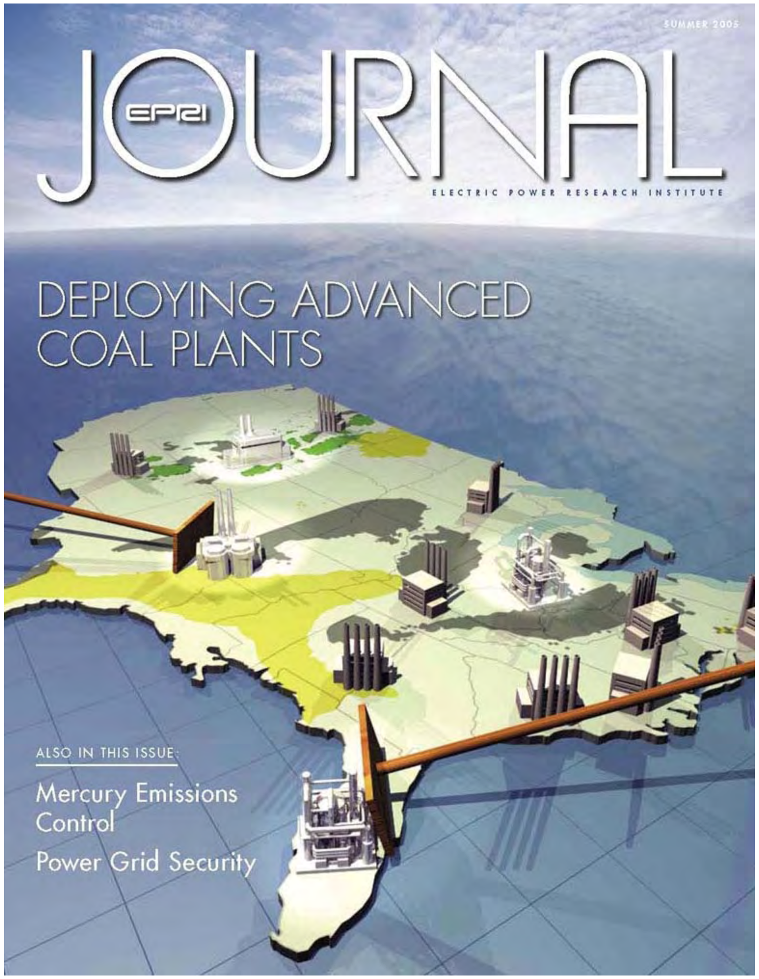

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Clean Coal Technology to Address Global Climate Change – Presentation at ASERTTI's 2006 State Energy Forum

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Overview

- Role of technology in addressing climate change – the role of clean coal and CO_2 capture
- Types of Coal Generation
- What is Clean Coal Technology?
- IGCC
- What about CO_2?
- CO_2 Capture and Storage
  - What is it?
  - What are the costs?
  - Other issues?

