Comparative Assessments of PC, NGCC and IGCC Power Plants With and Without CO_2 Capture and Storage

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Objectives

- Compare the performance and cost of current fossil fuel power systems with and without CO_2 capture and storage (CCS)
  - Pulverized coal combustion (PC)
  - Integrated coal gasification combined cycle (IGCC)
  - Natural gas combined cycle (NGCC)

What's New Here?

- We explore a broader range of conditions that influence comparisons among these technologies
- We highlight the implications of CCS energy penalties on resource requirements, multi-pollutant emissions, and cross-media environmental impacts
- We use the (publicly available) IECM computer model to systematically evaluate all three systems

The Integrated Environmental Control Model (IECM)

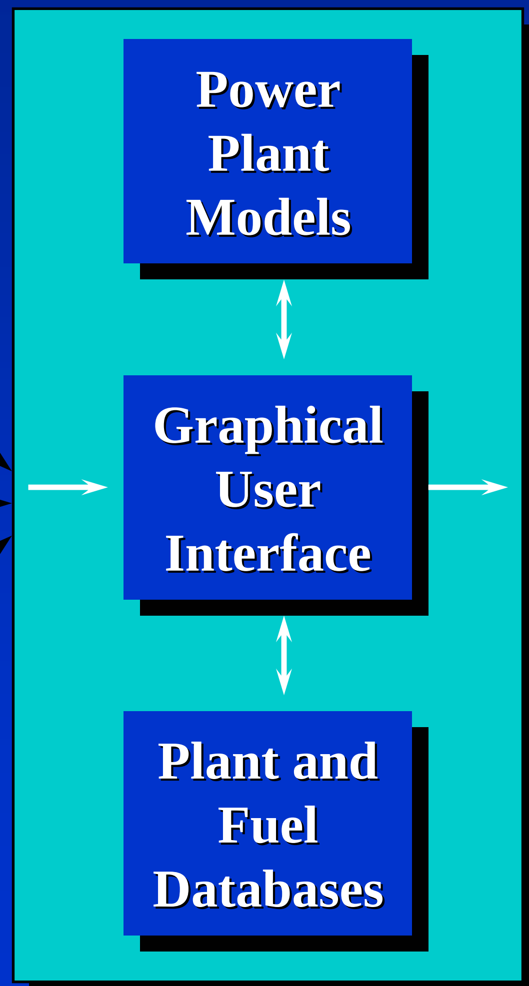
- Estimates the performance, emissions, and cost of power generation and emissions control for a single facility (based on user-specified configuration and parameters)
- Developed for DOE/NETL, originally to model options for controlling air pollutants at coal-fired power plants
- Expanded in recent years to include CCS technologies, and a broader array of fossil fuel power systems
- Provides users with a flexible and systematic framework to evaluate and compare alternative options (including effects of uncertainties, if desired)

IECM Software Package

Fuel Properties
- Heating Value
- Composition
- Delivered Cost

Plant Design
- Conversion Process
- Emission Controls
- Solid Waste Mgmt
- Chemical Inputs

Cost Data
- O&M Costs
- Capital Costs
- Financial Factors

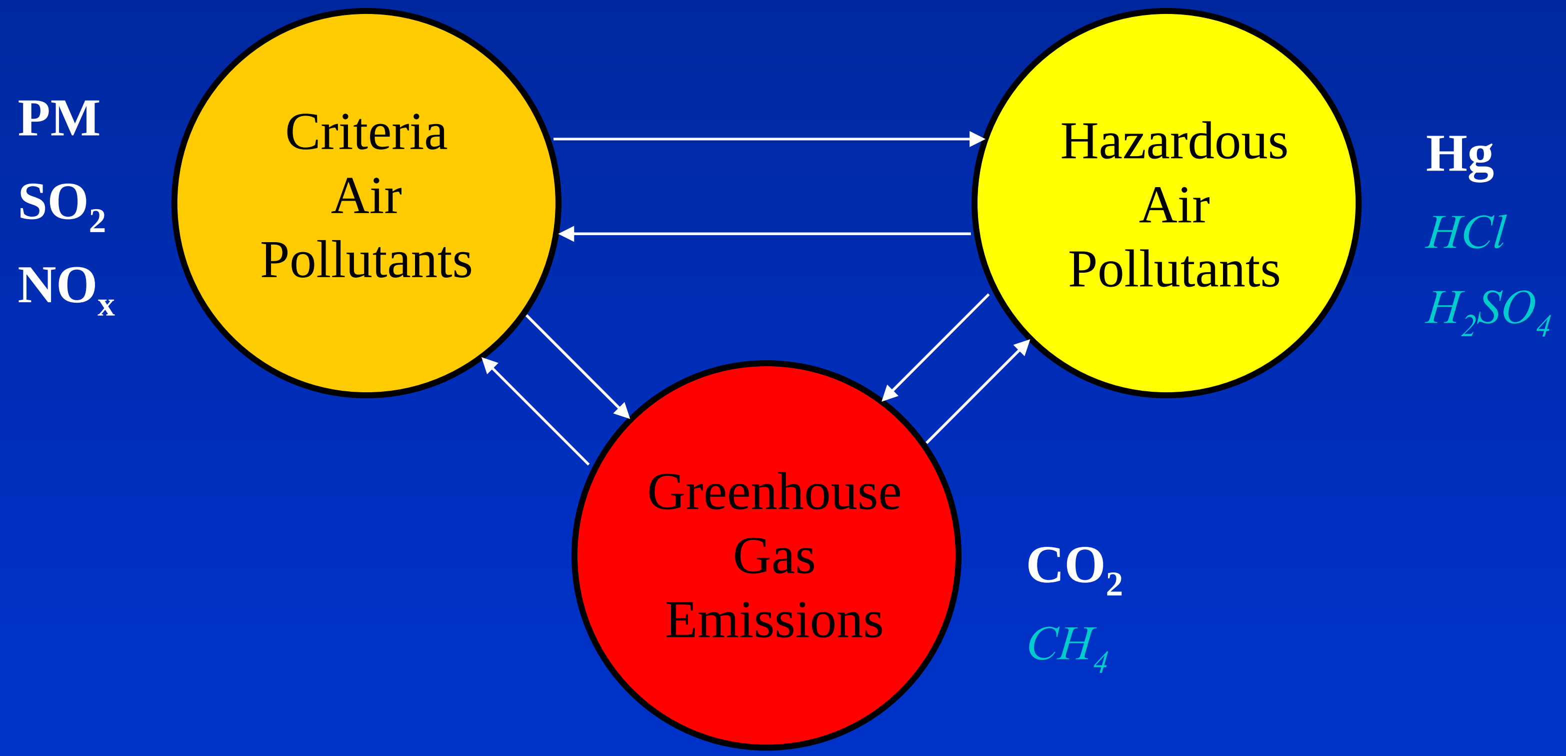


Plant & Process Performance
- Efficiency
- Resource use

Environmental Emissions
- Air, water, land

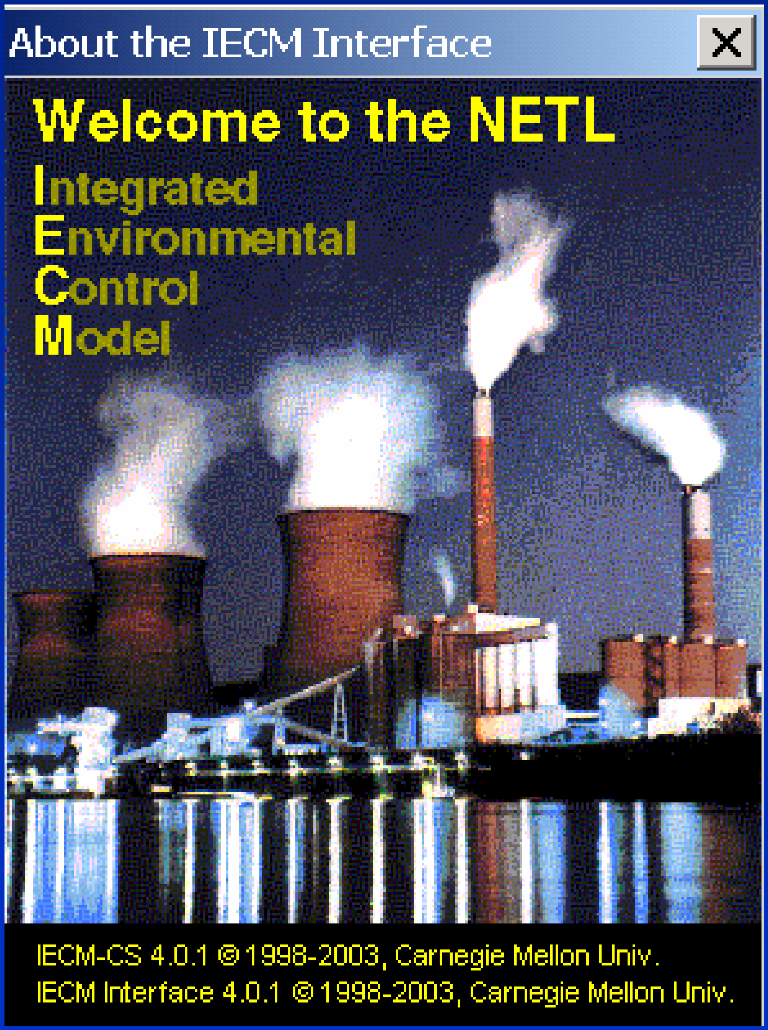
Plant & Process Costs
- Capital
- O&M
- COE

