CO_2 Capture and Storage: Options, Costs and Impacts

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Motivating Questions

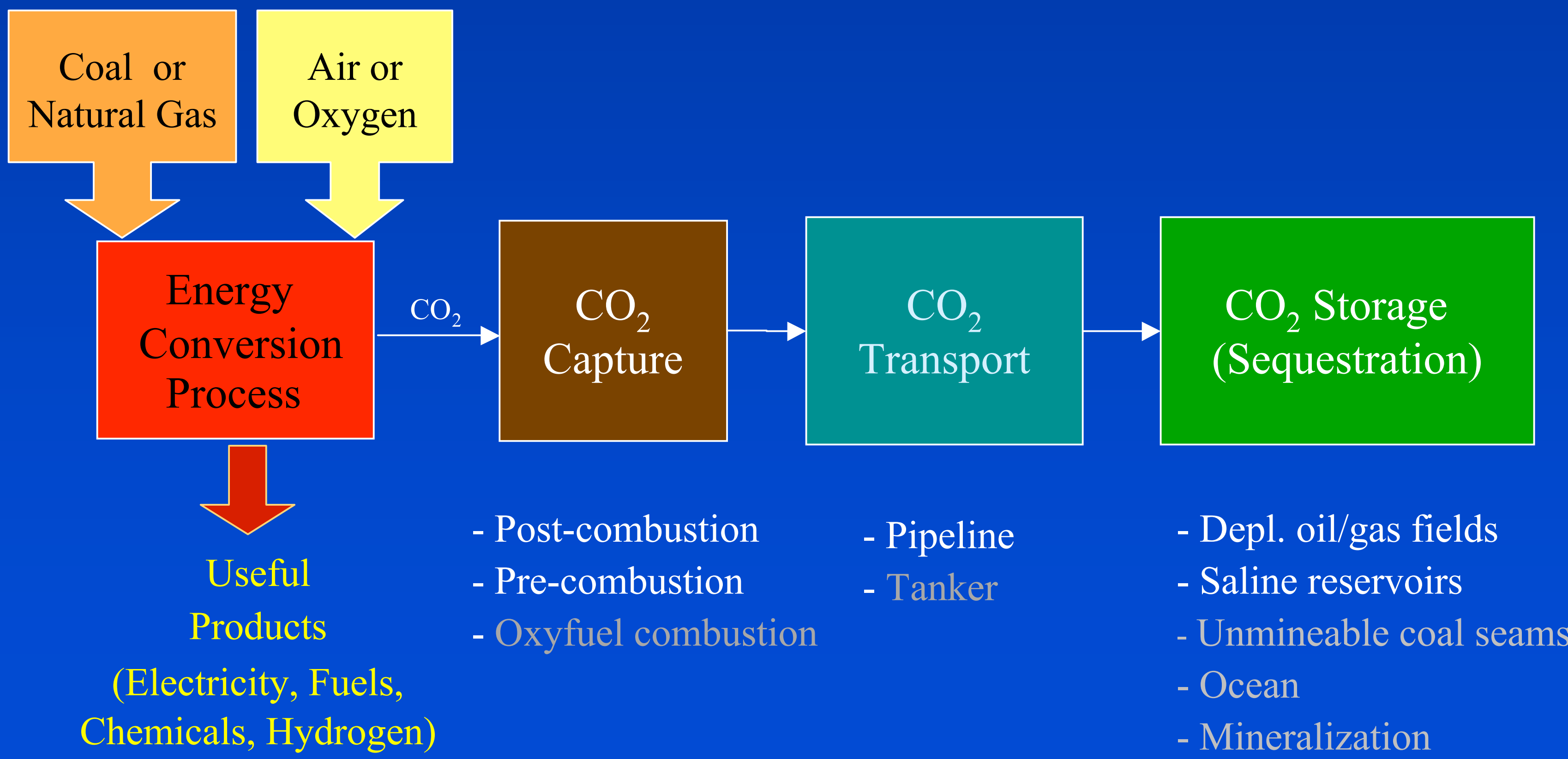
- Why the recent interest in CO_2 sequestration (here called capture and storage, CCS)?
- What are the technological options available now, and in the foreseeable future?
- What is the cost of CCS?
- What are its major environmental impacts, especially with regard to health-related air pollutants and greenhouse gases?

Why the Interest in CCS?

- The international goal of stabilizing atmospheric GHG concentrations will require very large reductions in anthropogenic CO_2 emissions. But …
- Fossil fuels will continue to be used extensively for many decades to come—alternatives not likely to get large CO_2 reductions in time frames of policy interest
- CCS offers a way to allow fossil fuels to be used with little CO_2 emissions—a potential bridging strategy
- Energy models indicate that CCS, in addition to other measures, can significantly lower the cost of stabilization

Technology Options

Schematic of a CCS System



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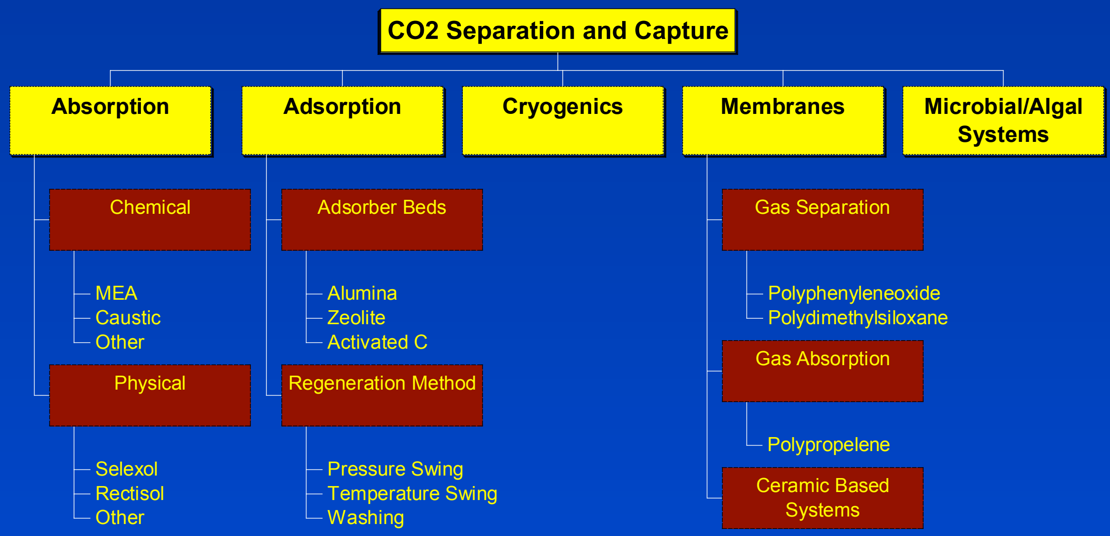
Many Ways to Capture CO_2



- Separation and capture of CO_2 from industrial gas streams has been practiced commercially for many decades, mainly in the petroleum and petrochemical industries.
- Several applications to boiler combustion products, but at scales much smaller than a modern power plant (and with no transport and storage)