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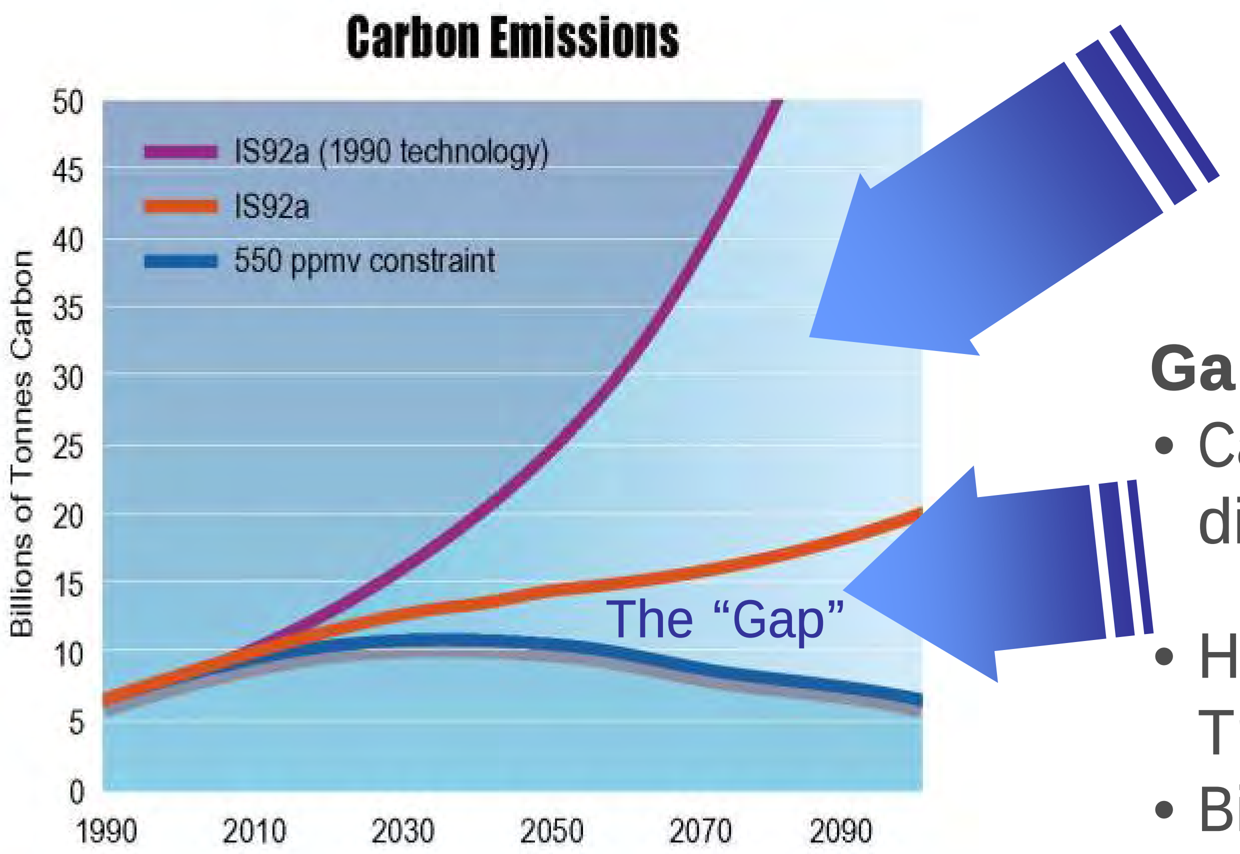
Stabilizing CO_2
Base Case and "Gap" Technologies



Assumed Advances In

- Fossil Fuels
- Energy intensity
- Nuclear
- Renewables

Gap technologies

- Carbon capture & disposal
  - Adv. fossil
- H2 and Adv. Transportation
- Biotechnologies
  - Soils, Bioenergy, adv. Biological energy

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Types of Coal Generation

- **Pulverized coal** (PC) finely ground coal that is burned then the flue gasses are cleaned up – conventional coal in place at over a thousand plants in the US
- Very **high-temperature versions of PC** called supercritical (SC) or ultrasupercritical (USC)
- **Circulating Fluidized Bed Combustion** (CFBC or FBC)– where larger pieces are "fluidized" by combustion air – entrained as they burn with a "sorbent" like limestone to remove sulfur
- **Gasification** of coal – where only part of the oxygen needed is used giving a small stream of "gaseous fuel" – including mixed gases like CO, hydrogen and methane. This is cleaned and burned in a combined cycle (combustion & steam turbine) to give an "integrated gasification combined cycle" (IGCC)