Multi-Pollutant Interactions

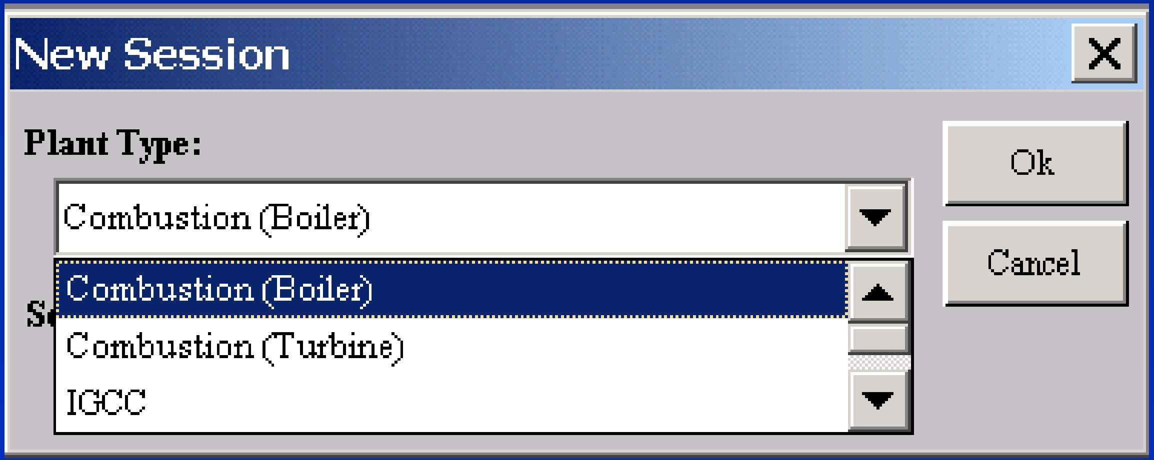


Sample Screens from the User Interface

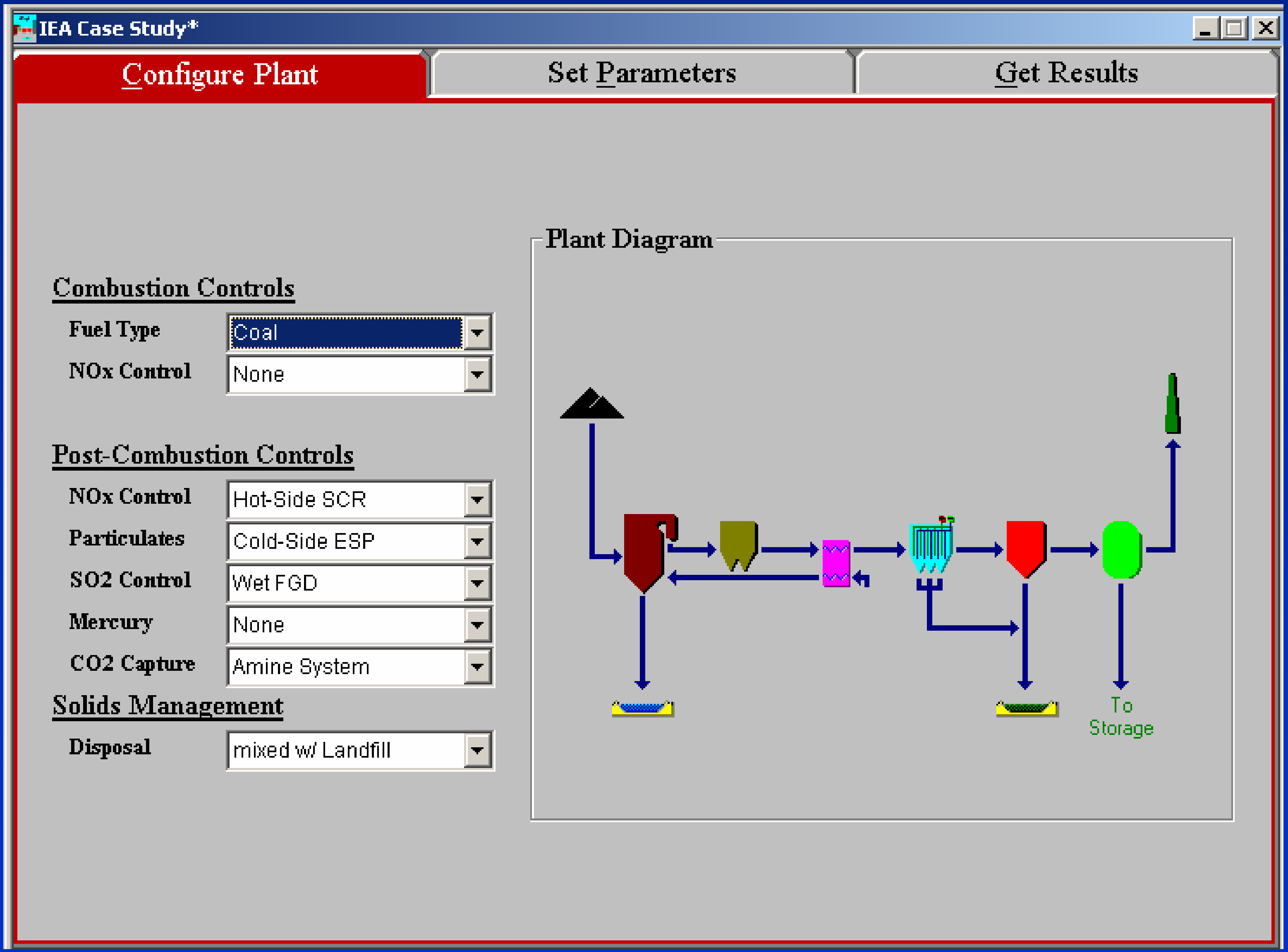
(IECM 4.0.1)