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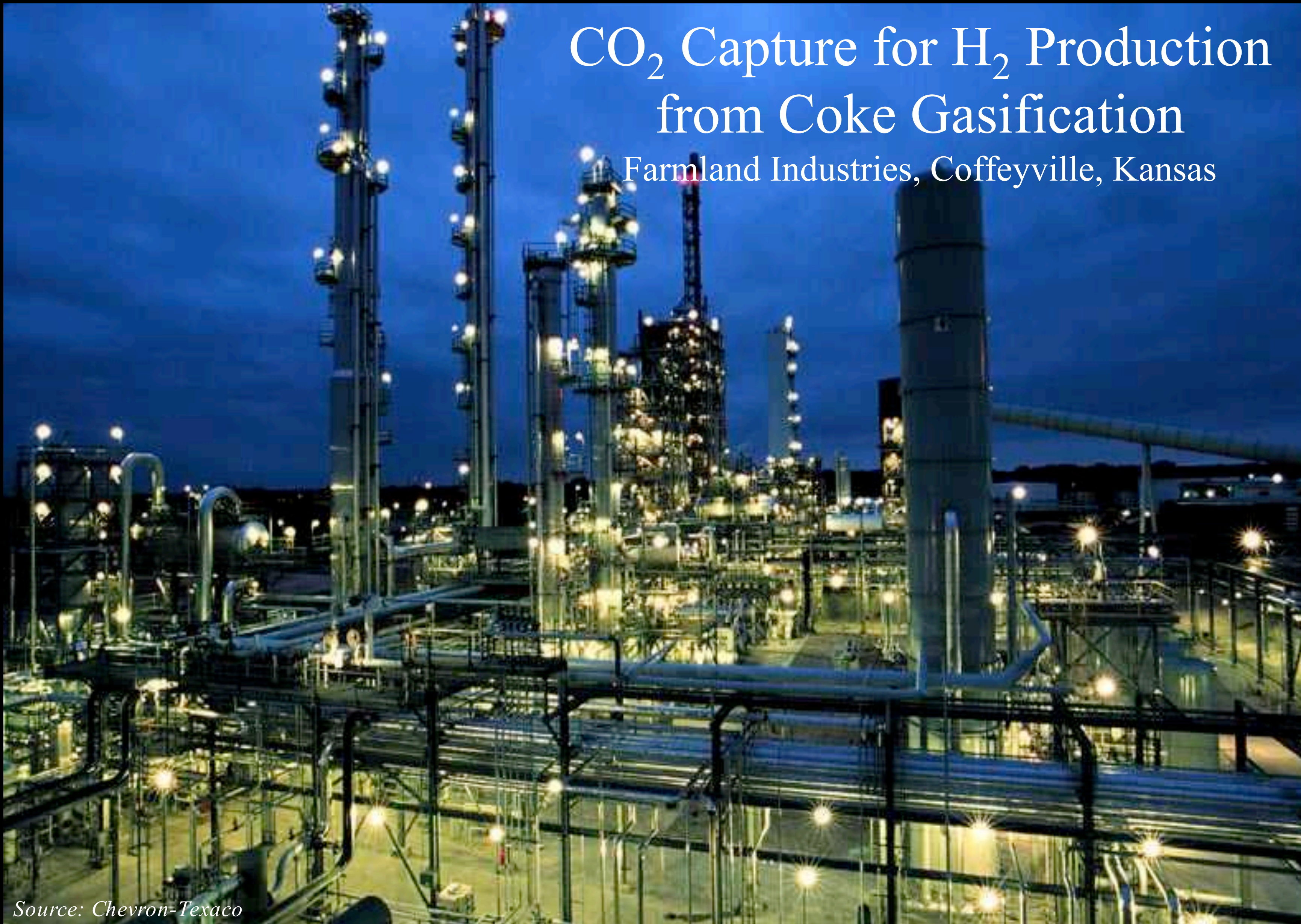
CO_2 Capture at a Coal-Fired Power Plant

(Shady Point, Oklahoma)

Source: ABB Lummus

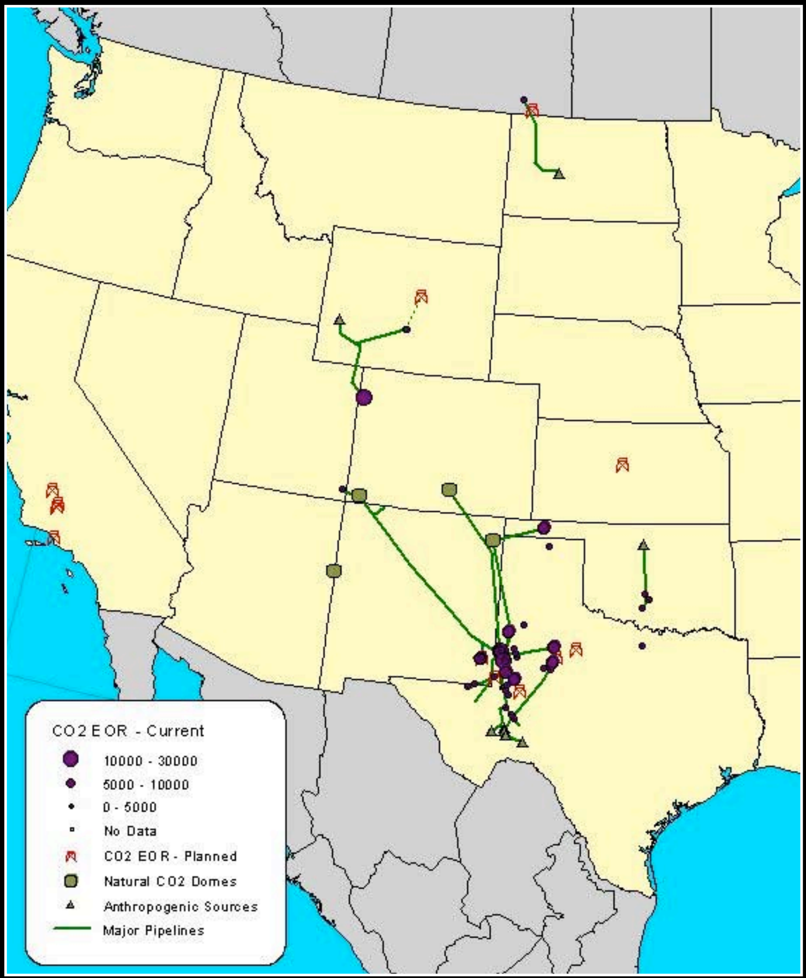
CO_2 Capture for H_2 Production from Coke Gasification

Farmland Industries, Coffeyville, Kansas



Source: Chevron-Texaco

Existing CO_2 Pipelines for Enhanced Oil Recovery (EOR)



Source: USDOE/Battelle

Source: NRDC

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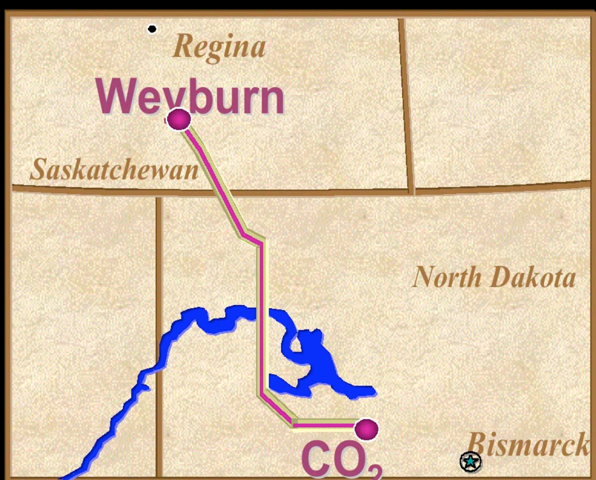
Weyburn CO_2 Pipeline & Storage Project

