Assessments of CO_2 Capture and Storage for Fossil Fuel Power Plants

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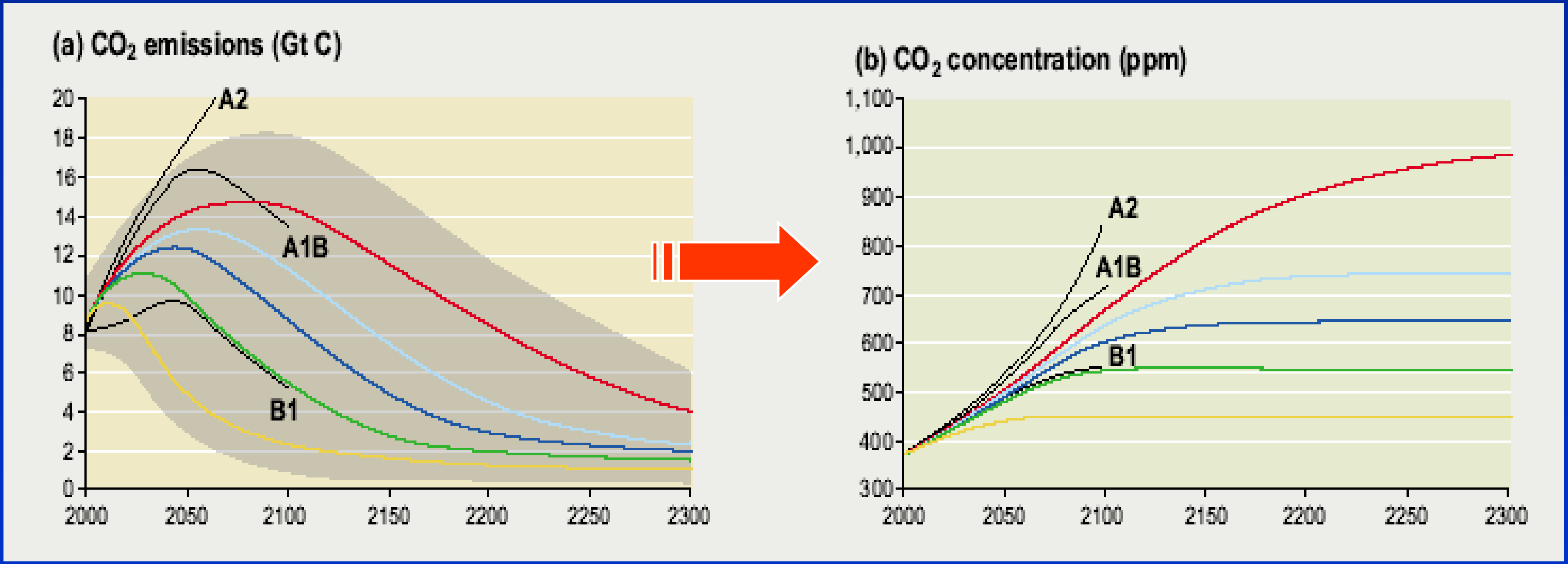
Background

- Global climate change induced by human activity has been widely recognized as a major environmental threat now facing the world
- The source of the problem is the accumulation in the atmosphere of “greenhouse gases”– mainly carbon dioxide (CO_2) from the combustion of the carbon-laden fossil fuels (oil, coal and gas) that supply most of the world’s energy needs
- To address the problem, the 1992 U.N. Framework Convention on Climate Change calls for “stabilization of greenhouse gas concentrations in the atmospheric at a level that would prevent dangerous anthropogenic interference with the climate system”

Stabilization Will Require Large Reductions in CO_2 Emissions

(a) CO_2 Emission Scenarios

(b) Resulting Atmospheric Concentration



Source: IPCC, 2001

Large emission reductions are needed,
no matter what target is selected for stabilization!

What Options Are Available to Reduce CO_2 Emissions?

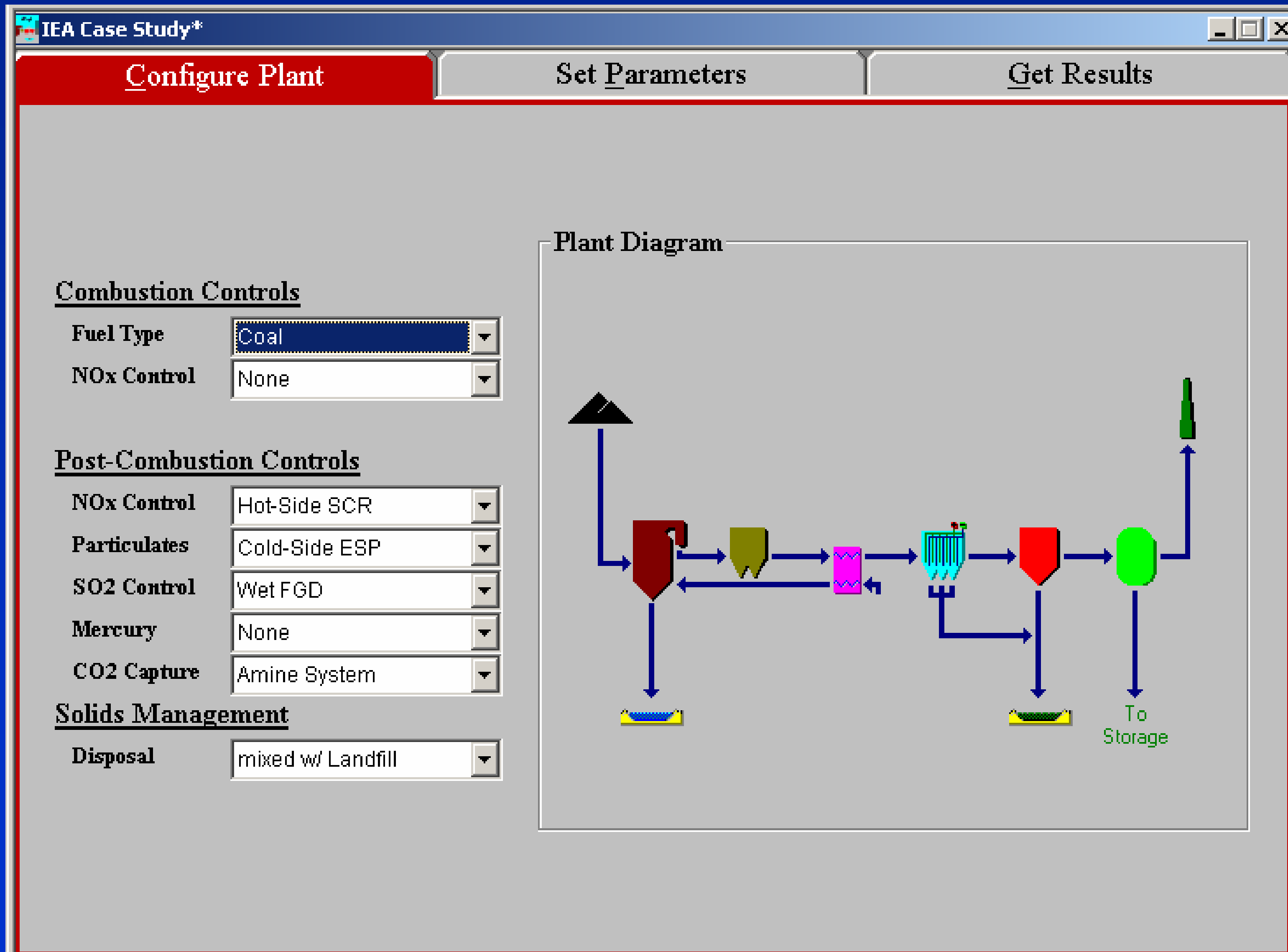
- Improve energy efficiency
- Switch to lower-carbon fuels
- Switch to zero-carbon fuels
- Capture and sequester the CO_2 emitted by major point sources (primarily electric power plants)

Objectives of This Study

- 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)
- Characterize and quantify the major resource requirements and multi-media environmental emissions associated with these systems