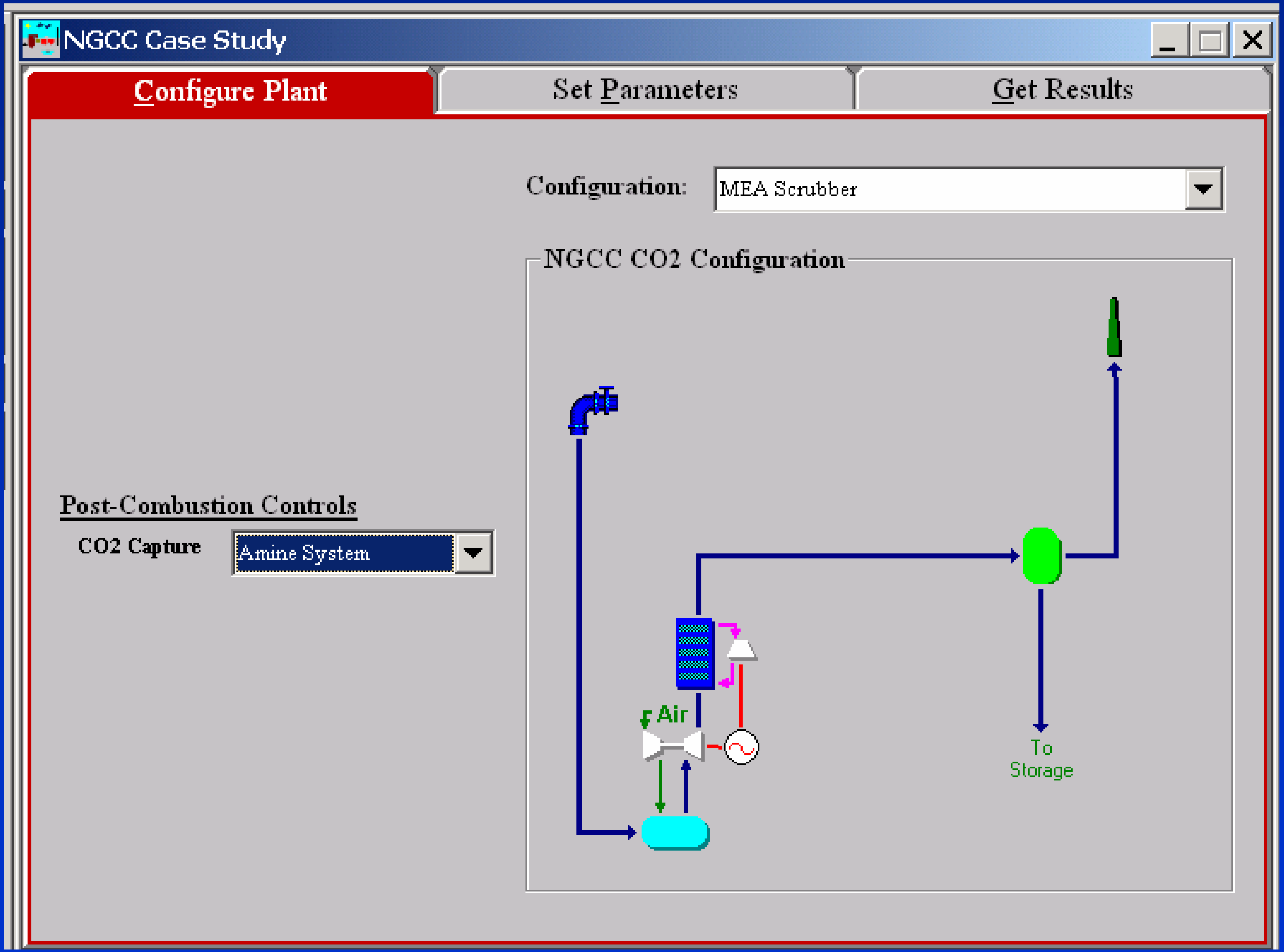
Select Plant Type



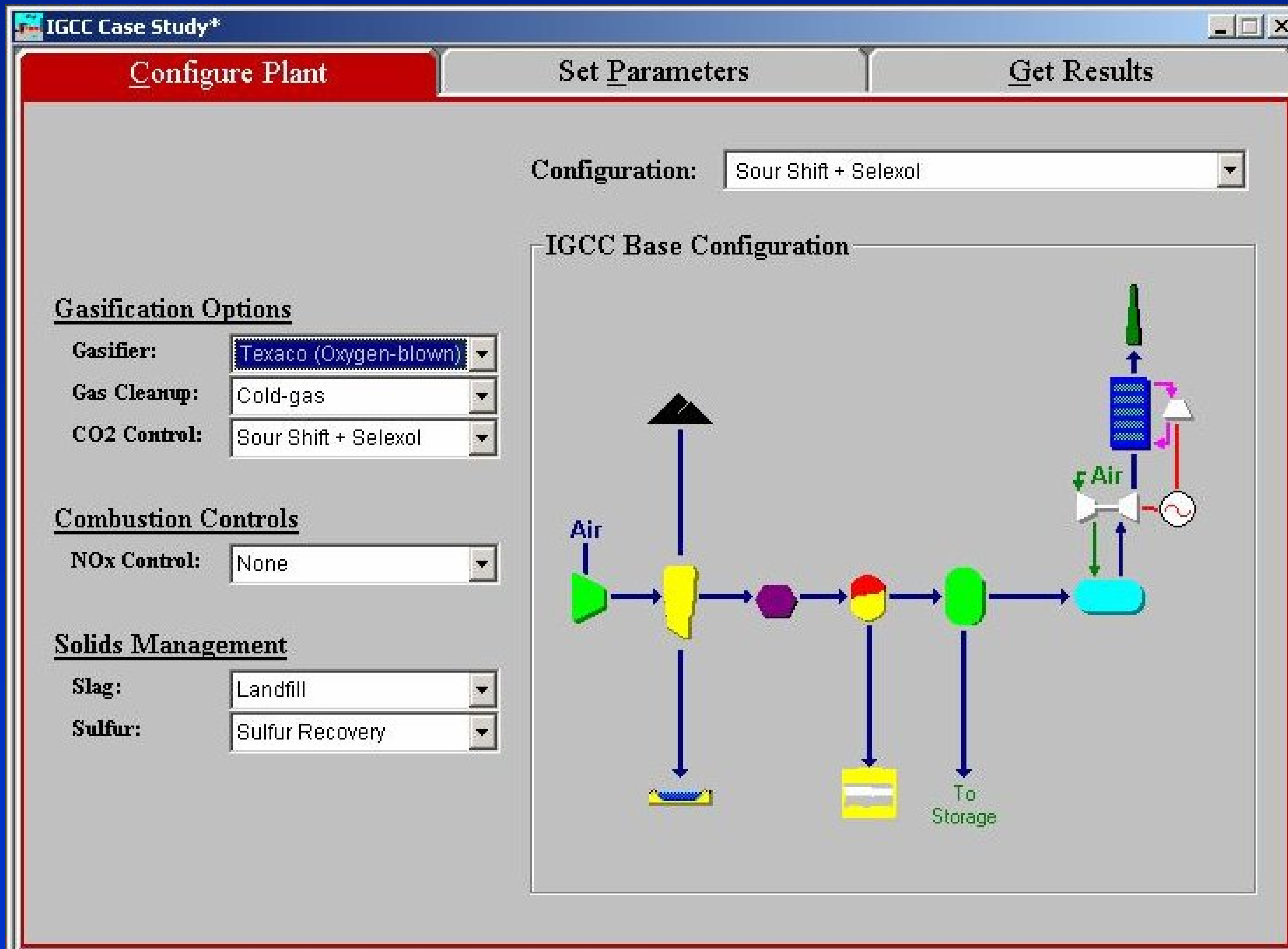
PC Plant with CO_2 Capture



NGCC Plant with CO_2 Capture



IGCC Plant with CO_2 Capture



Set Financial Parameters

IGCC Case Study*

Configure Plant | **Set Parameters** | Get Results

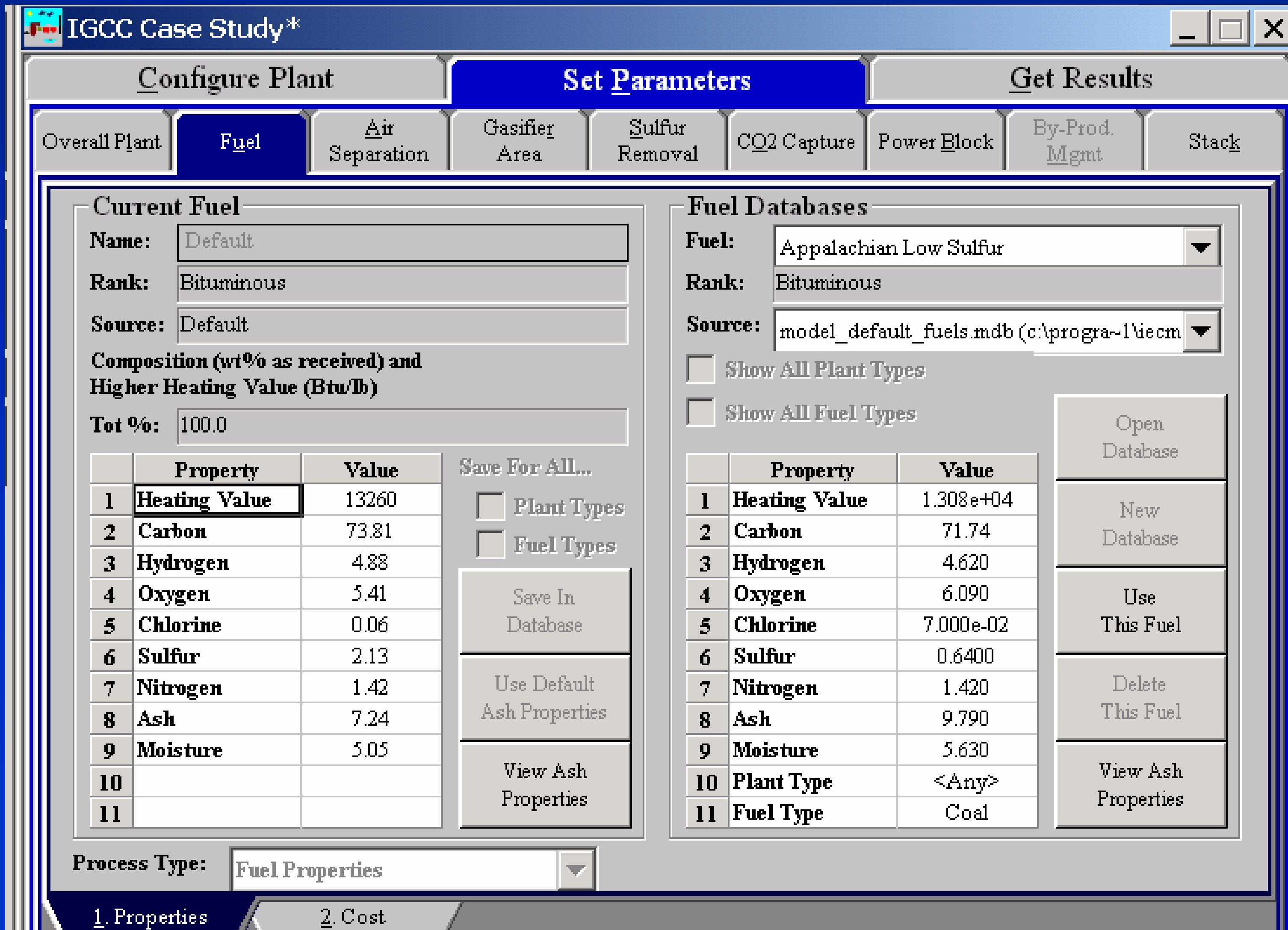
Overall Plant | Fuel | Air Separation | Gasifier Area | Sulfur Removal | CO2 Capture | Power Block | By-Prod. Mgmt | Stack

	Title	Units	Unc	Value	Calc	Min	Max	Default
1	Year Costs Reported			2000		Menu	Menu	2000
2	Constant or Current Dollars?			Constant		Menu	Menu	Constant
3	Fixed Charge Factor (FCF)	fraction		0.1480	✓	0.0	1.000	calc
4	Discount Rate (Before Taxes)	fraction		0.1030	✓	0.0	2.000	calc
5	*Or, specify all the following:*							
6	Inflation Rate	%/yr		0.0	✓	0.0	20.00	calc
7	Plant or Project Book Life	years		30.00		5.000	60.00	30.00
8	Real Bond Interest Rate	%		9.000		0.0	15.00	9.000
9	Real Preferred Stock Return	%		8.500		0.0	20.00	8.500
10	Real Common Stock Return	%		12.00		0.0	25.00	12.00
11	Percent Debt	%		45.00		0.0	100.0	45.00
12	Percent Equity (Preferred Stock)	%		10.00		0.0	100.0	10.00
13	Percent Equity (Common Stock)	%		45.00	✓	0.0	100.0	calc
14								
15	Federal Tax Rate	%		35.00		15.00	50.00	35.00
16	State Tax Rate	%		4.000		0.0	10.00	4.000
17	Property Tax Rate	%		2.000		0.0	5.000	2.000
18	Investment Tax Credit	%		0.0		0.0	20.00	0.0

Process Type: Overall Plant

1. Diagram | 2. Performance | 3. Financing

Specify Fuel Properties



Set Power Block Performance Parameters

IGCC Case Study*

Configure Plant | **Set Parameters** | Get Results

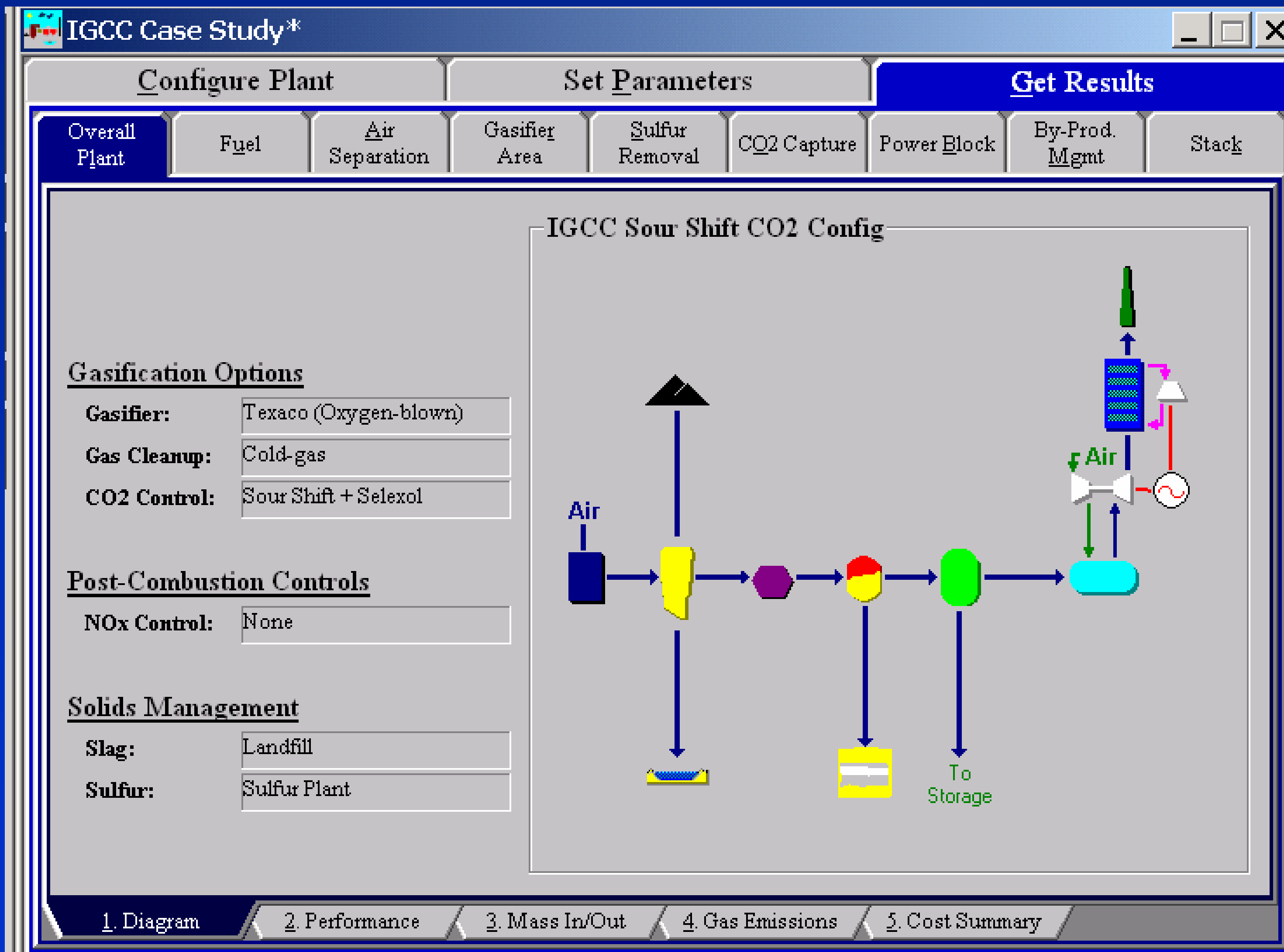
Overall Plant | Fuel | Air Separation | Gasifier Area | Sulfur Removal | CO2 Capture | **Power Block** | By-Prod. Mgmt | Stack

