineering and Construction Management
  - Project and Process Contingencies

- **Excludes**
  - Owner's costs
    - Land, licensing and permitting, AFUDC
  - Escalation to period of performance
  - Taxes (except payroll)
  - Site specific considerations
  - Labor incentives in excess of 5 day/10 hour work week
  - EPC premiums

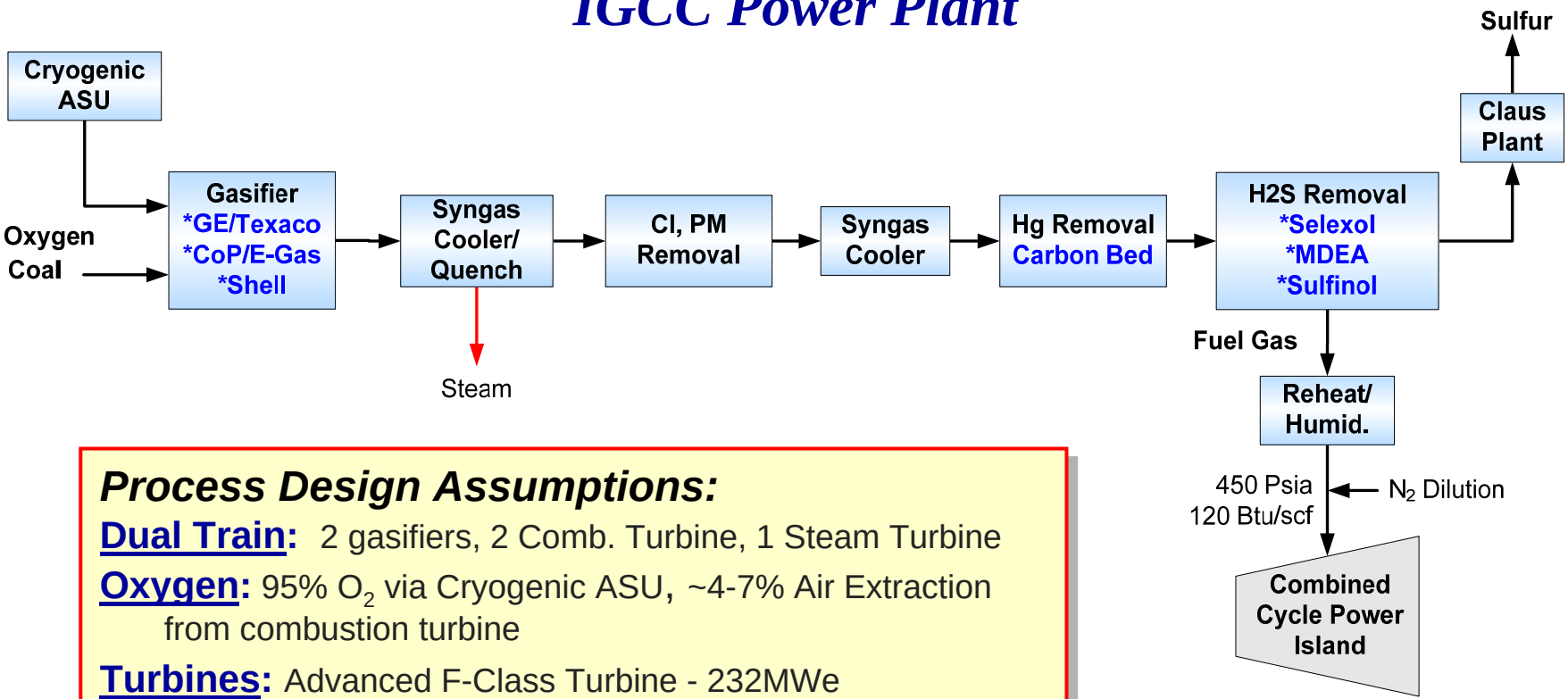
Costs do not include “Risk Wrap”

- **Contract approach assumed for study**
  - EPCM (engineering, procurement, construction management)
    - Owner has control of project
    - Risk is reduced with time as scope definition improves by time of contract award
- **as opposed to…..**
  - EPC (engineer, procure, construct)
    - Lump sum contract where contractor assumes all risk for performance, schedule, and cost
    - If willing to accept risk, premiums applied can raise costs dramatically

Power Plant Configurations

Current State-of-the-Art

Current Technology
IGCC Power Plant



Process Design Assumptions:

Dual Train: 2 gasifiers, 2 Comb. Turbine, 1 Steam Turbine

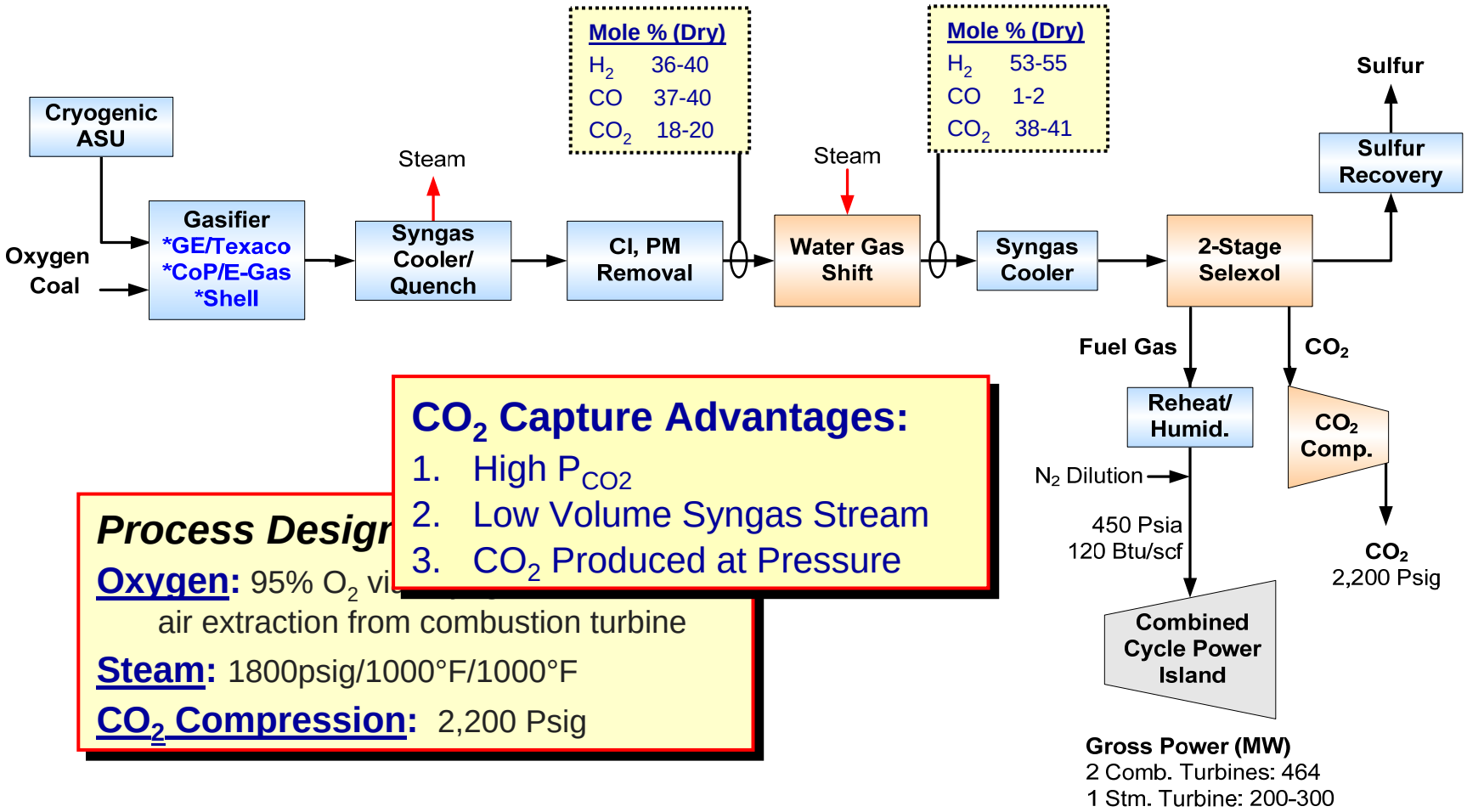
Oxygen: 95% O_2 via Cryogenic ASU, ~4-7% Air Extraction from combustion turbine

Turbines: Advanced F-Class Turbine - 232MWe
N_2 dilution employed to full extent in all cases
Humidification/steam injection used only when necessary to meet syngas specification of ~120 Btu/scf LHV

Steam: 1800psig/1050°F/1050°F

Pre-Combustion Current Technology

IGCC Power Plant with CO_2 Scrubbing



CO_2 Capture Advantages:

1. High P_{CO2}
2. Low Volume Syngas Stream
3. CO_2 Produced at Pressure

Process Desigr

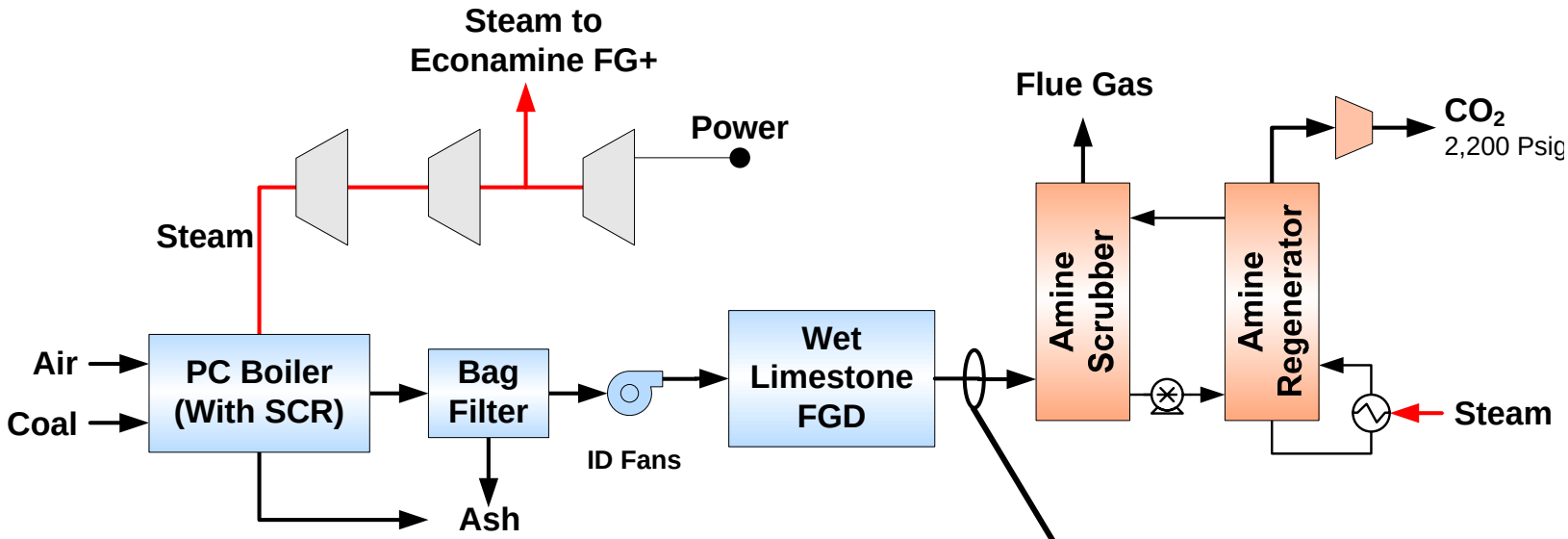
Oxygen: 95% O_2 vi
air extraction from combustion turbine

Steam: 1800psig/1000°F/1000°F

CO_2 Compression: 2,200 Psig

Post-Combustion Current Technology

Pulverized Coal Power Plant with CO_2 Scrubbing



Process Design Assumptions:

Steam:

Subcritical → 2400psig/1050°F/1050°F

Supercritical → 3500psig/1100°F/1100°F

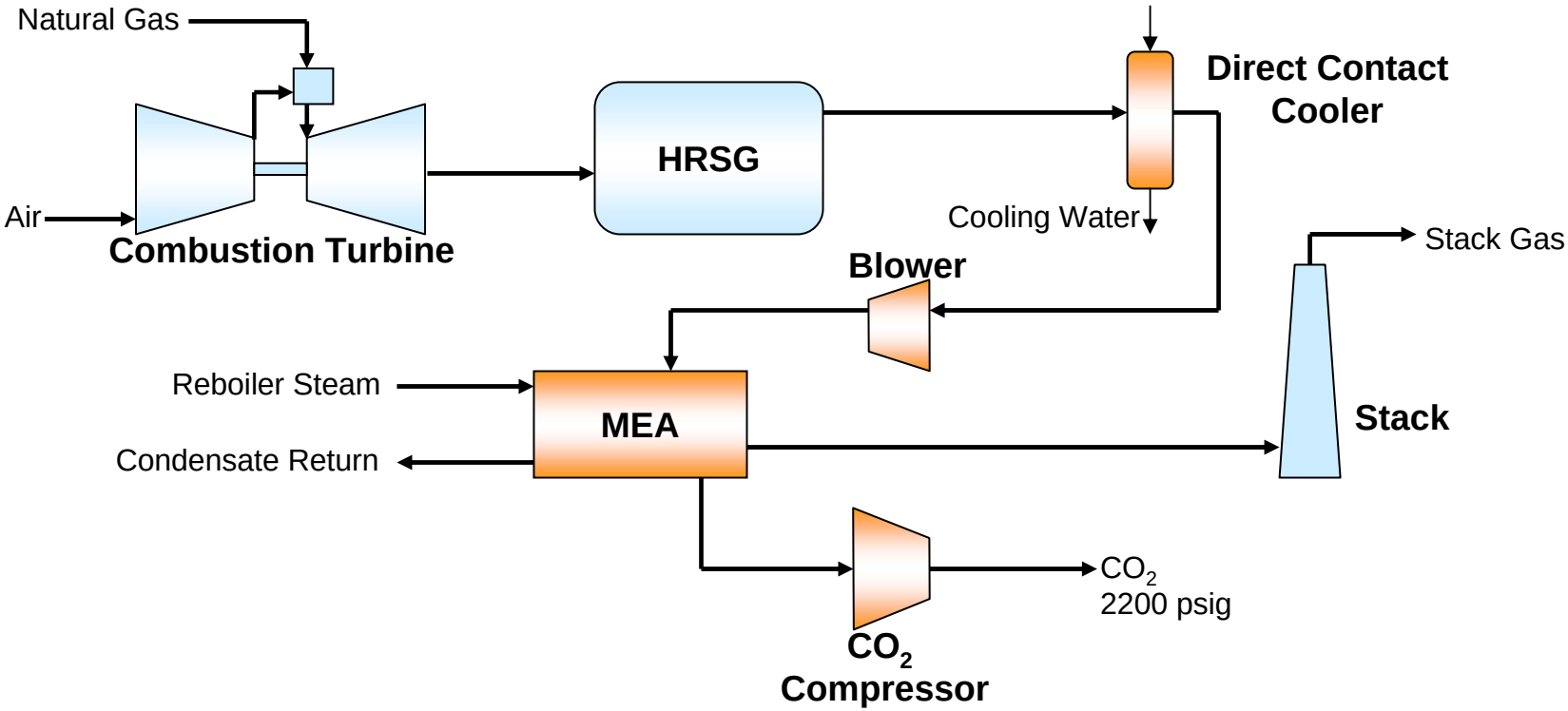
**Orange Blocks Indicate Unit Operations Added for CO_2 Capture Case*

CO_2 Capture Challenges:

1. Dilute Flue Gas (10-14% CO_2)
2. Low Pressure CO_2
3. 1.5 Million scfm
4. 17,000 ton CO_2/day removed
5. Large Parasitic Loads (Steam + CO_2 Compression)

Current Technology
*Natural Gas Combined Cycle**

***Orange Blocks Indicate Unit Operations Added for CO_2 Capture Case**



NOx Control: LNB + SCR to maintain 2.5 ppmvd @ 15% O_2

Steam Conditions: 2400 psig/1050°F/950°F

IGCC Power Plant
Cost and Performance

No CO_2 capture

IGCC Performance Results

No CO_2 Capture

	GE Energy	E-Gas	Shell
Gross Power (MW)	**770**	**742**	**748**
Auxiliary Power (MW)			
Base Plant Load	23	25	21
Air Separation Unit	103	91	90
Gas Cleanup	4	3	1
Total Aux. Power (MW)	130	119	112
Net Power (MW)	640	623	636
Heat Rate (Btu/kWh)	8,922	8,681	8,304
Efficiency (HHV)	**38.2**	**39.3**	**41.1**

IGCC Economic Results

No CO_2 Capture

	GE Energy	E-Gas	Shell
Plant Cost ($/kWe)[1]			
Base Plant	1,323	1,272	1,522
Air Separation Unit	287	264	256
Gas Cleanup	203	197	199
Total Plant Cost ($/kWe)	**1,813**	**1,733**	**1,977**
Capital COE (¢/kWh)	4.53	4.33	4.94
Variable COE (¢/kWh)	3.27	3.20	3.11
Total COE[2] (¢/kWh)	**7.80**	**7.53**	**8.05**

[1]Total Plant Capital Cost (Includes contingencies and engineering fees)

[2]January 2007 Dollars, 80% Capacity Factor, 17.5% Capital Charge Factor, Coal cost $1.80/$10^6$Btu

IGCC Power Plant Cost and Performance

With CO_2 Capture

Impact of Adding CCS

	GE Energy	
CO_2 Capture	**NO**	**YES**
Gross Power (MW)	**770**	**745**
Auxiliary Power (MW)		
Base Plant Load	23	23
Air Separation Unit	103	121
Gas Cleanup/CO_2 Capture	4	18
CO_2 Compression	-	27
Total Aux. Power (MW)	130	189
Net Power (MW)	640	556
Heat Rate (Btu/kWh)	8,922	10,505
Efficiency (HHV)	**38.2**	**32.5**
Energy Penalty[1]	**-**	**5.7**