The Technologies

PC Plant w/ CO_2 Capture & Storage



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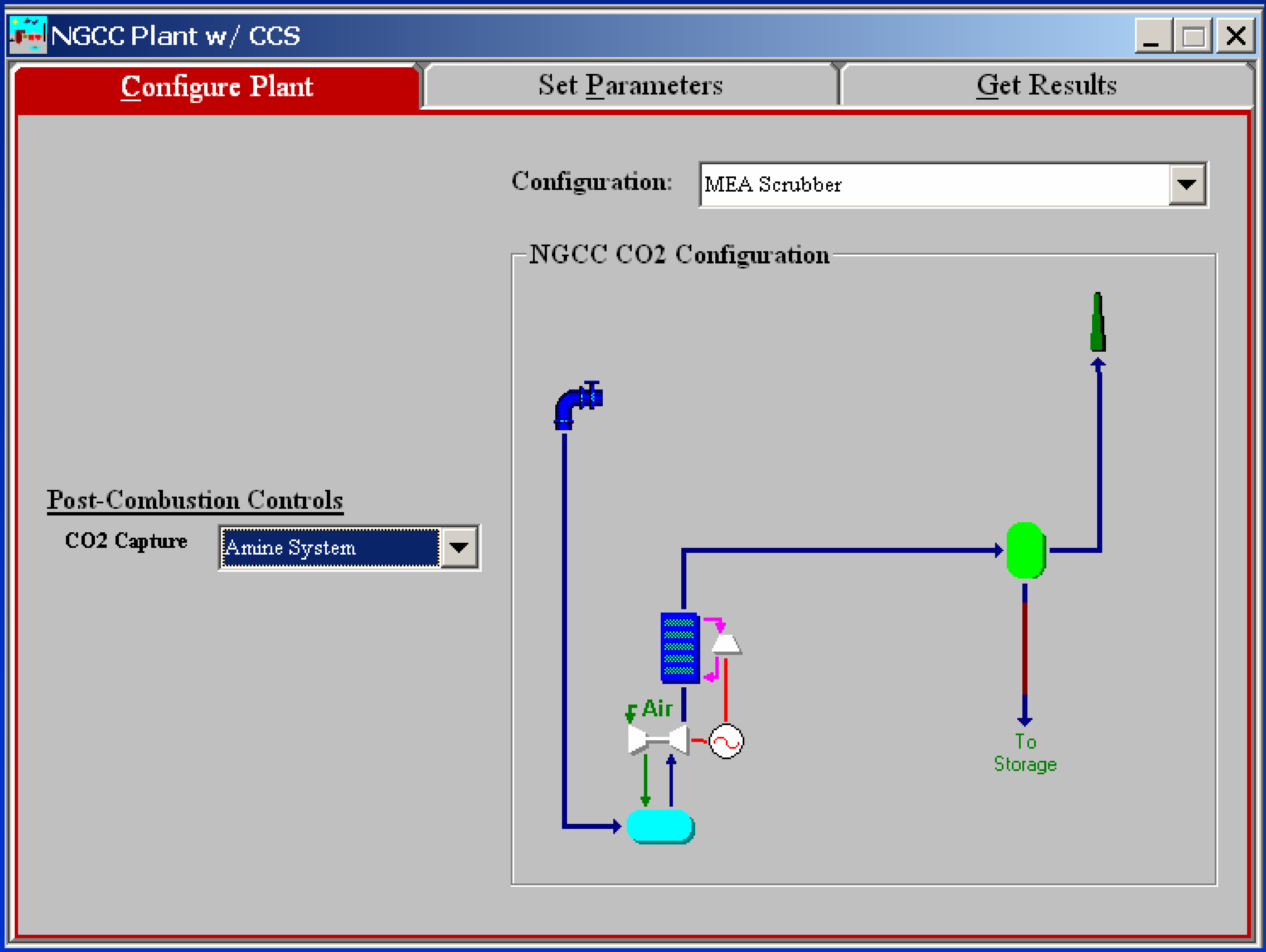
NGCC Plant w/ CO_2 Capture & Storage



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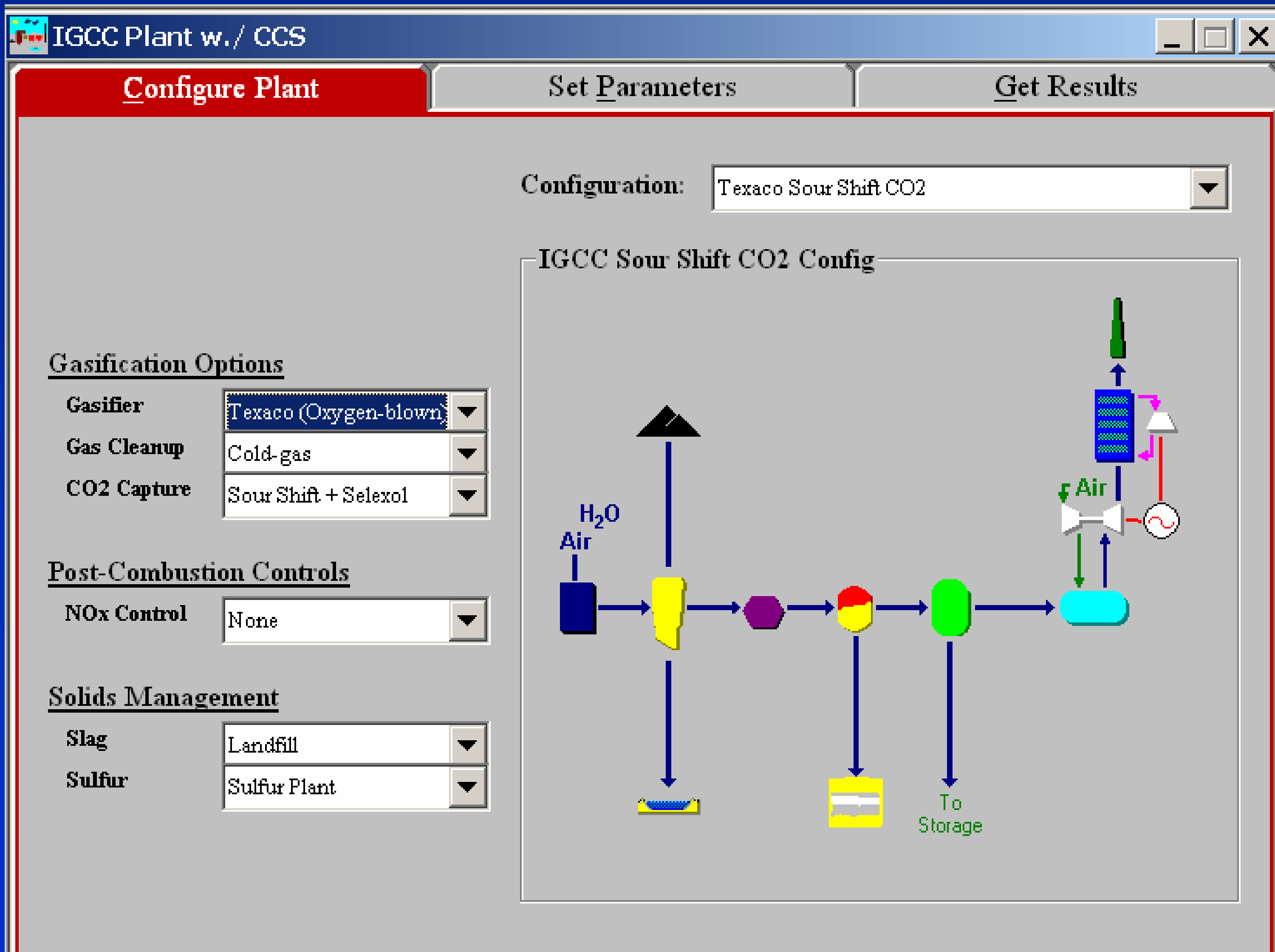
IGCC Plant w/ CO_2 Capture & Storage



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Comparative Cost Analyses

Summary of Recent Studies of CO_2 Capture Cost

(Includes compression, but excludes transport and storage costs)

Cost and Performance Measures	PC Plant		IGCC Plant		NGCC Plant	
	Range low-high	*Rep. value*	**Range low-high**	*Rep. value*	**Range low-high**	*Rep. value*
Ref. plant emissions (kg CO_2/MWh)	722-941	795	682-846	757	344-364	358
Percent CO_2 reduction per MWh (%)	80-93	85	81-91	85	83-88	87
Capital cost w/o capture ($/kW)	1100-1490	1260	1170-1590	1380	447-690	560
Capital cost with capture ($/kW)	1940-2580	2210	1410-2380	1880	820-2020	1190
Percent increase in capital cost (%)	67-87	77	19-66	36	37-190	110
COE w/o capture ($/MWh)	37-52	45	41-58	48	22-35	31
COE with capture ($/MWh)	64-87	77	54-81	65	32-58	46
Percent increase in COE w/capture (%)	61-84	73	20-55	35	32-69	48
Cost of CO_2 avoided ($/t CO_2)	42-55	47	13-37	26	35-74	47

Natural gas prices = $2-3/GJ; coal prices approx. $1.2/GJ. IGCC data are for bituminous coals only. Other assumptions vary across studies.