	Title	Units	Unc	Value	Calc	Min	Max	Default
1	Gas Turbine/Generator							
2	Gas Turbine Model			GE 7FA+		Menu	Menu	GE 7FA+e
3	Gas Turbine Size (Nominal)	MW		410.5	✓	0.0	5000	calc
4	No. of Gas Turbines	integer		2		Menu	Menu	2
5	Inlet Water Content	vol %		33.00	✓	0.0	100.0	calc
6	Turbine Inlet Temperature	deg. F		2420	✓	2000	2500	calc
7	Turbine Back Pressure	psia		2.000		0.0	10.00	2.000
8	Adiabatic Turbine Efficiency	%		95.00		0.0	100.0	95.00
9	Shaft/Generator Efficiency	%		98.00		0.0	100.0	98.00
10	Air Compressor							
11	Pressure Ratio (outlet/inlet)	ratio		15.70		1.000	25.00	15.70
12	Adiabatic Compressor Efficiency	%		70.00		0.0	100.0	70.00
13	Ambient Air Temperature	deg. F		77.00		-50.00	130.0	77.00
14	Ambient Air Pressure	psia		14.70		12.00	15.00	14.70
15	Combustor							
16	Combustor Inlet Pressure	psia		294.0		0.0	350.0	294.0
17	Combustor Pressure Drop	psia		4.000		0.0	10.00	4.000
18	Excess Air For Combustor	% stoich.		177.8	✓	0.0	400.0	calc

Process Type: Power Block

1. Gas Turbine | 2. Steam Cycle | 3. Emis. Factors | 4. Retrofit Cost | 5. Capital Cost | 6. O&M Cost

Get Results for Overall Plant



Get Results for Plant Mass Balance

IGCC Case Study*

Configure Plant | Set Parameters | **Get Results**

Overall Plant | Fuel | Air Separation | Gasifier Area | Sulfur Removal | CO2 Capture | Power Block | By-Prod. Mgmt | Stack

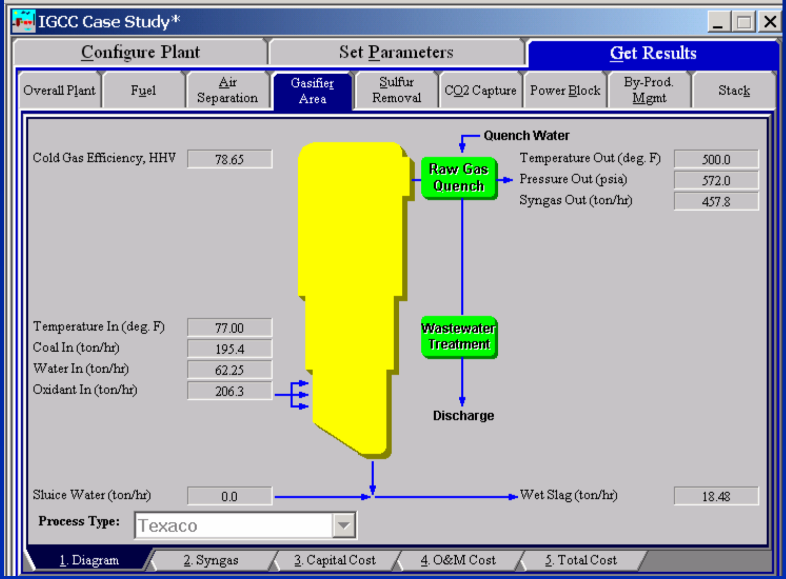
	Plant Inputs	Flow Rate (ton/hr)
1	Coal	195.4
2	Oil	0.6697
3	Natural Gas	0.0
4	Petroleum Coke	0.0
5	Other Fuels	5.860e-02
6	Total Fuels	196.1
7		
8	Lime/Limestone	0.0
9	Sorbent	0.0
10	Ammonia	0.0
11	Activated Carbon	0.0
12	Other Chemicals, Solvents & Catalyst	4.856e-03
13	Total Chemicals	4.856e-03
14		
15	Process Water	62.25

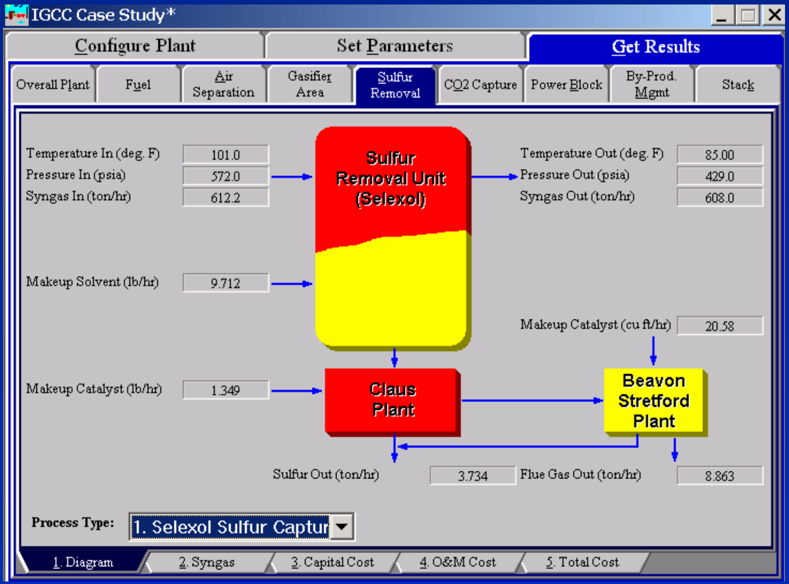
	Plant Outputs	Flow Rate (ton/hr)
1	Slag	18.48
2	Ash Disposed	0.0
3	Other Solids Disposed	0.0
4	Particulate Emissions to Air	2.591e-03
5	Captured CO2	464.9
6	By-Product Ash Sold	0.0
7	By-Product Gypsum Sold	0.0
8	By-Product Sulfur Sold	3.734
9	By-Product Sulfuric Acid Sold	0.0
10	Total Solids & Liquids	487.2
11		
12	*See Tab #4 for Total Gases*	
13		
14		
15		

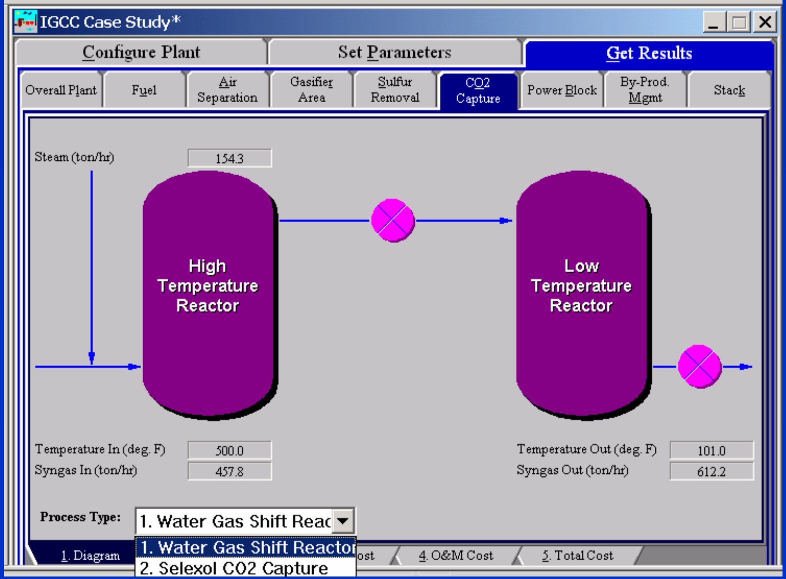
Process Type: Overall Plant

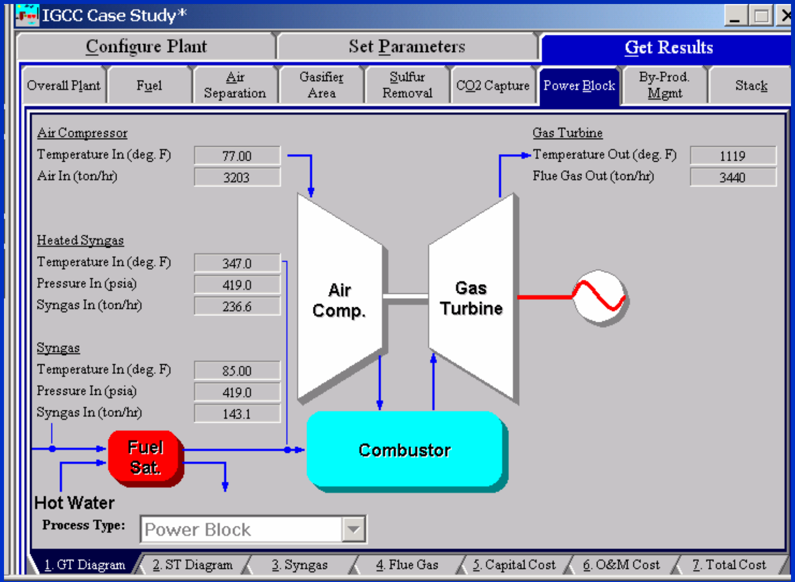
1. Diagram | 2. Performance | 3. Mass In/Out | 4. Gas Emissions | 5. Cost Summary

Get Results for Specific Components







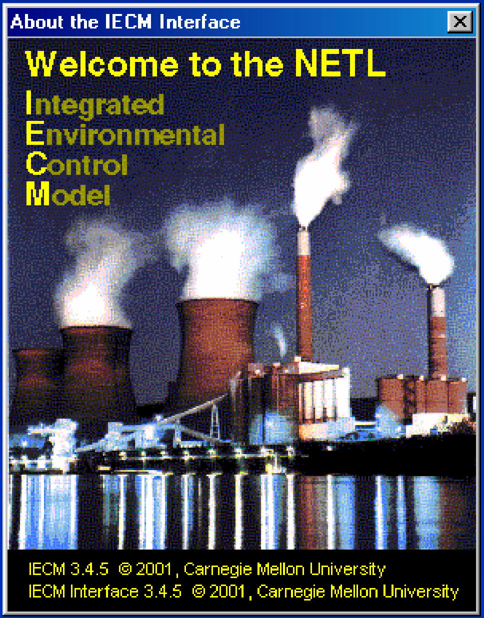


The IECM is Available At . . .

