Assessment of Carbon Capture and Sequestration Options for Power Plants

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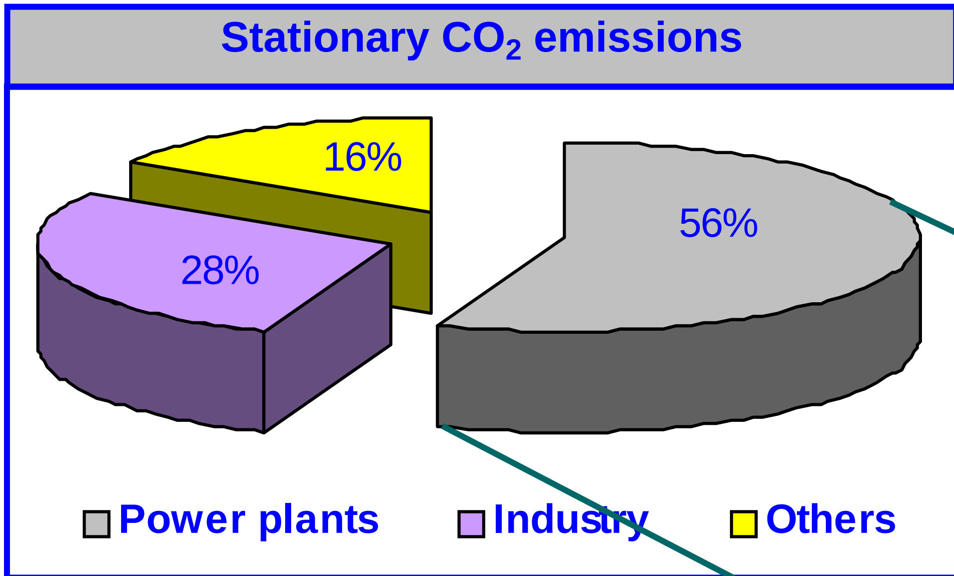
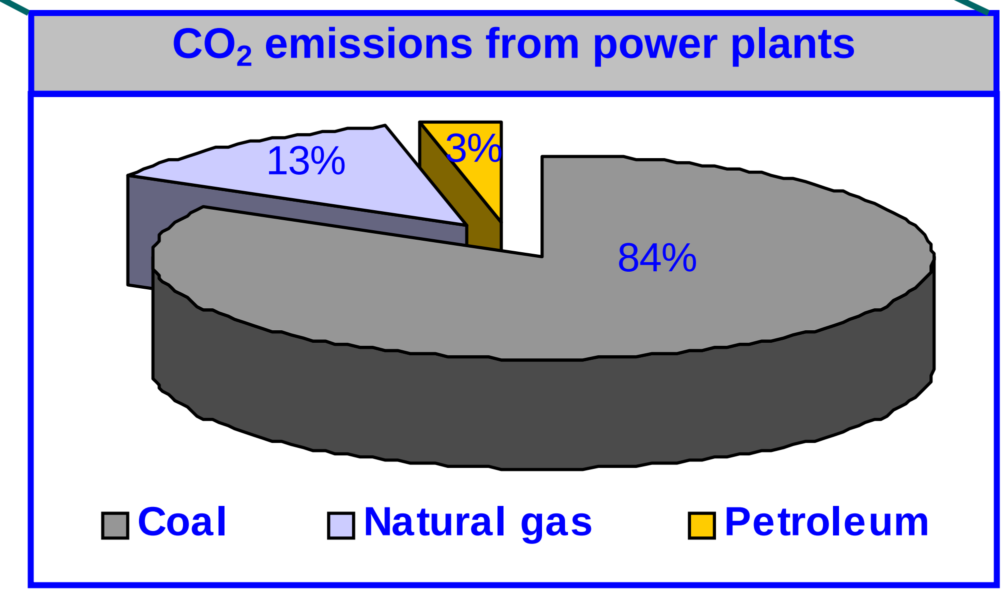
Major Objectives of Phase I CO2 Capture Task

- *CO_2 emission sources in Illinois Basin*
- *Technical evaluation of CO_2 capture technologies for different emission sources*
- *Techno-economic analysis of CO_2 capture technologies*
- *Optimization of integrated capture, transportation and storage options*

Annual CO_2 Emissions in the U.S. (in 2002)

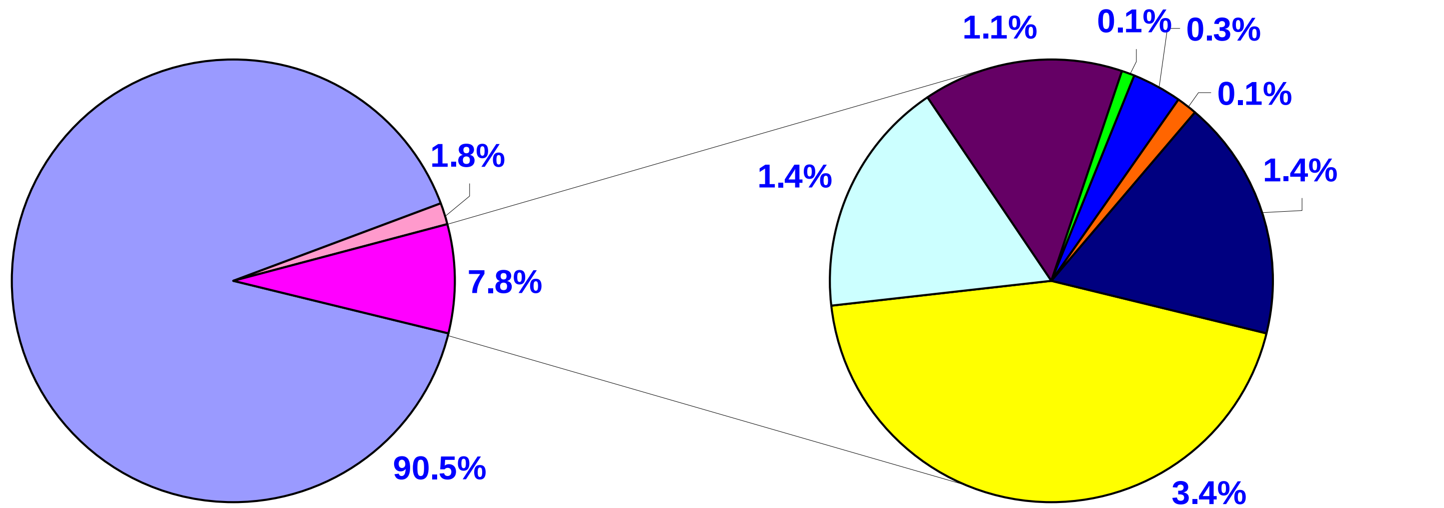


- *All sources = 5,782 Mt*
- *Stationary sources = 4,018 Mt (70%)*



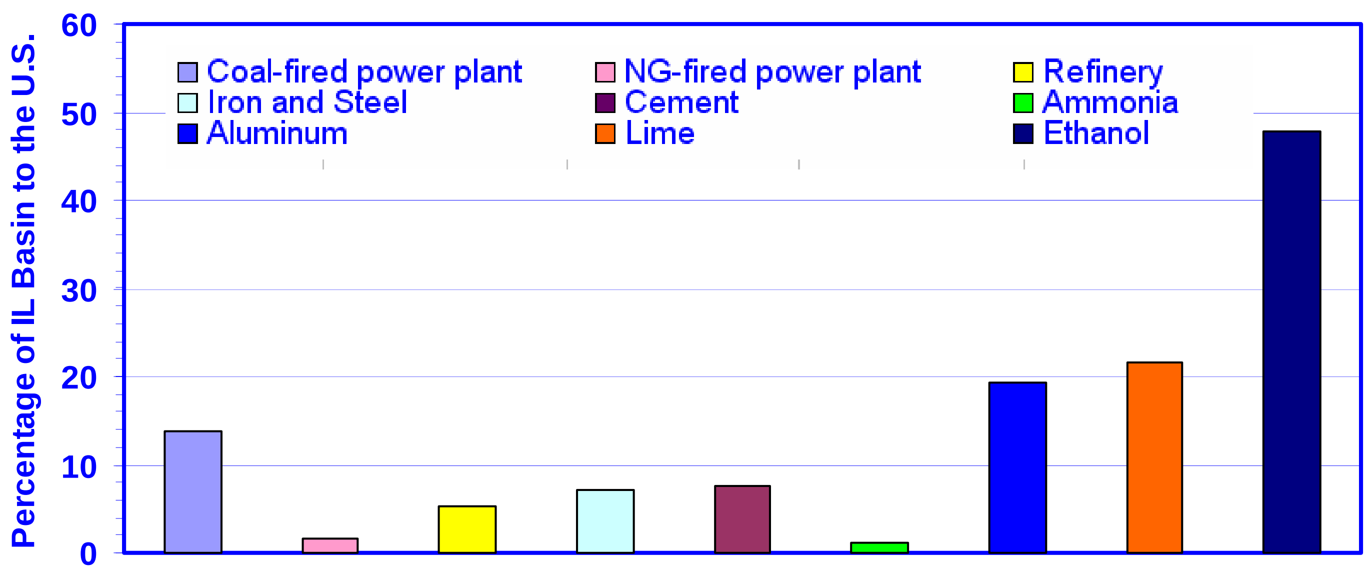
- *Coal-fired power plants = 1,868 Mt*
  - *32% of all sources*
  - *47% of stationary sources*

CO_2 Emissions in Illinois Basin



Total emissions: 283.3 million ton CO_2

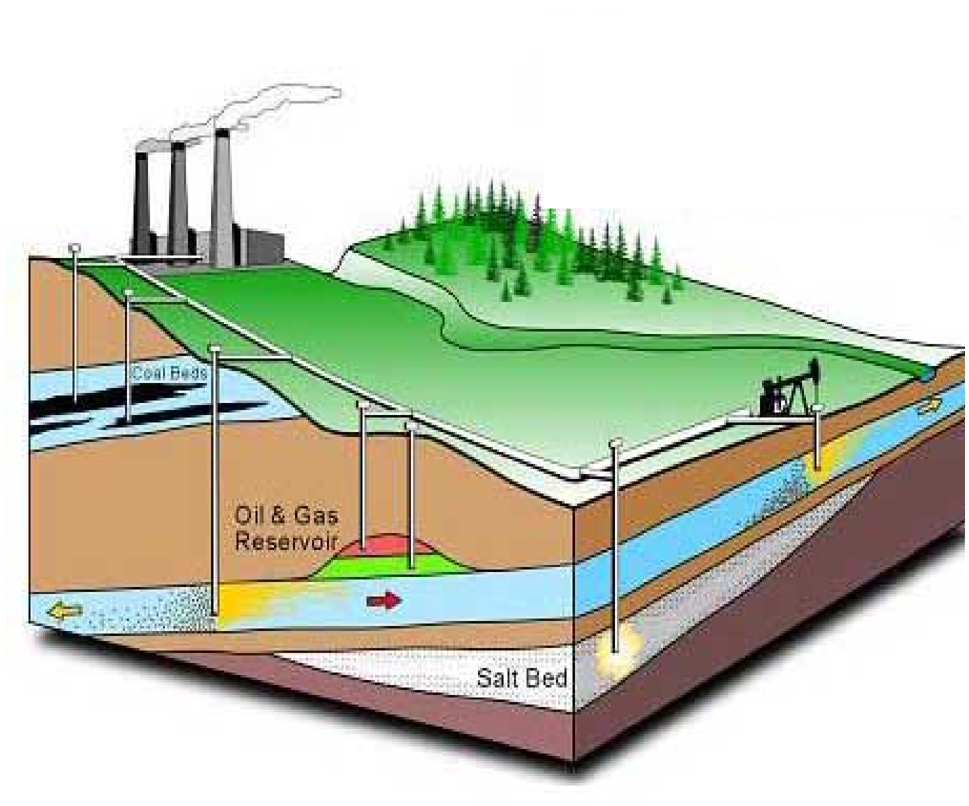
Industrial emissions: 22.0 million ton CO_2

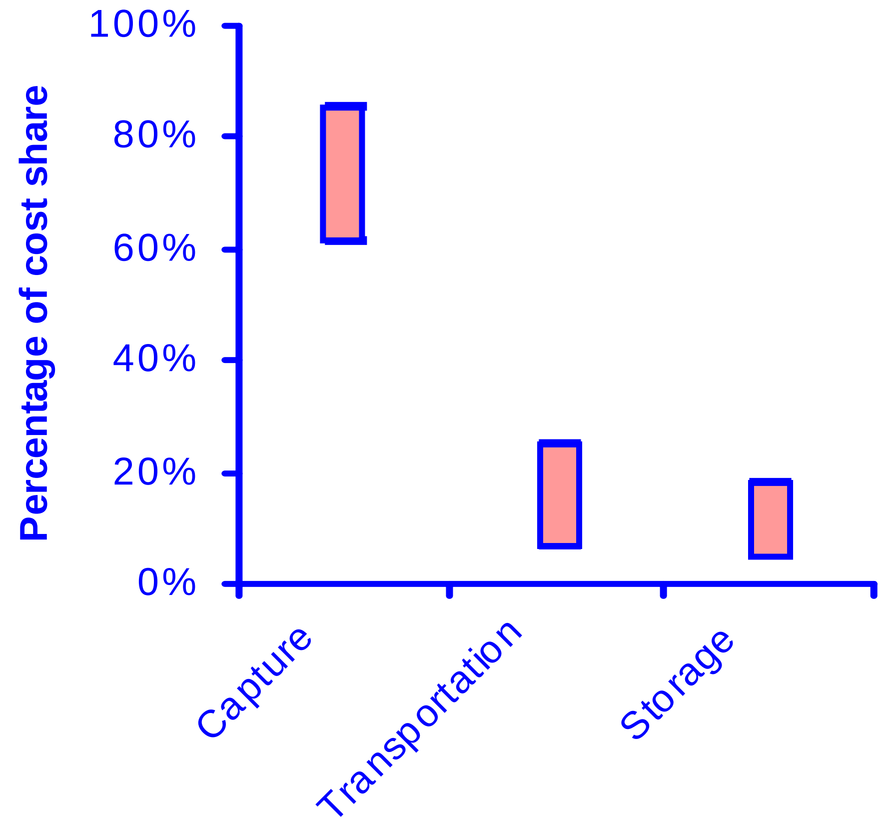


CO_2 Concentrations in Flue Gases

Source	CO_2 concentration (vol.%)
PC power station flue gas	14
Iron and steel blast furnace gas	20-27
Cement kiln off-gas	13-33
Lime manufacturing	13-33
Ammonia	>95
Oil refinery	8-15
Ethanol Plants	>85