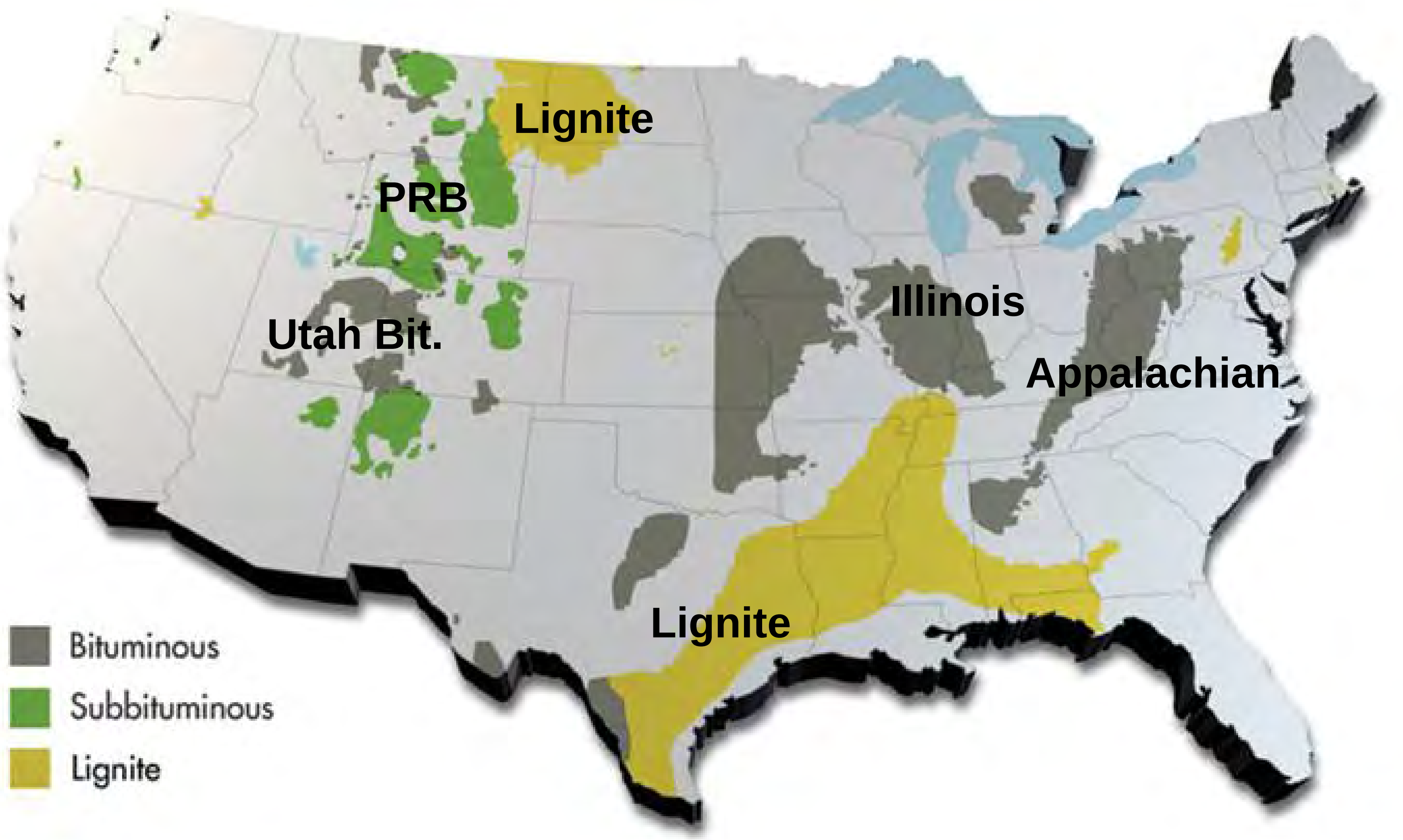
What is "Clean Coal"

- Even modern conventional coal plants are cleaner than prior designs but most people refer to designs meeting very stringent emission regulations as "clean coal"
- Gasification of coal has very low SO_2 and mercury emissions and is almost as clean as natural gas firing
- DOE, EPRI and the Coal Utilization Research Council have defined performance and emission goals for 2010 and 2020- available as the DOE/EPRI/CURC Roadmap at www.coal.org

PC Plants Status, Markets and Vendors

- 310 GW in US. Mostly built 25-50 years ago. Majority are subcritical but there are 150 supercritical plants at steam temperatures <1050F. Up to 1300 MW size.
- For new US plants subcritical or modest supercritical plants are being selected.
- Uncertainty and concern about potential regulation of CO_2.
- Main Vendors in US (and Worldwide) are Babcock& Wilcox, Alstom, Foster Wheeler, Hitachi, Babcock Hitachi, Mitsubishi, IHI, Mitsui Babcock.