- **CO_2 Version (Beta):**
  - Contacts: rubin@cmu.edu
    mikeb@cmu.edu

- **Web Access :**
  - www. iecm-online.com

- **Technical Support:**
  - PED.modeling@netl.doe.gov



Case 1:

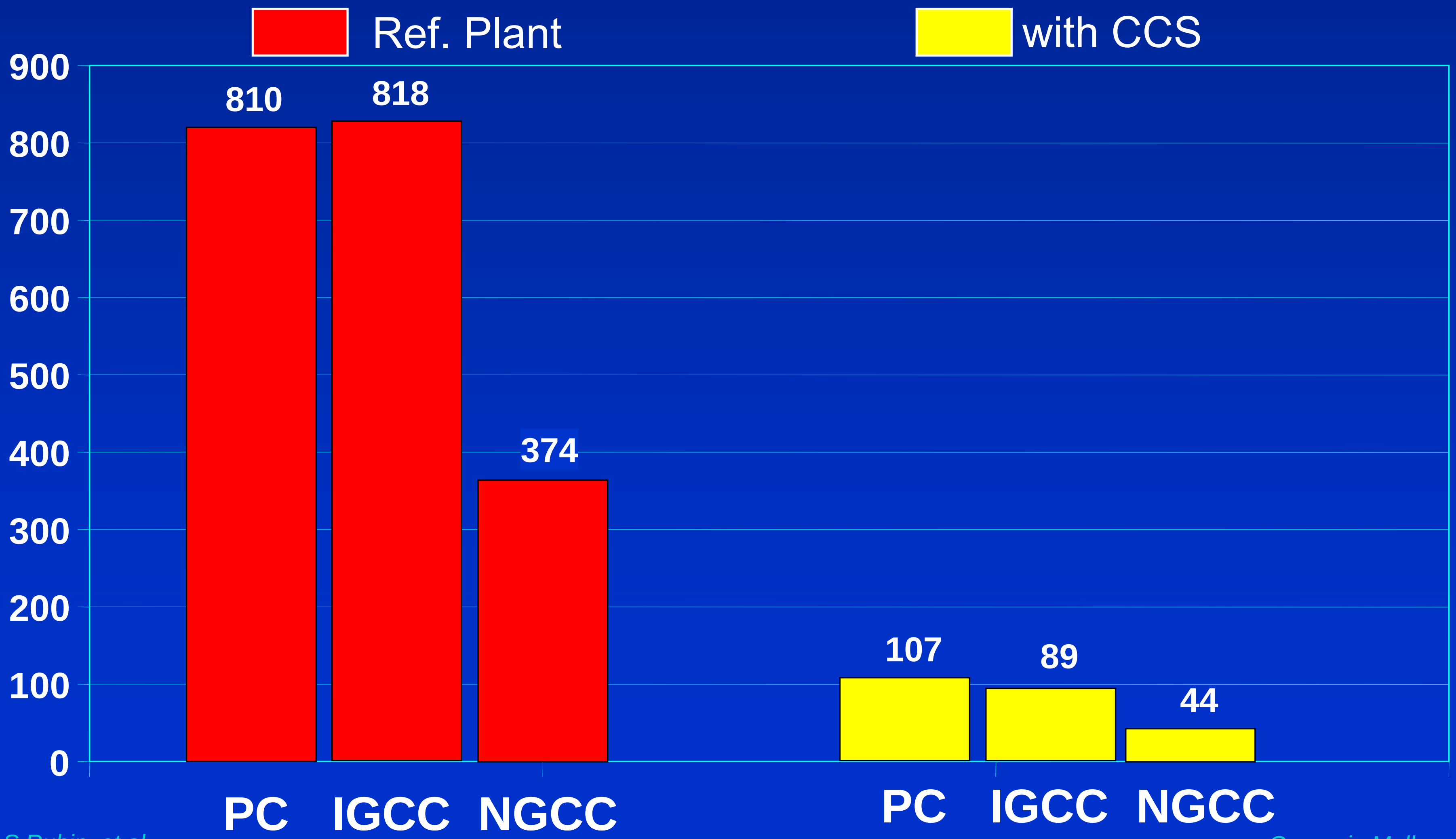
Nominal Assumptions

Nominal Case Study Assumptions

Parameter	NGCC	PC	IGCC
Reference Plant (~500 MW)	2 x 7FA	Supercritical	Texaco quench
Fuel Type	Nat. Gas	2%S Bit	2%S Bit
Net HHV Efficiency (%)	50.3	39.3	37.5
Capacity Factor (%)	75	75	75
Fuel Cost, HHV ($/GJ)	3.92	1.27	1.27
CCS Plant (~500 MW)			
CO_2 Capture System	Amine	Amine	Shift+Selexol
CO_2 Removal (%)	90	90	90
Pipeline Pressure (MPa)	13.8	13.8	13.8
Geologic Storage Option	Aquifer	Aquifer	Aquifer

Also: fixed charge factor = 0.148; all costs in constant 2002 US$

CO_2 Emission Rates (kg/MWh)



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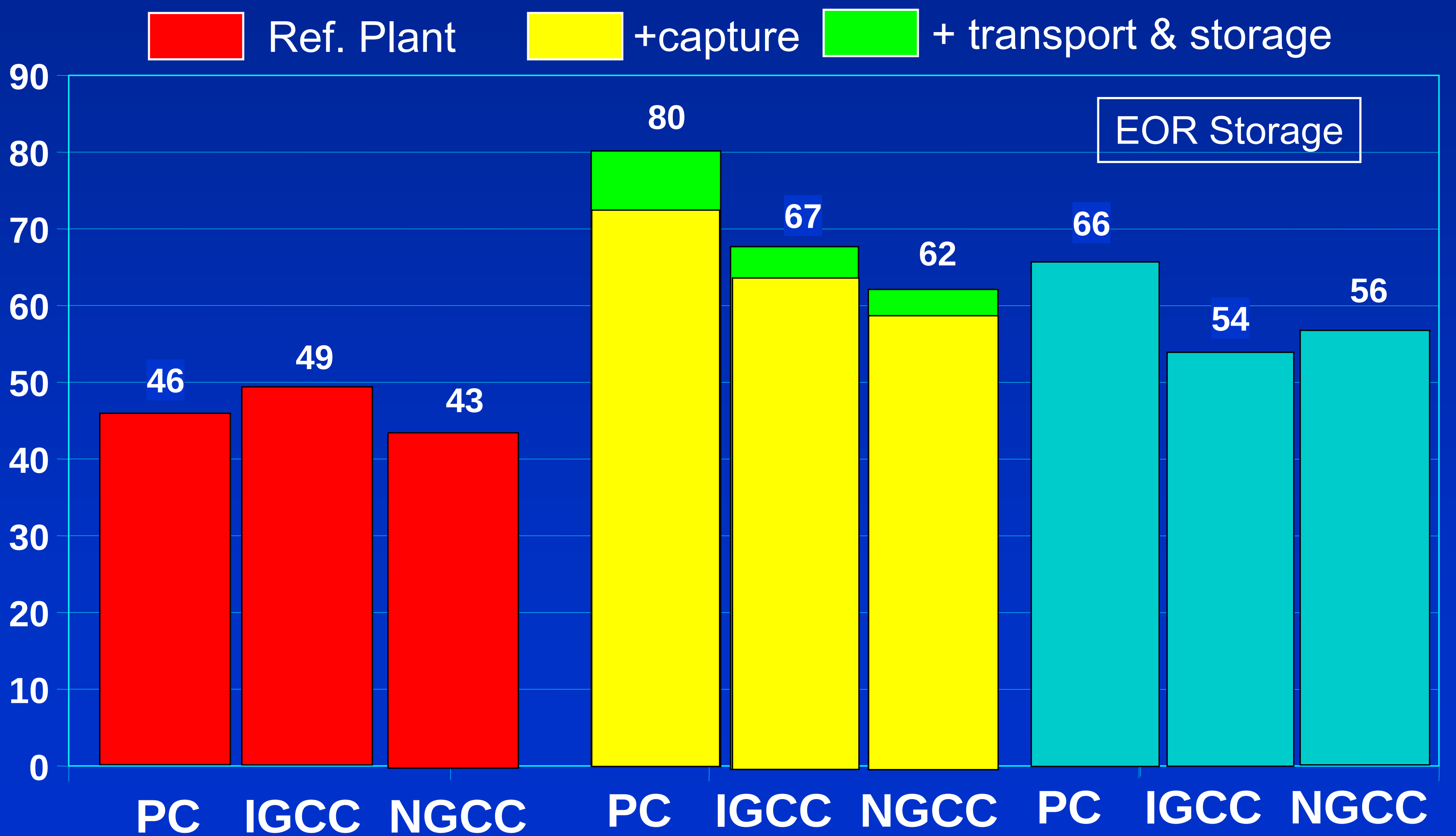
Cost of Electricity (COE)
(Levelized $/MWh)



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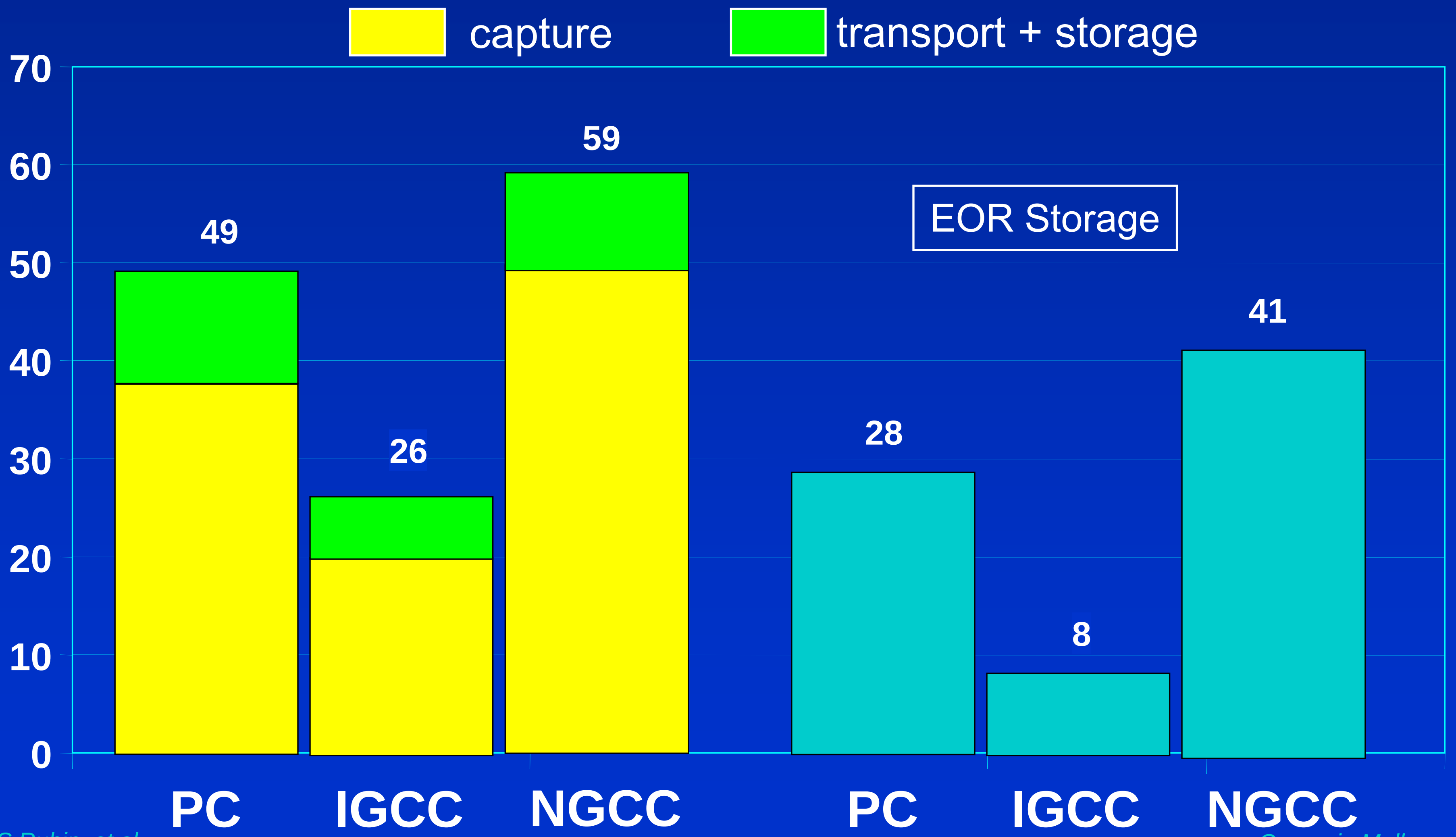
Cost of CO_2 Avoided (\$/tonne CO_2)