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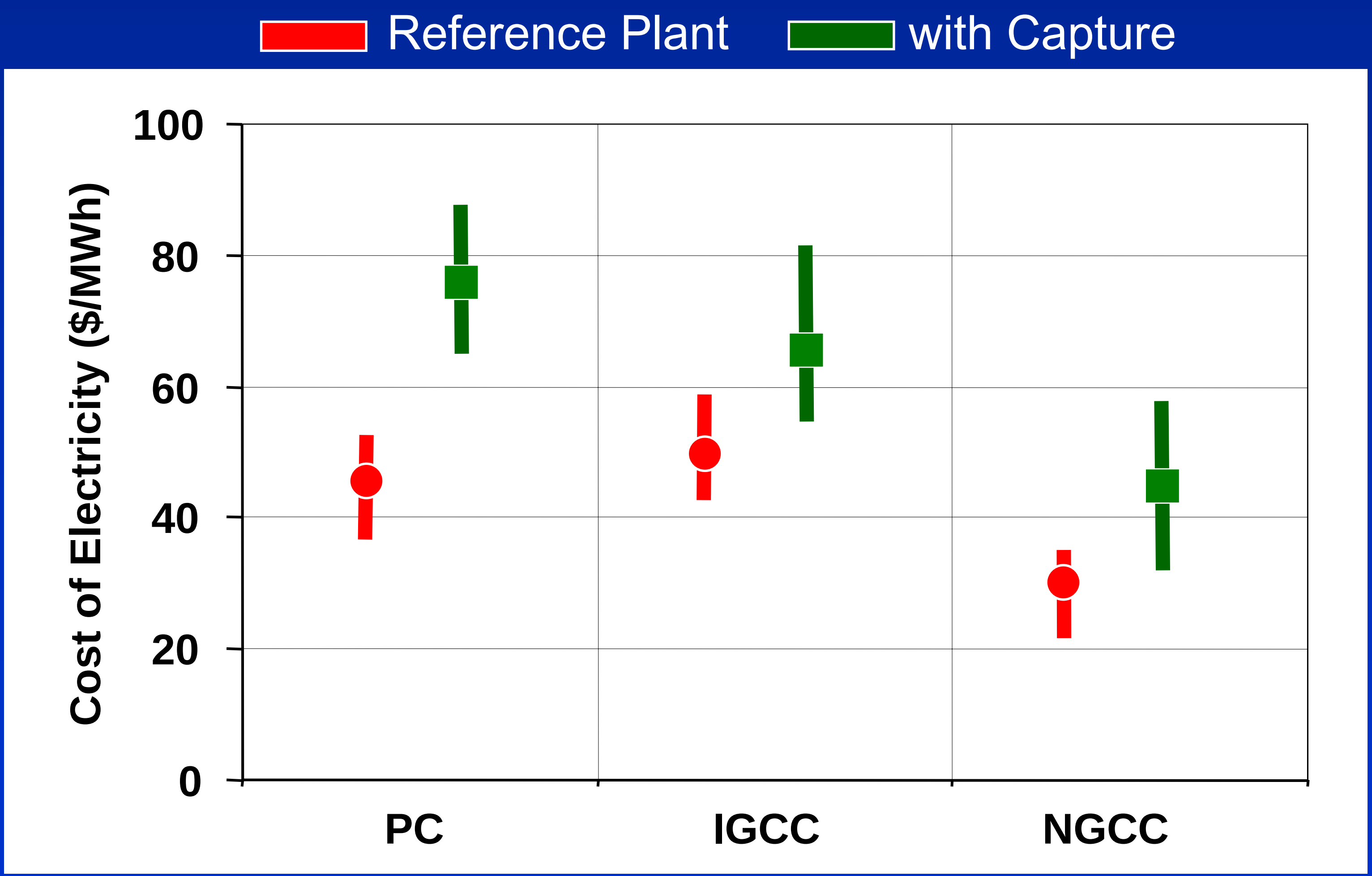
Recent CO_2 Capture Cost Estimates

(includes compression, but excludes transport & storage costs)



Natural gas cost = $2-3/GJ; coal cost approx. $1.2/GJ. IGCC data for bituminous coals only. Other assumptions vary.

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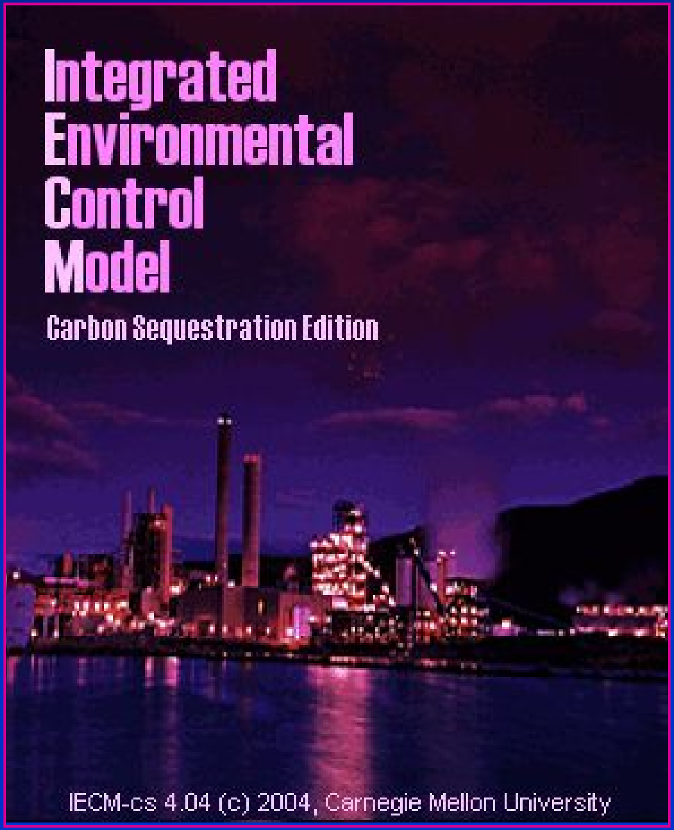
What's New Here?

- For cost comparisons, we explore a broader range of assumptions/conditions that influence the cost of these technologies (with and without capture)
- We include CO_2 transport and storage costs
- We highlight the implications of CCS energy requirements on plant-level resource consumption and ancillary environmental impacts
- We use the (publicly available) IECM computer model (Version 4.0.4) to evaluate all three systems

The IECM is Available At . . .