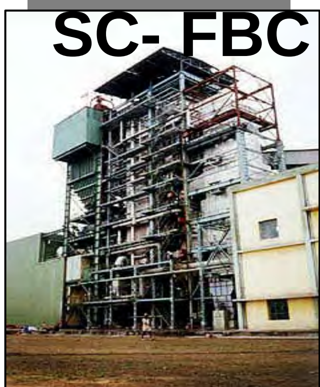
U.S. Coal Types and Basins



Typical U.S. Coal Analysis
(Coal Properties Differ Markedly)

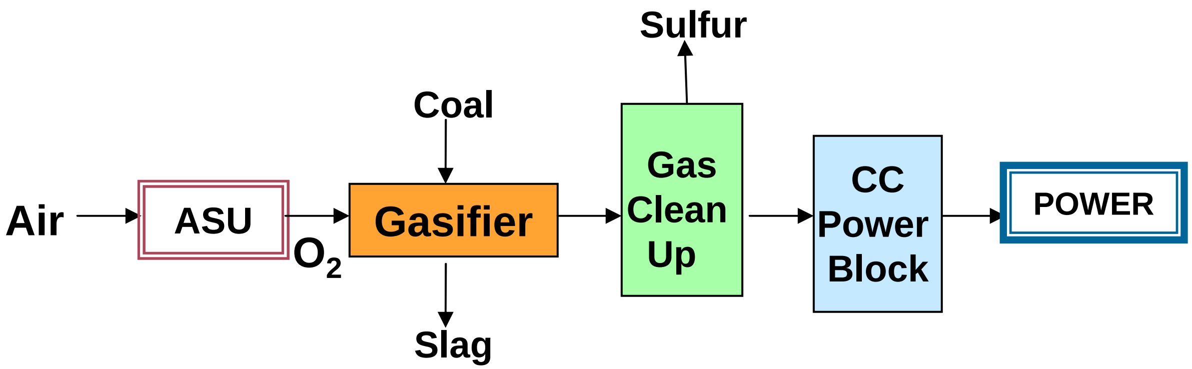
	Pittsburgh	Illinois	Wyoming	Texas	ND
	#8	#6	PRB	Lignite	Lignite
Ultimate Analysis					
Moisture	5.2	12.2	30.24	33.03	42
Carbon	73.8	61.0	48.18	35.04	
Hydrogen	4.9	4.25	3.31	2.68	
Nitrogen	1.4	1.25	0.70	0.77	
Chlorine	0.07	0.07	0.01	0.09	
Sulfur	2.13	3.28	0.37	1.16	0.89
Oxygen	5.4	6.95	11.87	11.31	
Ash	7.1	11.0	5.32	15.92	6.2
Higher Heating Value as received (Btu/lb)	13,260	10,982	8,340	6,010	6,054