Case 2:

Effects of Fuel Price and Plant Dispatch

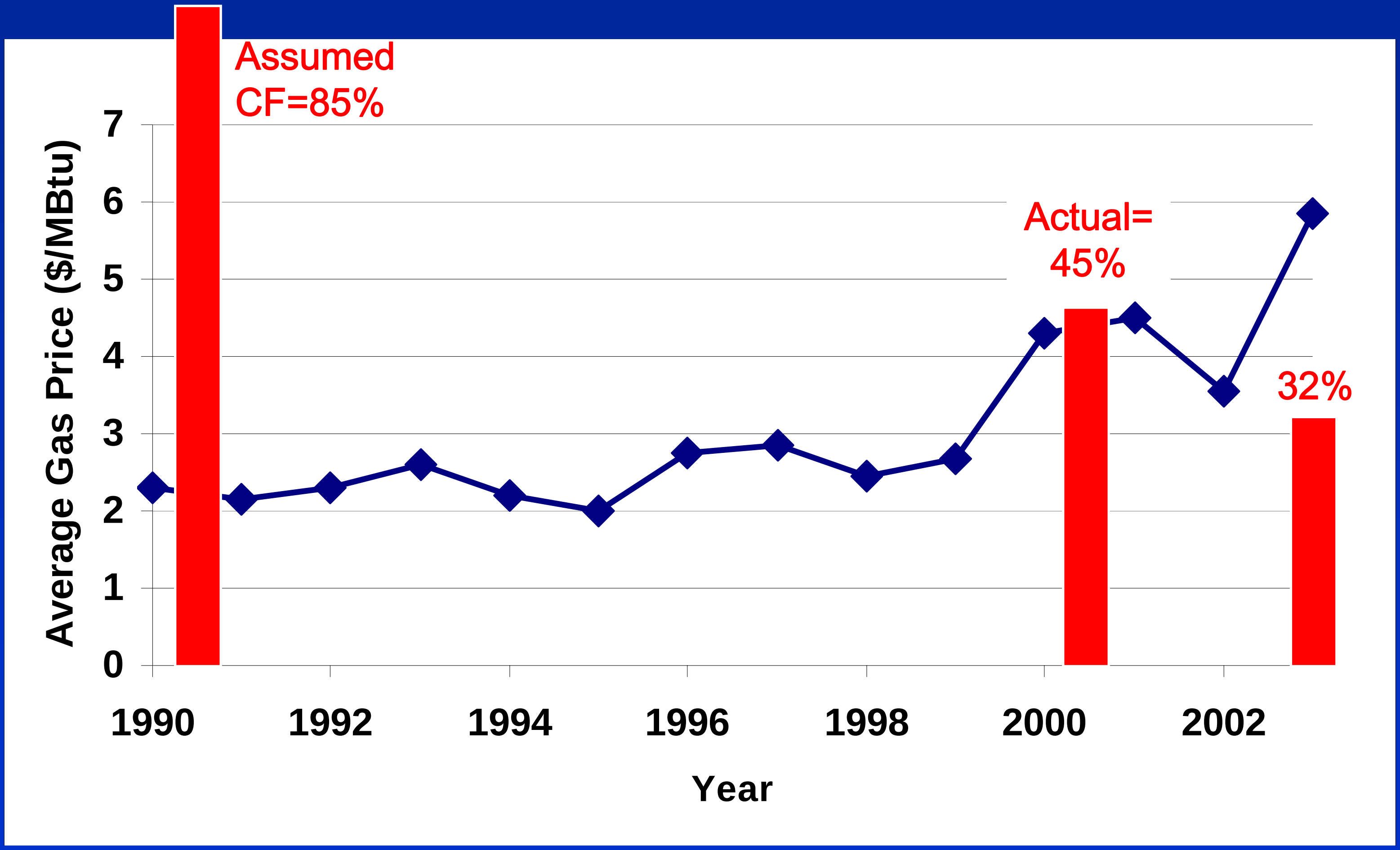
Differences in Total Variable Operating Cost ($/MWh)

(Includes fuel, chemicals, utilities, wastes and byproducts)

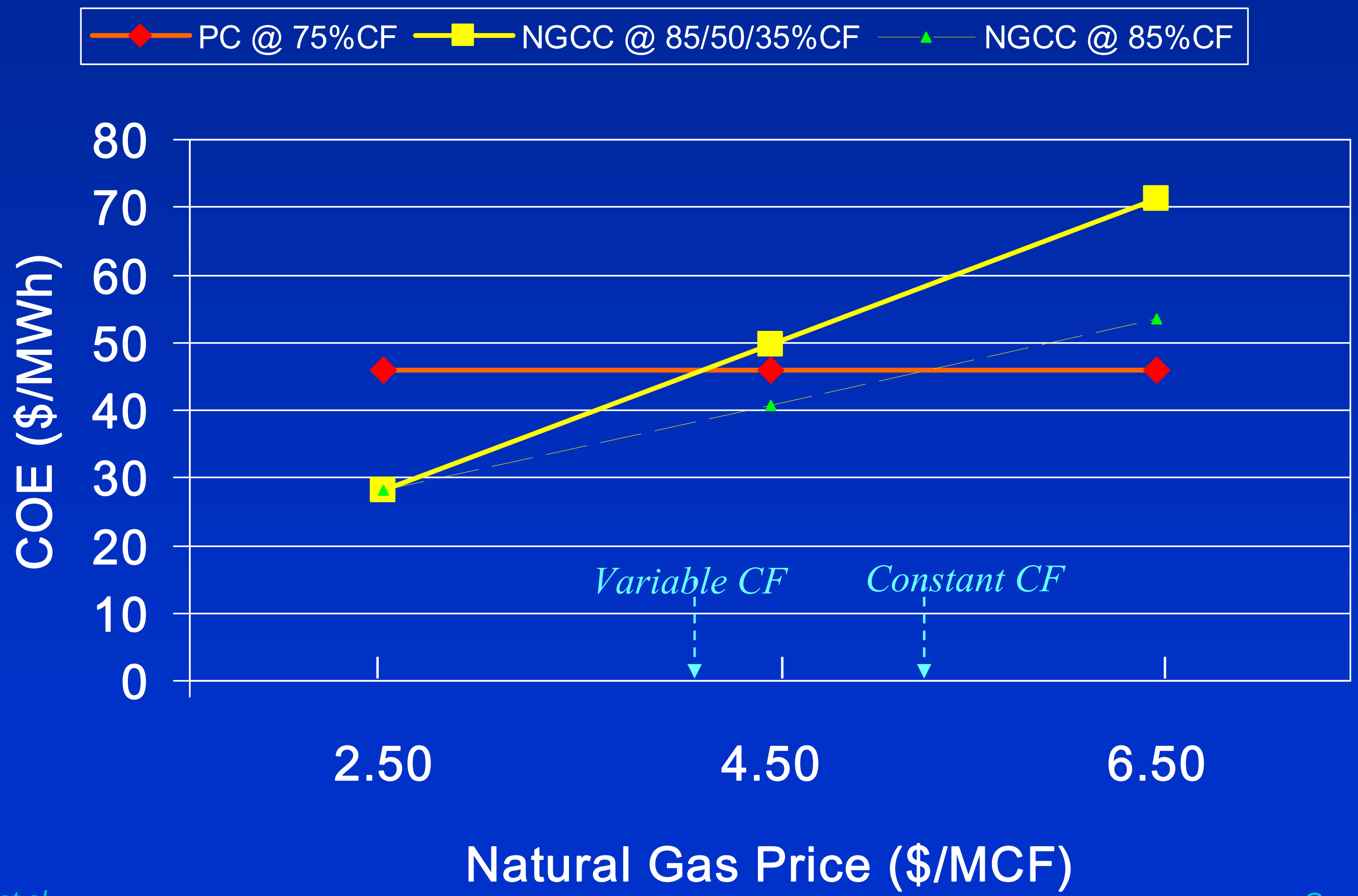
Plant	Fuel Price	Ref. Plant
PC	$1.27/ MBtu	(Base case)
IGCC	$1.27/ MBtu	~ 0
NGCC	$2.50/MCF	+ 3
	$4.50	+15
	$6.50	+27

<u>Implication</u>: *Decreasing dispatch of NGCC at higher gas prices if coal plants are available*