Cost Breakdown in CO_2 Sequestration

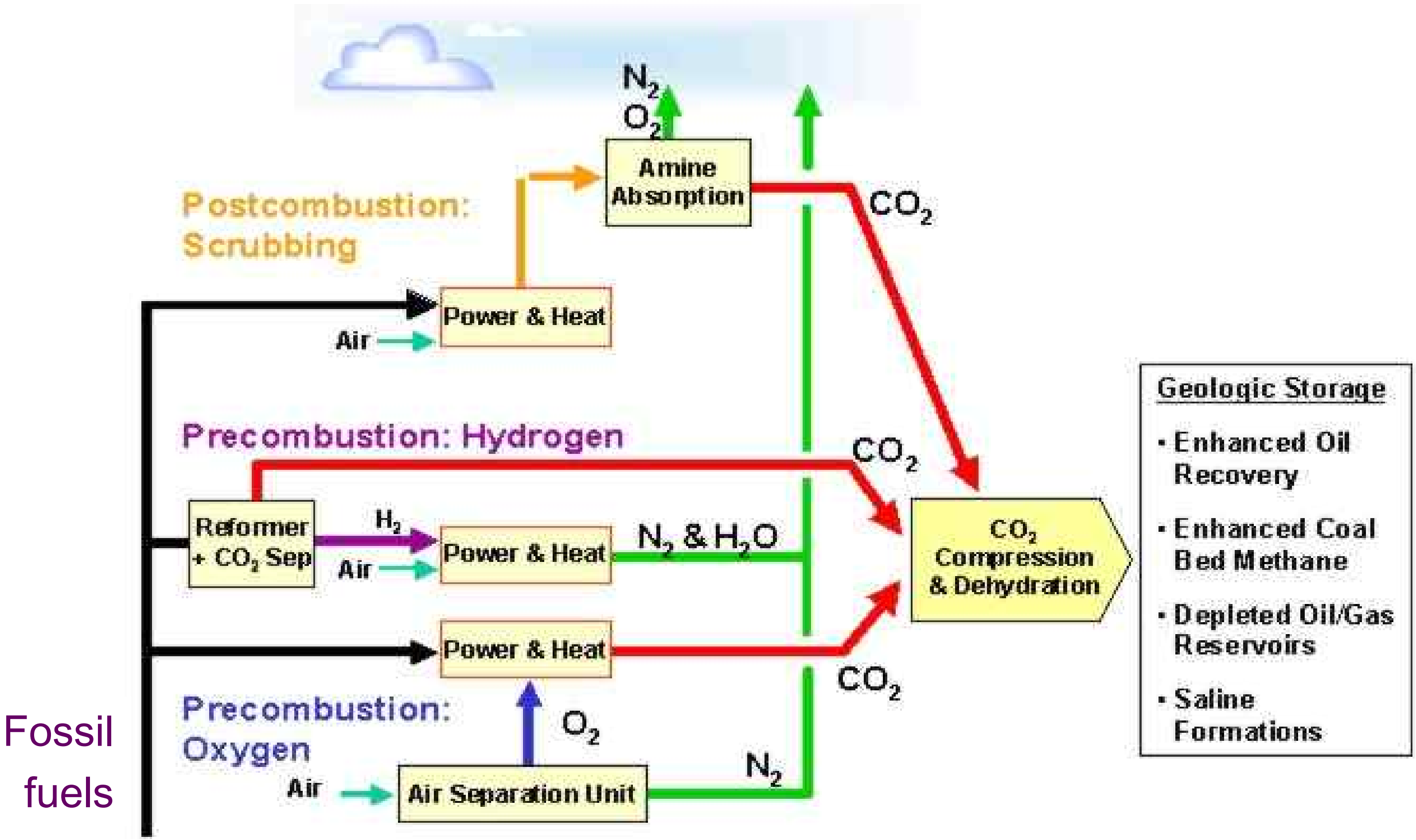




Cost assumptions:

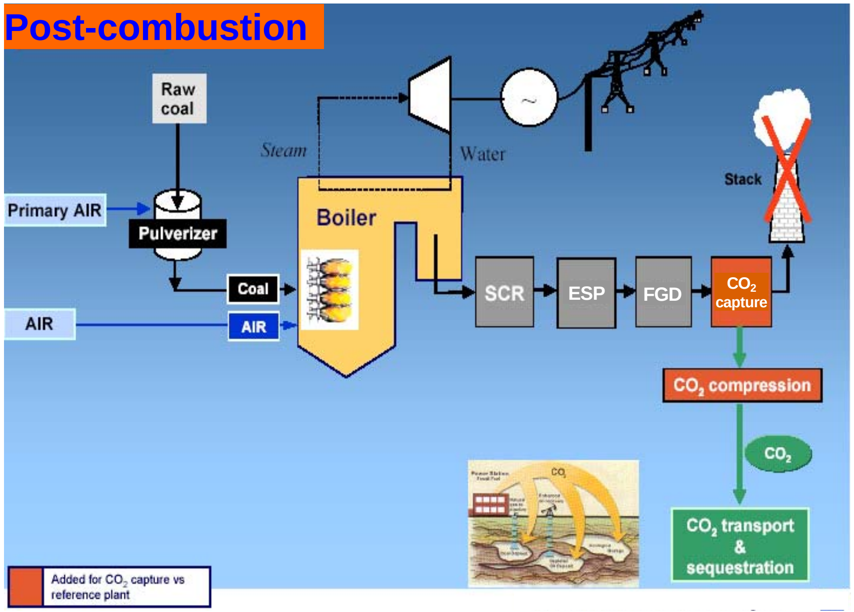
- *Capture: $40-60/t CO_2 avoided*
- *Pipeline: $0.02-0.06/t .km*
- *Transportation mileage: 250 km*
- *Storage: $5-10/t CO_2*

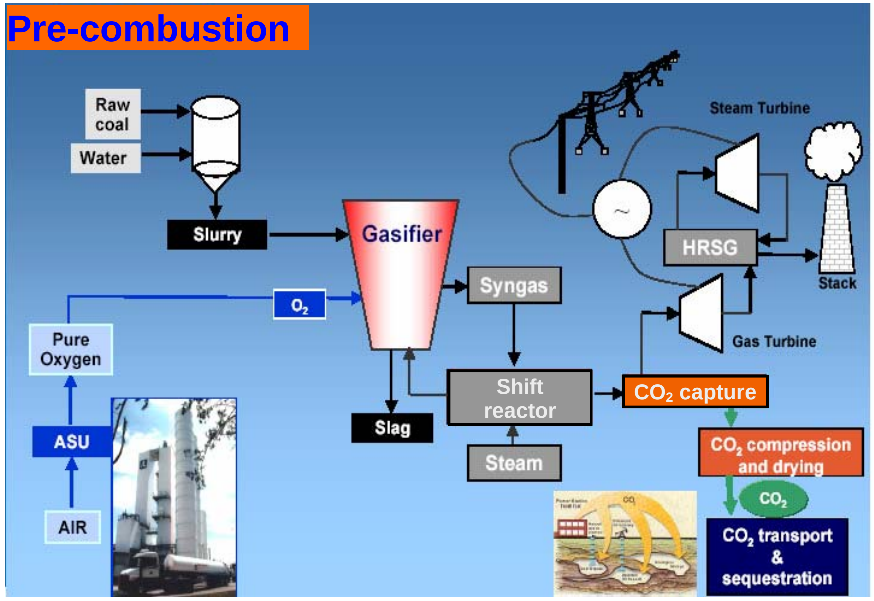
Configurations for CO_2 Capture

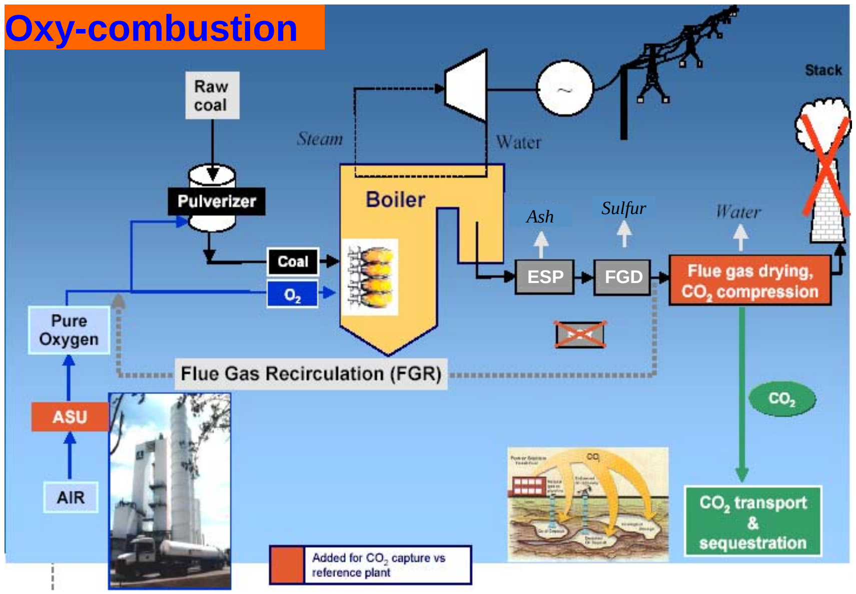


Info source: http://www.co2captureproject.org/technologies/index.htm

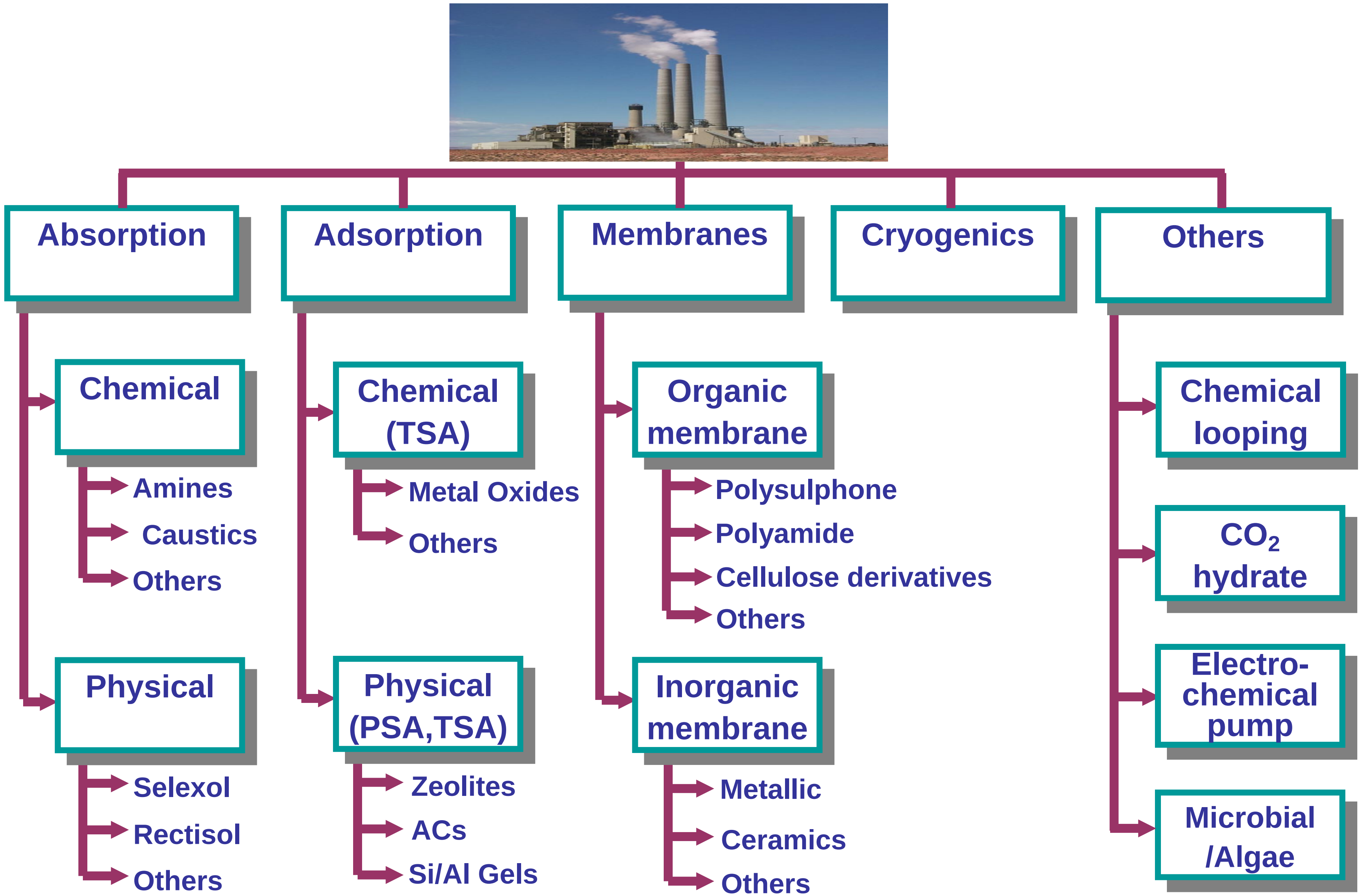
Configurations for CO_2 Capture



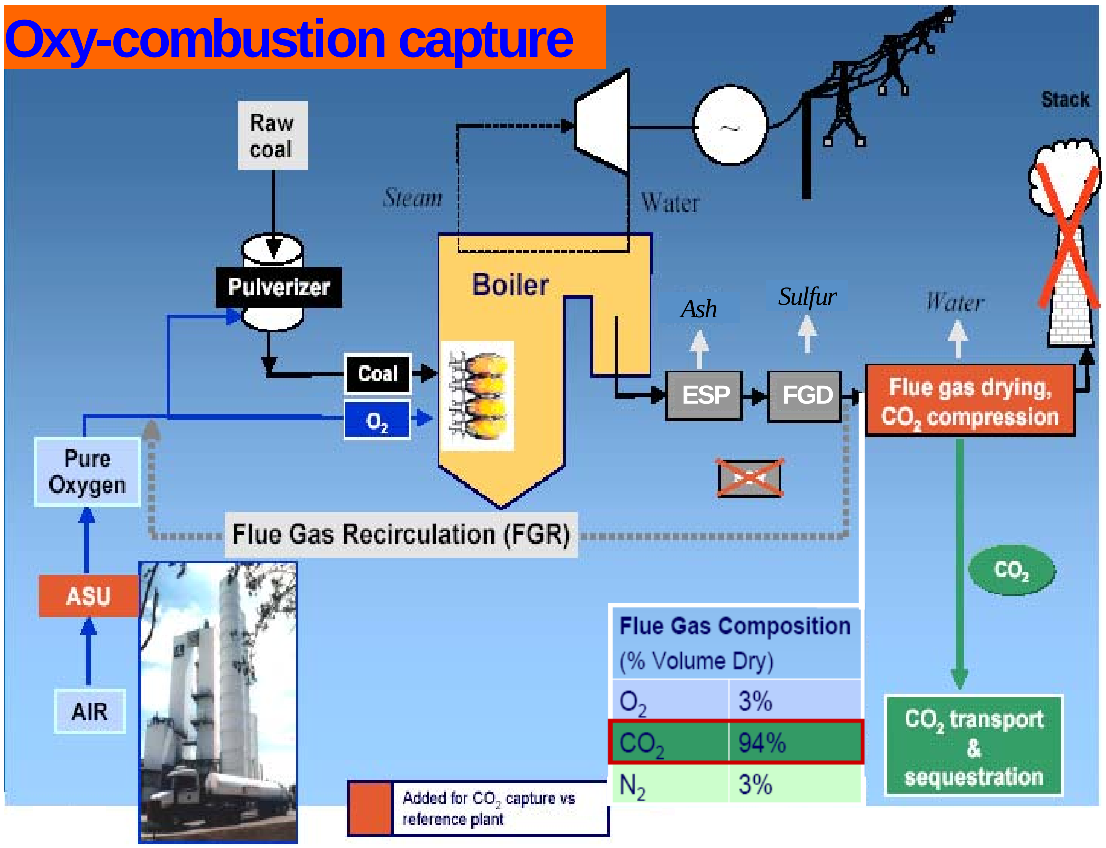




Technologies for CO_2 Capture



Oxy-Combustion



- *Pilot-tests*
  - *94% CO_2 (dry) compared to 15% in air-blown combustion (AC)*
  - *Flue gas volume 80% lower than AC*
  - *60 to 70% NOx reduction (0.08 to 0.1 lb/MM Btu)*
  - *Compact design for new boilers*
- *No commercial operations*