Steam for WGS and Selexol

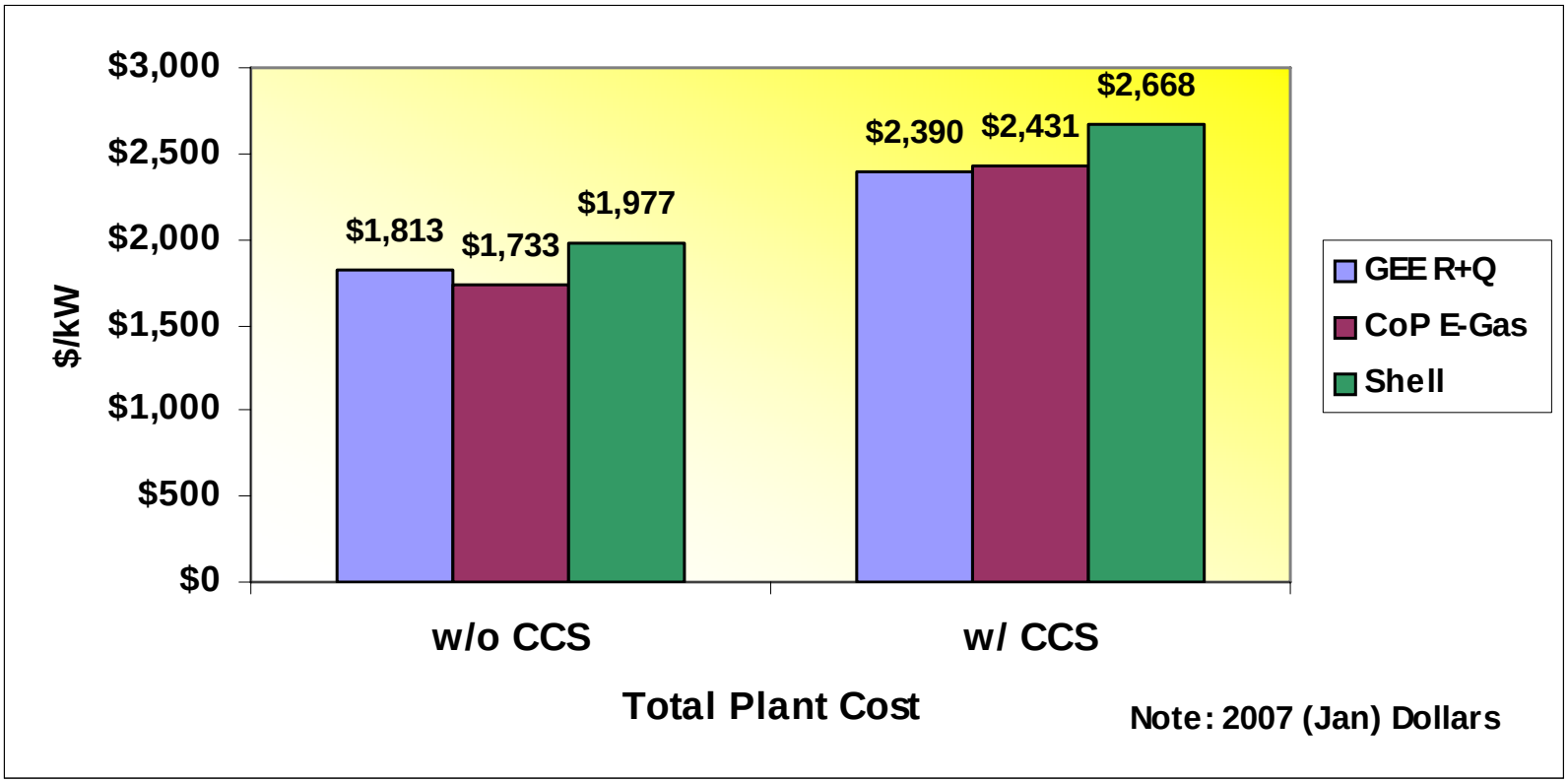
↑ in ASU air comp. load w/o CT integration

Includes H_2S/CO_2 Removal in Selexol Solvent

↑ in auxiliary load for compression to 2200 psig

[1] CO_2 Capture Energy Penalty = Percent points decrease in net power plant efficiency due to CO_2 Capture

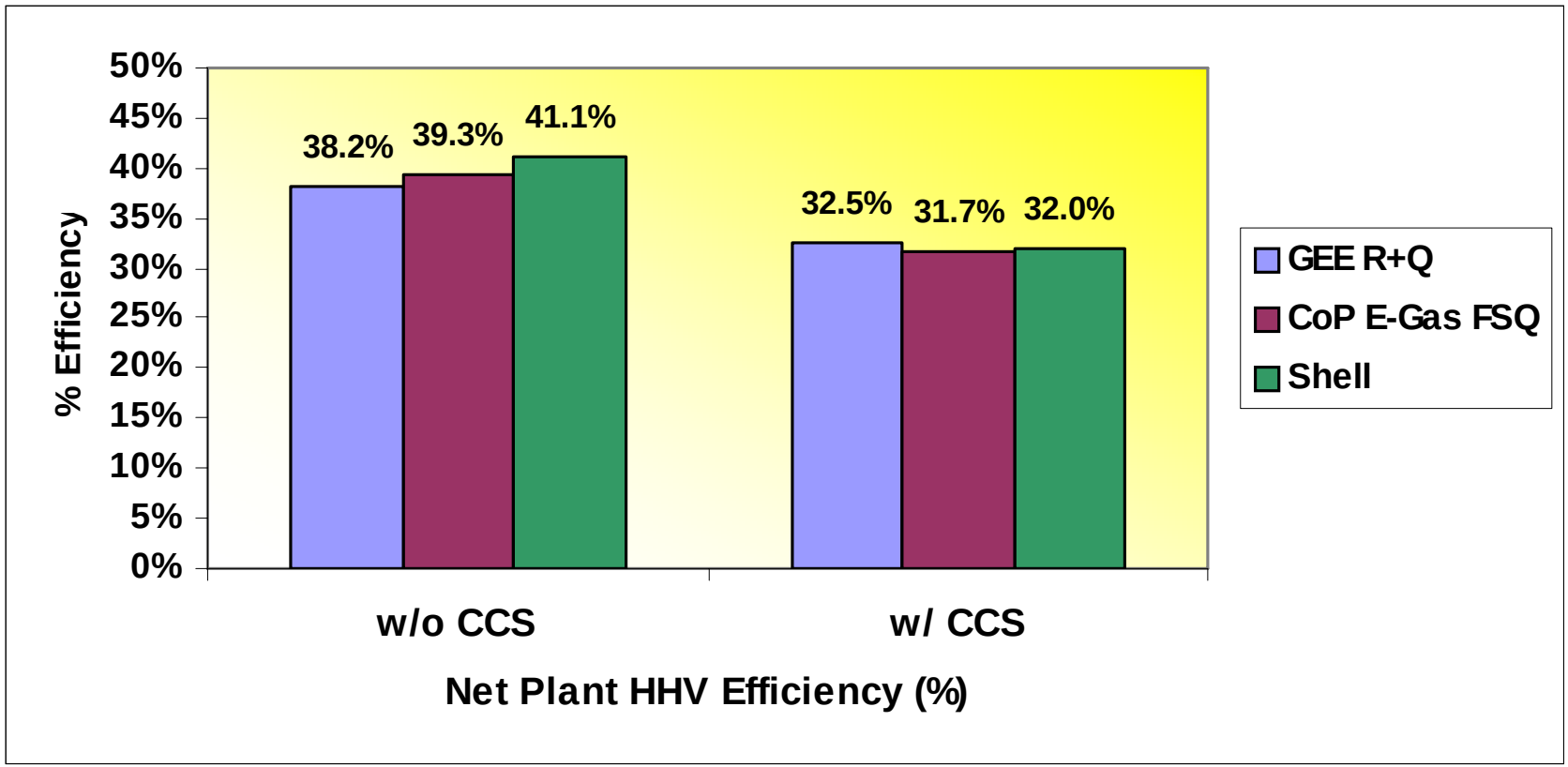
Impact of CCS on IGCC Capital Cost



CCS = Carbon capture and sequestration

CCS increases TPC by about 35 percent (or ~ $660/kW)

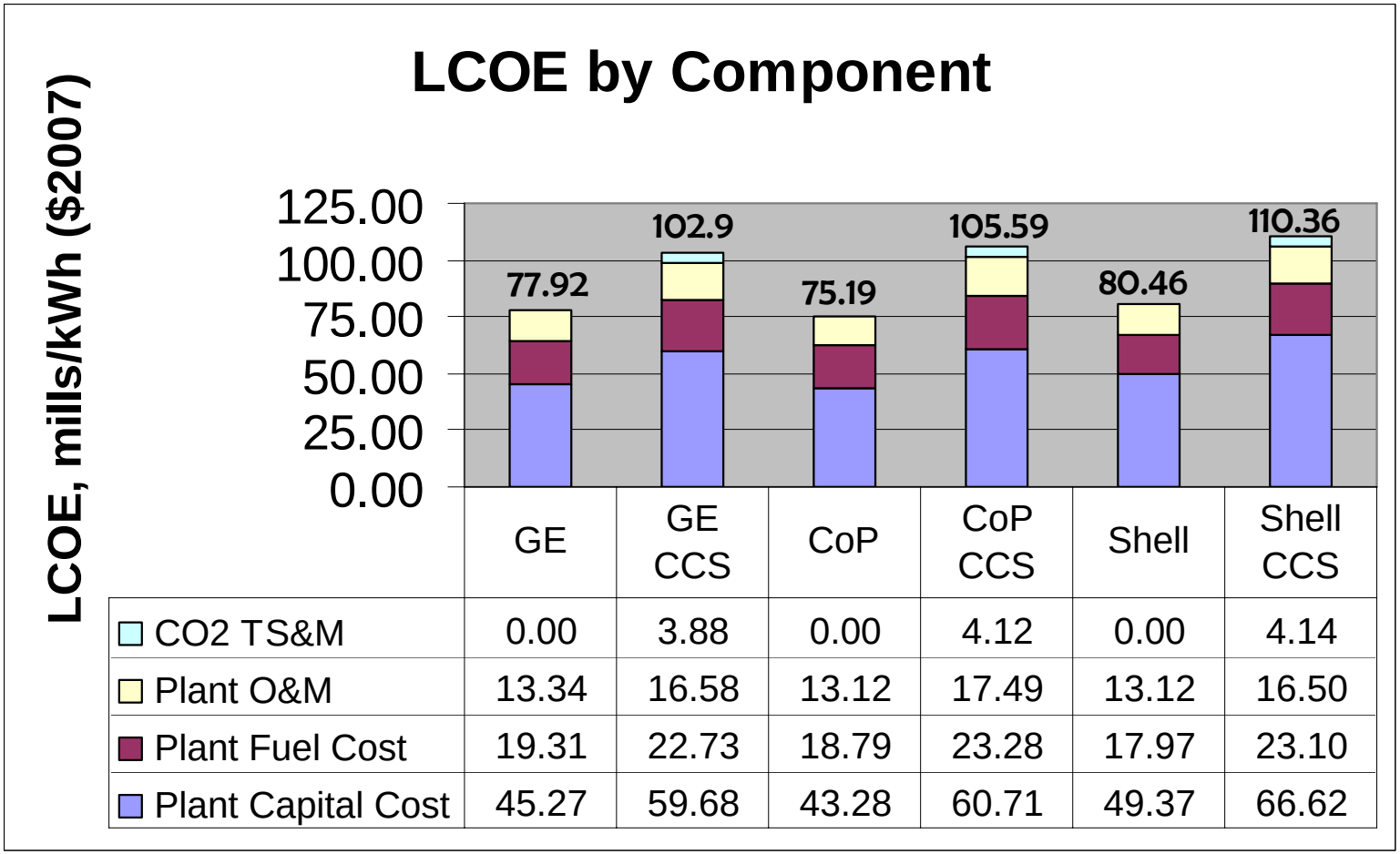
Impact of CCS on IGCC Efficiency



CCS = Carbon capture and sequestration

Average energy penalty for CCS is 7 percentage points

Impact of CCS on IGCC Cost of Electricity



	GE	GE CCS	CoP	CoP CCS	Shell	Shell CCS
CO2 TS&M	0.00	3.88	0.00	4.12	0.00	4.14
Plant O&M	13.34	16.58	13.12	17.49	13.12	16.50
Plant Fuel Cost	19.31	22.73	18.79	23.28	17.97	23.10
Plant Capital Cost	45.27	59.68	43.28	60.71	49.37	66.62