- **Free Web Download :**
  - www. iecm-online.com
- **Technical Support:**
  - PED.modeling@netl.doe.gov
- **Other Inquires:**
  - mikeb@cmu.edu
  - rubin@cmu.edu



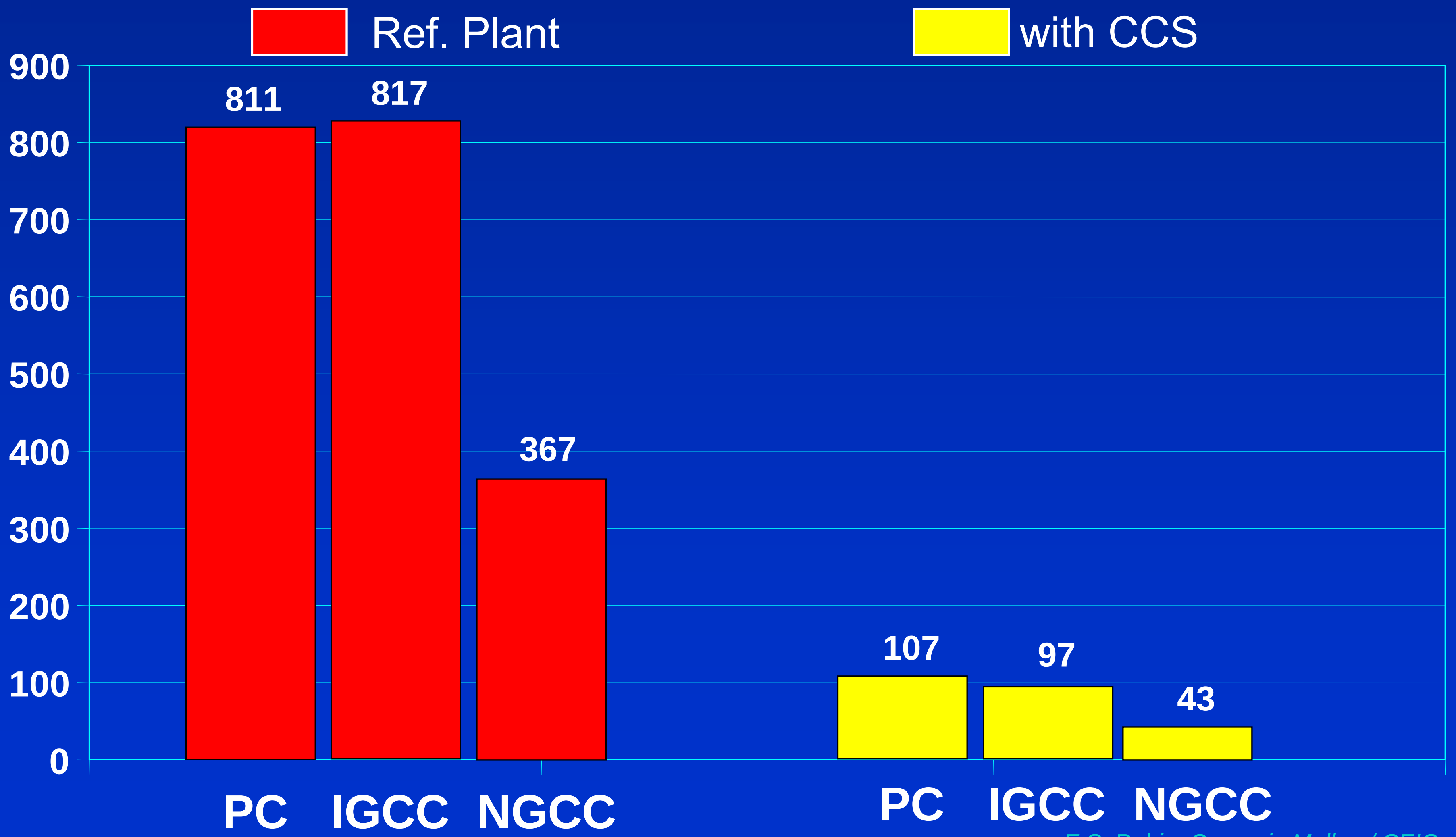
Results for Baseline Case Study Assumptions

Baseline Assumptions

Parameter	PC	IGCC	NGCC
Reference Plant (~500 MW)	Supercritical	Texaco quench	2 x 7FA
Fuel Type	2%S Bit	2%S Bit	Nat. Gas
Net HHV Efficiency (%)	39.5	37.5	50.3
Capacity Factor (%)	**75**	**75**	**75**
Fuel Cost, HHV ($/GJ)	1.2	1.2	**4.0**
CCS Plant (~500 MW_{net})			
CO_2 Capture System	Amine	Shift+Selexol	Amine
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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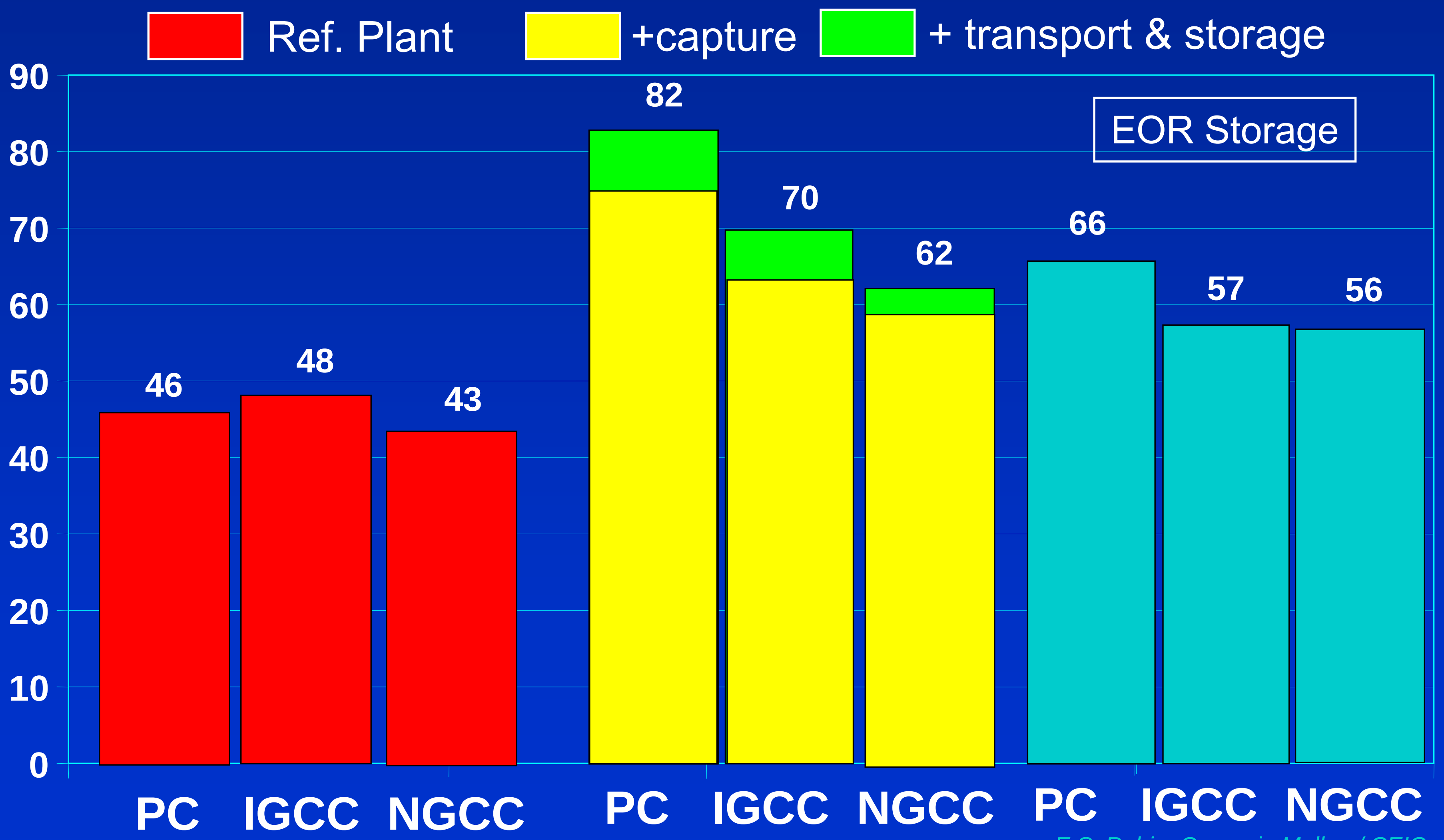
Cost of Electricity (COE)
(Levelized $/MWh)