Regional U.S. Coal Differences Favor Multiple Advanced Coal Options

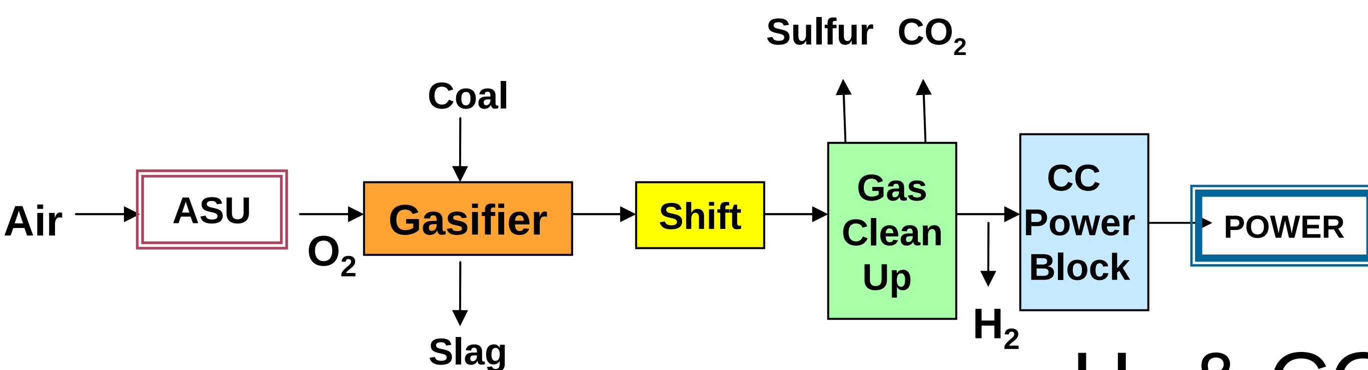


- **IGCC with slurry feed economics are best with “high-rank” bituminous coals or low-rank (PRB) coal plus petroleum coke (today's economics do not favor IGCC, but it has lower emissions)**
- **New IGCC designs may be better for low-rank coal and may be cheaper, but these designs are still developmental**