Geological Storage of CO_2 with Enhanced Oil Recovery



Sources: USDOE; NRDC

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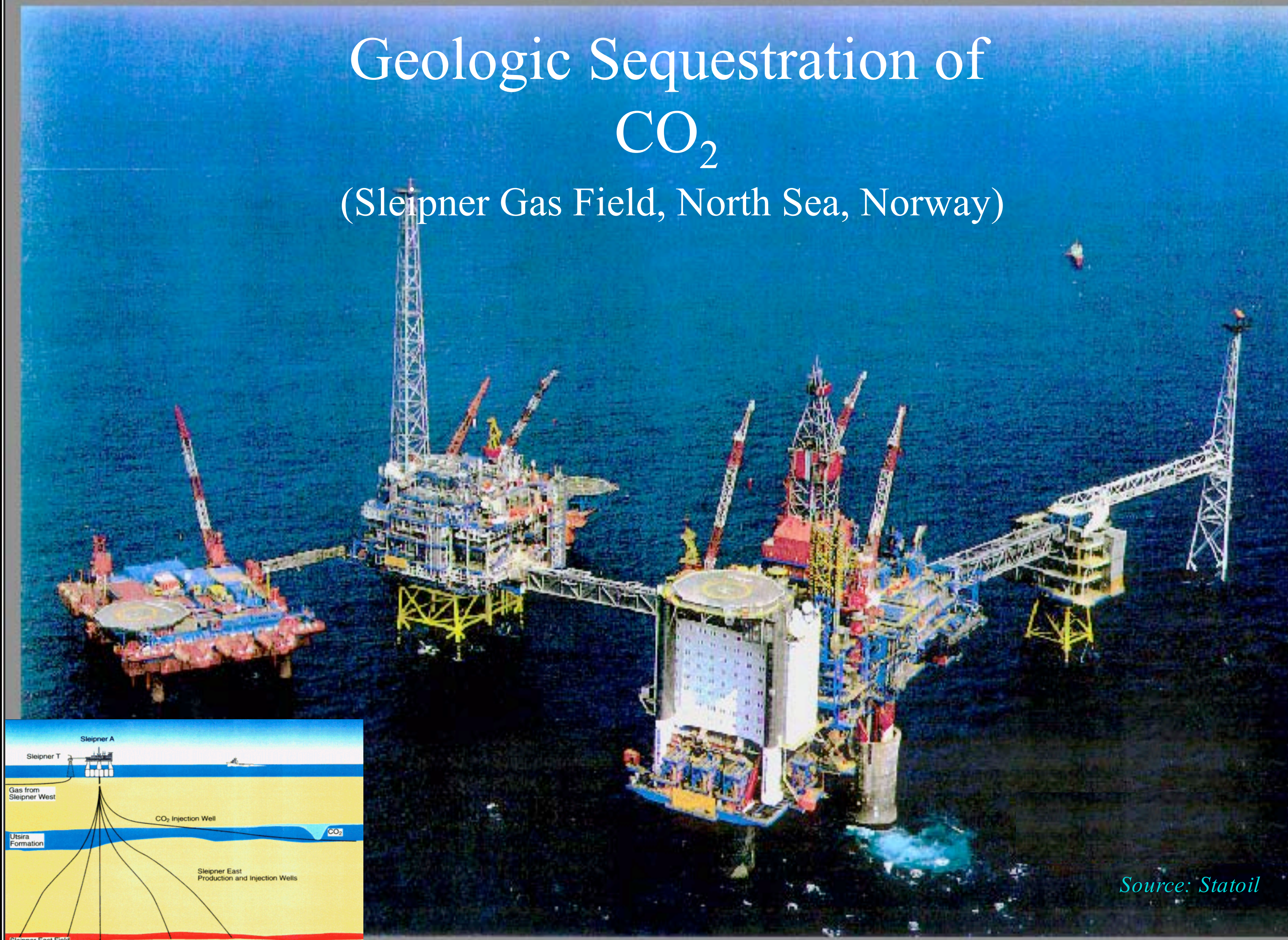
Geologic Sequestration of CO_2

(Sleipner Gas Field, North Sea, Norway)



Source: Statoil

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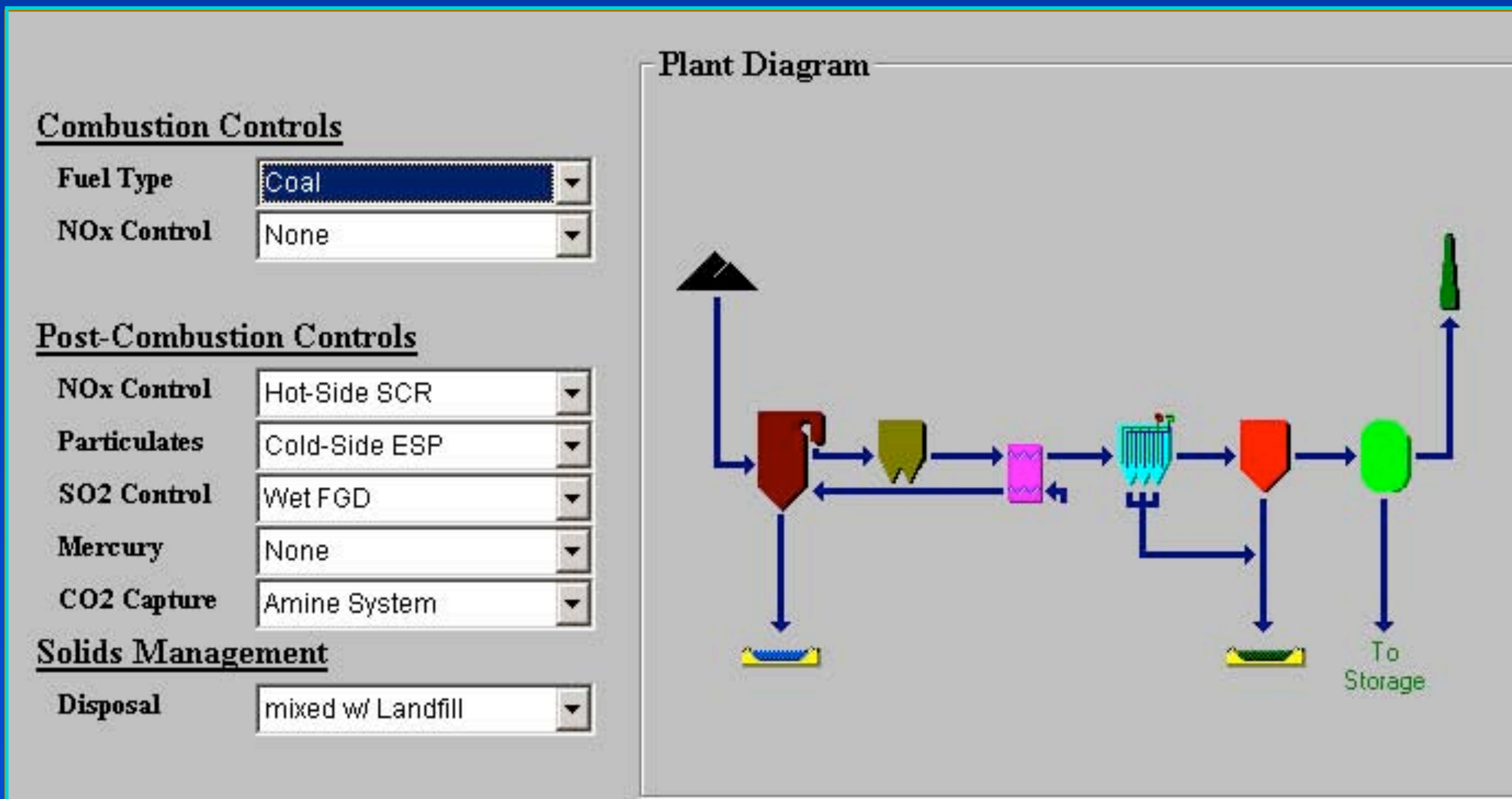
Leading Candidates for CCS

- Fossil fuel power plants
  - Natural gas combined cycle (NGCC)
  - Pulverized coal combustion (PC)
  - Integrated coal gasification combined cycle (IGCC)
- Other large industrial sources of CO_2, e.g.,
  - Refineries and petrochemical plants
  - Hydrogen production plants
  - Pulp and paper plants
  - Etc.