Candidate CO_2 Capture Technologies

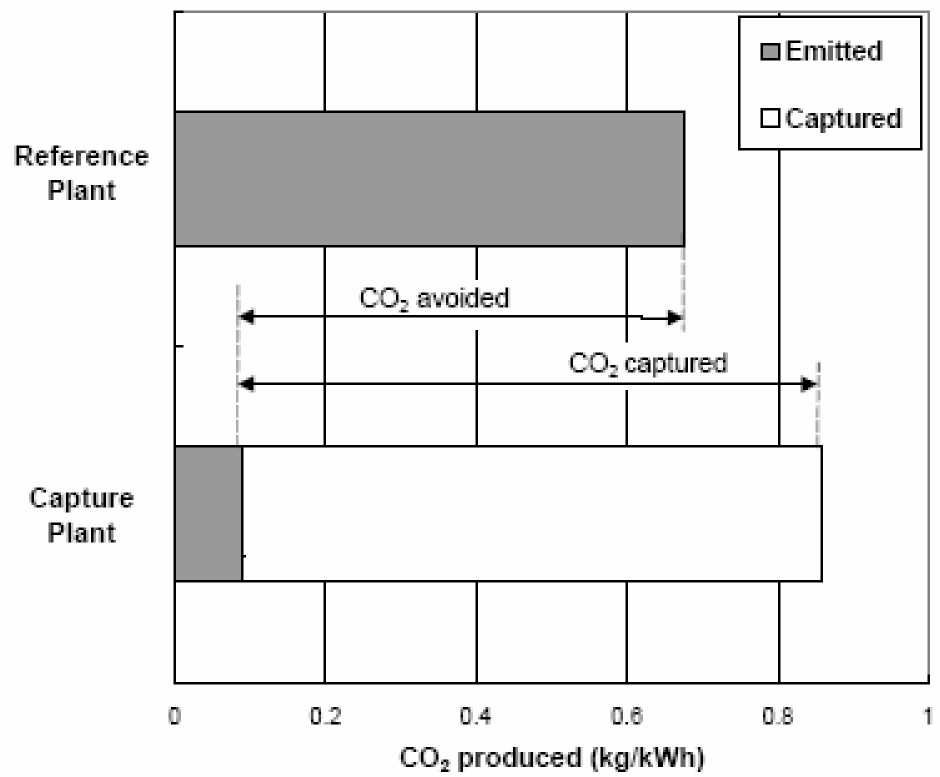
Source Type	Point of Capture	Amine Scrubbing	Ammonia Scrubbing	Physical Absorption	Gas Separation Membrane	Gas Absorption Membrane	Hydrate Formation	Oxyfuel + Drying/Compression
Power Plants Post-Combustion	Flue Gas	L	A	--	A	A	--	A
Power Plants Pre-Combustion	Shifted Syngas	--	--	L	A	--	A	--
Iron / Steel Facilities	Blast Furnace Gas (~60-70% of total CO_2)	L	--	L	A	S	S	--
Refineries	Heater/Boiler Flue Gas (~65-85% of total CO_2)	L	S	--	A	S	--	A
Cement Plants	Kiln Flue Gas	L	S	--	S	S	--	S

Likely (L); Attractive (A); Speculative (S)

Techno-Economic Analysis

- *Air-blown PC plant + chemical absorption process (MEA)*
- *IGCC + shift + physical absorption process (Selexol)*
- *Oxy-combustion*

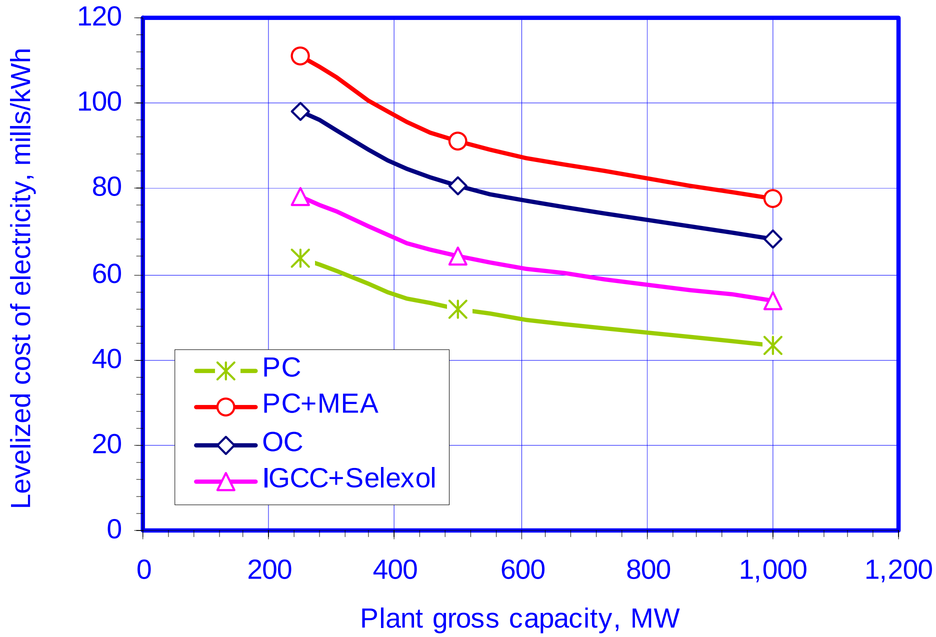
CO_2 Avoidance and CO_2 Capture



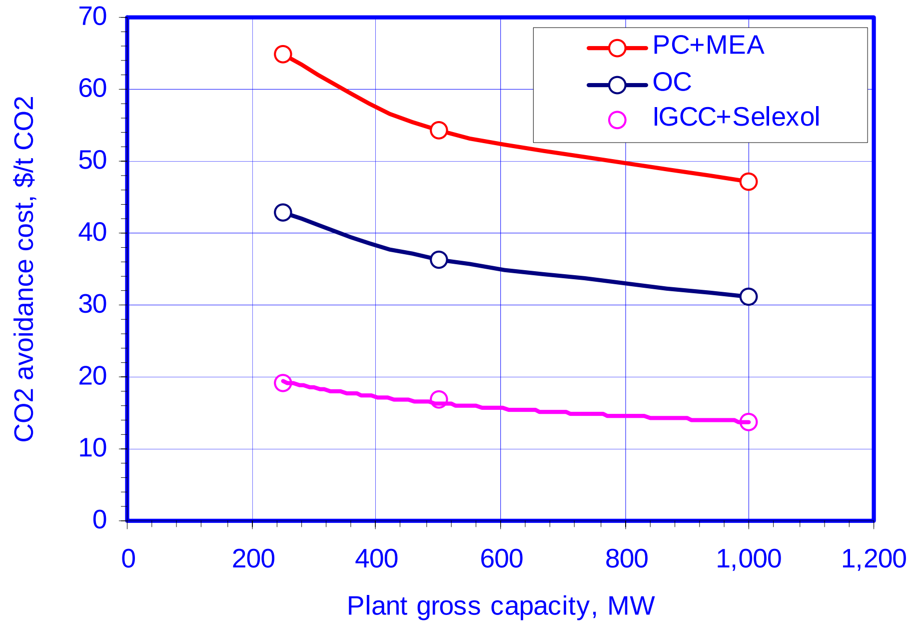
Cost of CO_2 avoidance = Δ cost of electricity / CO_2 avoided

Cost of CO_2 capture = Δ cost of electricity / CO2 captured

Costs of New Power Plants (IL coal)

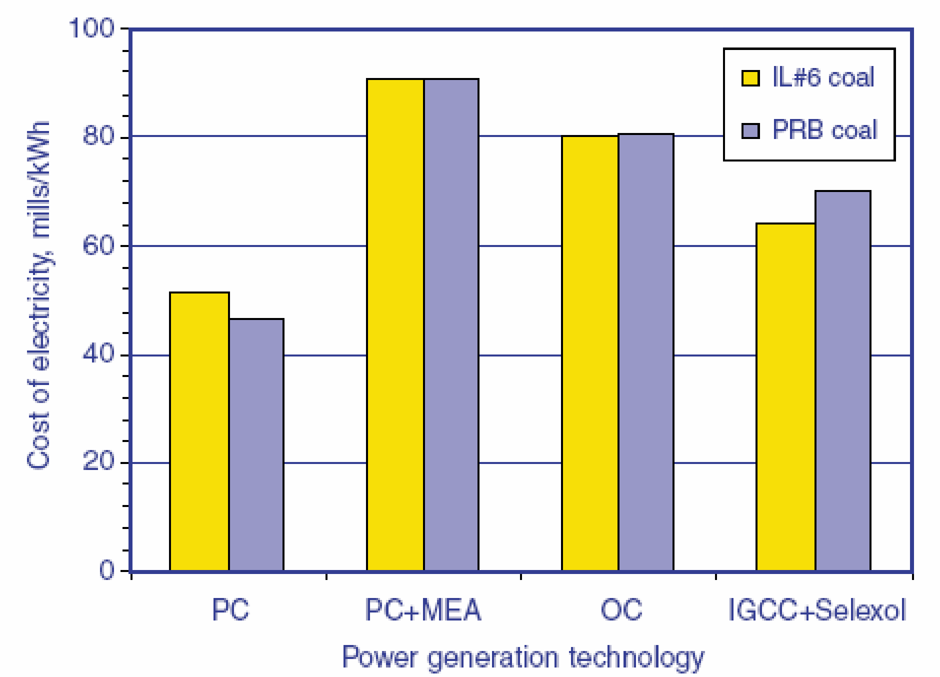


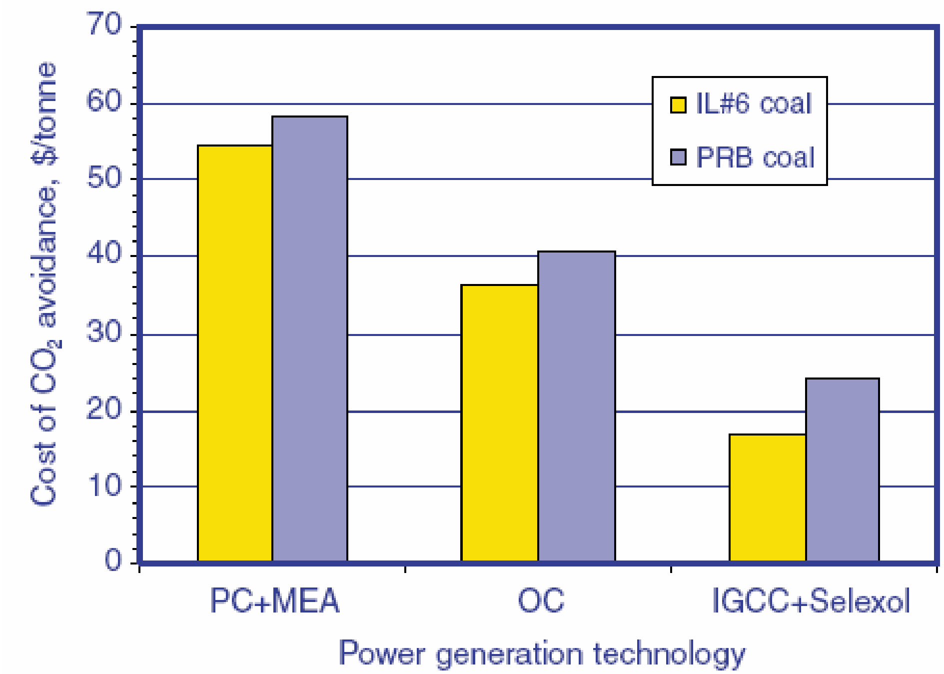
Cost of electricity



CO_2 avoidance cost

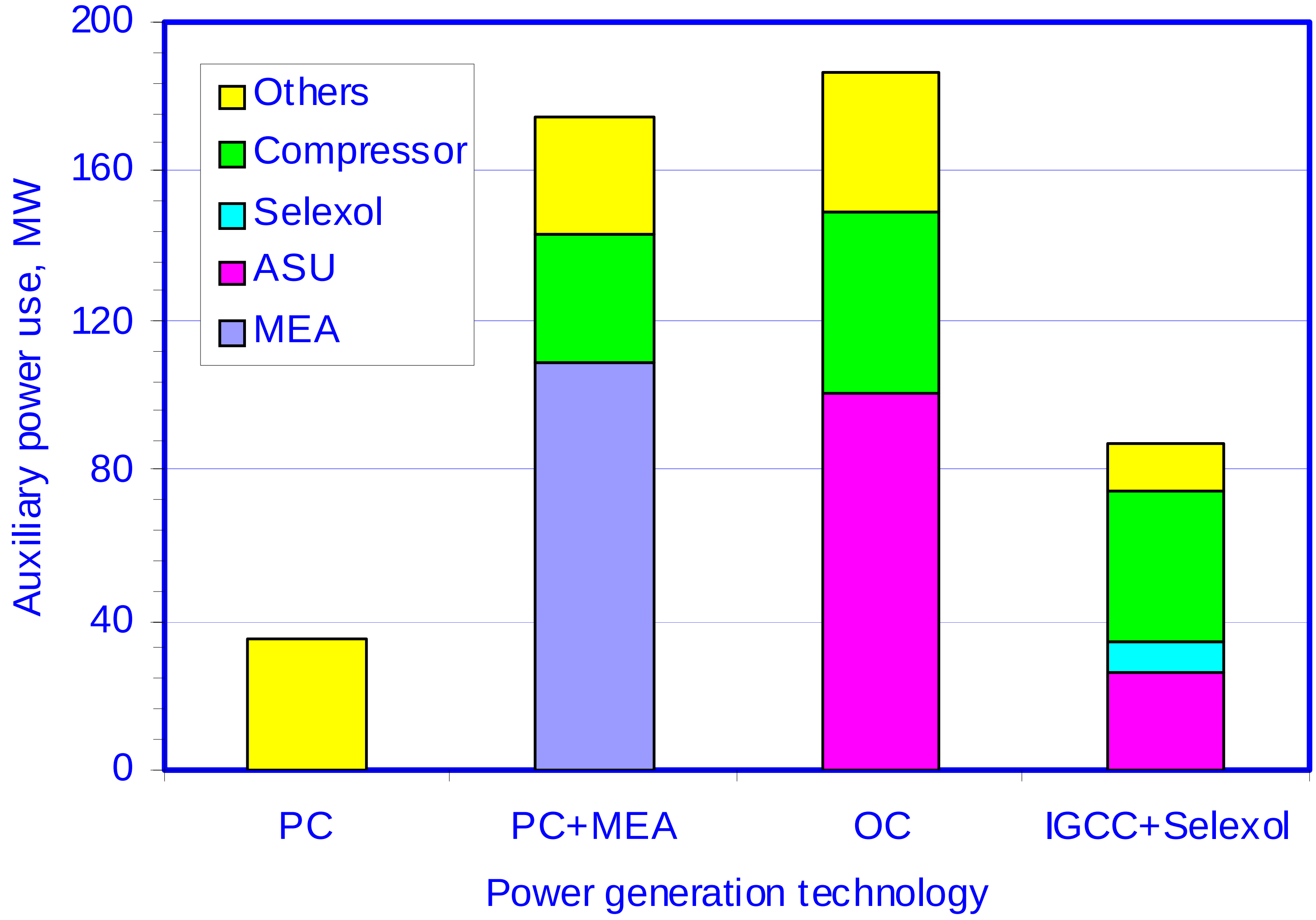
Cost Comparison between IL Coal and PRB Coal