- **Waste coals and biomass may be best in fluidized-bed combustion (FBC) units, but supercritical steam conditions are unproven**
- **Most U.S. plans are for new “conventional” pulverized coal due to lower fuel costs; in Europe and Japan, where fuel costs are high, ultra-supercritical (USC) designs are favored**

IGCC with and without CO_2 Removal



IGCC



H_2 & CO_2
(e.g.,FutureGen)

Today - Existing Coal-based IGCCs

Puertollano (Spain)

Wabash (Indiana)

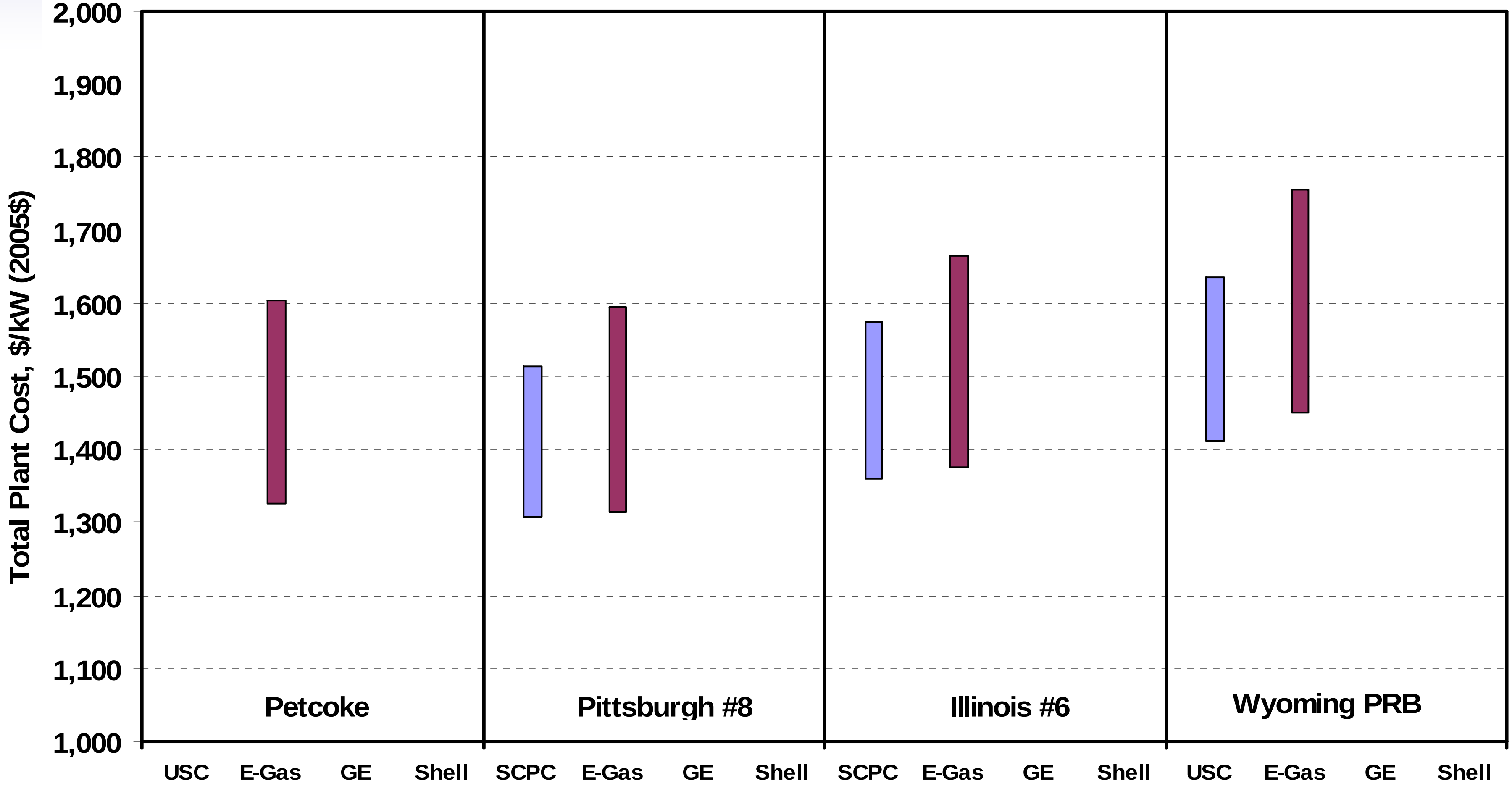
Polk (Florida)