Focus on power plants as the largest source of CO_2

CCS Costs and Impacts Based on Current Technology

PC Plant with CO_2 Capture



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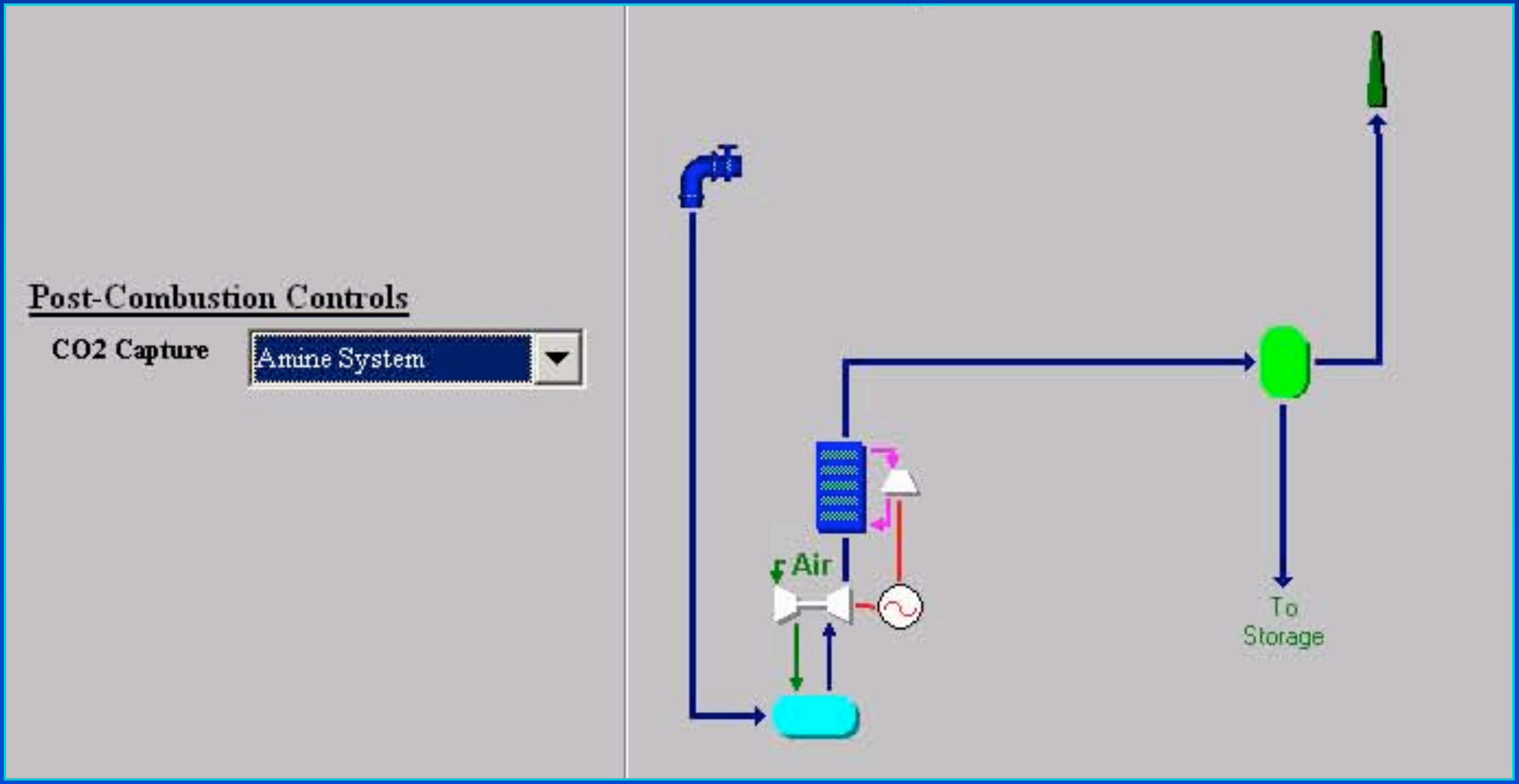
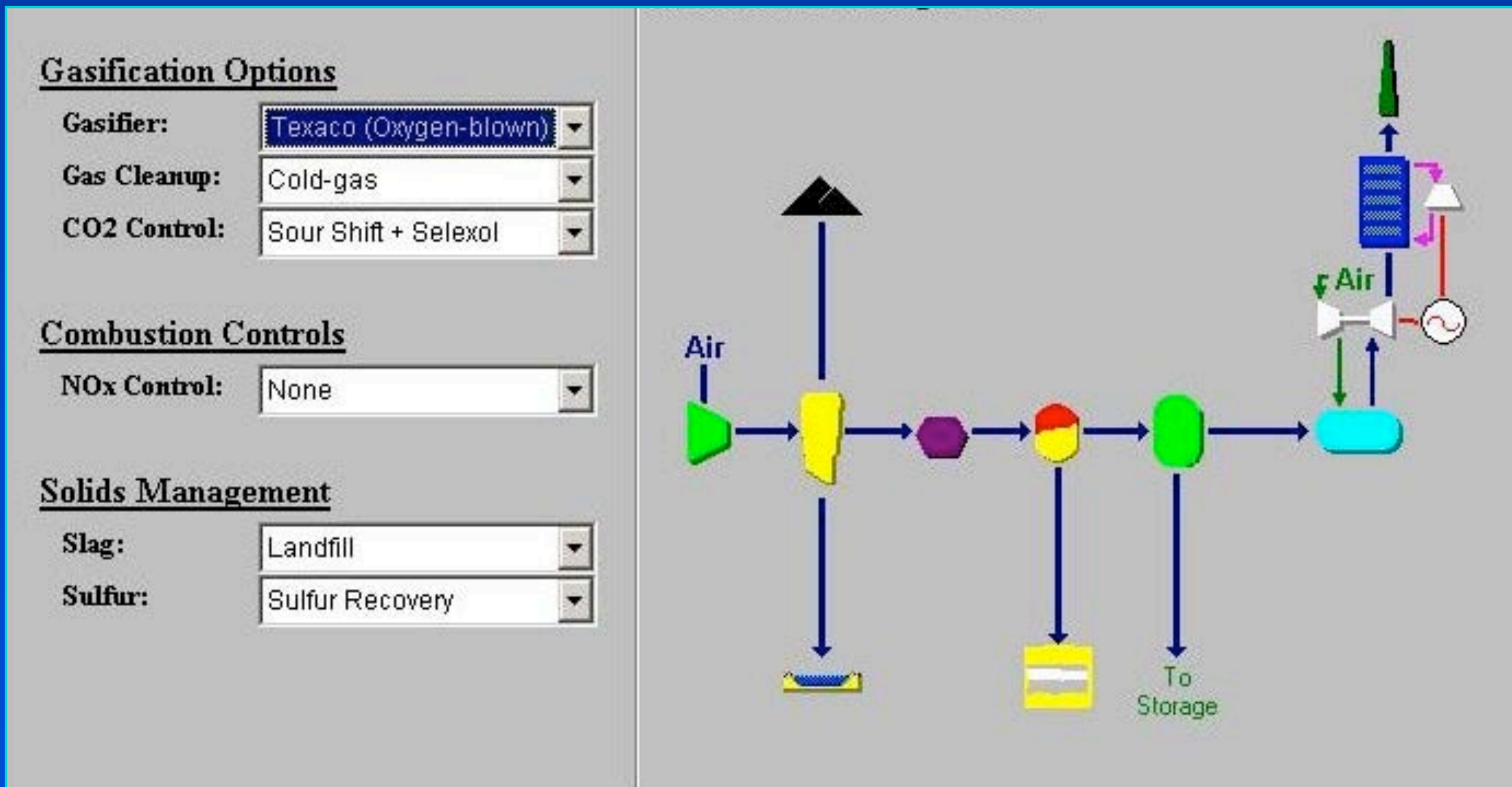
NGCC Plant with CO_2 Capture