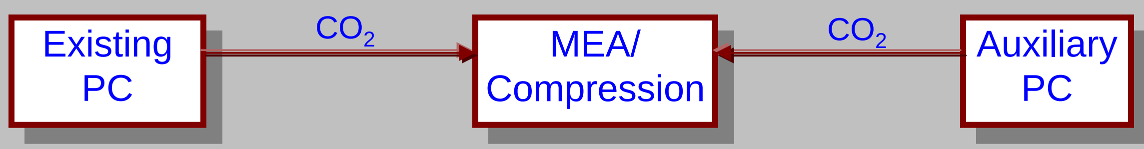


Electricity Loss of New Power Plants (IL coal)

Auxiliary power use of a 533 MW (gross) power plant

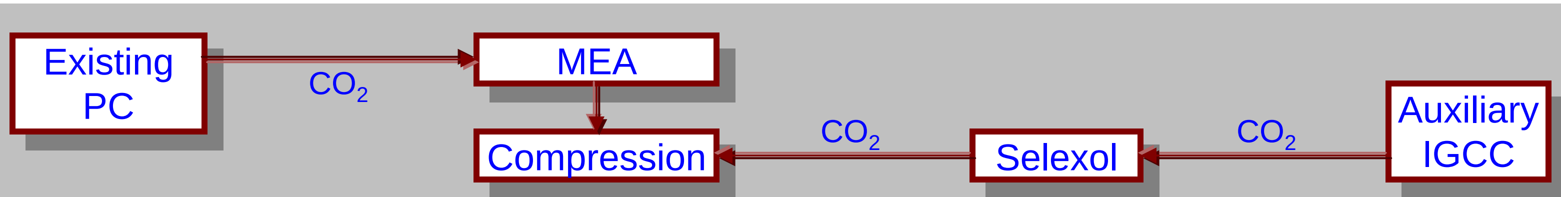


CO_2 Capture Retrofit of Existing Plants: Case Studies



Case 1: MEA retrofit + auxiliary PC with MEA

Case 2: MEA retrofit + auxiliary NGCC w/o CO_2 capture

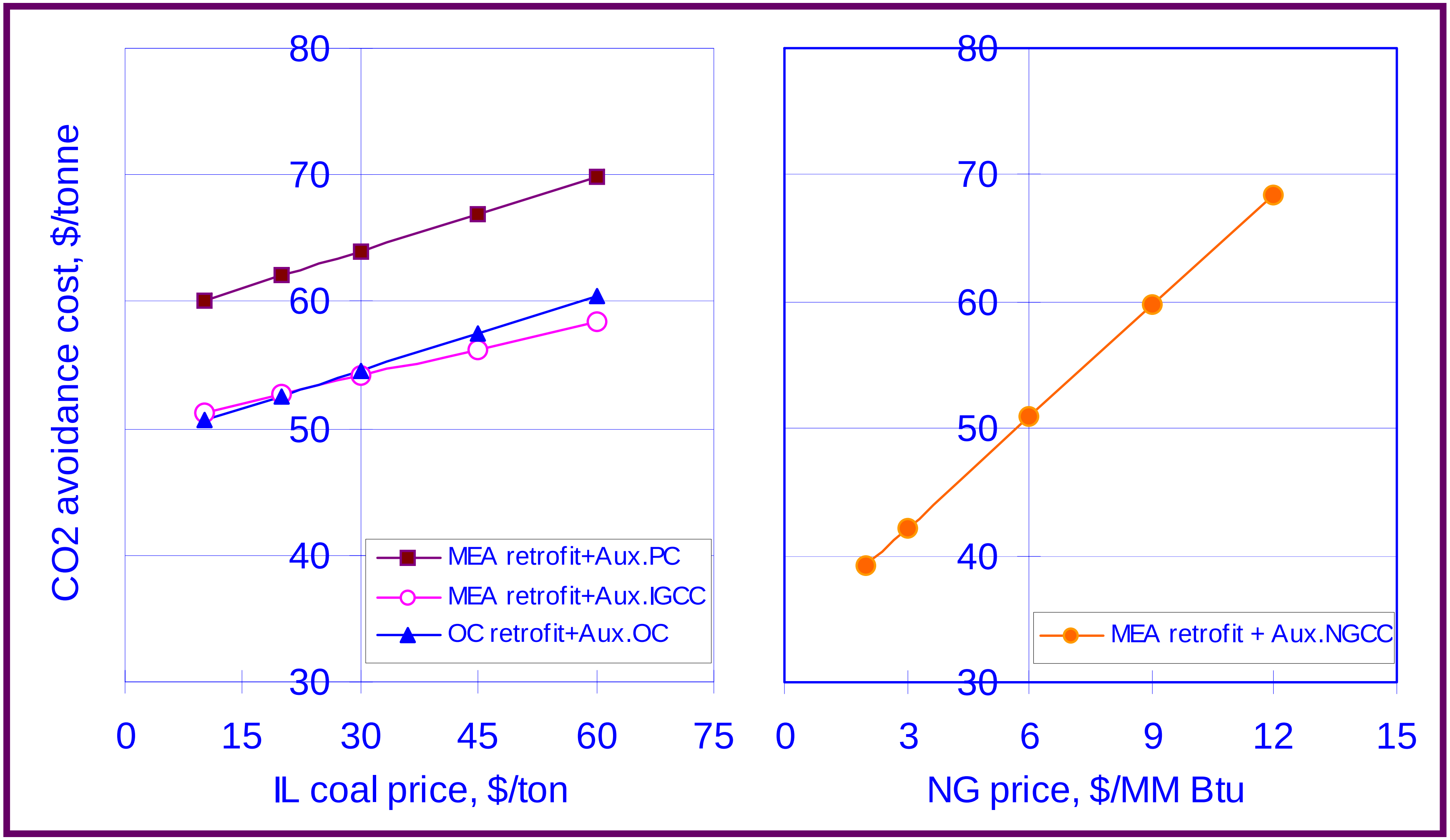


Case 3: MEA retrofit + auxiliary IGCC with Selexol

Case 4: Oxy-combustion (OC) retrofit + auxiliary OC

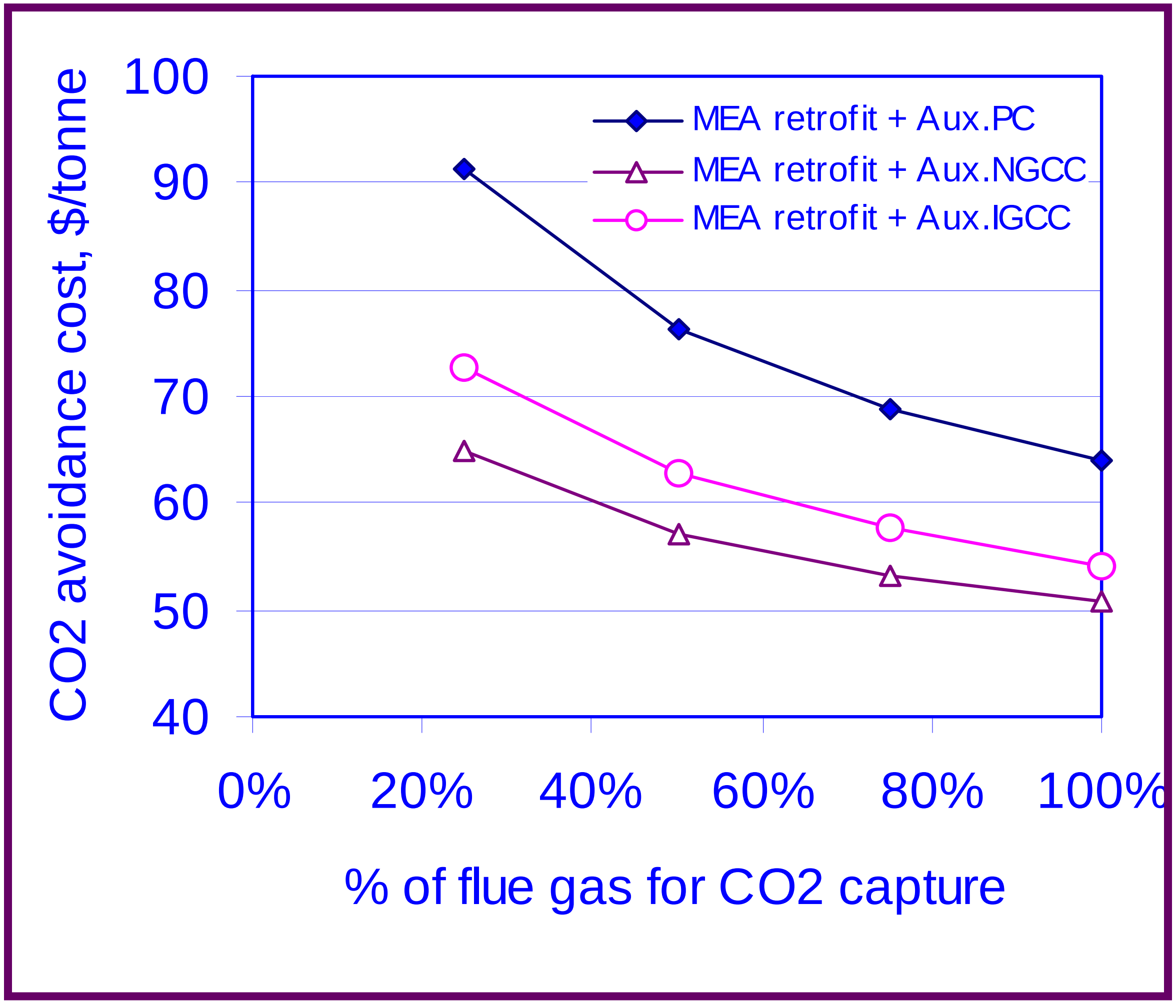
Costs of Power Plant Retrofit

Impact of fuel price



Costs of Power Plant Retrofit

Impact of retrofit scale



equiv. power plant size

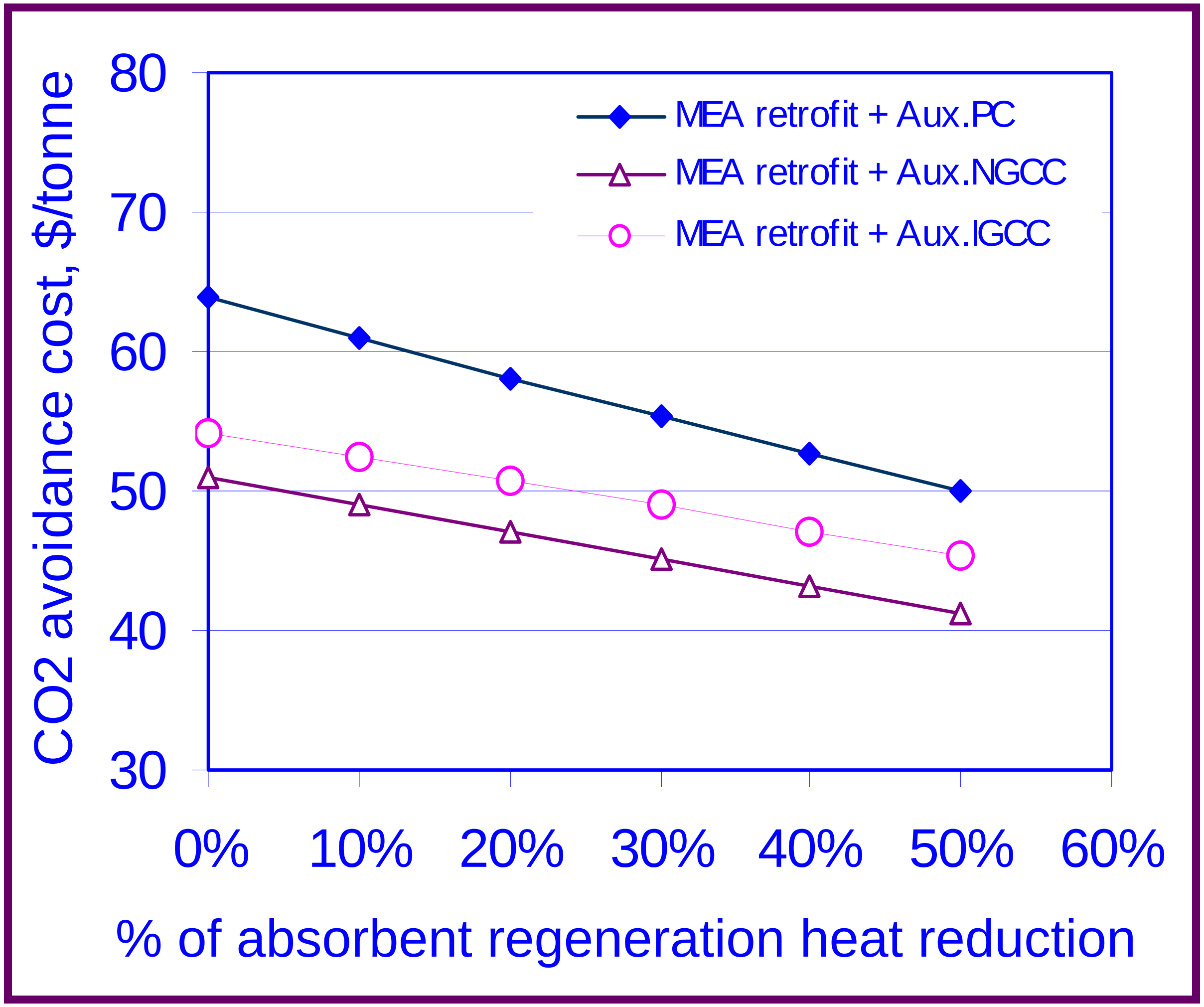
20%: 100MW

50%: 250MW

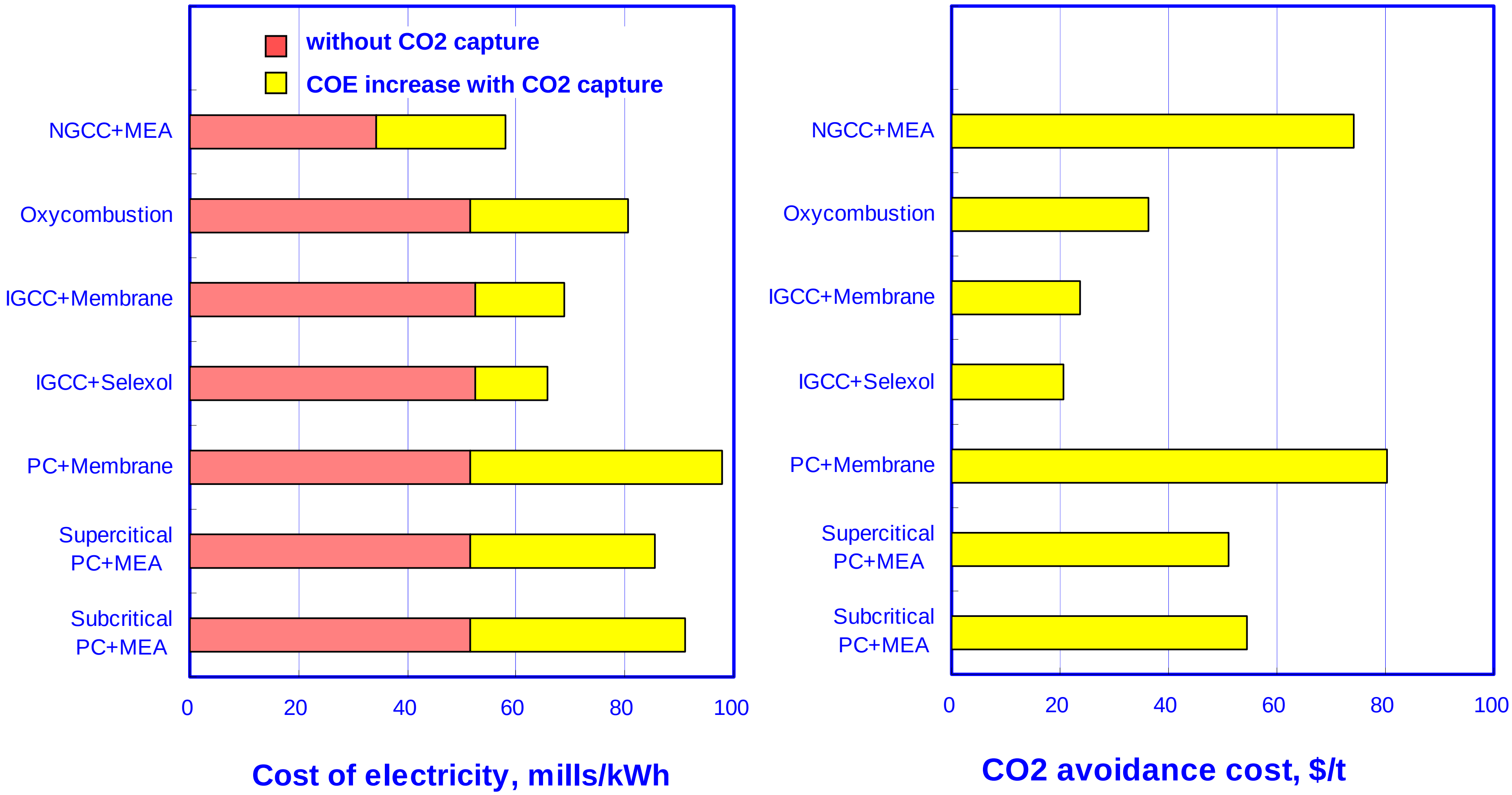
100%: 500MW

Costs of Power Plant Retrofit

Impact of chemical desorption heat



Cost Comparison of Potential Technologies



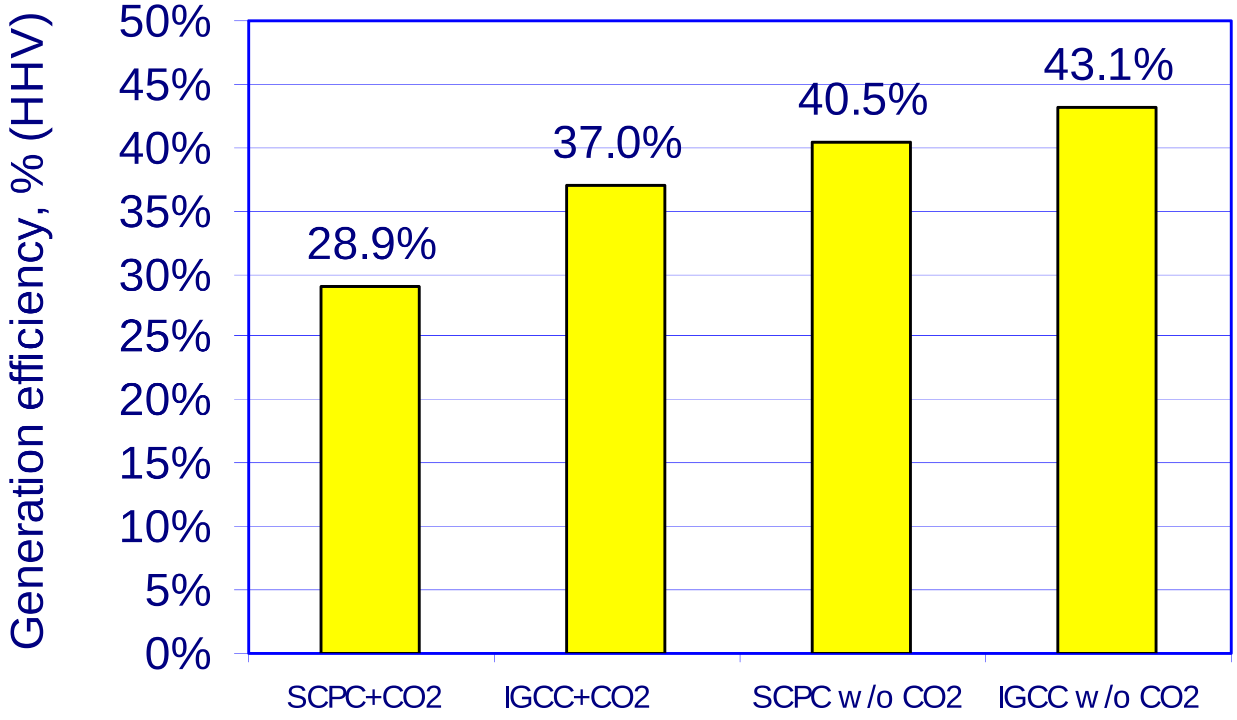
(All data in 2000 dollar; PC+ Membrane: 80% CO_2 recovery and 68% purity)

Data sources:

1. Hendriks C., Carbon Dioxide Removal from Coal-fired Power Plants, Kluwer Academic Publishers, The Netherlands, 1994.