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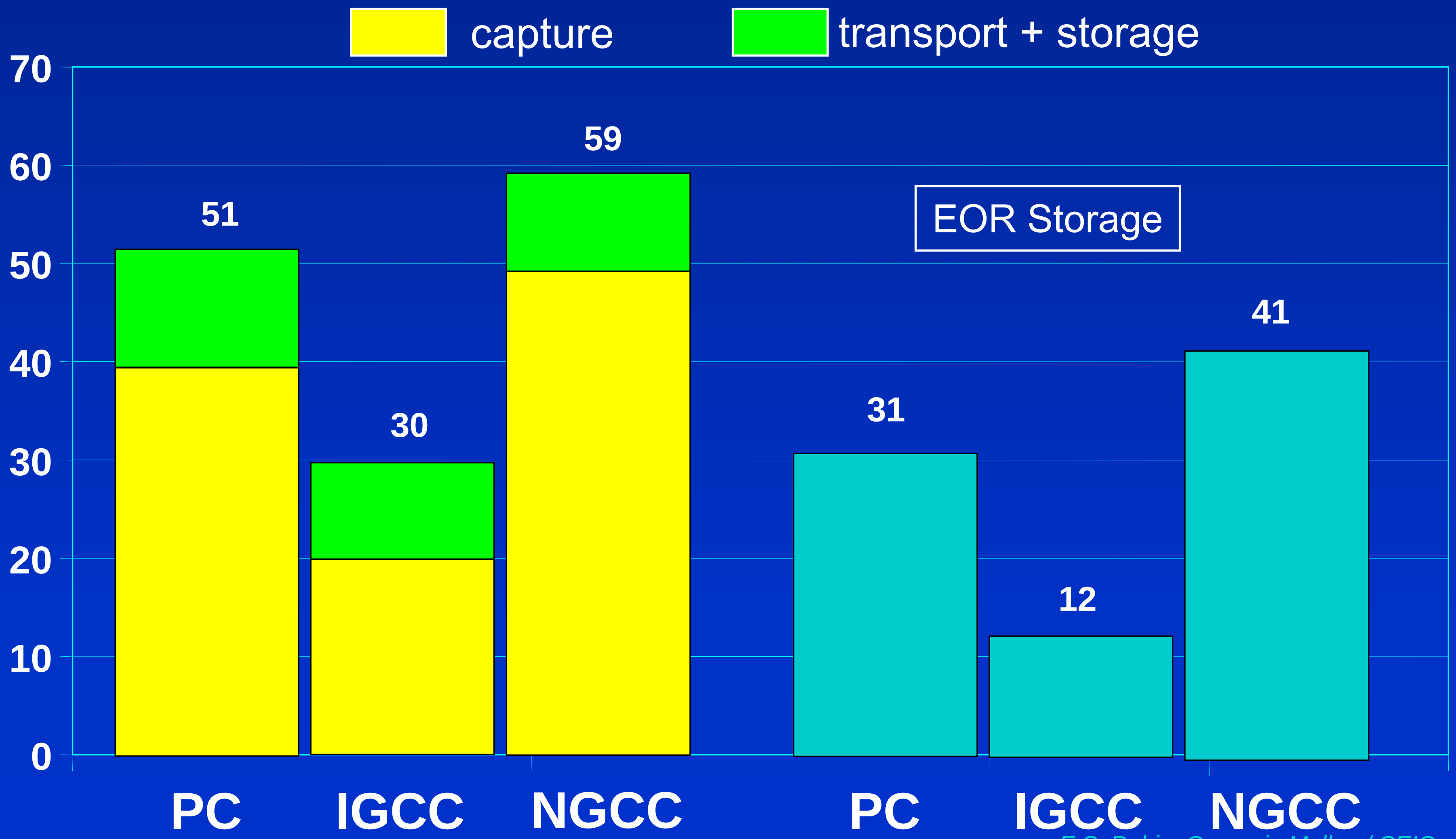
Cost of CO_2 Avoided ($/tonne CO_2)



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Effects of Fuel Price and Plant Dispatch

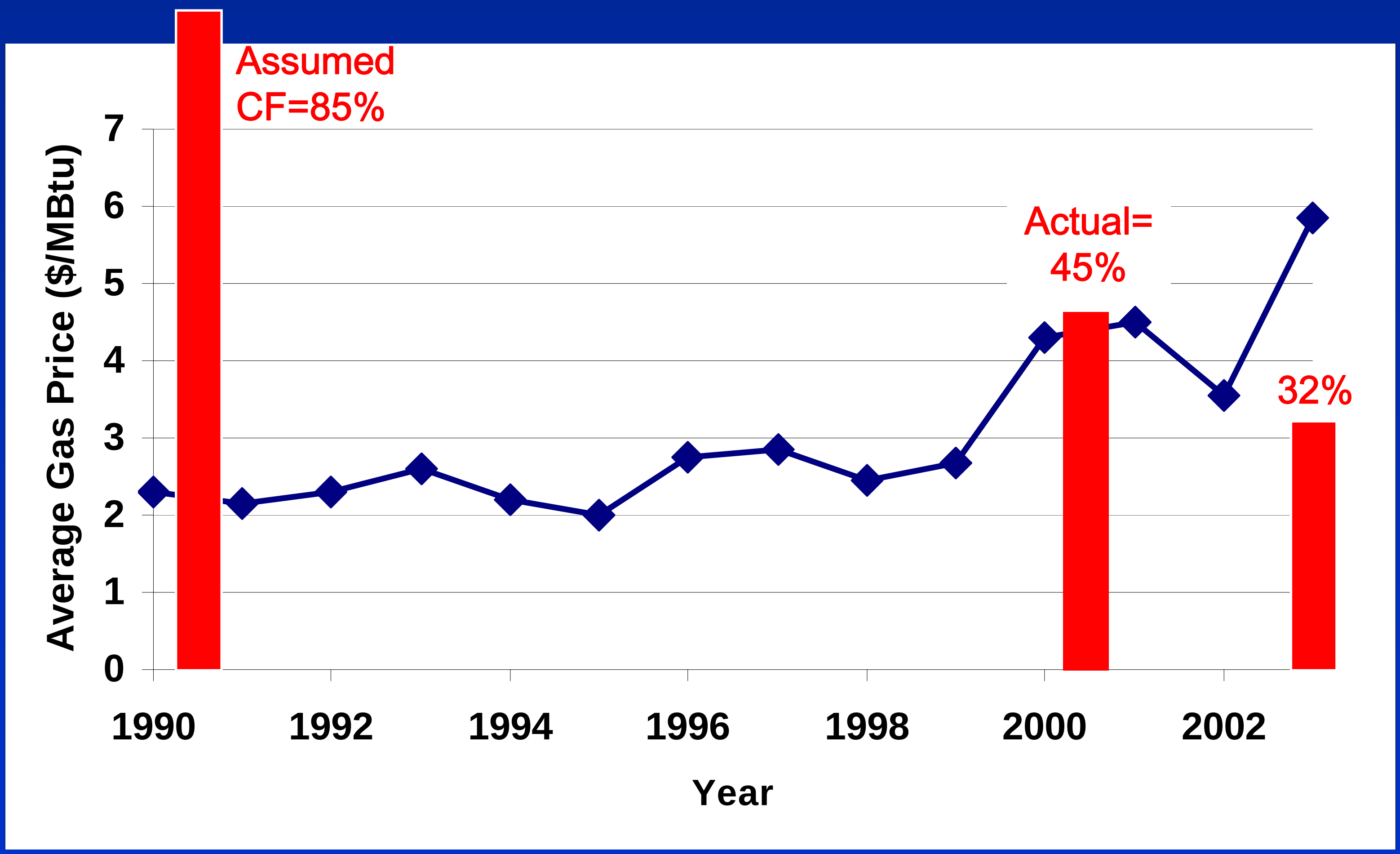
Differences in Total Variable Operating Cost w/o CCS ($/MWh)