IGCC Plant with CO_2 Capture



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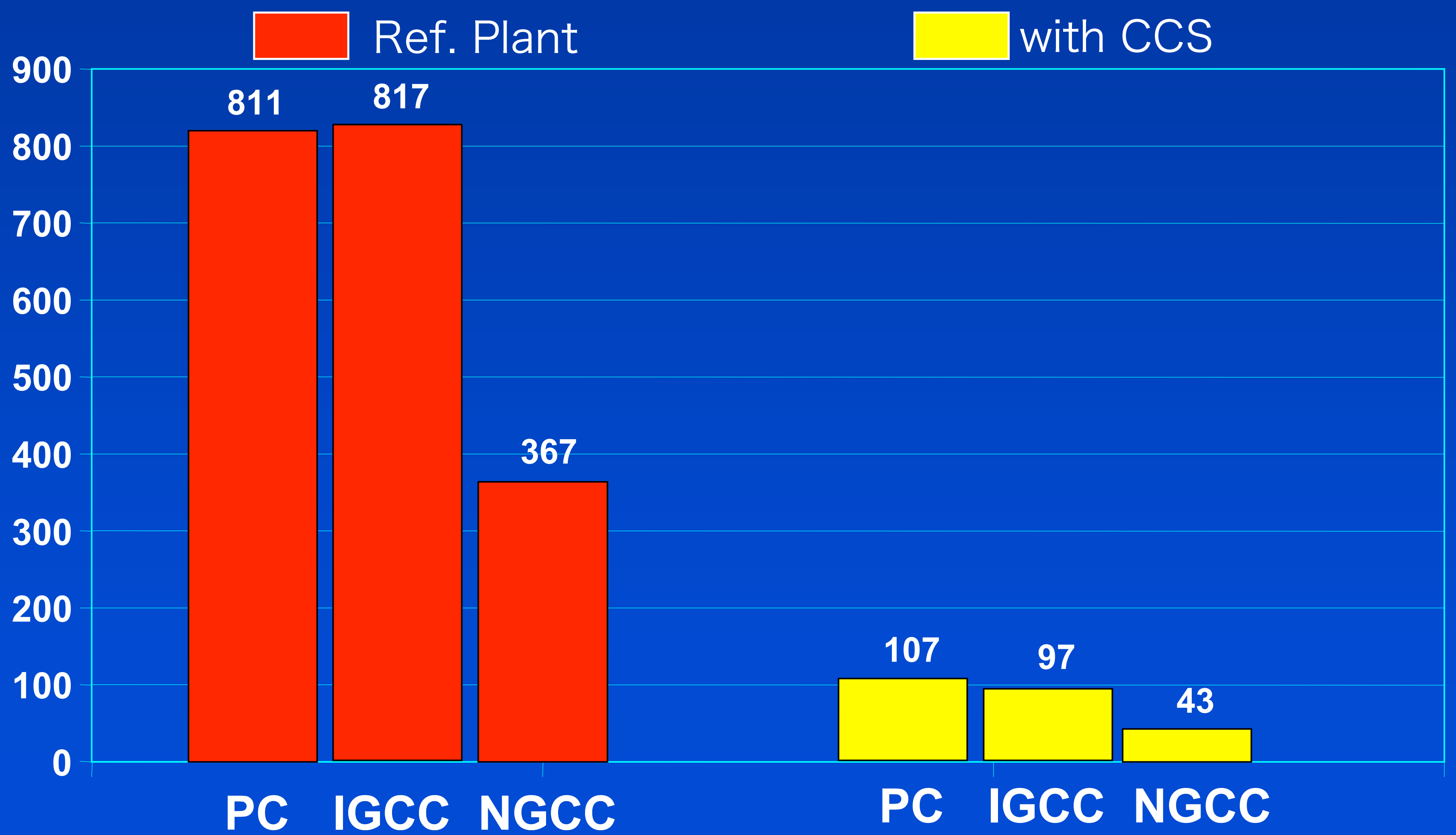
Baseline Assumptions

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
Storage Method	Geologic	Geologic	Geologic

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

CO_2 Emission Rates (kg/MWh)



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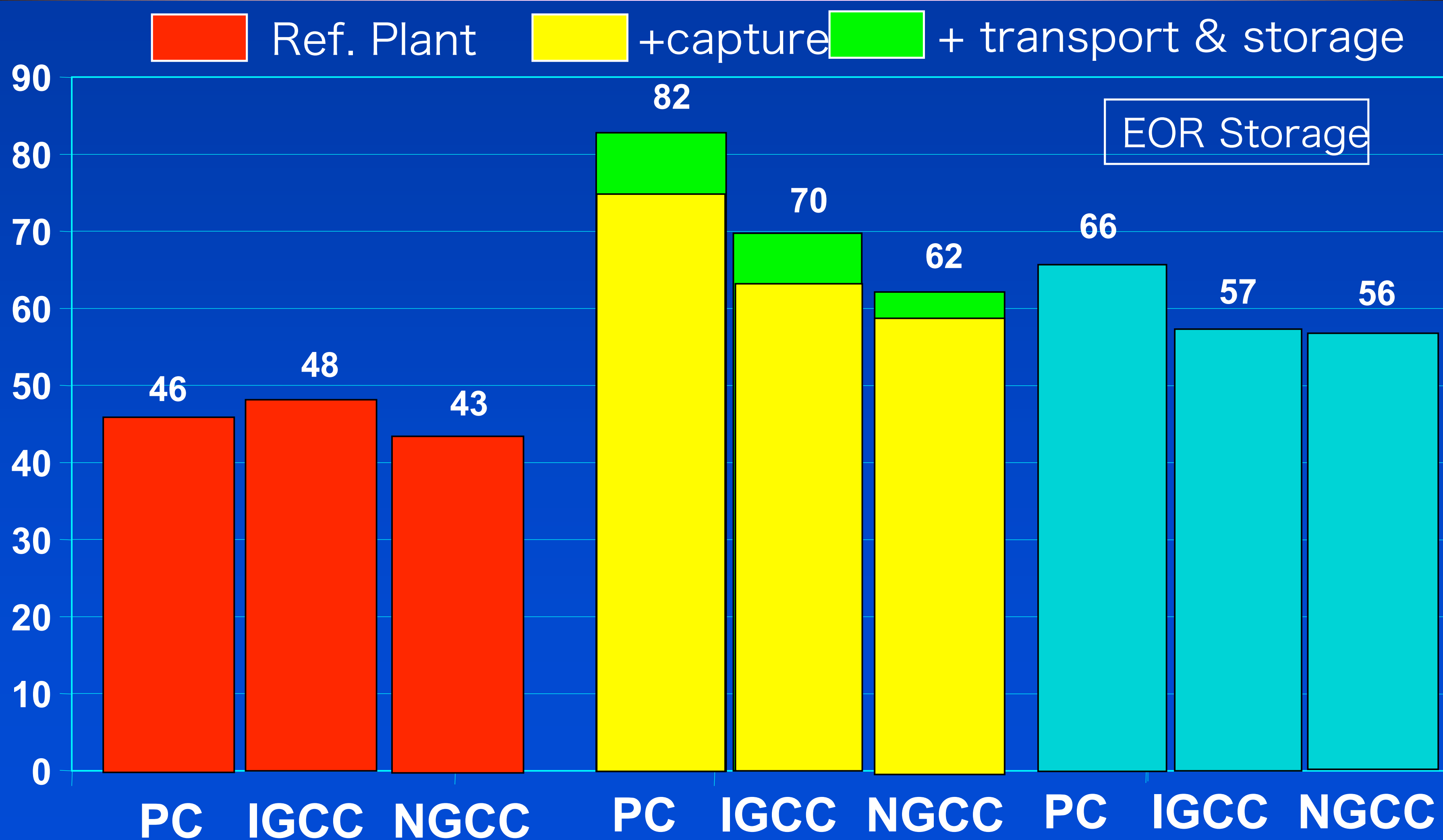
Cost of Electricity (COE)
(Levelized $/MWh)