2. Parsons Energy and Chemicals Group Inc., Evaluation of Innovative Fossil Fuel Power Plants with CO_2 Removal, DOE Interim Report 1000316, 2002
3. Chen S.G., Lu Y. and Rostam-Abadi M., Assessment of Geological Carbon Sequestration Options in the Illinois Basin - Task 2: Assess Carbon Capture Options for Illinois Basin Carbon Dioxide Sources, DE-FC26-03NT41994, March 2005.

Comparison between Super-Critical PC and IGCC

Electricity generation efficiency, %



Data source: *Parsons Energy and Chemicals Group Inc., Evaluation of Innovative Fossil Fuel Power Plants with CO2 Removal, DOE Interim Report 1000316, 2002*

Comparison between Super-Critical PC and IGCC

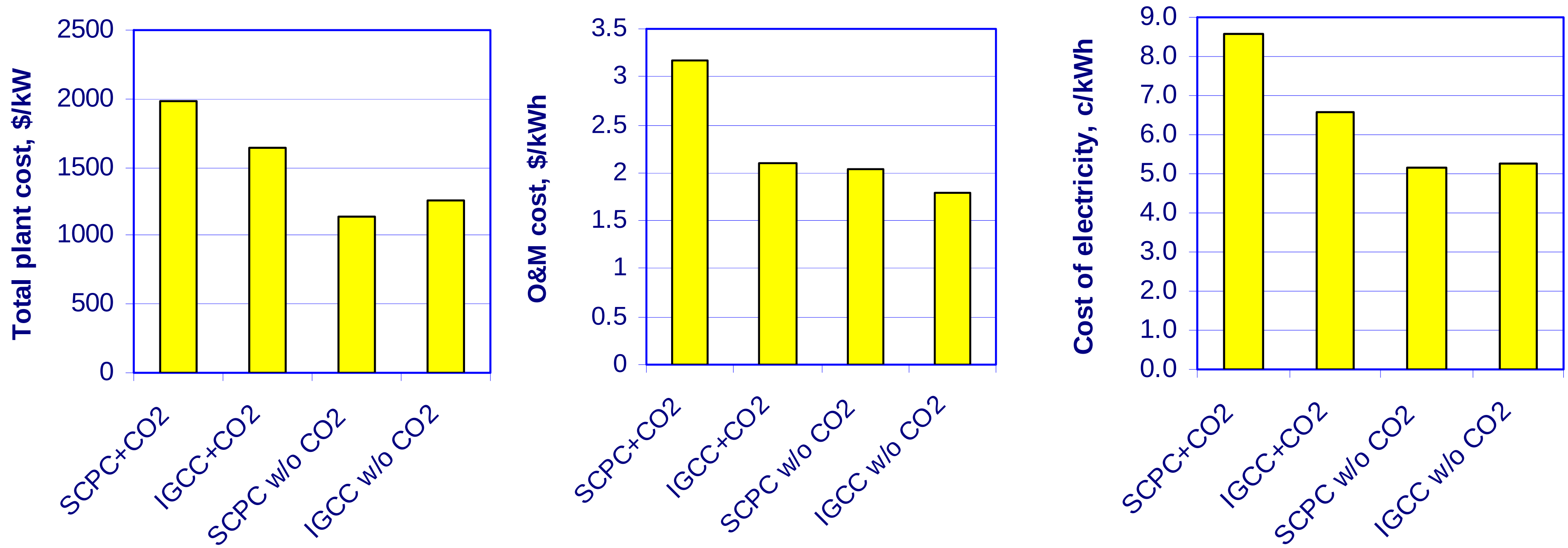
Environmental emissions

	lb/MM Btu (HHV)		lb/MWh	
SO_2	0.086	neg.	1.01	neg.
NOx	0.157	<0.028	1.85	0.25
PM	0.01	neg.	0.12	neg.
CO_2	203*/20.2**	200/21.4	1707/237	1582/162

*** without CO_2 removal***
***** with CO_2 removal (MEA+SCPC, Selexol+IGCC)***

Comparison between Super-Critical PC and IGCC

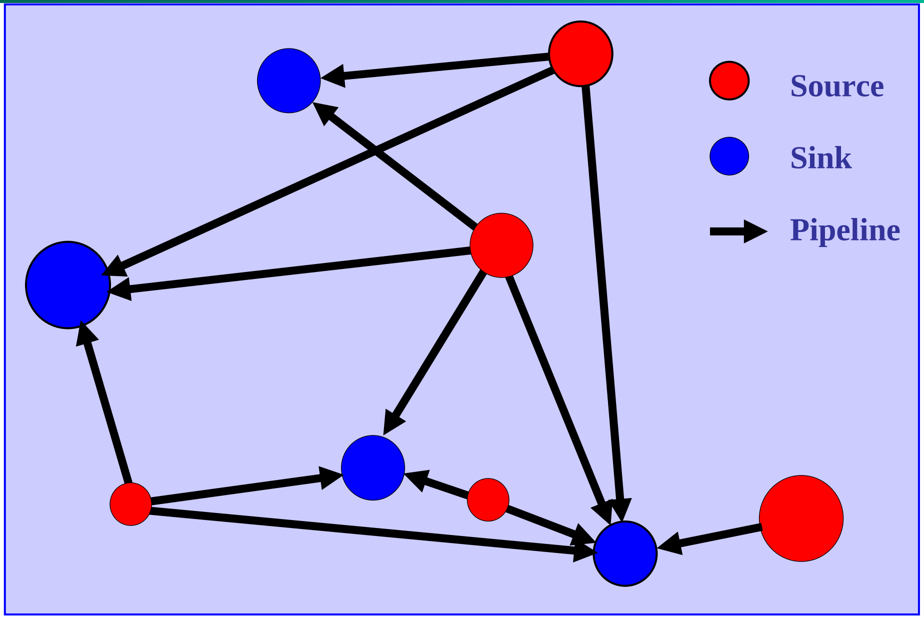
Costs of capital, O&M and electricity

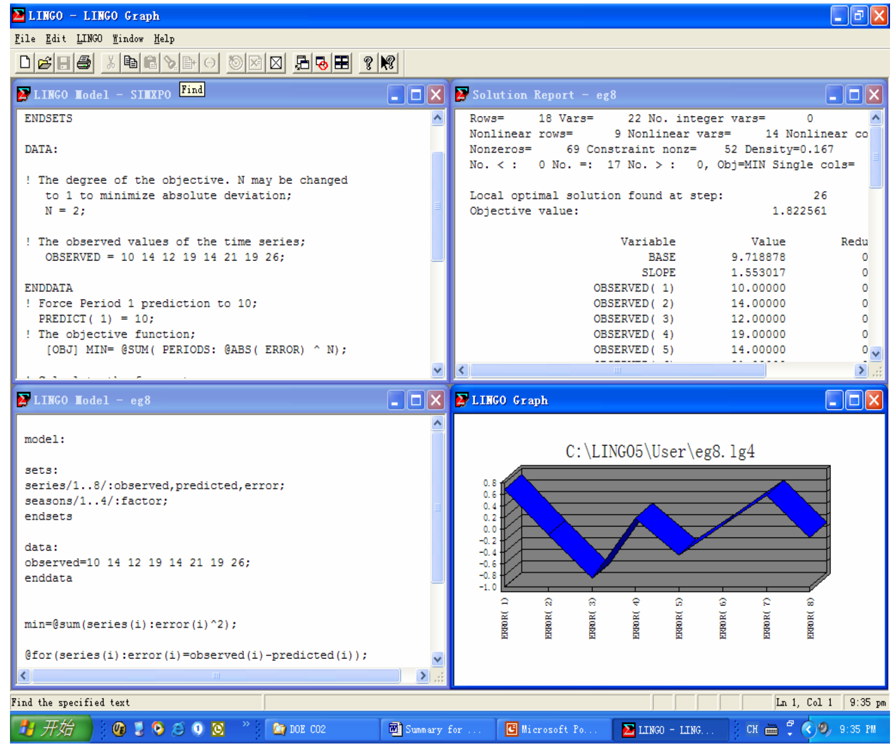


Based on assumptions : coal price of 1.24 MM Btu; 65% loading factor.