Recent Trends for NGCC Plants



Effect of Variable Capacity Factor on Breakeven NG Price



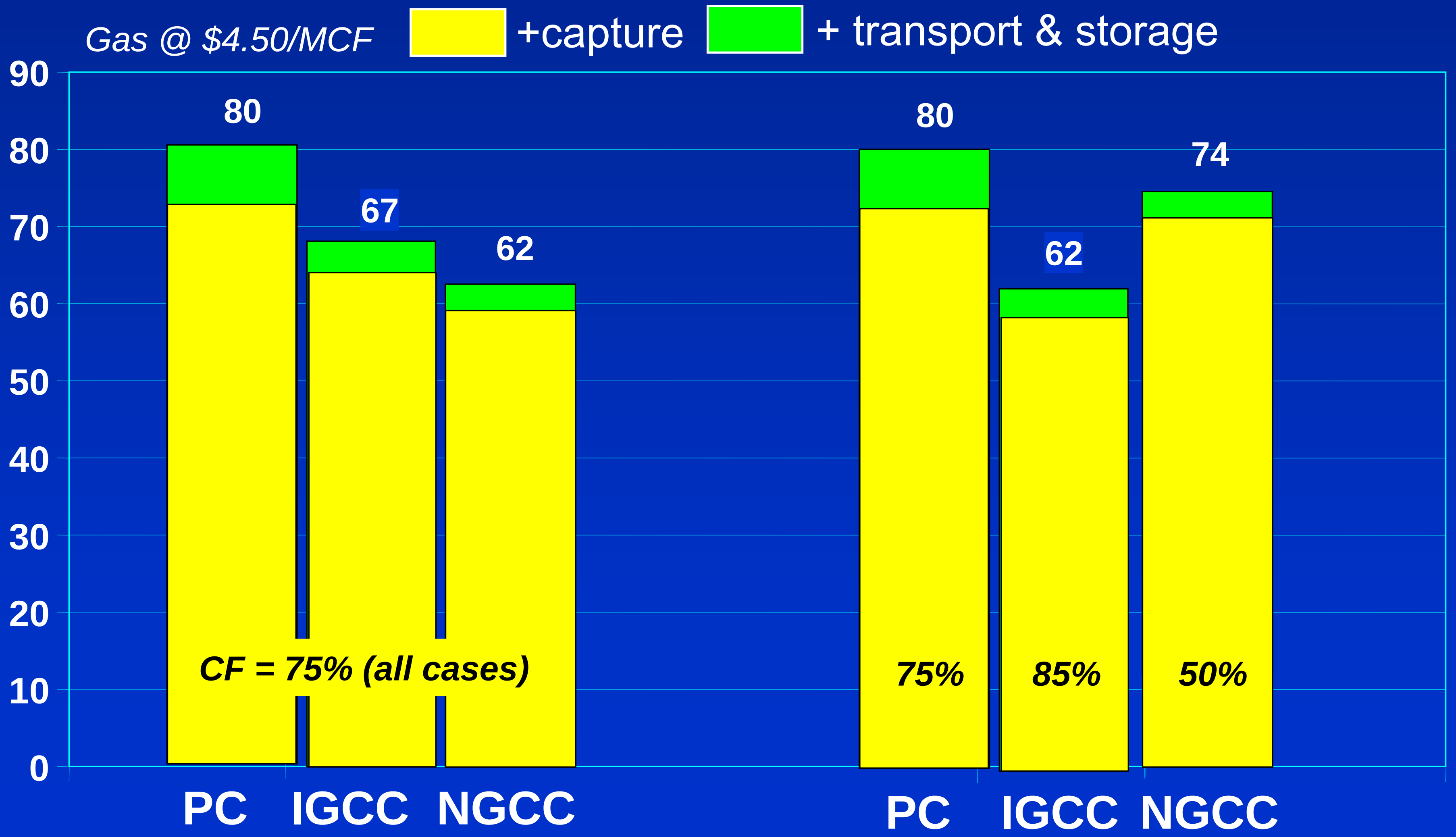
Differences in Total Variable Operating Cost w/ CCS ($/MWh)

(Includes fuel, chemicals, utilities, wastes and byproducts)

Plant	Fuel Price	CCS Plant
PC	$1.27/ MBtu	(Base case)
IGCC	$1.27/ MBtu	**– 10**
NGCC	$2.50/MCF	– 7
	$4.50	+ 8
	$6.50	+38

Implication: *Increasing dispatch of IGCC*

Cost of Electricity ($/MWh) w/ Differential Capacity Factors



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Case 3:

Effects of IGCC Financing & Operation

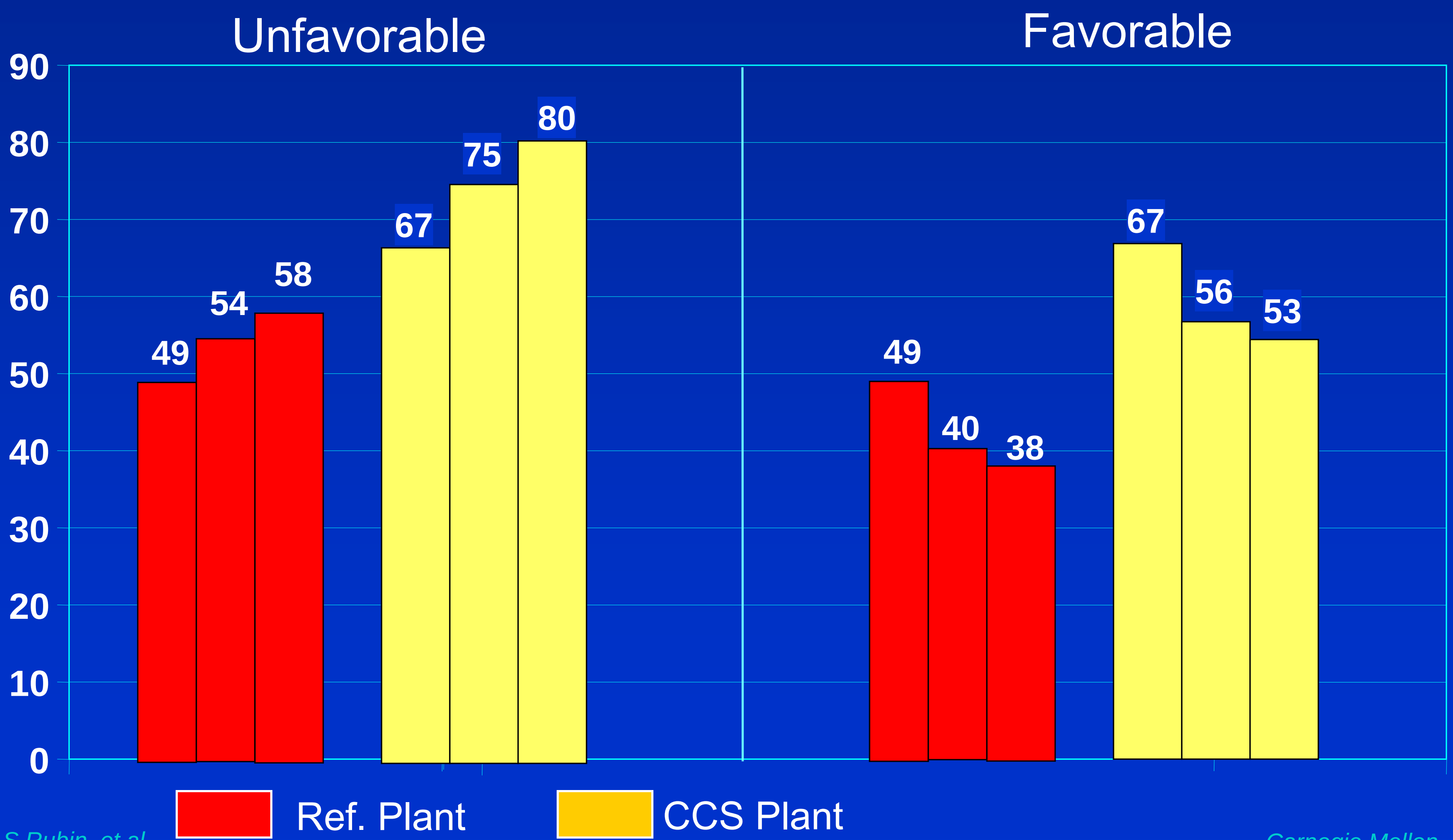
IGCC — Can You Build It?

- Today, IGCC plants are generally more expensive than conventional PC plants, based on expected COE
- IGCC technology is also perceived as “riskier” by the financial community, and by many utility companies
- Several efforts underway to develop more attractive financing and ownership arrangements to facilitate deployment of IGCC in the U.S. power market

Two New Scenarios for IGCC Financing and Operation

- *Unfavorable*
  - Higher fixed charge rate of 17.3% (20% risk premium on rates of return)
  - Lower plant utilization (CF=70%)
- *Favorable*
  - Lower fixed charge rate of 10.4% (e.g., Harvard 3-Party Covenant)
  - Higher plant utilization (CF=80%)

Cost of Electricity ($/MWh) for the Two New Scenarios



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Case 4:

CCS Energy Penalty Impacts on Resource Consumption and Multi-media Emissions

Energy Penalty Defined

- Commonly defined as the reduction in plant output for a constant fuel input (i.e., plant derating) due to CCS
- More general definition is based on change in net plant heat rate or efficiency (η):

$$EP = 1 - (\eta_{ccs} / \eta_{ref})$$

Case study energy penalties:

PC = 24%, IGCC = 14%, NGCC = 15%

An Alternative Definition

- An alternative definition of the energy penalty is the increase in plant inputs per unit of output (EP*):

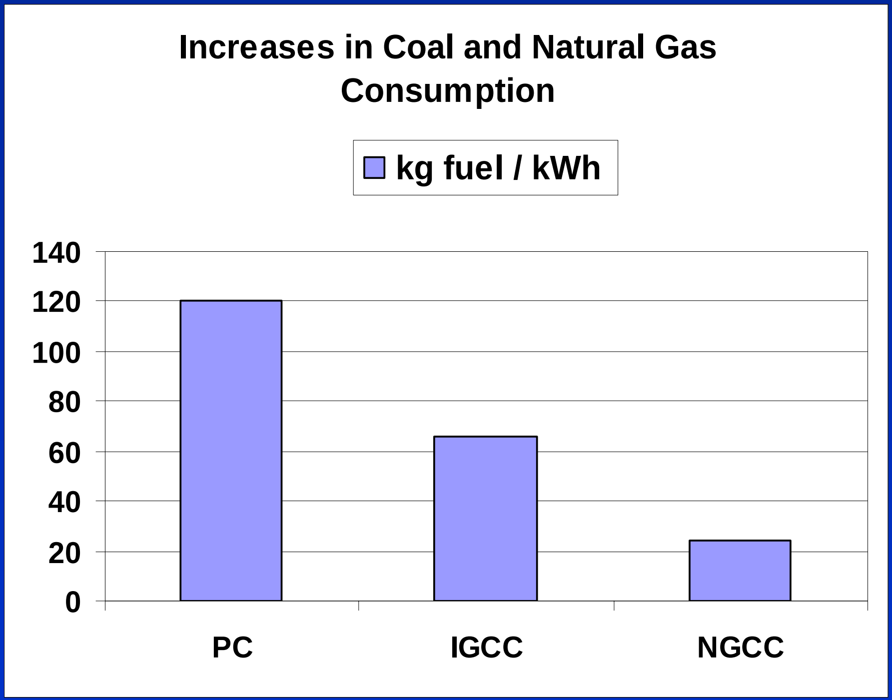
$$EP^* = EP / (1 - EP)$$

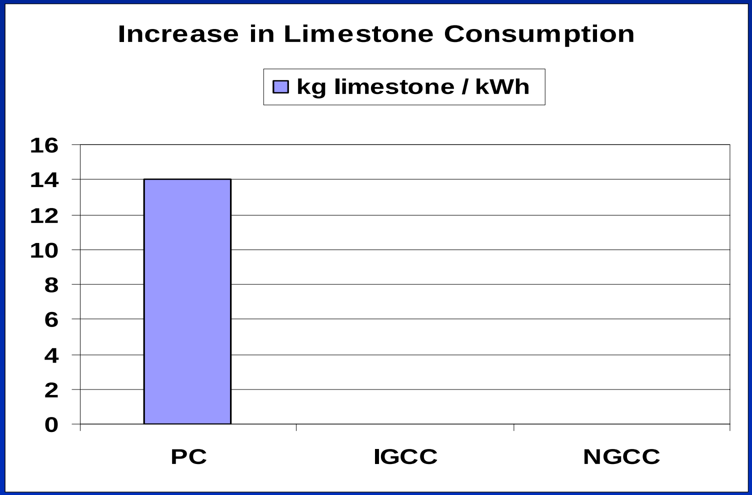
- This measure reflects increases per unit of product for:
  - Plant fuel consumption
  - Other resource requirements
  - Solid and liquid wastes
  - Air pollutants not captured by CCS
  - Upstream (life cycle) impacts