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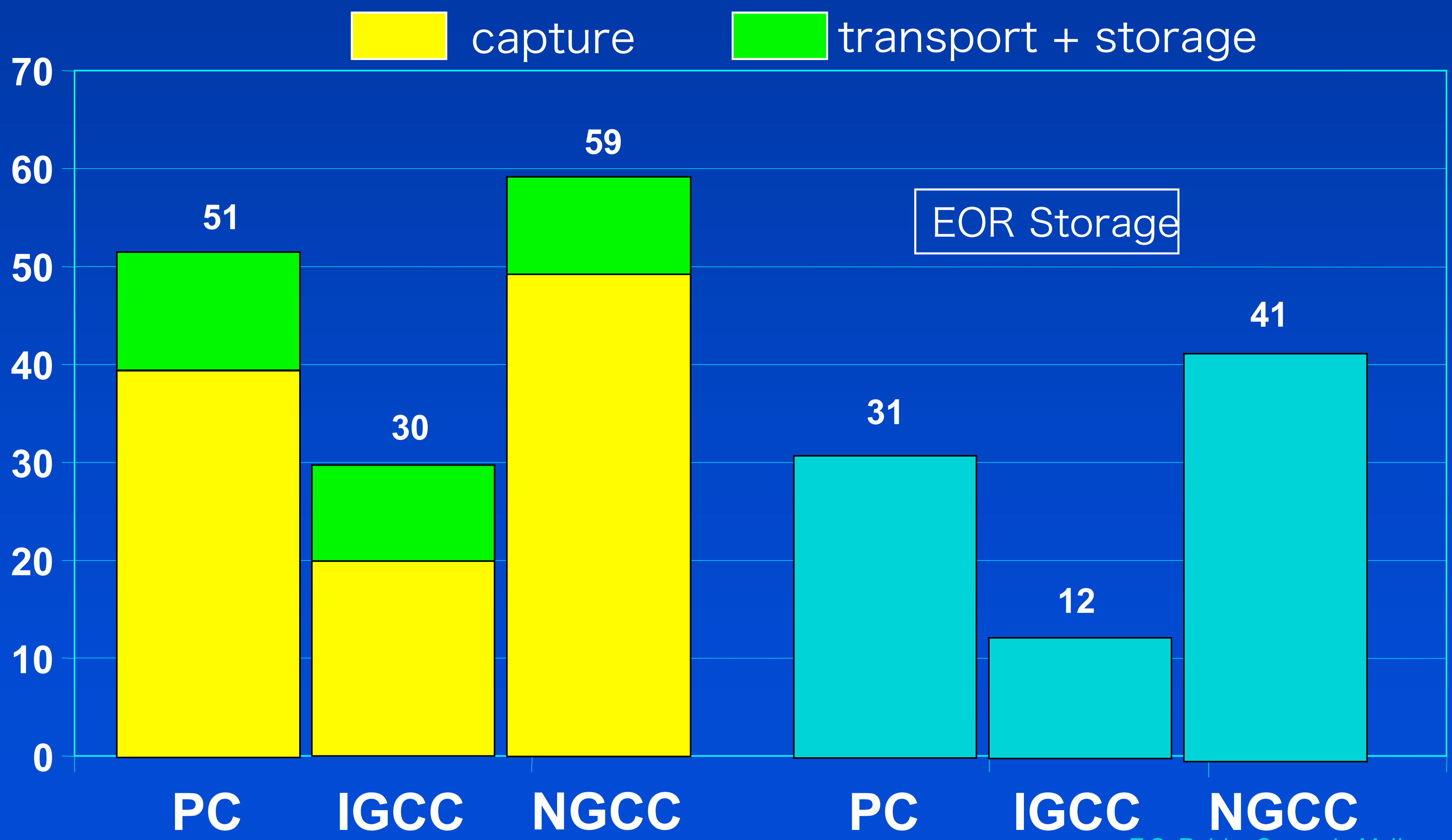
Cost of CO_2 Avoided ($/tonne CO_2)

(relative to a similar reference plant without capture)



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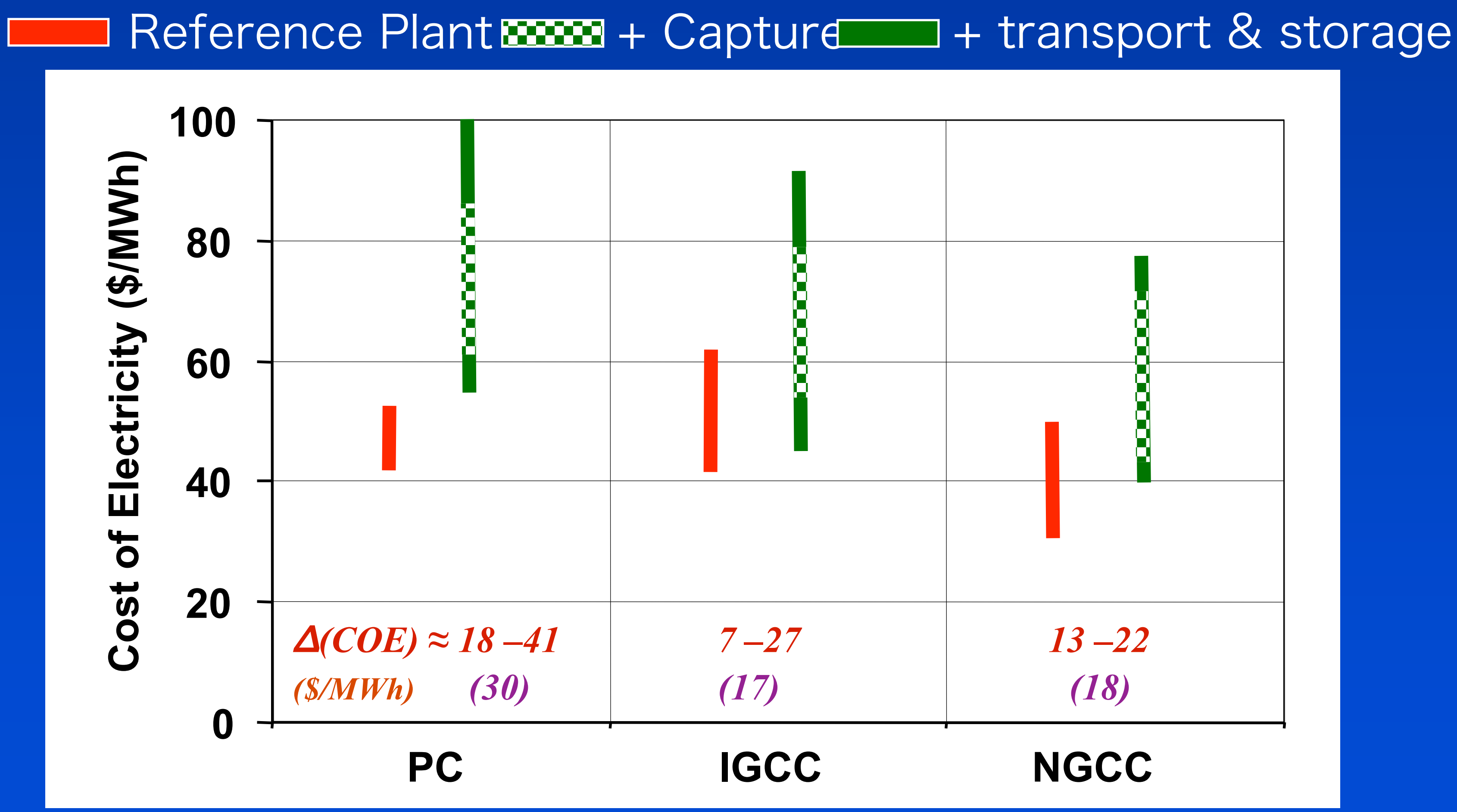
Many Factors Affect CCS Costs