CO_2 avoidance costs: \$40-50 /metric ton CO_2 avoided for SCPC
\$20-30 /metric ton CO_2 avoided for IGCC

CO_2 Sequestration Optimization: Principles





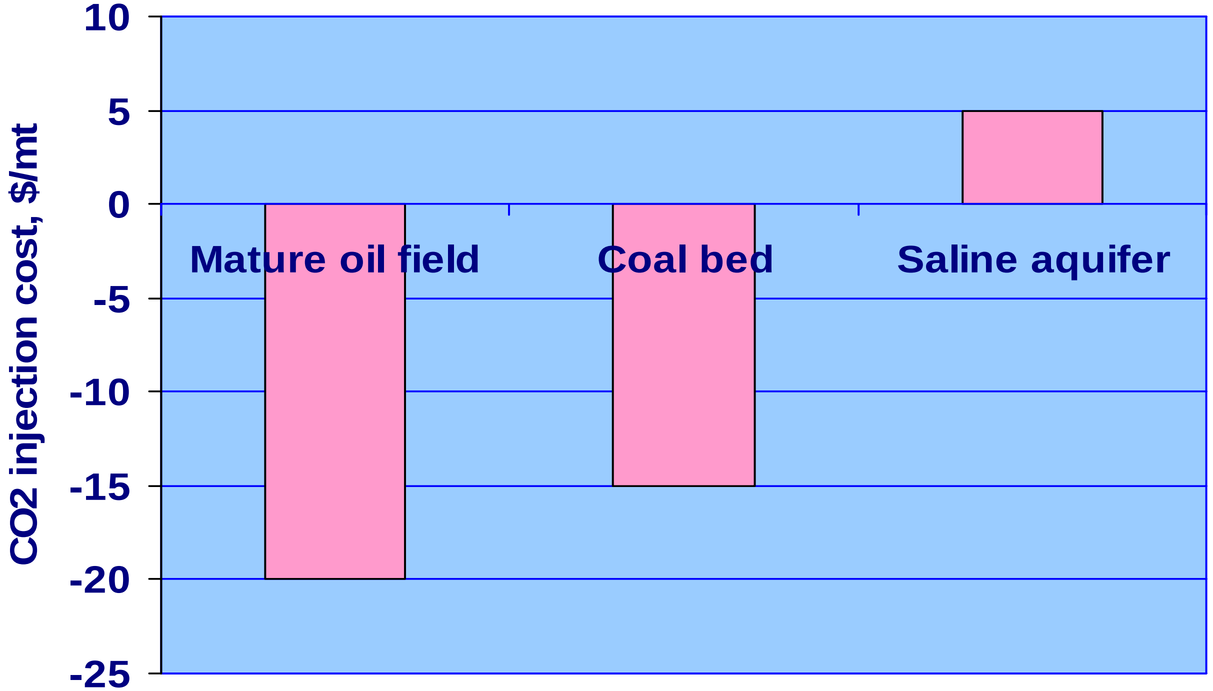
$$\min \sum_i \sum_l R_i X_i (C_i + F_{il} C_{il} + F_{il} C_l)$$

$$st. \begin{cases} \sum_i R_i X_i = R_{target} \\ Xi = \{0,1\}, \quad \forall i = 1,\ldots,122 \\ \sum_l F_{il} = 1, \quad \forall i = 1,\ldots,122 \\ \sum_i R_i X_i F_{il} \le Cap_l, \quad \forall l = 1,\ldots,24 \\ F_{il} \ge 0, \quad \forall i = 1,\ldots,122; l = 1,\ldots,24 \end{cases}$$

Lingo: Non-linear optimization software tool

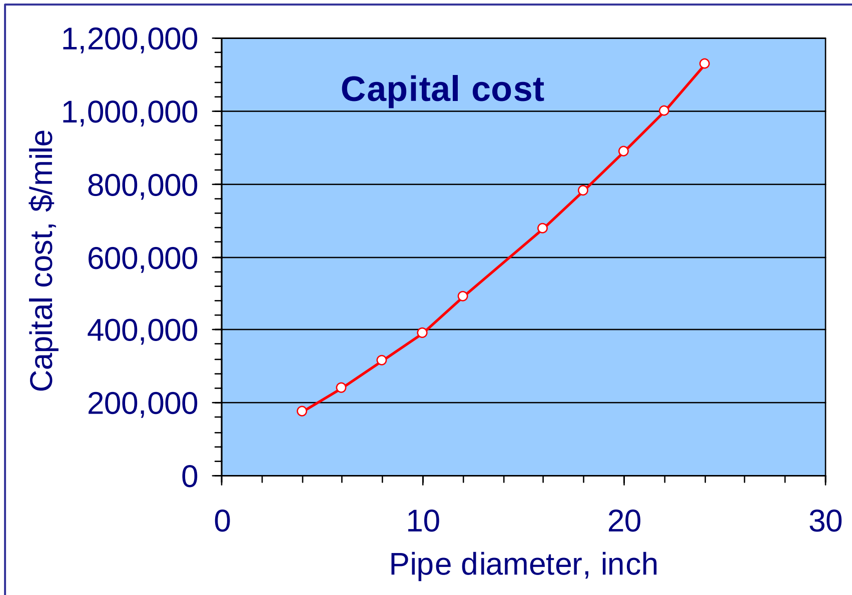
Mathematical model

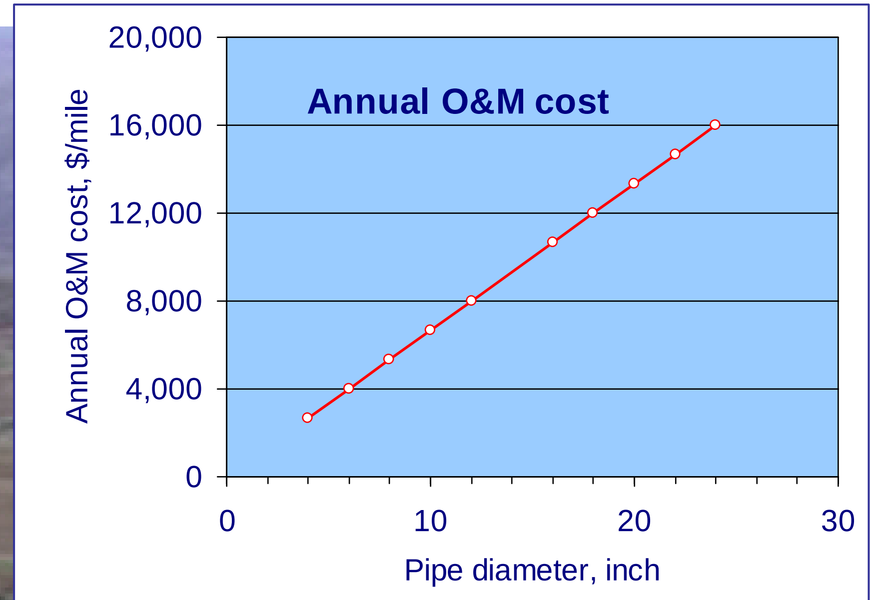
Geological Storage Costs

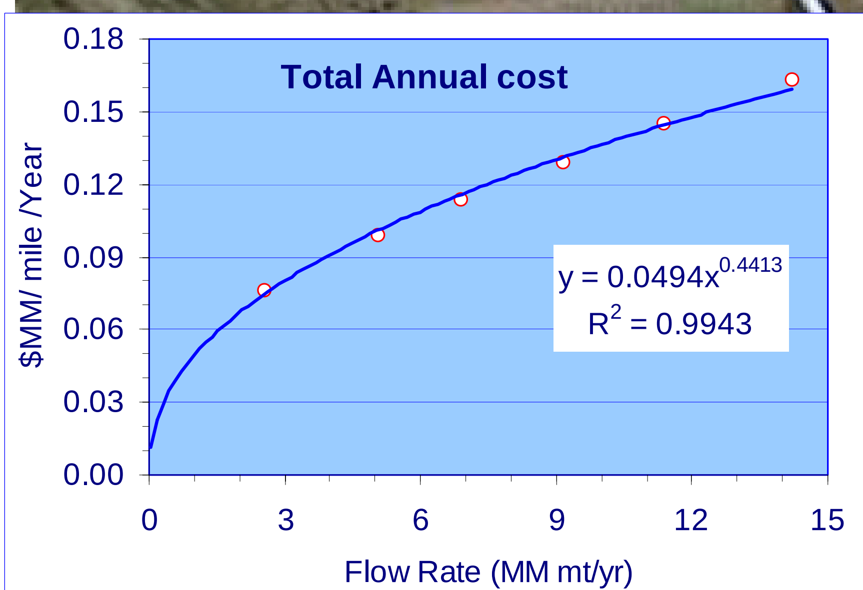


- *Saline aquifer: $5/mt CO_2*
- *Coal bed: $15/mt CO_2 credit for enhanced coal-bed methane recovery*
- *Mature oil field: $20/mt CO_2 credit for enhanced oil recovery (corresponding to an oil price of $25/barrel)*

Pipeline Transportation



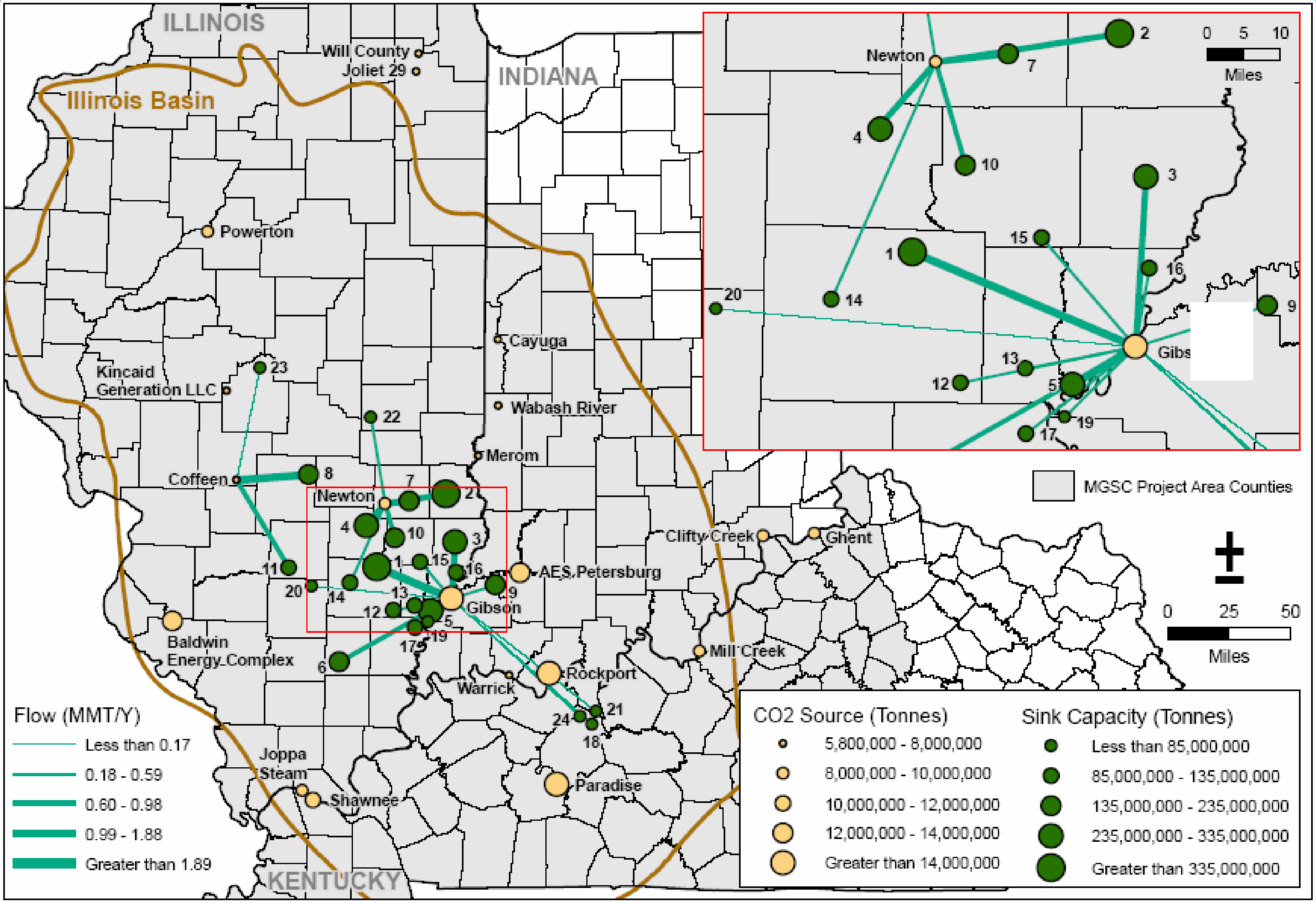




- *Total annual cost= annualized capital cost + O&M cost*
- *Capital cost annualized by 13.05%/year*
- *Pipe diameter correlated with flow rate*