CCS = Carbon capture and sequestration

PC Power Plant
Cost and Performance

Pulverized Coal Performance Summary

	Subcritical		Supercritical	
Coal Flow Rate	**5,252**	**7,759**	**4,935**	**7,039**
CO_2 Captured (Ton/day)	**0**	**16,566**	**0**	**15,029**
Gross Power (MW)	**584**	**681**	**580**	**664**
Auxiliary Power (MW)				
Base Plant Load	19	36	21	32
Forced + Induced Draft Fans	10	14	9	13
Flue Gas Cleanup	4	5	3	5
CO_2 Capture	-	24	-	21
CO_2 Compression	-	52	-	47
Total Aux. Power (MW)	**33**	**131**	**30**	**118**
Net Power (MW)	**550**	**550**	**550**	**546**
Efficiency (%HHV)	**36.8**	**25.0**	**39.1**	**27.2**
Energy Penalty (% Points)	**-**	**11.8**	**-**	**11.9**

CO_2 Capture decreases net efficiency by ~12 percentage points

Subcritical PC Performance

	Subcritical	
Coal Flow Rate	**5,252**	**7,759**
CO_2 Captured (Ton/day)	**0**	**16,566**
Gross Power (MW)	**584**	**681**
Auxiliary Power (MW)		
Base Plant Load	19	36
Forced + Induced Draft Fans	10	14
Flue Gas Cleanup	4	5
CO_2 Capture	-	24
CO_2 Compression	-	52
Total Aux. Power (MW)	**33**	**131**
Net Power (MW)	**550**	**550**
Efficiency (%HHV)	**36.8**	**25.0**
Energy Penalty (% Points)	**-**	**11.8**

48% Increase in Coal Flow Rate

Larger Base Plant

MEA Scrubbing

~17,000 TPD to 2,200 Psig

Pulverized Coal Economic Results

	Subcritical		Supercritical	
CO_2 Capture	**NO**	**YES**	**NO**	**YES**
Plant Cost ($/kWe)[1]				
Base Plant	1,302	1,689	1,345	1,729
Gas Cleanup (SOx/NOx)	246	323	229	302
CO_2 Capture	-	792	-	752
CO_2 Compression	-	89	-	85
Total Plant Cost ($/kWe)	**1,549**	**2,895**	**1,575**	**2,870**
Capital COE (¢/kWh)	3.41			
Variable COE (¢/kWh)	2.99			
CO_2 TS&M COE (¢/kWh)	0.00	0.43	0.00	0.39
Total COE[2] (¢/kWh)	**6.40**	**11.88**	**6.33**	**11.48**
Increase in COE (%)	**-**	**85**	**-**	**81**
$/tonne CO_2 Avoided	-	75	-	75

PC CO_2 capture results in:
Increase in Capital Cost (TPC) ~ $1,325/kW
Increase in COE ~5 cents/kWh (~ ↑83%)

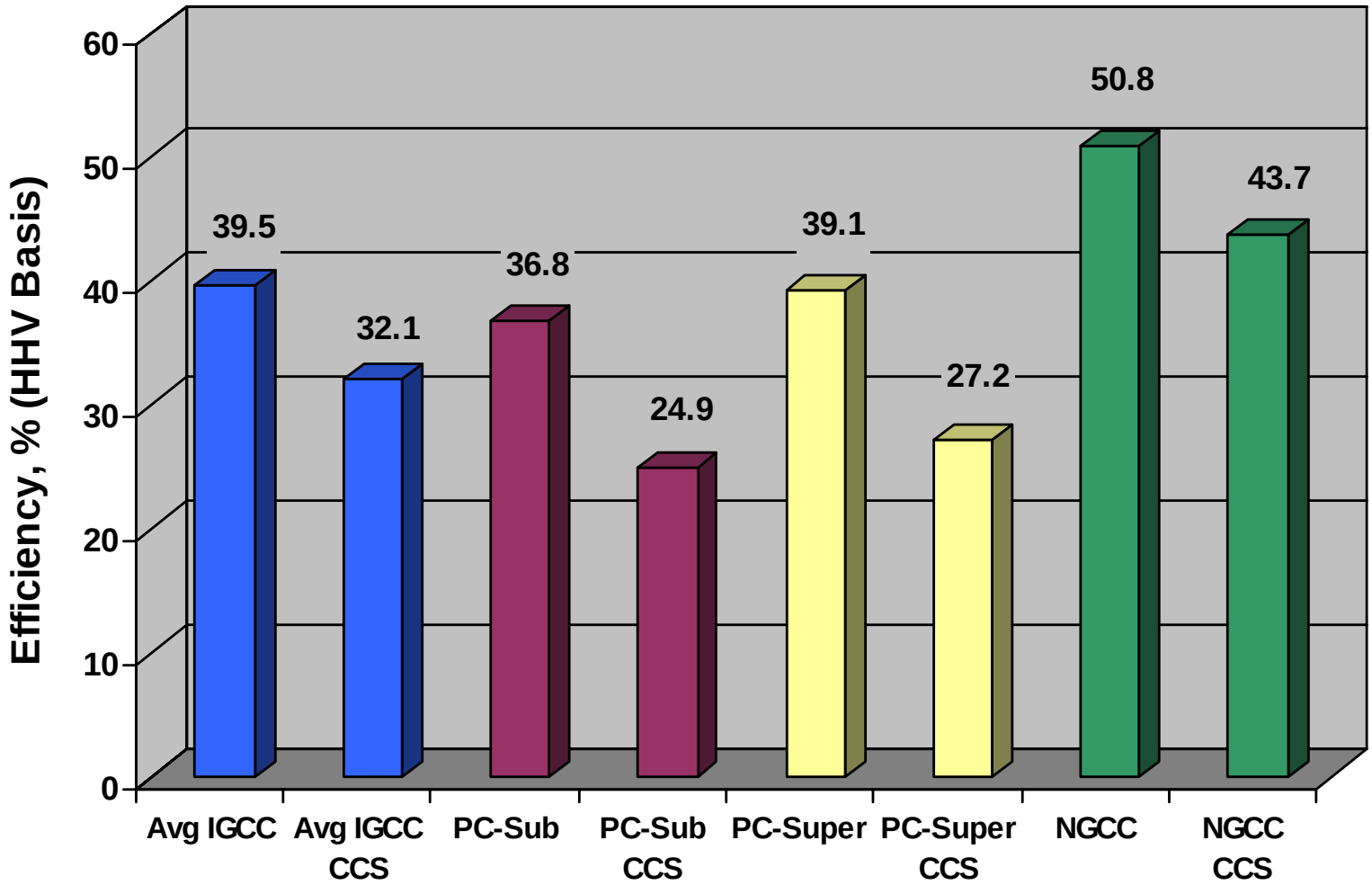
[1]Total Plant Capital Cost (Includes contingencies and engineering fees)

[2]January 2007 Dollars, 85% Capacity Factor, 16.4% (no capture) 17.5% (capture) Capital Charge Factor, Coal cost $1.80/$10^6$Btu, Natural Gas cost $6.75/$10^6$Btu