- Key factors affecting CCS costs for a particular plant type include:
  - Plant Size
  - Fuel Properties
  - Capacity Factor
  - Fixed Charge Rate
  - Transport Distance
  - Plant Efficiency
  - Fuel Cost
  - Capture efficiency
  - Capital Cost Factors
  - Storage Method

- The variability of such factors across studies accounts for most of the differences in published cost estimates

Range of Power Generation Costs Based on Recent Studies



Based on current technology using bituminous coals and supercritical PC units;
Natural gas prices $2.8-4.4/GJ (LHV), coal price ~$1.2/GJ

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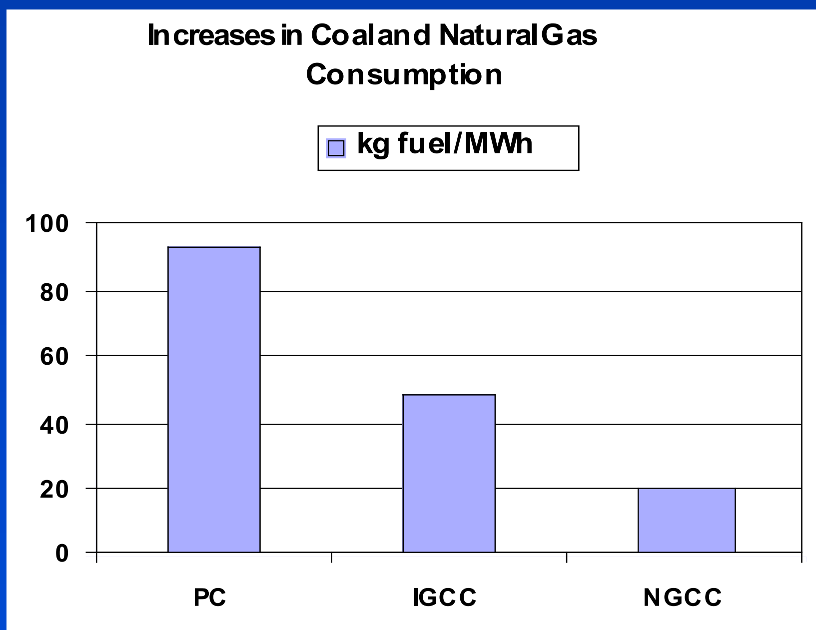
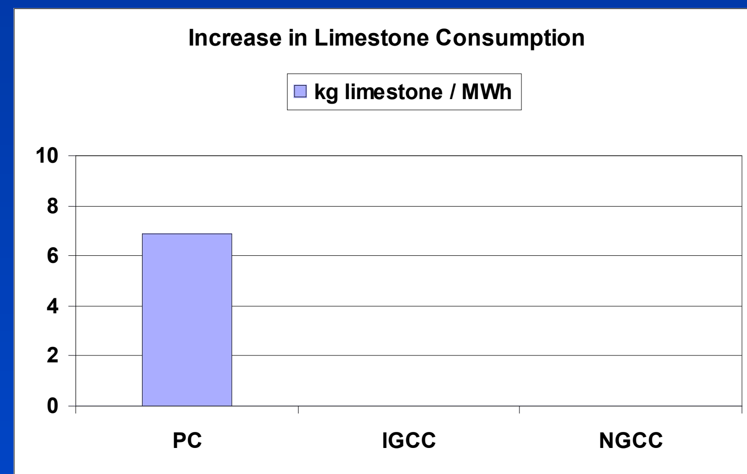
Impacts on Other Emissions and Resource Consumption

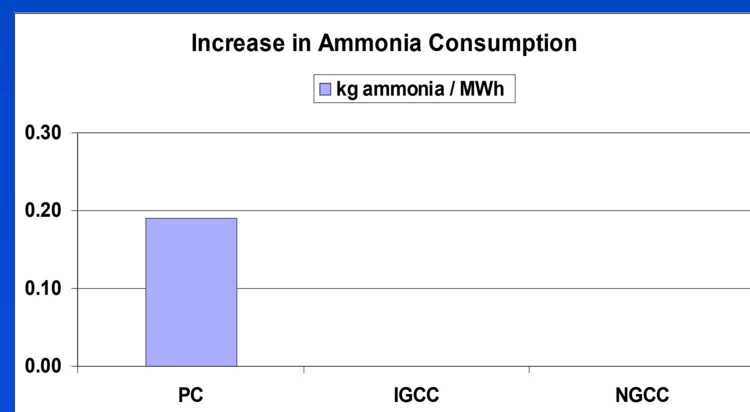
Importance of the CCS "Energy Penalty"

- CCS energy requirements are defined here as the *increase in energy input per unit of product output* (relative to a similar plant without capture)
- This measure directly affects the plant-level resource requirements and emissions per MWh of:
  - Fuel and reagent use
  - Air pollutant emissions
  - Solid and liquid wastes
  - Upstream (life cycle) impacts
- Energy penalty for case study plants:
  - PC = 31 %; IGCC = 16%; NGCC = 18%

Case Study Increases in Fuel and Reagent Consumption







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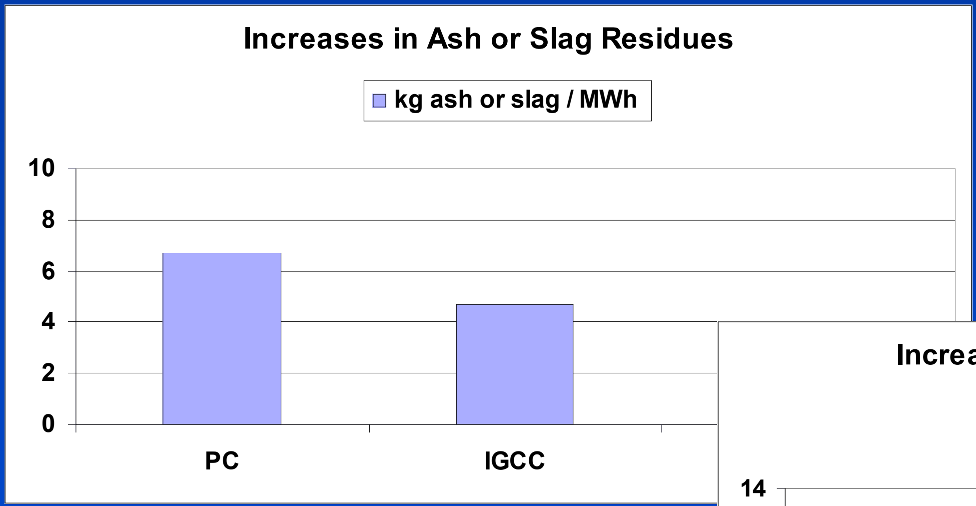
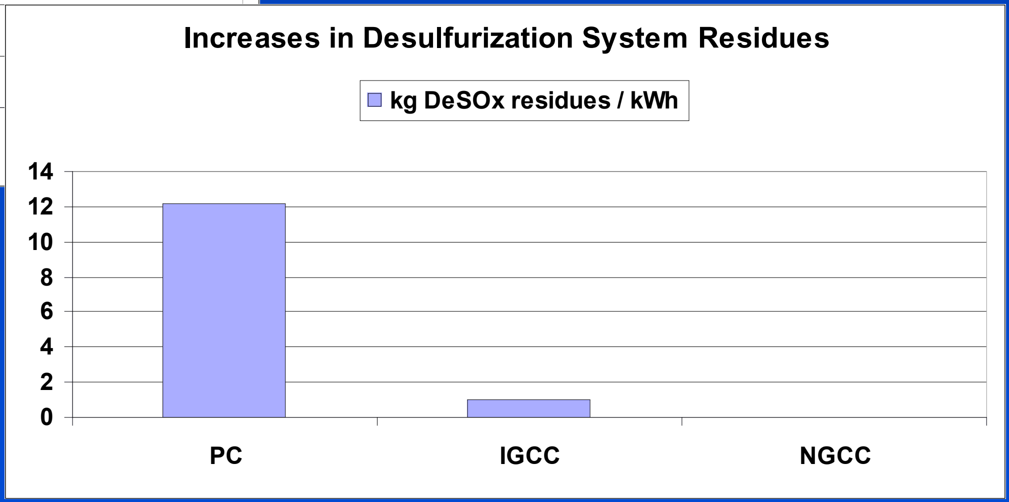
Case Study Increases in Solid Wastes & Plant Byproducts