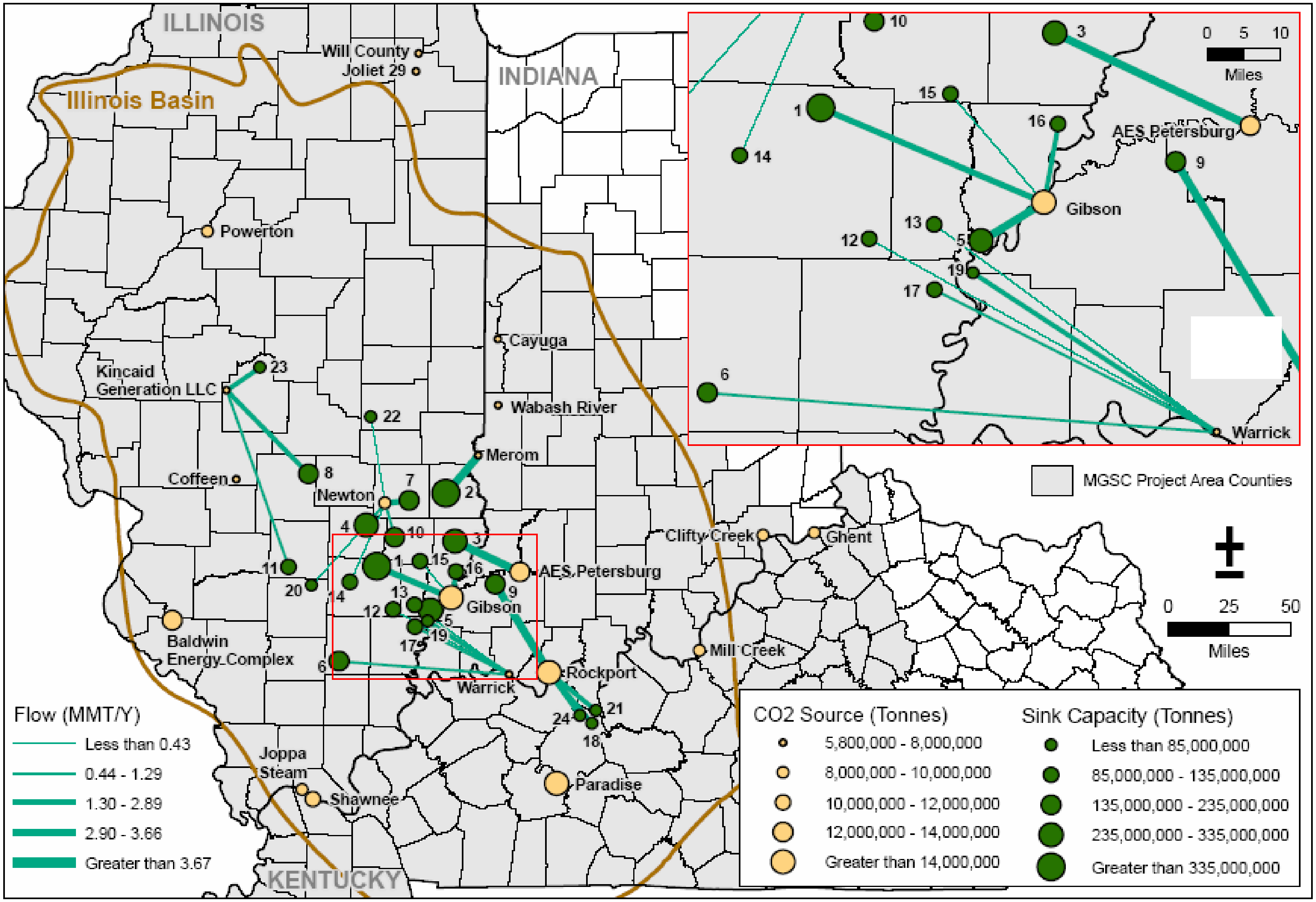
Data source: MGSC Topical Report "Assess Carbon Dioxide Transportation Options in the Illinois Basin", 2004

10% Reduction



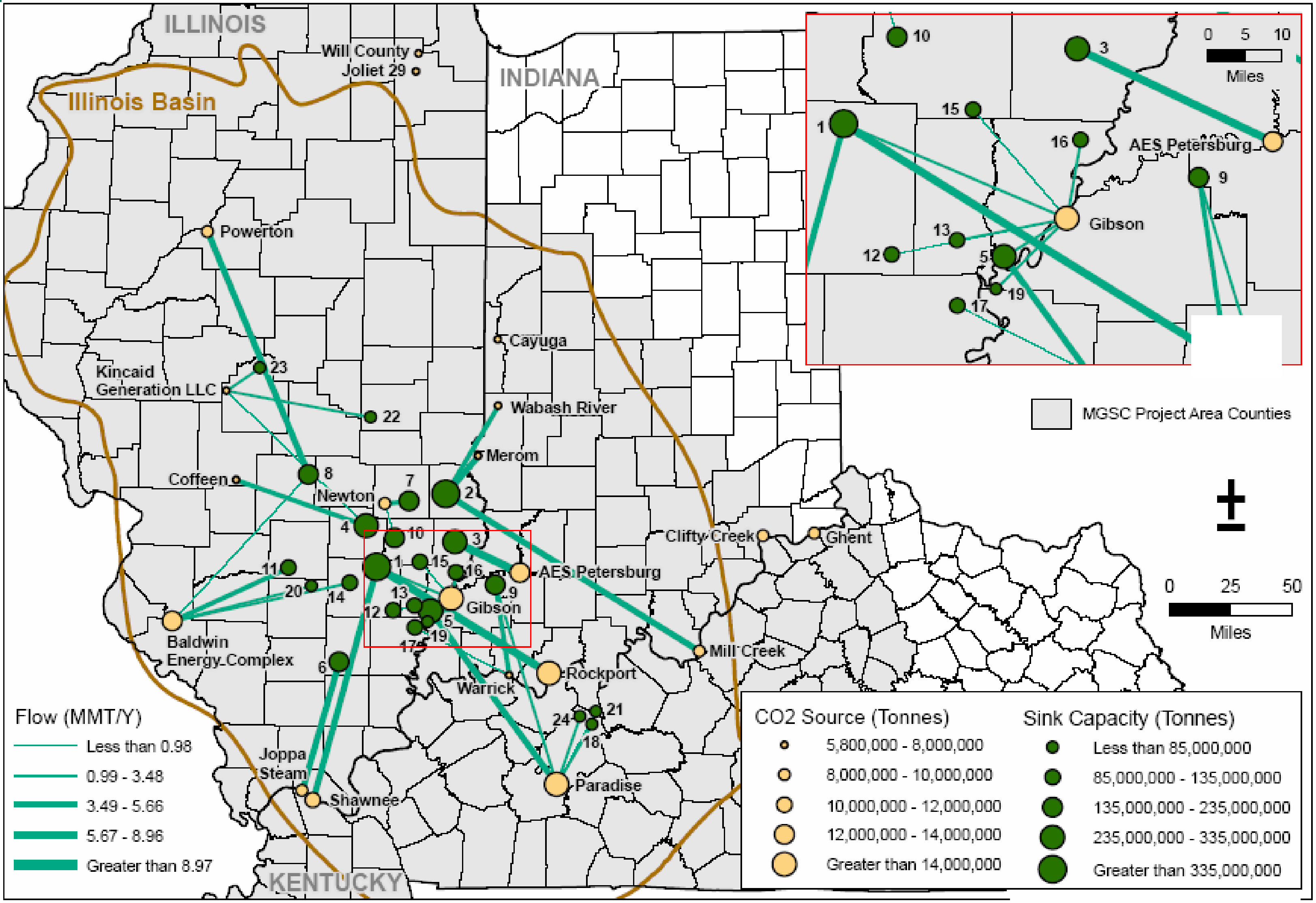
- ***3 power plants, 27 MM mt/y CO_2 reduction, ~1634 MW electricity loss***
- ***17% of storage capacity including all EOR and ECBM***
- ***Average pipeline distance 22.61 miles***

25% Reduction



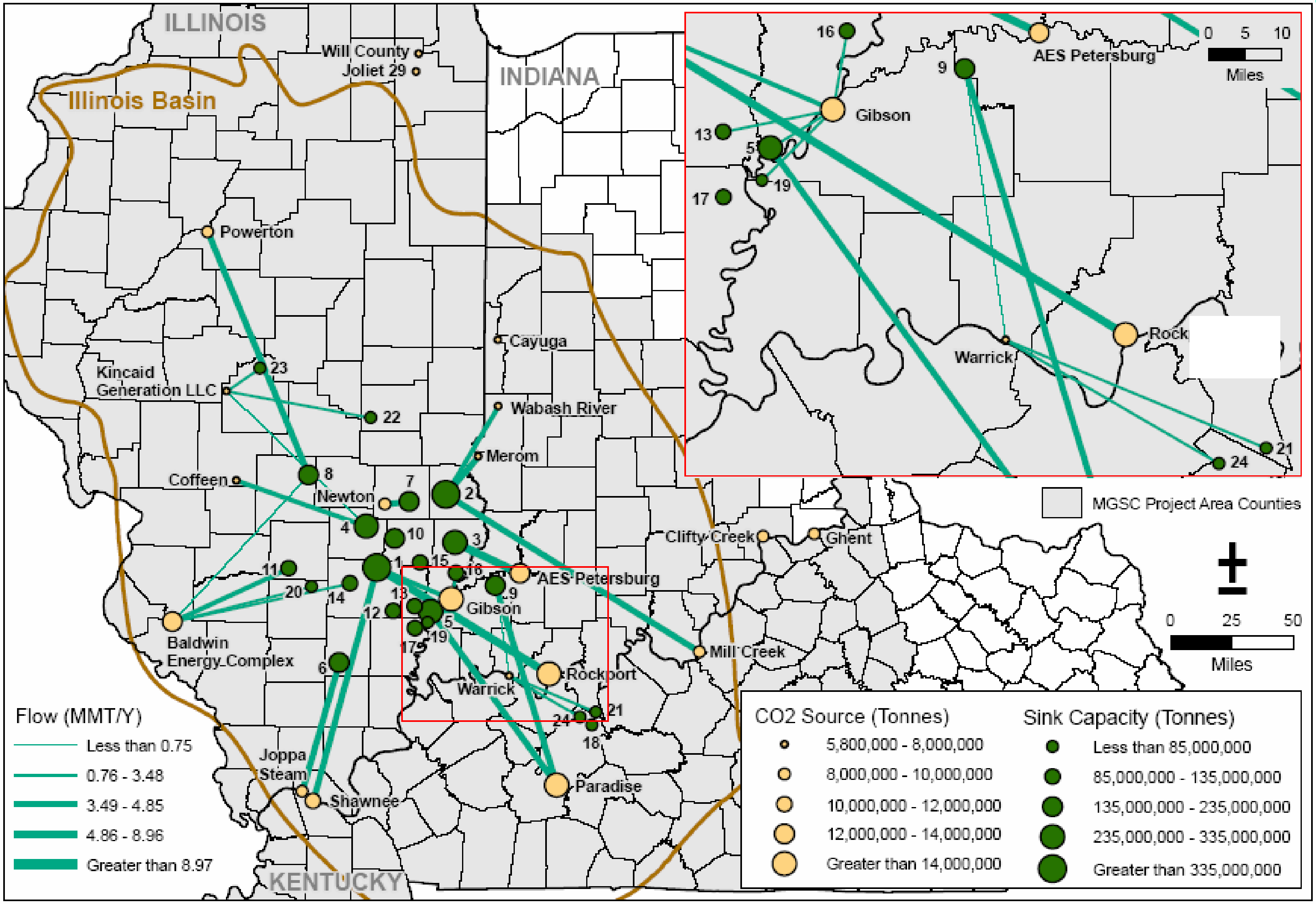
- *7 power plants, 64 MM mt/y CO_2 reduction , ~3873 MW electricity loss*
- *41% of storage capacity including all EOR and ECBM*
- *Average pipeline distance 26.68 miles*

50% Reduction



- 15 power plants, 128 MM mt/y CO_2 reduction , ~7746 MW electricity loss
- 82% of storage capacity including all EOR and ECBM
- Average pipeline distance 57.37 miles

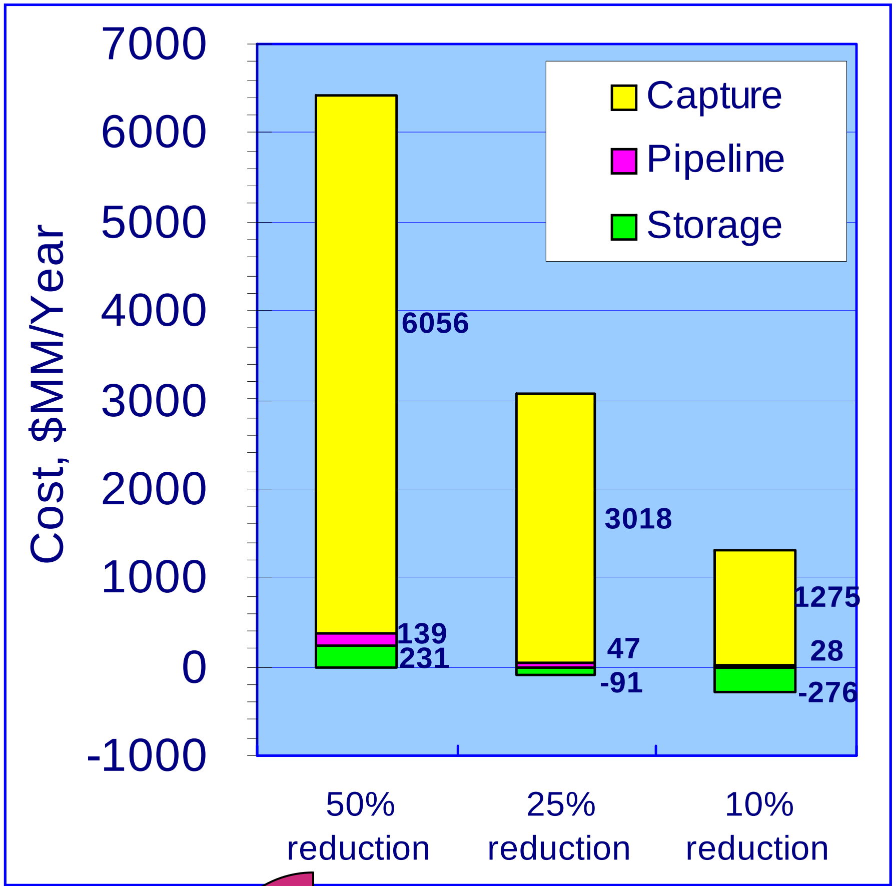
50% Reduction without EOR and ECBM benefits



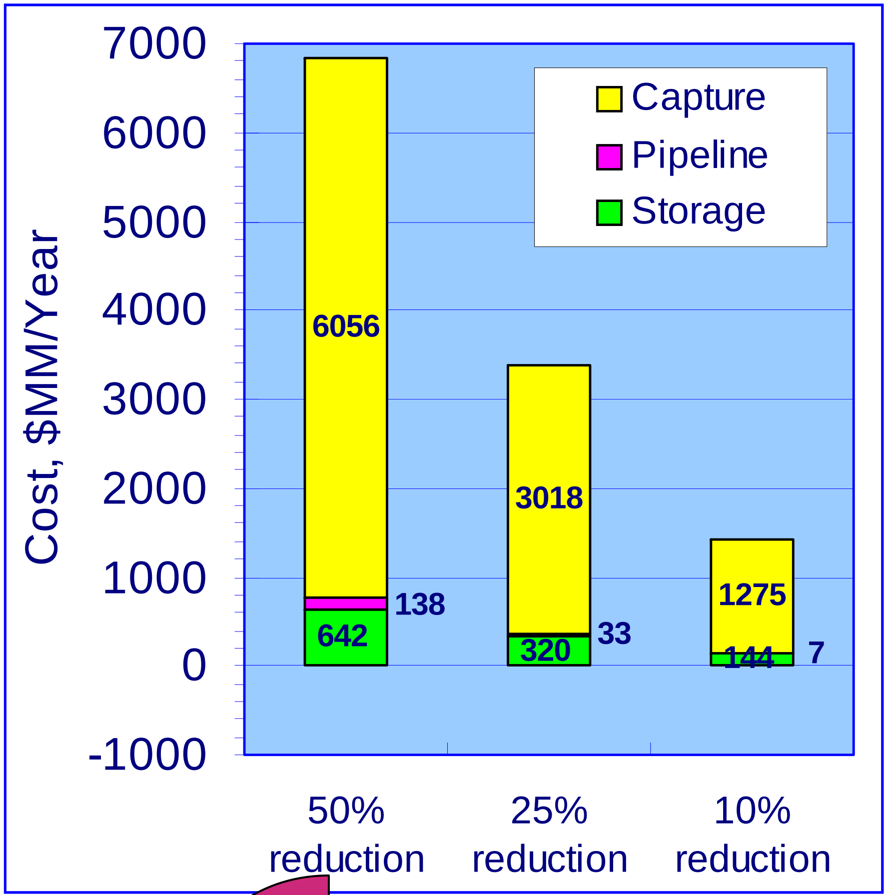
- *No impacts on power plant selection and electricity loss*
- *20 sinks, 82% of storage capacity*
- *Average pipeline distance 59.52 miles*