Technology Comparison

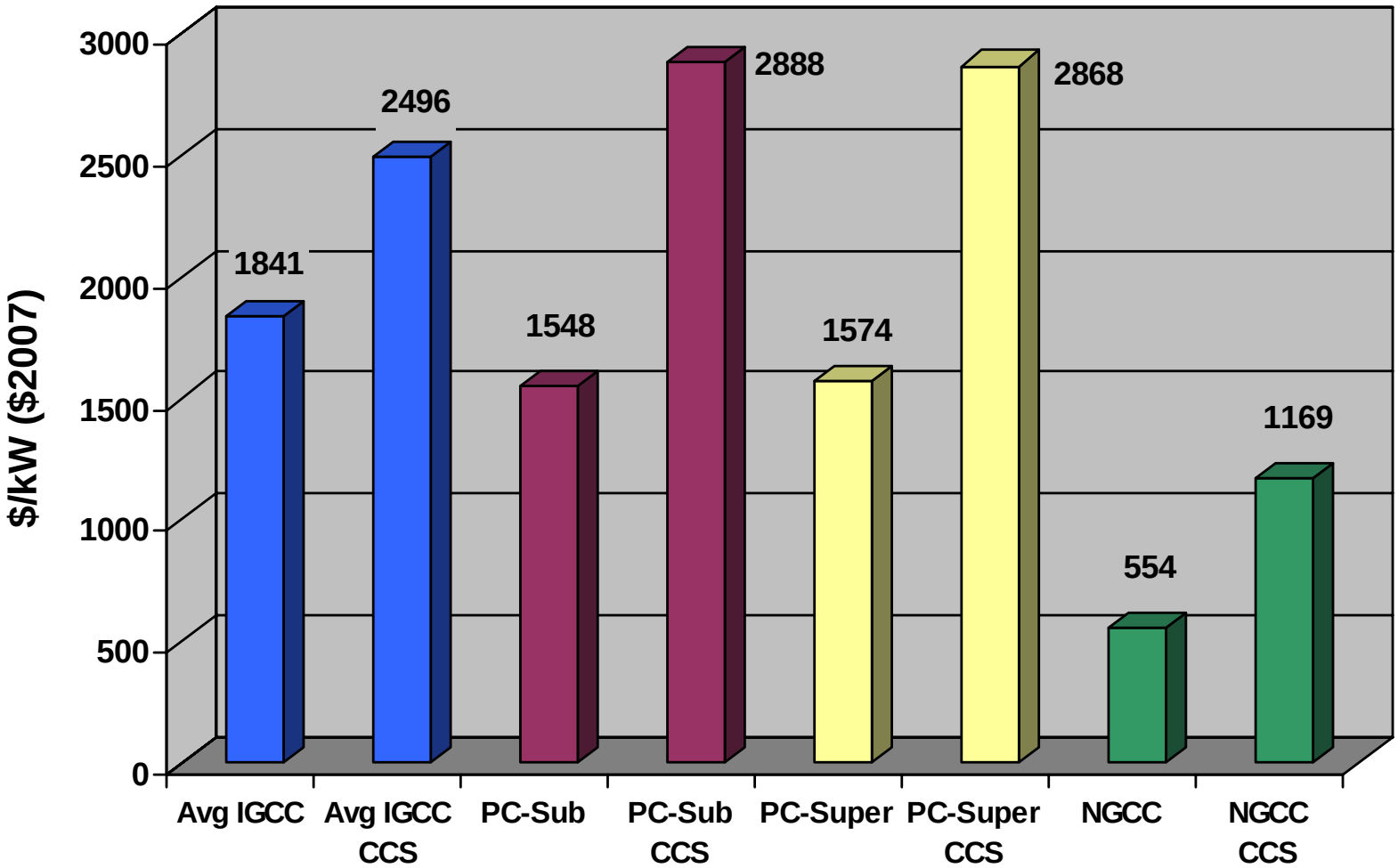
IGCC, PC and NGCC

Net Plant Efficiency



CCS = Carbon capture and sequestration

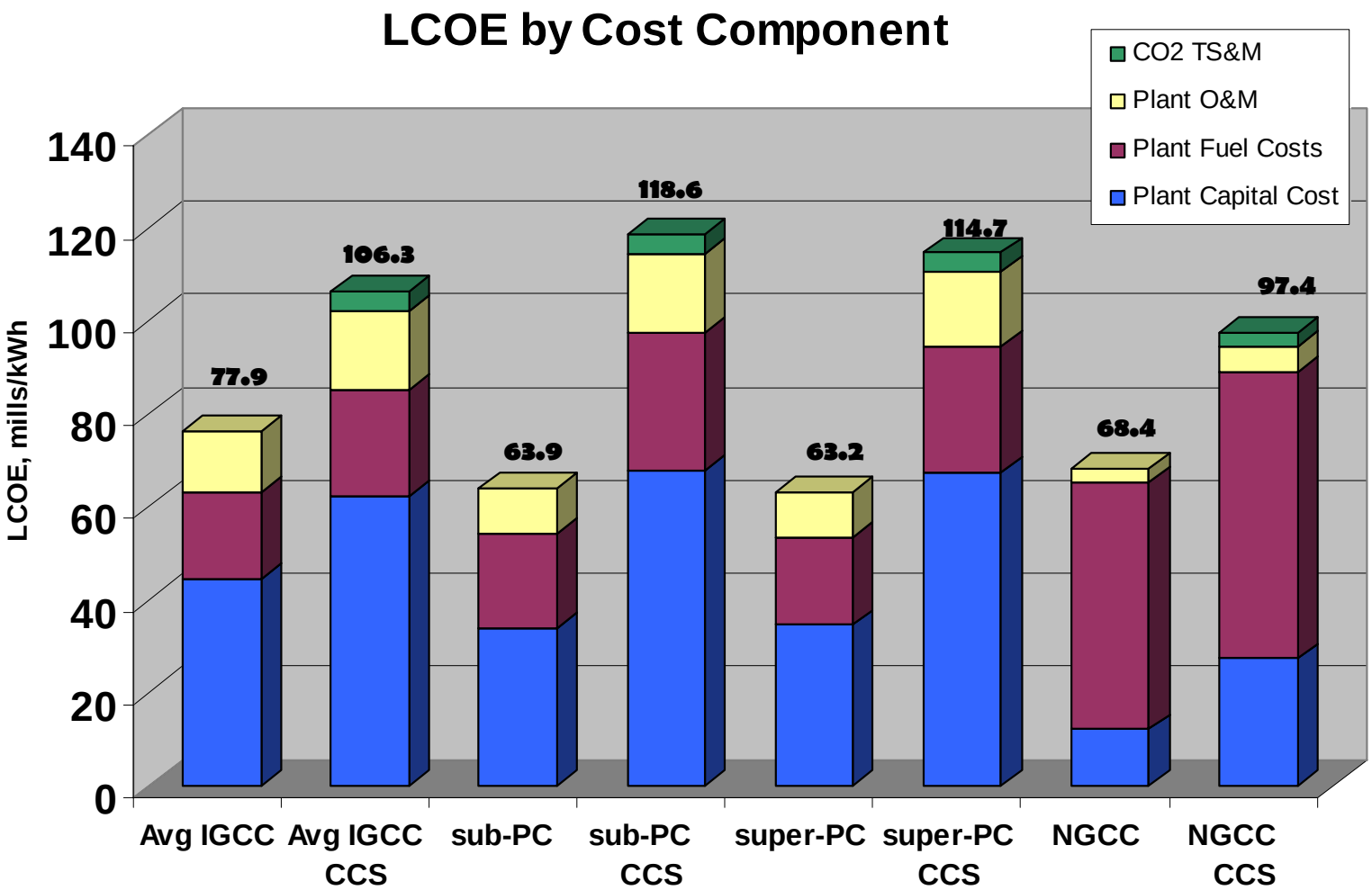
Total Plant Cost



Total Plant Capital Cost includes contingencies and engineering fees

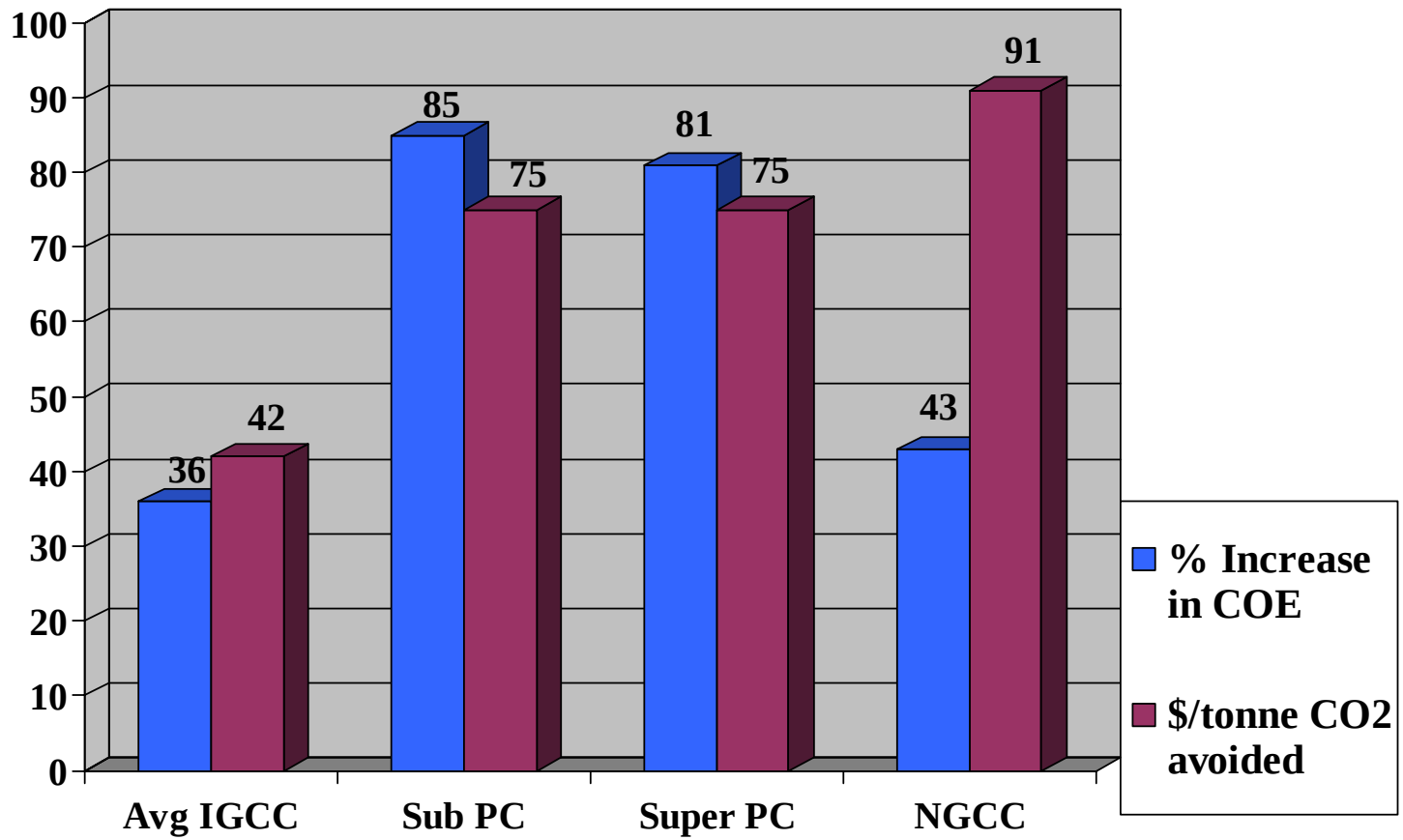
CCS = Carbon capture and sequestration

Cost of Electricity

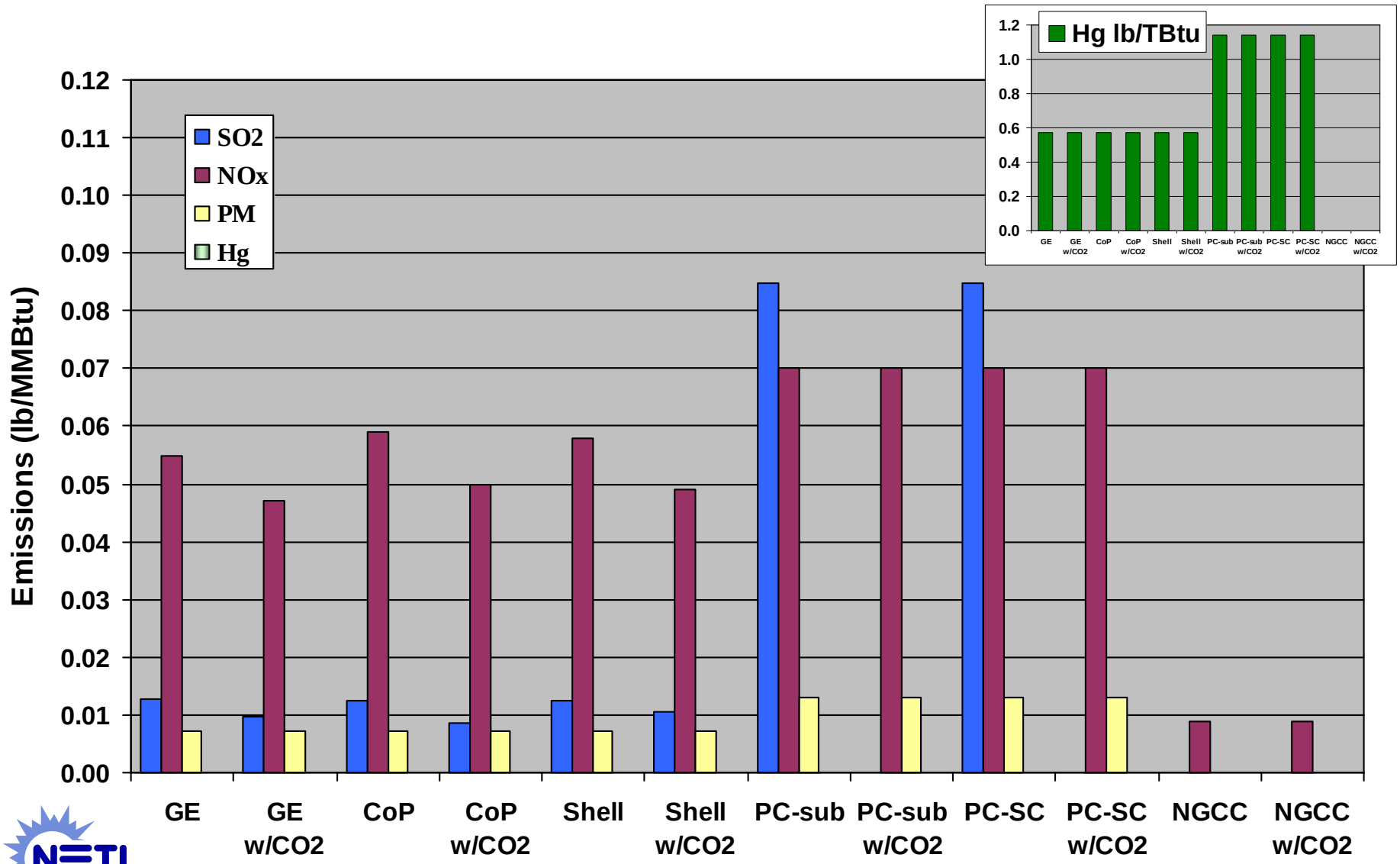


January 2007 Dollars, Coal cost $1.80/10^{6}Btu, Gas cost $6.75/10^{6}Btu
CCS = Carbon capture and sequestration
TS&M = transport, storage, and monitoring

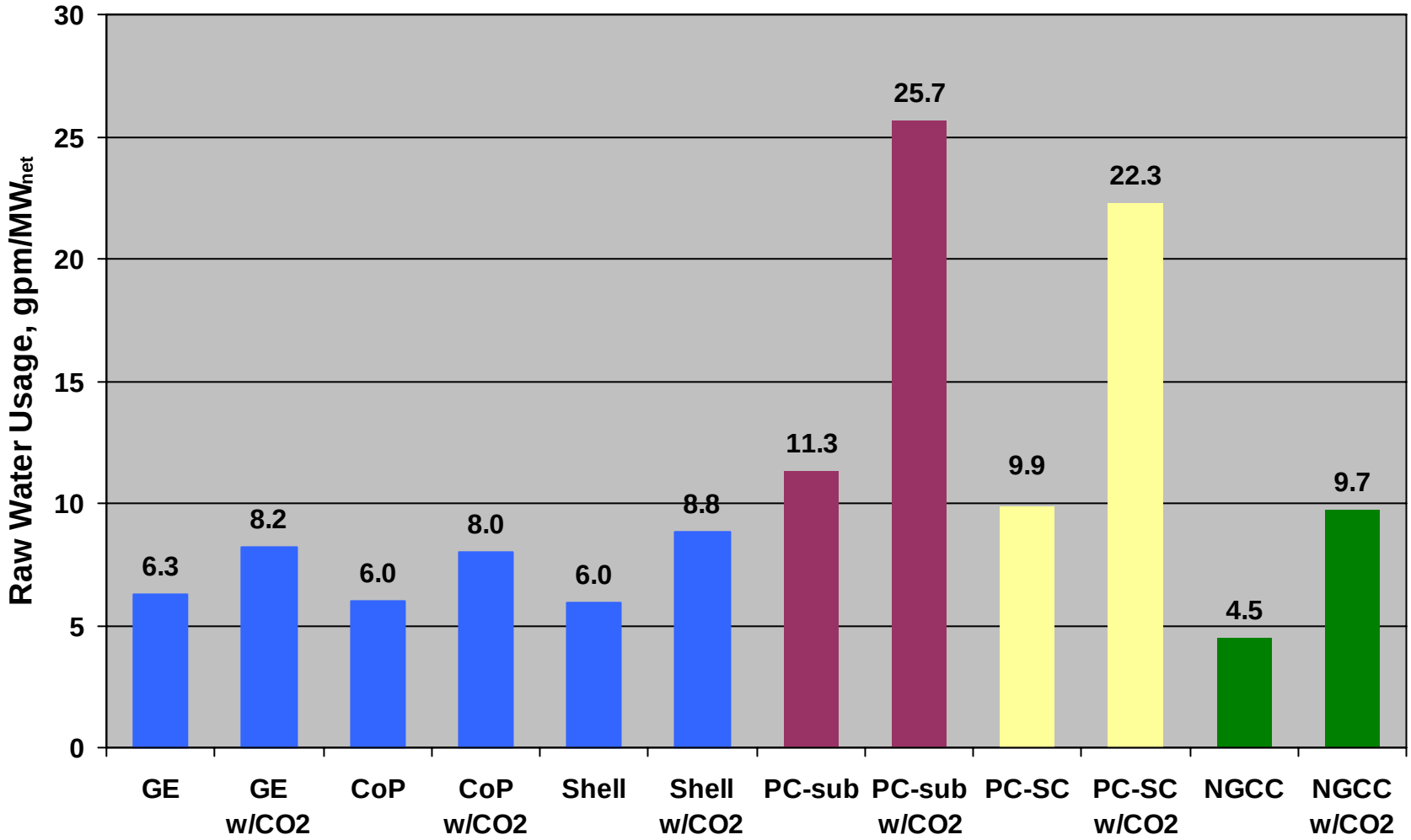
CO_2 Mitigation Costs



Criteria Pollutant Emissions for All Cases



Raw Water Usage per MW_{net}
(Absolute)



Result Highlights

- **Coal-based plants using today's technology are efficient and clean**

- **20 year levelized COE: PC lowest cost generator**
  - IGCC total plant cost ~20% higher than PC

- **With CCS: IGCC lowest coal-based option for CCS**
  - PC TPC > IGCC TPC
  - PC efficiency < IGCC efficiency

- **LCOE* equal when natural gas price is:**
  - No Capture IGCC: $7.99/MMBtu PC: $6.15/MMBtu
  - With Capture IGCC: $7.73/MMBtu PC: $8.87/MMBtu

* At baseline coal cost of $1.80/MMBtu

NETL Viewpoint

- **Improved efficiencies and reduced costs are required to improve competitiveness of advanced coal-based systems**
  - In today's market and regulatory environment
  - Also in a carbon constrained scenario
- **Opportunities for Fossil Energy RD&D**
  - Improve performance and cost of clean coal power systems including development of new approaches to capture and sequester greenhouse gases

Thank You!!

Report, Desk Reference & Slides Available

http://www.netl.doe.gov/technologies/coalpower/refshelf.html

"Cost and Performance Baseline of Fossil Energy Plants," DOE/NETL-2007/1281, May 2007.

"Fossil Energy Power Plant Desk Reference" DOE/NETL-2007/1282, May 2007.