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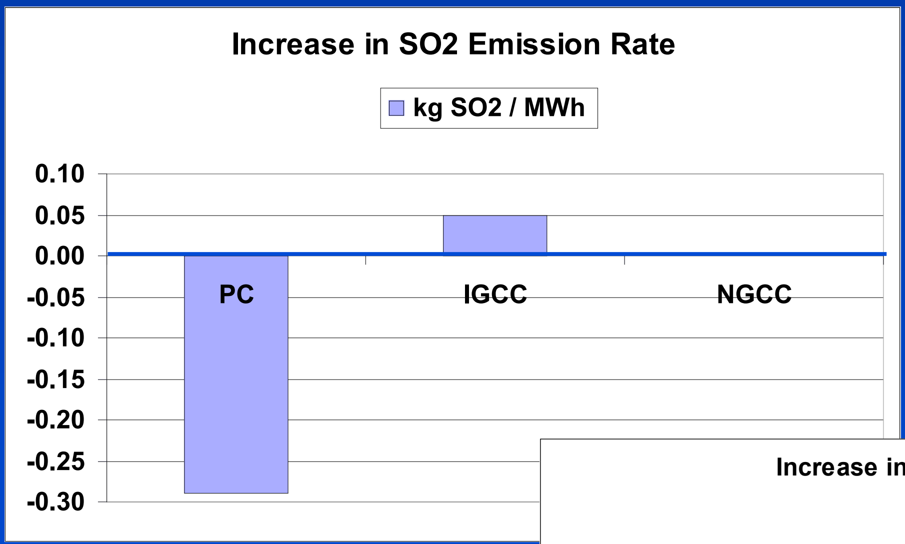
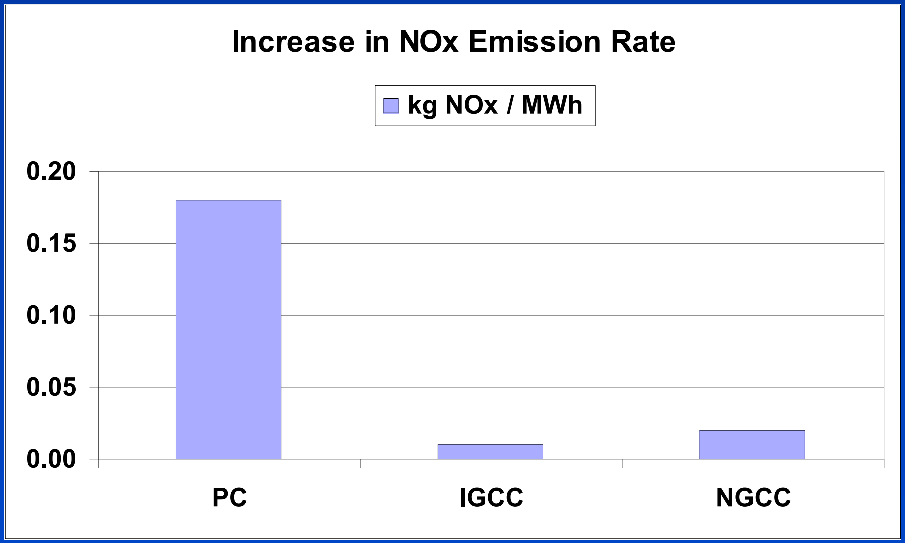
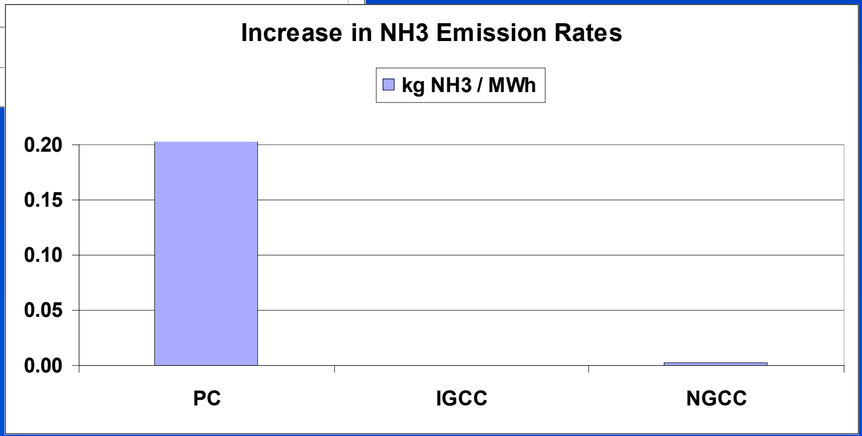
Case Study Increases in Air Emission Rates







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Summary of CCS Impacts on Emission & Resource Use Rates

Capture Plant Parameter [a]	PC [b]		IGCC [c]		NGCC [d]	
	Rate	**Increase**	**Rate**	**Increase**	**Rate**	**Increase**
Resource Consumption	**(all values in kg/MWh)**					
Fuel	390	93	361	49	156	23
Limestone	27.5	6.8	-	-	-	-
Ammonia	0.80	0.19	-	-	-	-
CCS Reagents	2.76	2.76	0.005	0.005	0.80	0.80
Solid Wastes/ Byproduct						
Ash/slag	28.1	6.7	34.2	4.7	-	-
FGD residues	49.6	12.2	-	-	-	-
Sulfur	-	-	7.53	1.04	-	-
Spent CCS sorbent	4.05	4.05	0.005	0.005	0.94	0.94
Atmospheric Emissions						
CO_2	107	*–704*	97	*–720*	43	*–342*
SO_x	0.001	*– 0.29*	0.33	0.05	-	-
NO_x	0.77	0.18	0.10	0.01	0.11	0.02
NH_3	0.23	0.22	-	-	0.002	0.002

Conclusions for Current Technology

- Current capture systems can significantly reduce CO_2 emissions from power plants and other large point sources
- The large energy requirements for CCS can exacerbate other environmental impacts and resources needed to produce useful products (like electricity); however, net impacts must be assessed in the context of a particular situation or scenario
- The cost of CCS depends on many site-specific factors; current tech. adds roughly $20–30/MWh to the generating cost of a new plant; costs for existing plants would be higher.
- NGCC plants with CCS tend to have the lowest costs and impacts for gas prices up to ~ $4/GJ; for bituminous coal-based plants, IGCC w/CCS generally offers lower costs and impacts than PC plants w/CCS

Future Outlook

- Many technical, legal, environmental and regulatory issues remain to be resolved before CCS is accepted as a viable method of CO_2 abatement
- New or improved power generation and CO_2 capture technologies promise to lower costs *and* reduce adverse secondary impacts by:
  - Improving overall plant efficiency
  - Reducing CCS energy requirements
  - Maximizing co-capture of other pollutants
- These technology innovations will require sustained R&D, together with government actions/policies to stimulate deployment of CCS technologies in the marketplace