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

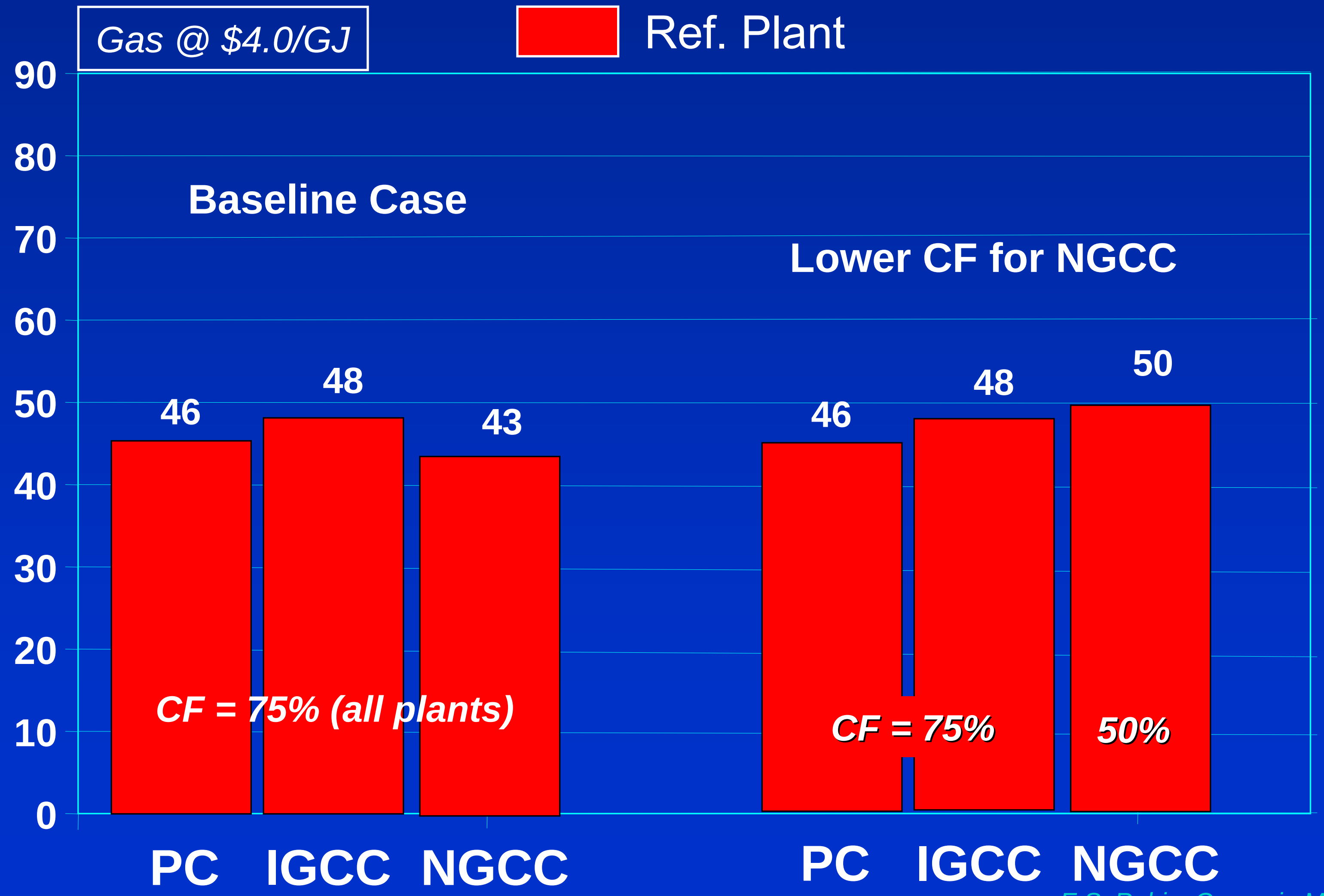
Plant	Fuel Price	Ref. Plant
PC	$1.2/ GJ	(Base case)
IGCC	$1.2/ GJ	~ 0
NGCC	$2.2/ GJ	+ 3
	$4.0/ GJ	+16
	$5.8/ GJ	+29

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

Recent Trends for NGCC Plants Confirm Gas Price Effect on CF



Cost of Electricity, Revisited
(Levelized $/MWh)



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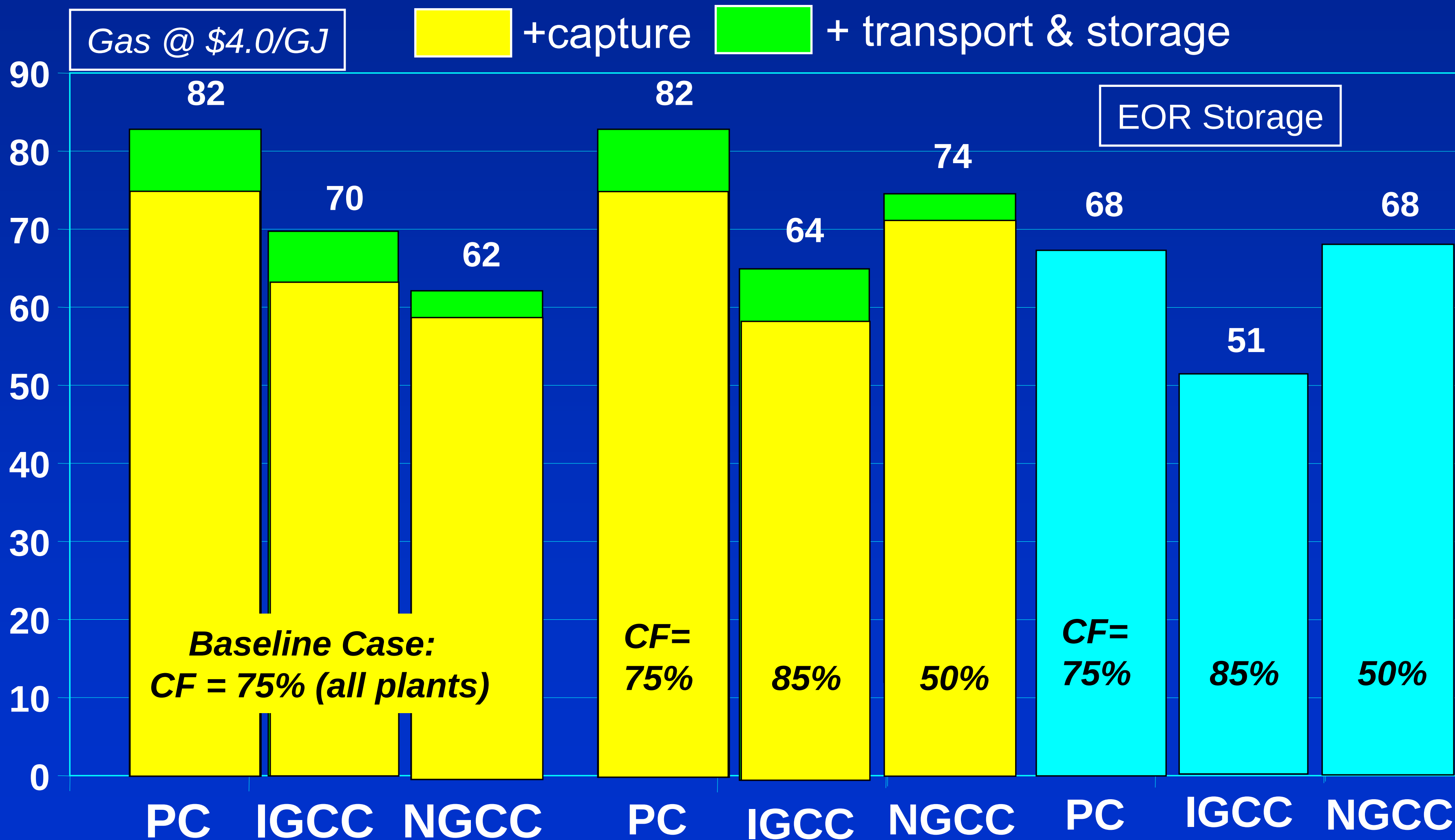
Differences in Total Variable Operating Cost w/ CCS ($/MWh)

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

Plant	Fuel Price	CCS Plant
PC	$1.2/ GJ	(Base case)
IGCC	$1.2/ GJ	**– 9**
NGCC	$2.2/ GJ	– 7
	$4.0/ GJ	+ 8
	$5.8/ GJ	+24

Implication: *Increasing dispatch of IGCC, and less use of NGCC, when CCS is added*

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



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Effects of IGCC Financing & Operation