Backup Slides

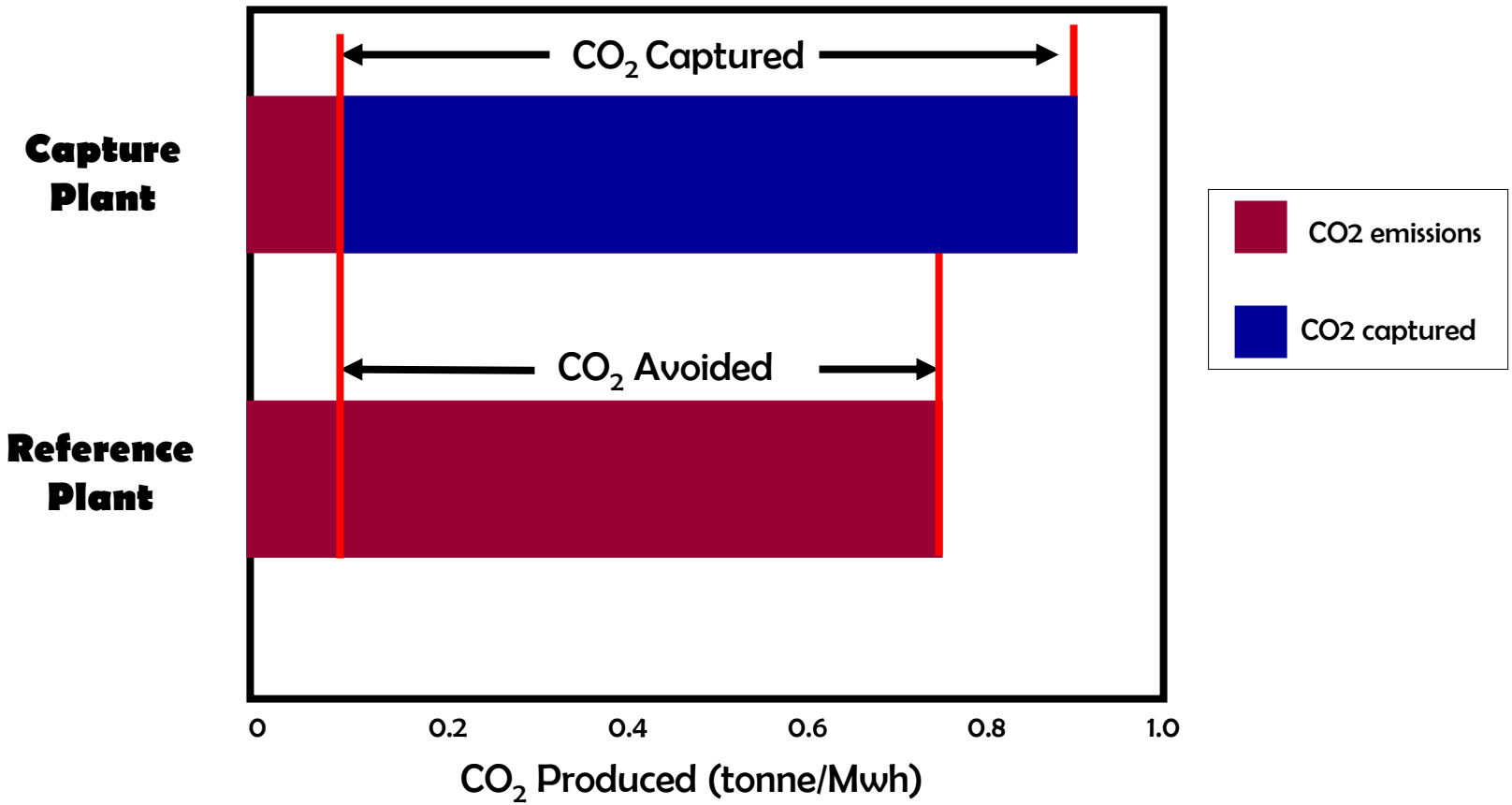
Removal Cost versus Avoided Cost

- **$/tonne of CO2 captured (removed)**
  - Function of the bulk quantity of CO2 removed from the capture power plant and the increase in COE required for capture
    - Difference in COE divided by amount of CO2 captured in the capture plant

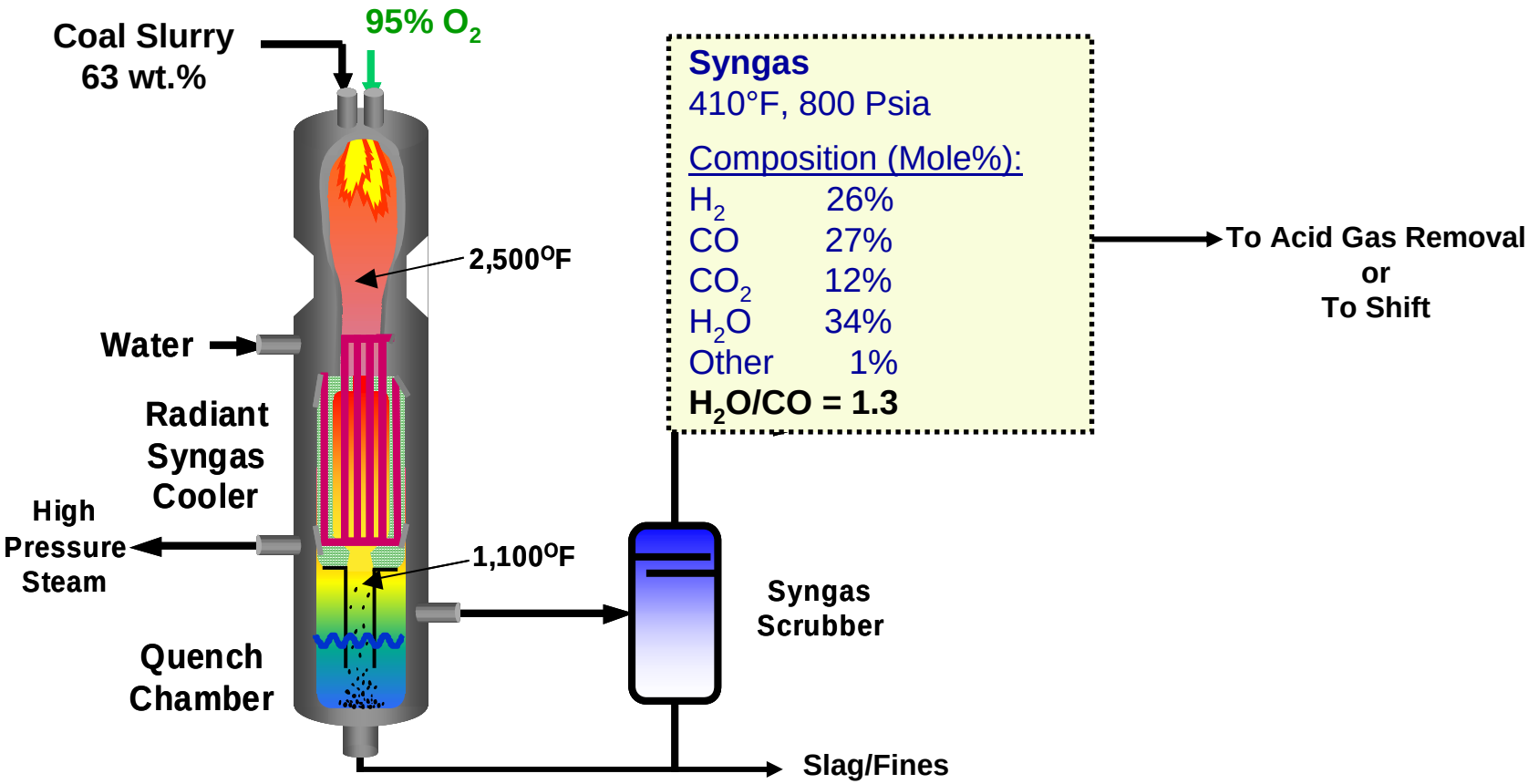
- **$/tonne of CO2 avoided (mitigation cost)**
  - Accounts for the extra energy (auxiliary power) spent to capture CO2, which increases total CO2 per net MWh
    - Difference in COE divided by difference in emissions between reference plant and capture plant

Comparison of CO2 Removed and Avoided

The amount of CO2 avoided is always less than the amount of CO2 captured



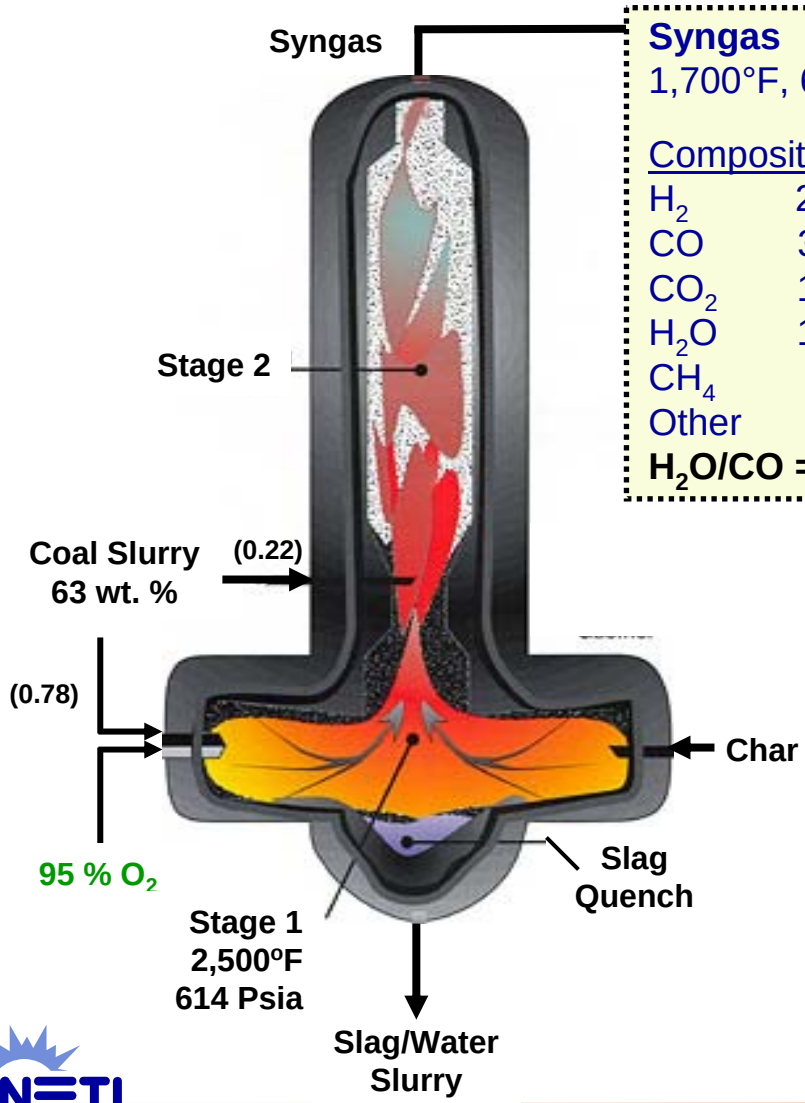
GE Energy Radiant



Design: Pressurized, single-stage, downward firing, entrained flow, slurry feed, oxygen blown, slagging, radiant and quench cooling