Cost Comparison: Annual Total Cost ($MM/Year)

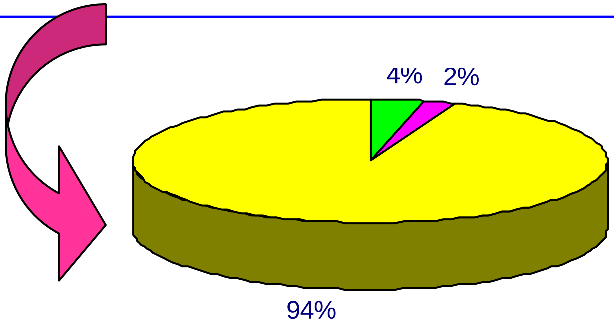
With EOR/ECBM credits



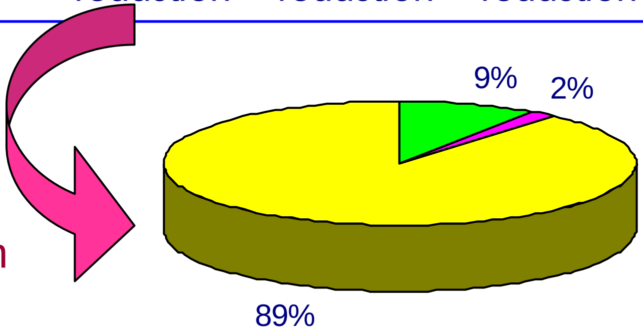
Without EOR/ECBM credits



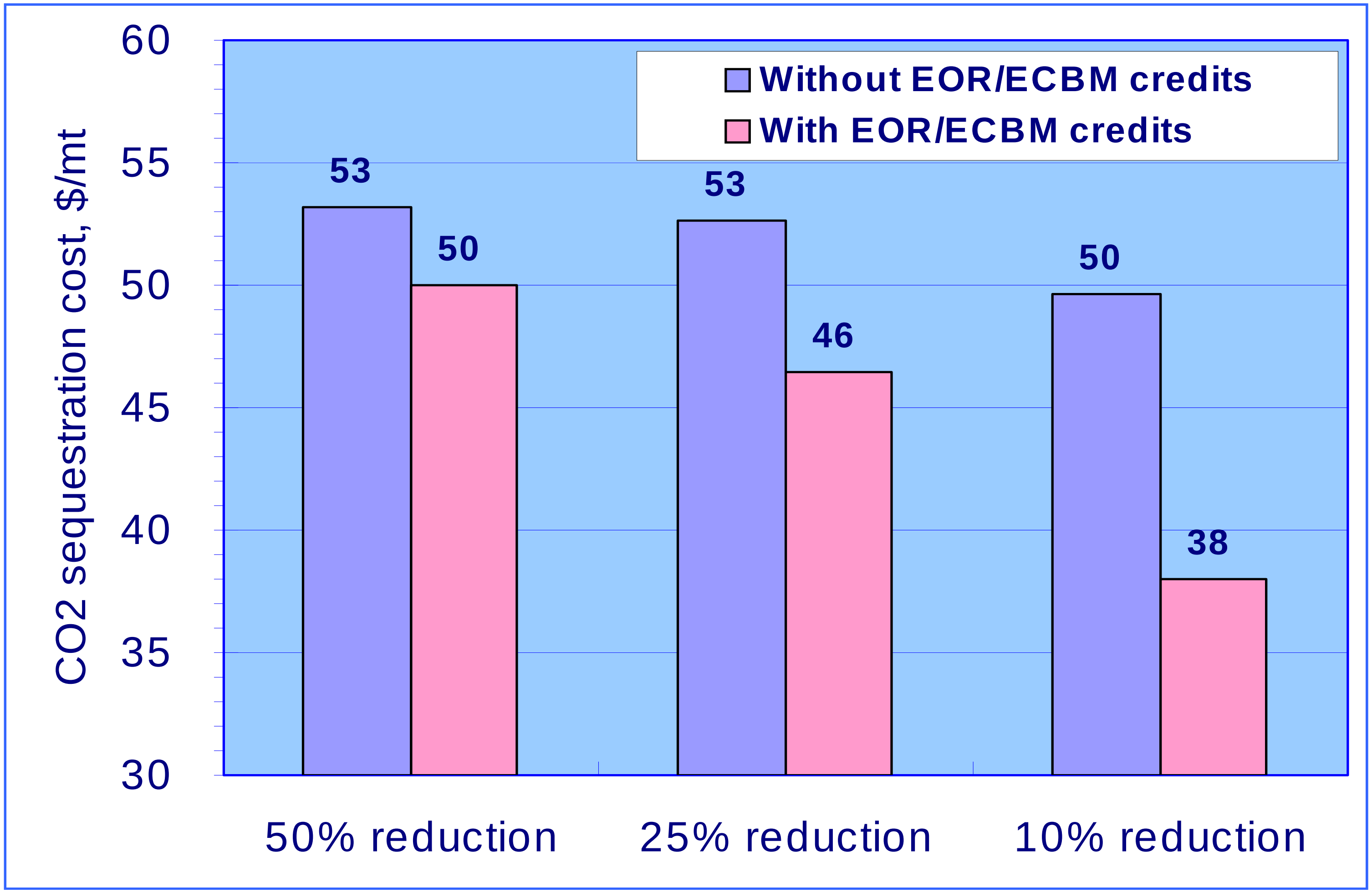
Cost distribution



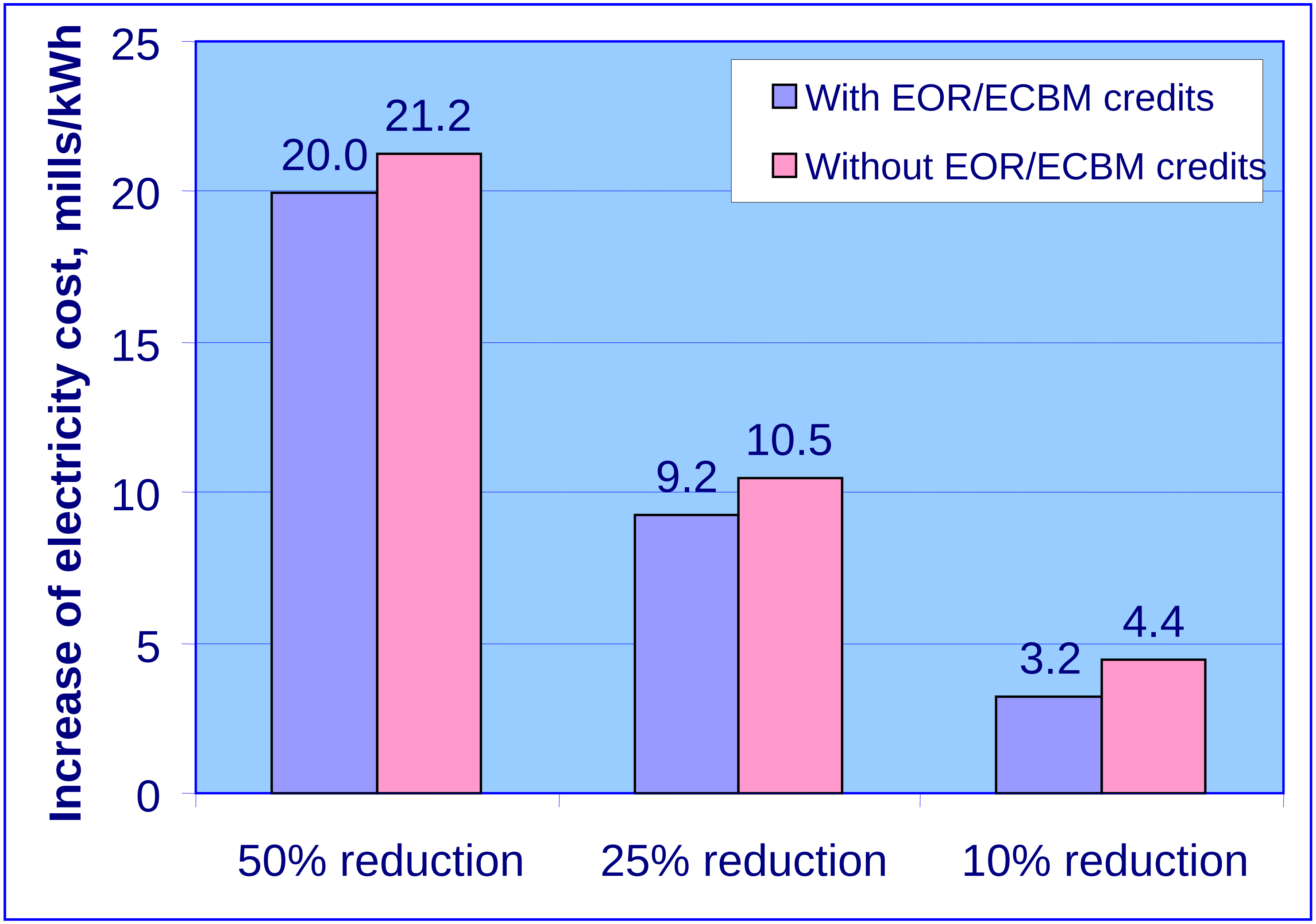
Cost distribution



CO_2 Sequestration Cost ($/mt)

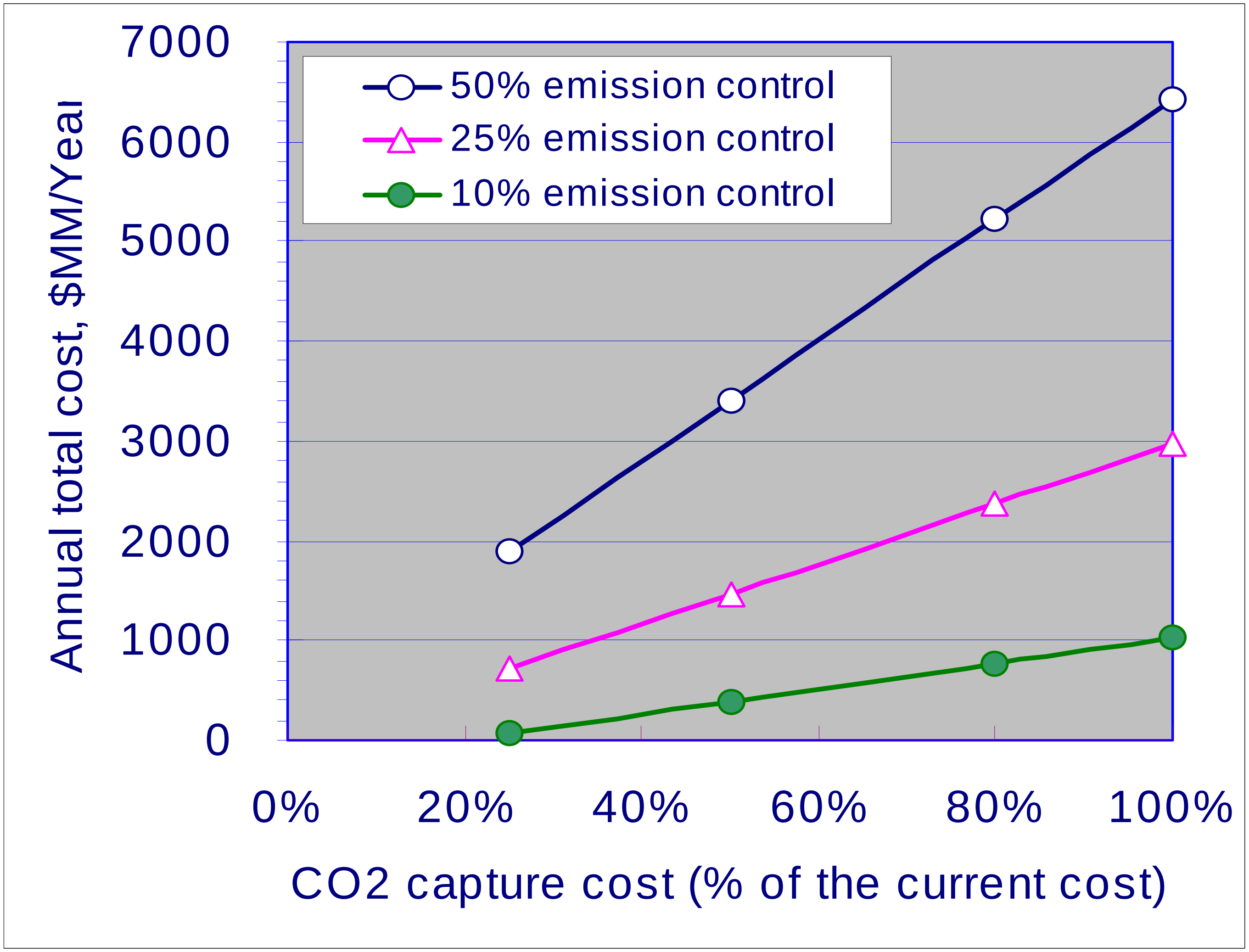


Increase in Electricity Cost (mills/kWh)



Sequestration costs are shared by all utilities in the Basin

Impact of CO_2 Capture Cost



Summaries

- *CO_2 capture cost generally contributes about 70-90% of sequestration system*
- *Absorption process is currently most feasible option for post-combustion CO_2 capture*
- *Current amine-based absorption processes are expensive ($40-60/t CO_2 avoided) and energy intensive (30% loss of electricity output)*
- *Oxy-combustion is potentially attractive for retrofits of existing plants (commercial demonstration is required)*
- *Membrane and physical absorption processes are economically attractive for CO_2 capture in IGCC*

Summaries (continued)

- *CO_2 capture from large power plants is generally more economically attractive*
- *CO_2 storage in EOR and ECBM fields are economically preferred regardless of their locations in the Basin*
- *Sequestration cost ranges from $38 to $50/mt CO_2 for 10% to 50% control levels*
- *Sequestration cost significantly decreases at 10% control level if benefits from EOR and ECBM are included*


Thank you !