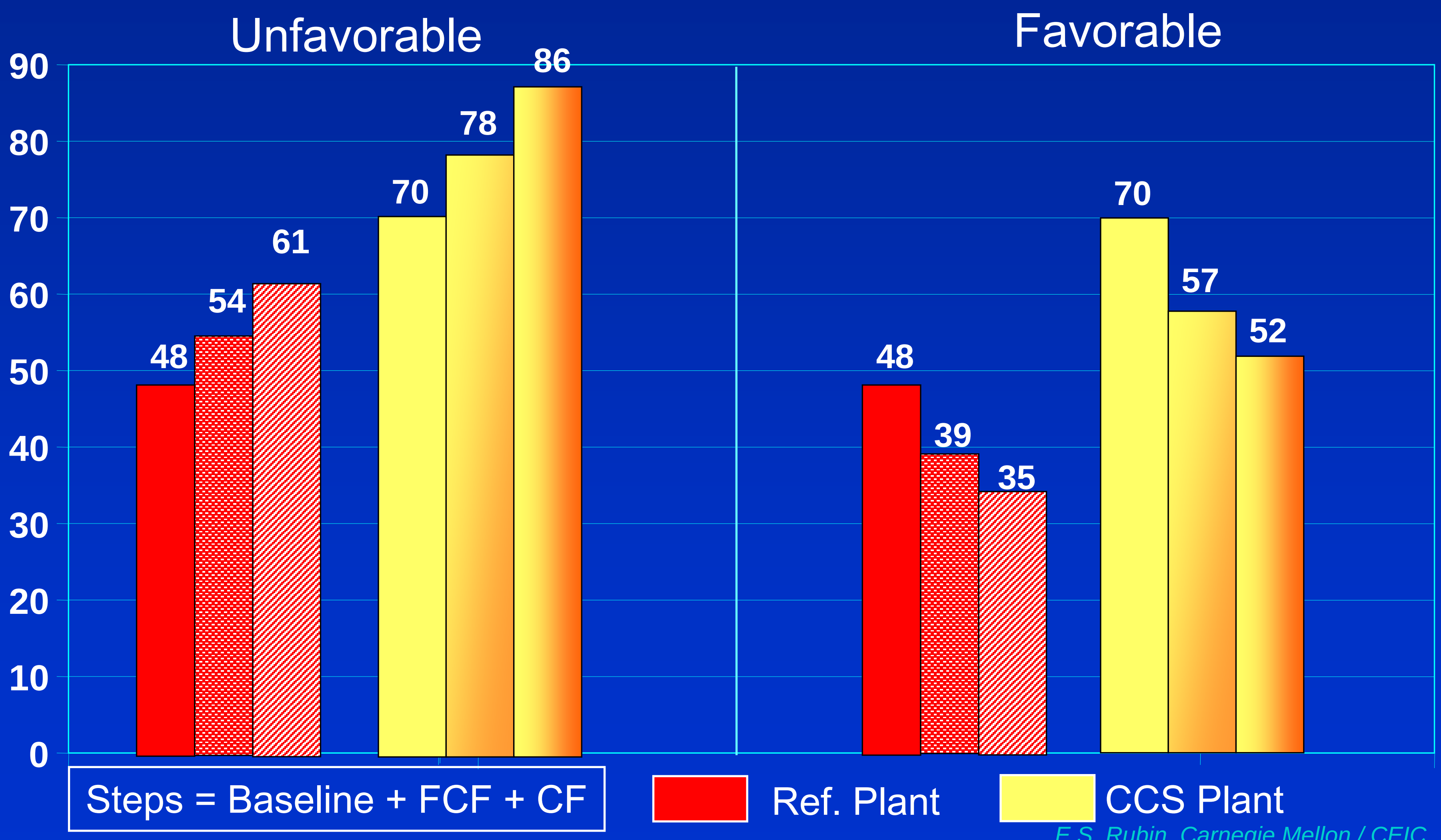
IGCC — Can You Build It?

- 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=65%)
- *Favorable*
  - Lower fixed charge rate of 10.4% (e.g., Harvard 3-Party Covenant)
  - Higher plant utilization (CF=85%)

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



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Conclusions from Case Studies *(1)*

- Many factors affect the costs of fossil fuel power plants, with and without CCS; the variability of such factors accounts for most differences in published cost estimates
- The recent literature has not adequately characterized realistic ranges and interdependencies of key factors that affect cost comparisons; consideration of such factors can significantly alter the "conventional wisdom" regarding the relative costs of alternative systems
- Buyer beware! Caution and caveats needed when using results of CCS cost studies!

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., the plant derating) due to the CCS system
- On this basis, the case study plant energy penalties are:
  - PC = 24%
  - IGCC = 14%
  - NGCC = 15%

An Alternative Definition

- Arguably, a more meaningful definition of the CCS energy requirement is the *increase in energy input per unit of product output*
- This measure directly affects the increased resource requirements and environmental emissions <u>per unit of product</u>:
  - Plant fuel consumption
  - Other resource requirements
  - Solid and liquid wastes
  - Air pollutants not captured by CCS
  - Upstream (life cycle) impacts

CCS Energy Penalty—Redefined

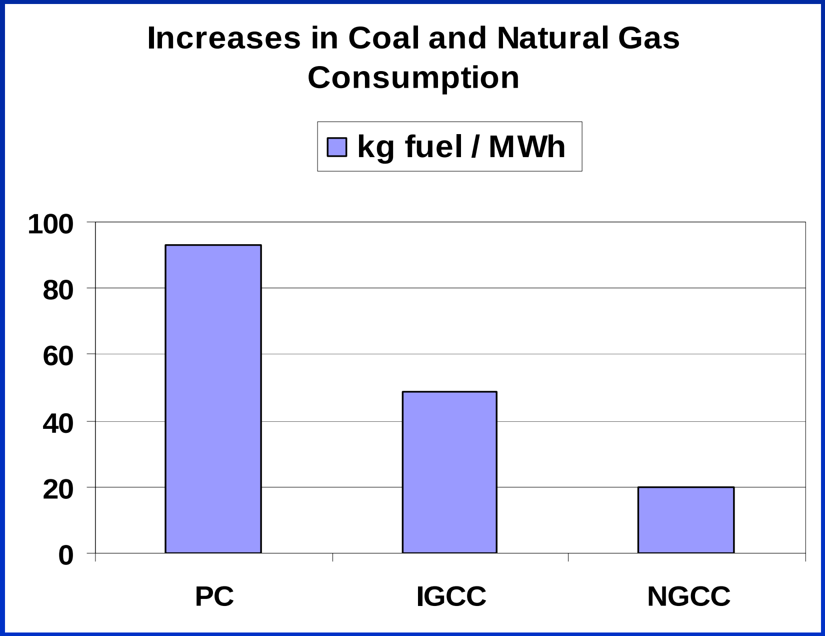
- Increased energy input (EP) determined by change in net plant efficiency (η) relative to a reference plant without CCS:

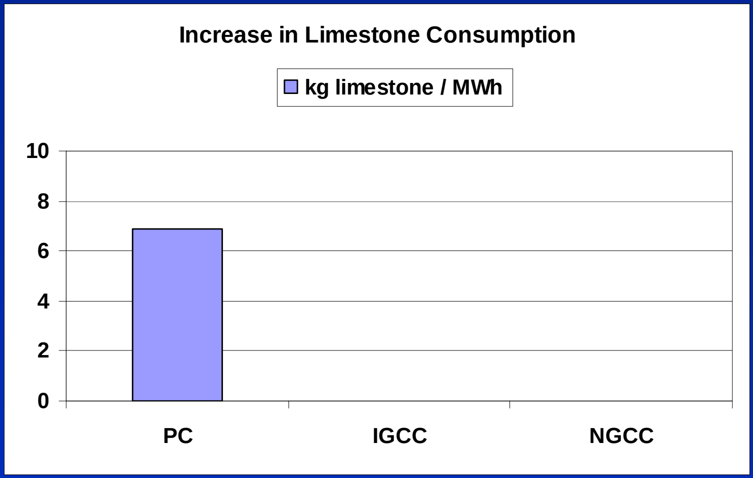
$$EP = (\eta_{ref} / \eta_{ccs}) - 1$$

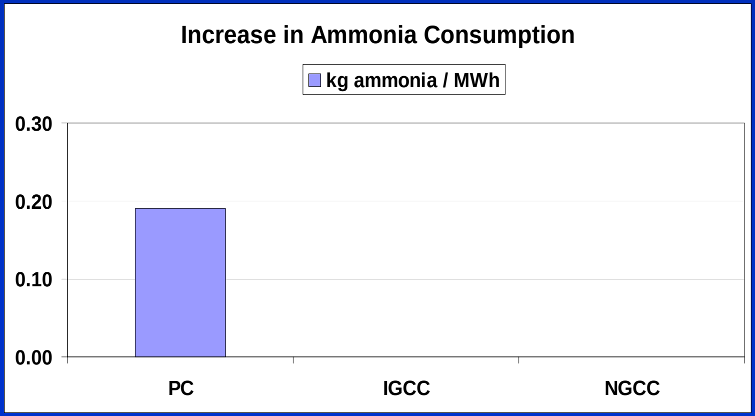
- On this basis, energy penalty for case study plants:
  - PC = 31 %; IGCC = 16%; NGCC = 18%