Buggenum (Netherlands)

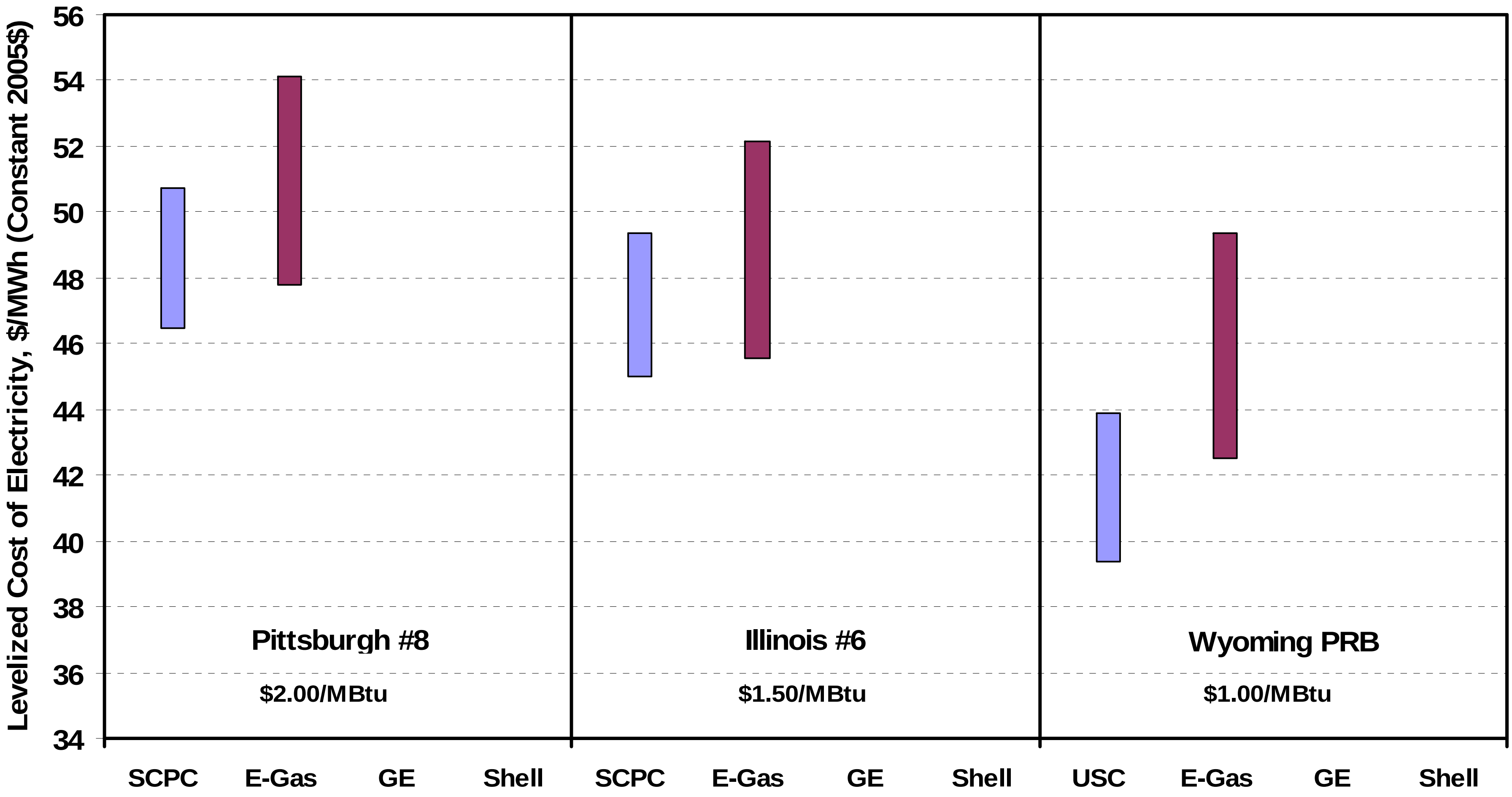
IGCC Environmental Control

- Sulfur is removed (99.5+%) from syngas
- NOx emissions are controlled similar to NG –SCR possible
- Particulates are removed from the syngas by filters and water wash prior to combustion so emissions are negligible.
- Current IGCC design studies with SCR plan ~3ppmv each of SOx, NOx.
- Mercury >90% can be removed from the syngas by absorption on activated carbon bed.
- Byproduct slag is vitreous and inert and often salable.
- CO_2 under pressure takes less energy to remove than from PC flue gas at atmospheric pressure. (Gas volume is <1% of flue gas from same MW size PC).
- Water use - ~ 70% of a conventional coal plant

Total Plant Cost vs. Fuel Type for CoP IGCC and USC PC Plants



30-Year Levelized Cost-of-Electricity vs. Fuel Type for CoP IGCC and USC PC Plants