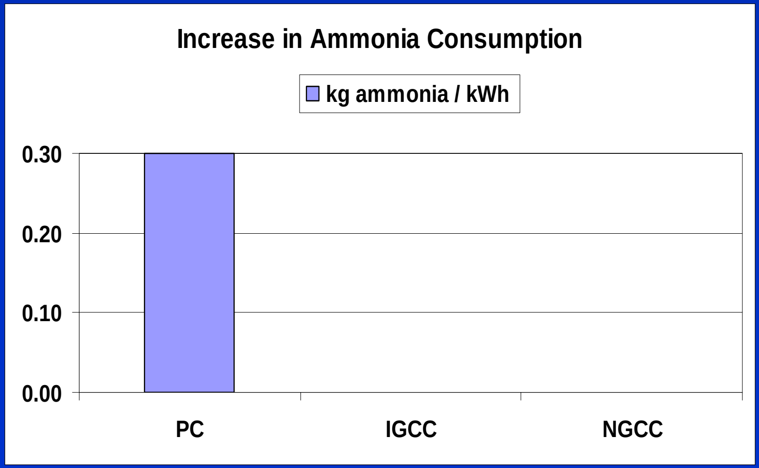
CCS Energy Penalties

- Case study energy penalties for current technologies based on EP*:
  - PC = 31 %
  - IGCC = 16%
  - NGCC = 18%

Increases in Fuel and Reagent Consumption*

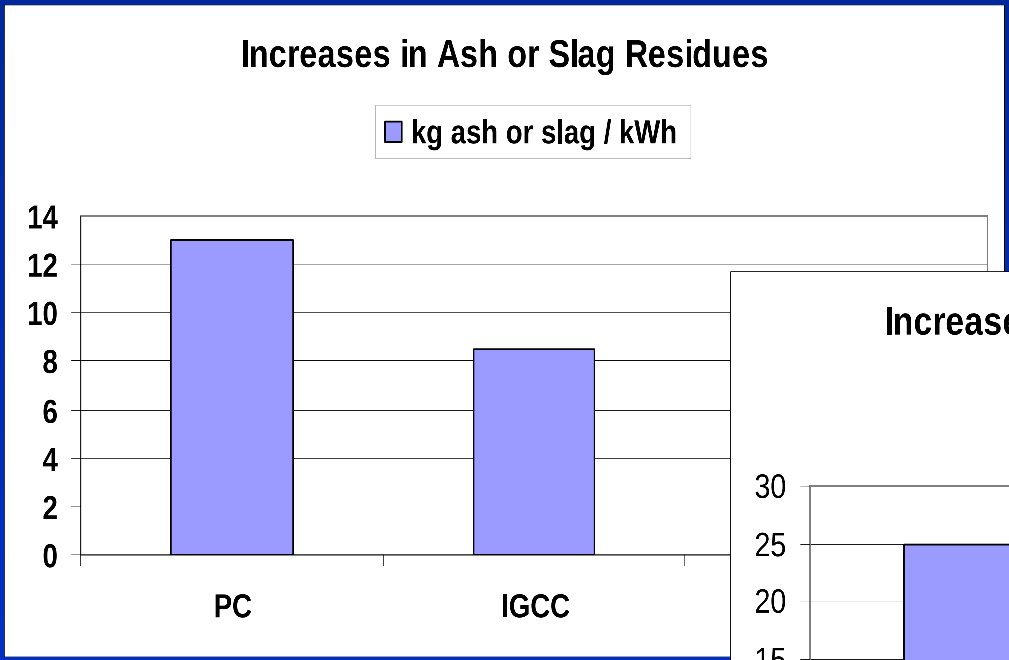


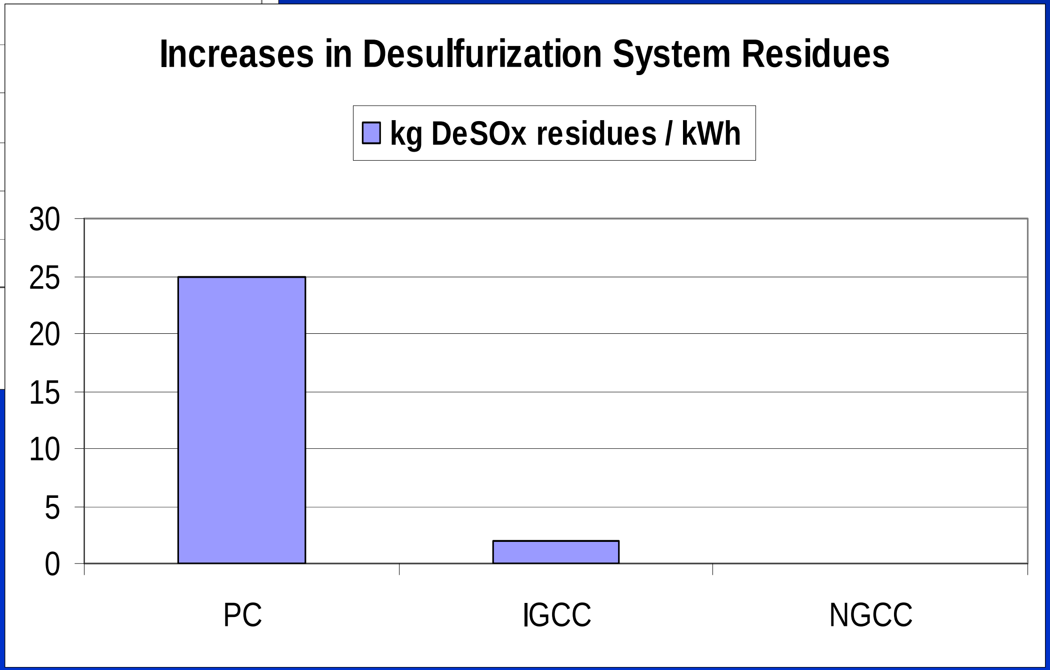




**Based on Illinois #6 coal*

Increases in Solid Wastes & Plant Byproducts*





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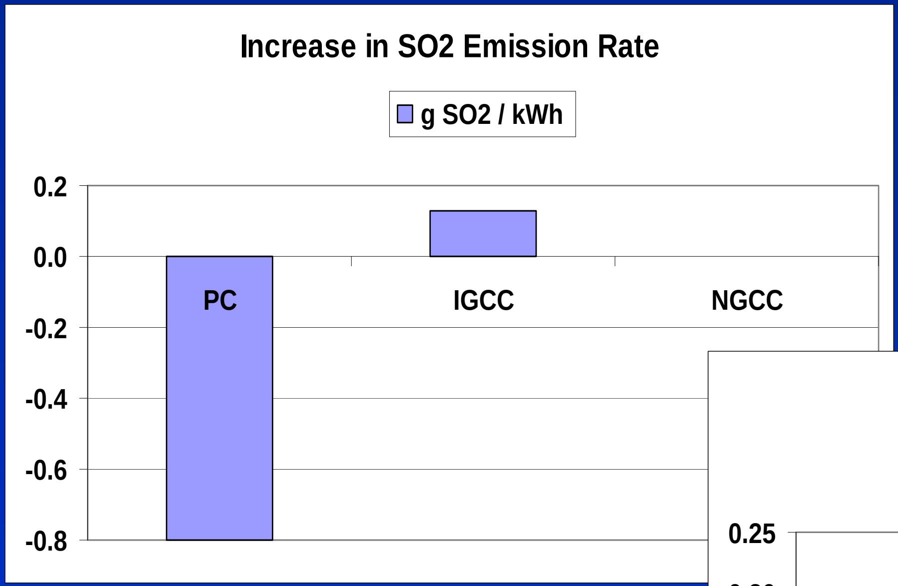
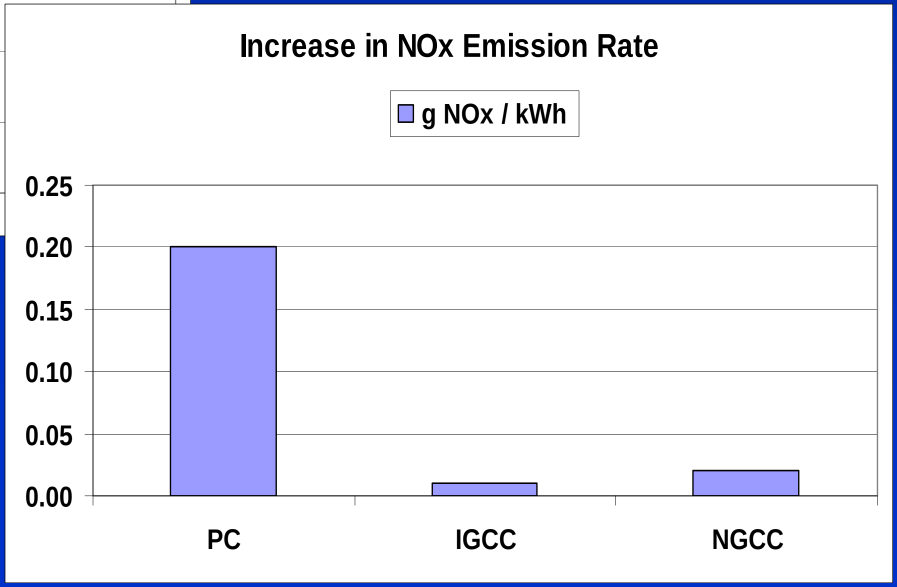
Increases in Air Emission Rates*





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The Critical Importance of Technology Innovation

- New or improved technologies for power generation and CO_2 capture can lower the cost of CCS, *and* significantly reduce adverse secondary impacts by:
  - Improving overall plant efficiency
  - Reducing CCS energy penalties
  - Maximizing co-capture of other pollutants

Work in Progress at CMU

- *Incorporate performance and cost models of advanced power systems and CO_2 capture options:*
  - Oxyfuel combustion
  - ITM oxygen production
  - Advanced IGCC designs
  - Advanced NGCC
- *Expand and regionalize transport & storage models*
- *Comparative analyses of CO_2 capture options for new and existing power plants*
  - Advanced PC, NGCC and IGCC systems
  - Repowering or rebuild of existing units
- *Assessments of R&D Benefits*