Note: All gasification performance data estimated by the project team to be representative of GE gasifier

ConocoPhillips E-Gas™



Syngas
1,700°F, 614 psia

Composition (Mole%):

H_2	26%
CO	37%
CO_2	14%
H_2O	15%
CH_4	4%
Other	4%

H_2O/CO = 0.4

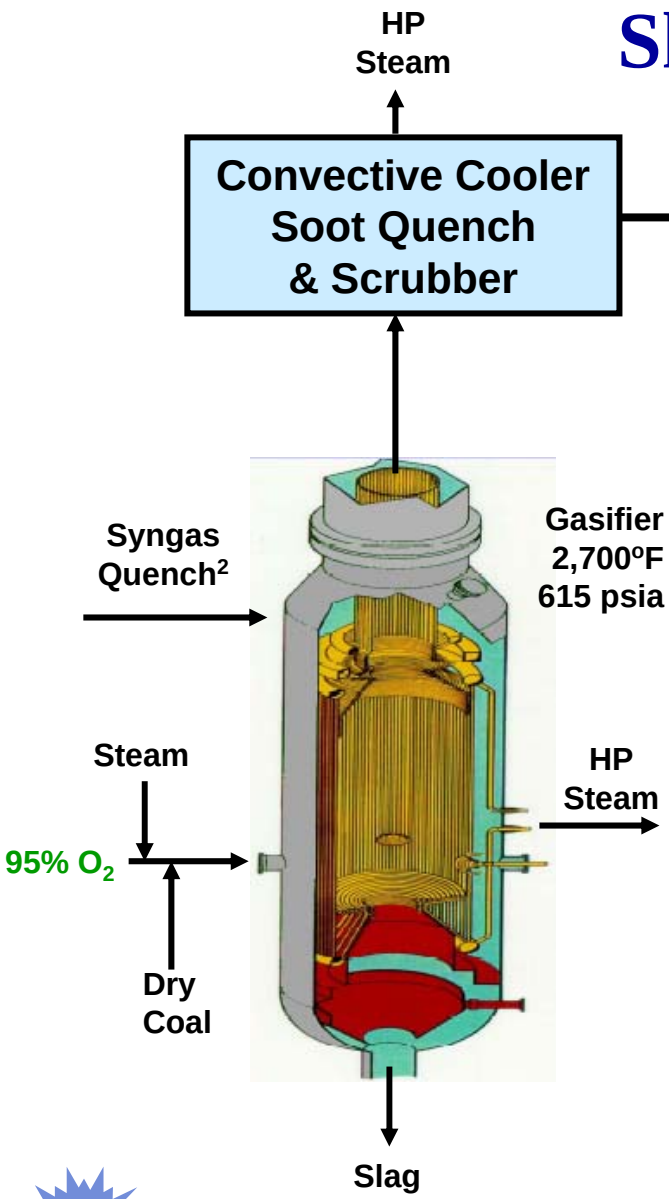
To Fire-tube boiler

To Acid Gas Removal or To Shift

Design: Pressurized, two-stage, upward firing, entrained flow, slurry feed, oxygen blown, slagging, fire-tube boiling syngas cooling, syngas recycle

Note: All gasification performance data estimated by the project team to be representative of an E-Gas gasifier

Shell Gasification



Design: Pressurized, single-stage, downward firing, entrained flow, dry feed, oxygen blown, convective cooler

Notes:

1. All gasification performance data estimated by the project team to be representative of Shell gasifier.
2. CO_2 capture incorporates full water quench instead of syngas quench.

650°F

Syngas
350°F, 600 Psia

Composition (Mole%):

H_2	29%
CO	57%
CO_2	2%
H_2O	4%
Other	8%

H_2O/CO = 0.1

To Acid Gas Removal or To Shift

Source: "The Shell Gasification Process", Uhde, ThyssenKrupp Technologies

IGCC Performance Results

	GE Energy		E-Gas		Shell	
CO_2 Capture	**NO**	**YES**	**NO**	**YES**	**NO**	**YES**
Gross Power (MW)	**770**	**745**	**742**	**694**	**748**	**693**
Auxiliary Power (MW)						
Base Plant Load	23	23	25	26	21	19
Air Separation Unit	103	121	91	109	90	113
Gas Cleanup/CO_2 Capture	4	18	3	15	1	16
CO_2 Compression	-	27	-	26	-	28
Total Aux. Power (MW)	130	189	119	176	112	176
Net Power (MW)	640	556	623	518	636	517
Heat Rate (Btu/kWh)	8,922	10,505	8,681	10,757	8,304	10,674
Efficiency (HHV)	**38.2**	**32.5**	**39.3**	**31.7**	**41.1**	**32.0**
Energy Penalty[1]	**-**	**5.7**	**-**	**7.6**	**-**	**9.1**

[1] CO_2 Capture Energy Penalty = Percent points decrease in net power plant efficiency due to CO_2 Capture

IGCC Economic Results

	GE Energy		E-Gas		Shell	
CO_2 Capture	**NO**	**YES**	**NO**	**YES**	**NO**	**YES**
Plant Cost ($/kWe)[1]						
Base Plant	1,323	1,566	1,272	1,592	1,522	1,817
Air Separation Unit	287	342	264	329	256	336
Gas Cleanup/CO_2 Capture	203	414	197	441	199	445
CO_2 Compression	-	68	-	69	-	70
Total Plant Cost ($/kWe)	**1,813**	**2,390**	**1,733**	**2,431**	**1,977**	**2,668**
Capital COE (¢/kWh)	4.53	5.97	4.33	6.07	4.94	6.66
Variable COE (¢/kWh)	3.27	3.93	3.20	4.09	3.11	3.97
CO_2 TS&M COE (¢/kWh)	0.00	0.39	0.00	0.41	0.00	0.41
Total COE[2] (¢/kWh)	**7.80**	**10.29**	**7.53**	**10.57**	**8.05**	**11.04**
Increase in COE (%)	**-**	**32**	**-**	**40**	**-**	**37**
$/tonne CO_2 Avoided	-	35	-	45	-	46

[1]Total Plant Capital Cost (Includes contingencies and engineering fees)

[2]January 2007 Dollars, 80% Capacity Factor, 17.5% Capital Charge Factor, Coal cost $1.80/$10^6$Btu

PC and NGCC Performance Results

	Subcritical		Supercritical		NGCC	
CO_2 Capture	**NO**	**YES**	**NO**	**YES**	**NO**	**YES**
Gross Power (MW)	**583**	**680**	**580**	**663**	**570**	**520**
Base Plant Load	29	48	26	43	10	13
Gas Cleanup/CO_2 Capture	4	30	4	27	0	10
CO_2 Compression	-	52	-	47	0	15
Total Aux. Power (MW)	**33**	**130**	**30**	**117**	**10**	**38**
Net Power (MW)	550	550	550	546	560	482
Heat Rate (Btu/kWh)	9,276	13,724	8,721	12,534	6,719	7,813
Efficiency (HHV)	**36.8**	**24.9**	**39.1**	**27.2**	**50.8**	**43.7**
Energy Penalty[1]	**-**	**11.9**	**-**	**11.9**	**-**	**7.1**

[1]CO_2 Capture Energy Penalty = Percent points decrease in net power plant efficiency due to CO_2 Capture

PC and NGCC Economic Results

	Subcritical		Supercritical		NGCC	
CO_2 Capture	NO	YES	NO	YES	NO	YES
Plant Cost ($/kWe)[1]						
Base Plant	1,302	1,689	1,345	1,729	554	676
Gas Cleanup (SOx/NOx)	246	323	229	302	-	-
CO_2 Capture	-	792	-	752	-	441
CO_2 Compression	-	89	-	85	-	52
Total Plant Cost ($/kWe)	**1,549**	**2,895**	**1,575**	**2,870**	**554**	**1,172**
Capital COE (¢/kWh)	3.41	6.81	3.47	6.75	1.22	2.75
Variable COE (¢/kWh)	2.99	4.64	2.86	4.34	5.62	6.70
CO_2 TS&M COE (¢/kWh)	0.00	0.43	0.00	0.39	0.00	0.29
Total COE[2] (¢/kWh)	**6.40**	**11.88**	**6.33**	**11.48**	**6.84**	**9.74**
Increase in COE (%)	**-**	**85**	**-**	**81**	**-**	**43**
$/tonne CO_2 Avoided	-	75	-	75	-	91

[1]Total Plant Capital Cost (Includes contingencies and engineering fees)

[2]January 2007 Dollars, 85% Capacity Factor, 16.4% (no capture) 17.5% (capture) Capital Charge Factor, Coal cost $1.80/10^{6}Btu, Natural Gas cost $6.75/10^{6}Btu