- *Following slides show some of the implications of CCS energy requirements for the case study plant*

Case Study Increases in Fuel and Reagent Consumption







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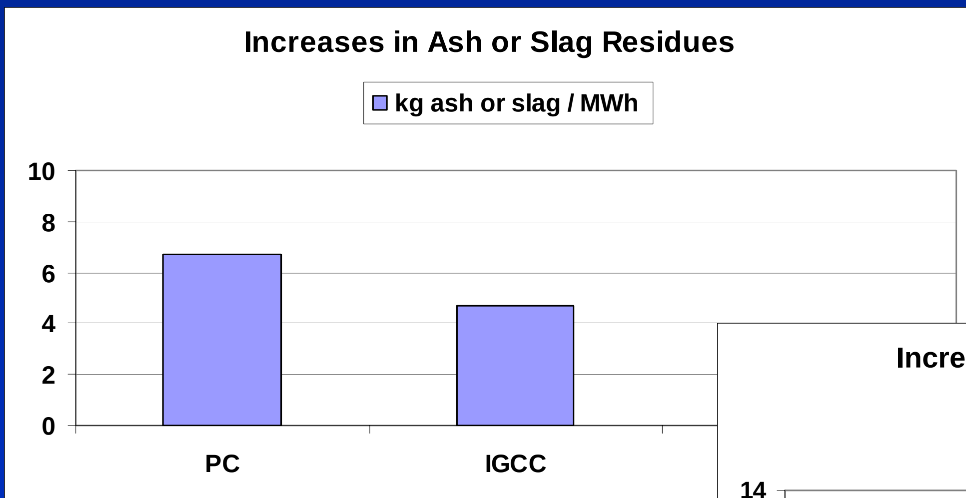
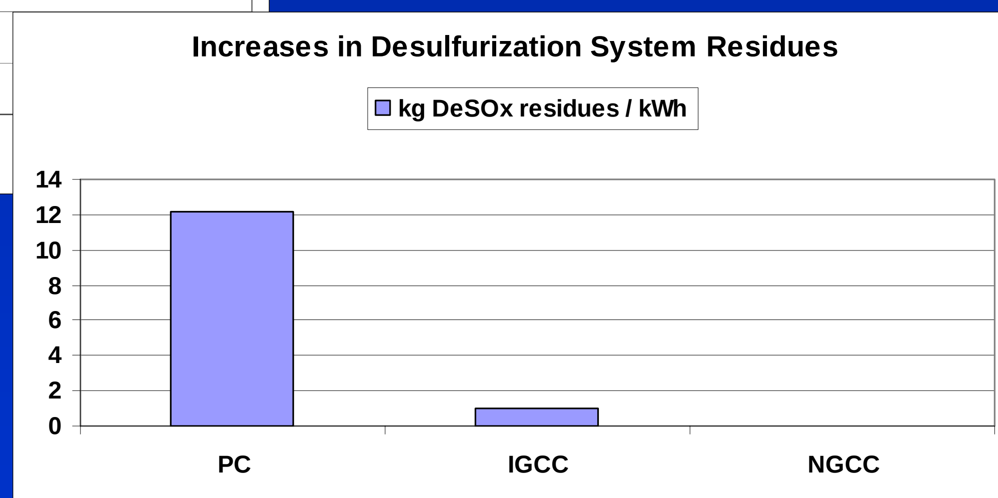
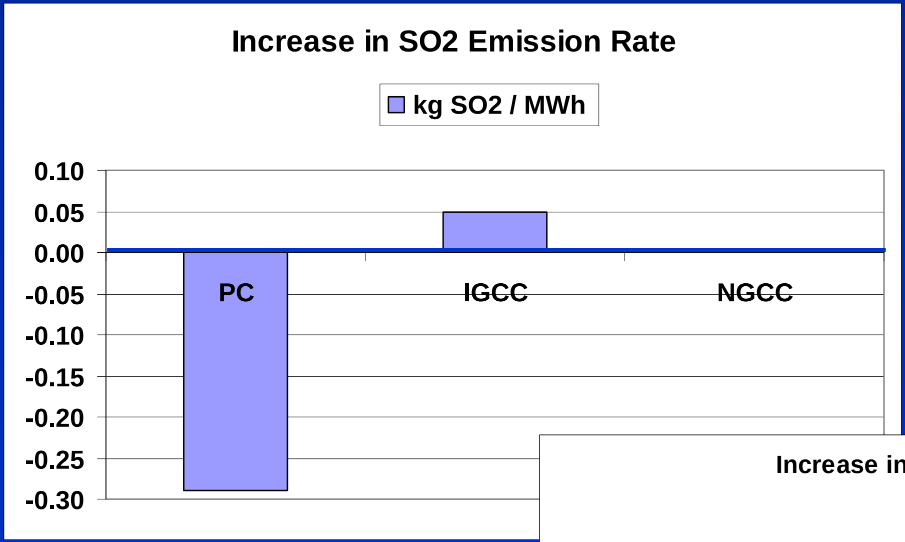
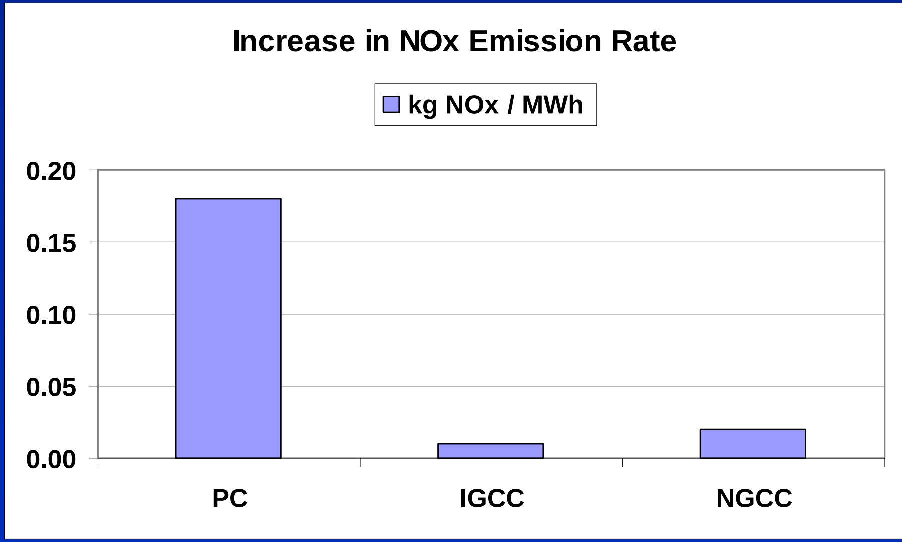
Case Study Increases in Solid Wastes & Plant Byproducts

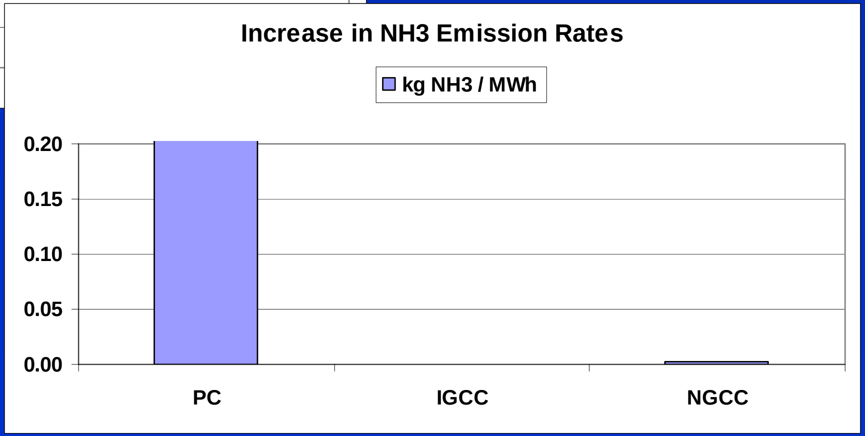




Case Study Increases in Air Emission Rates







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Conclusions from Case Studies *(2)*

- Current CO_2 capture systems can significantly exacerbate the multi-media environmental impacts and resources required to produce useful products (like electricity)
- Minimizing CCS energy requirements is essential for minimizing these adverse ancillary impacts

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 requirements
  - 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*