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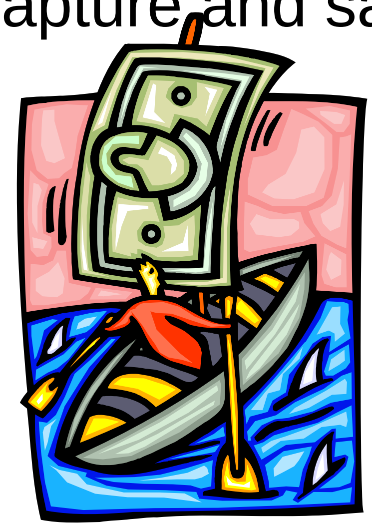
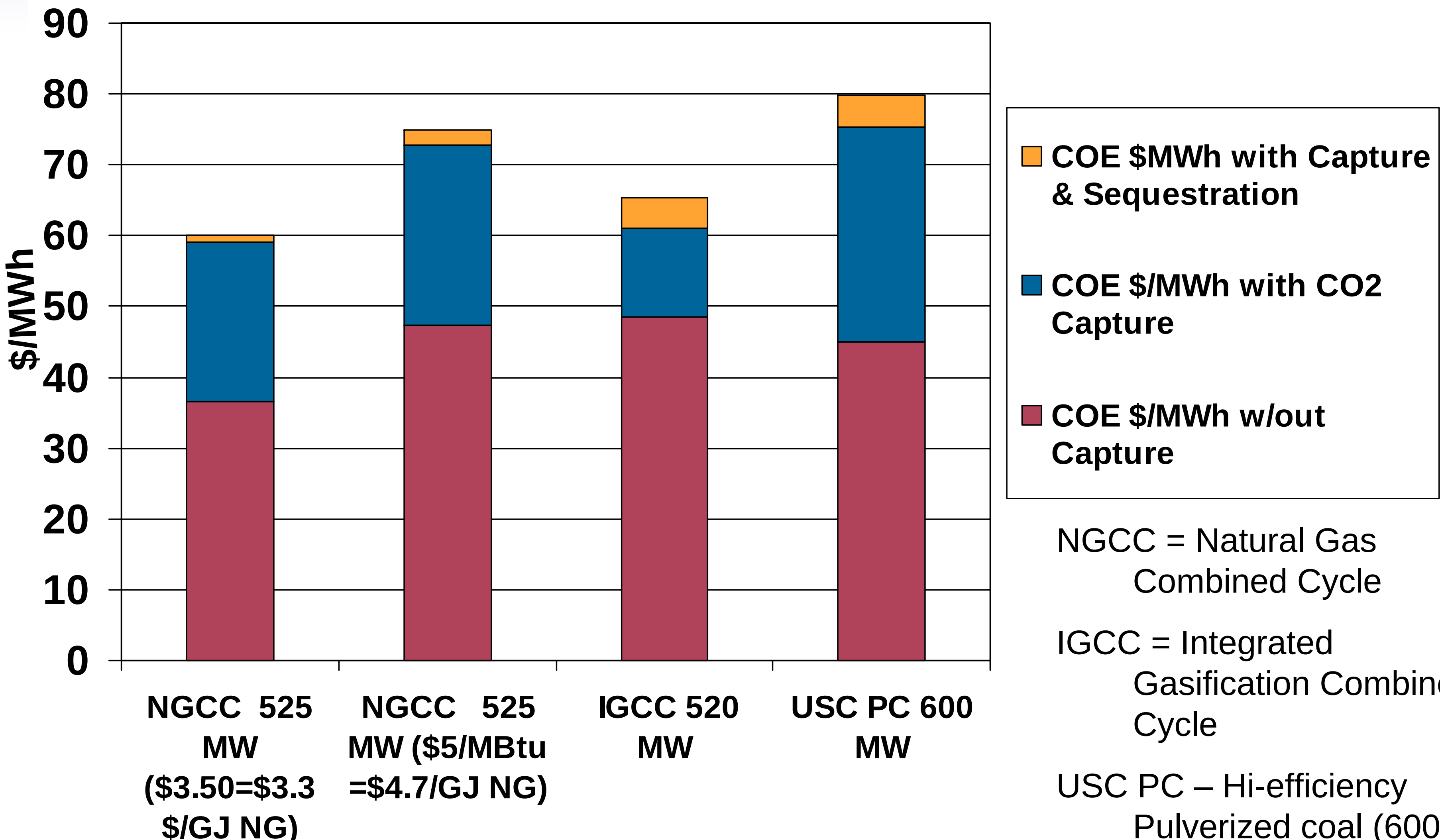
What About CO2?

- Higher efficiency designs inherently produce less CO_2 per kWh
- **Neither IGCC nor pulverized coal inherently captures CO_2**
- US and world efforts are aimed at developing better options for high efficiency generation and understanding how to economically capture and safely store CO_2



Costs of Electricity from New Fossil Fuel Power Plants with CO_2 Capture and Sequestration (Bituminous Coal, 2003 study)



NGCC = Natural Gas Combined Cycle

IGCC = Integrated Gasification Combined Cycle

USC PC – Hi-efficiency Pulverized coal (600ºC)

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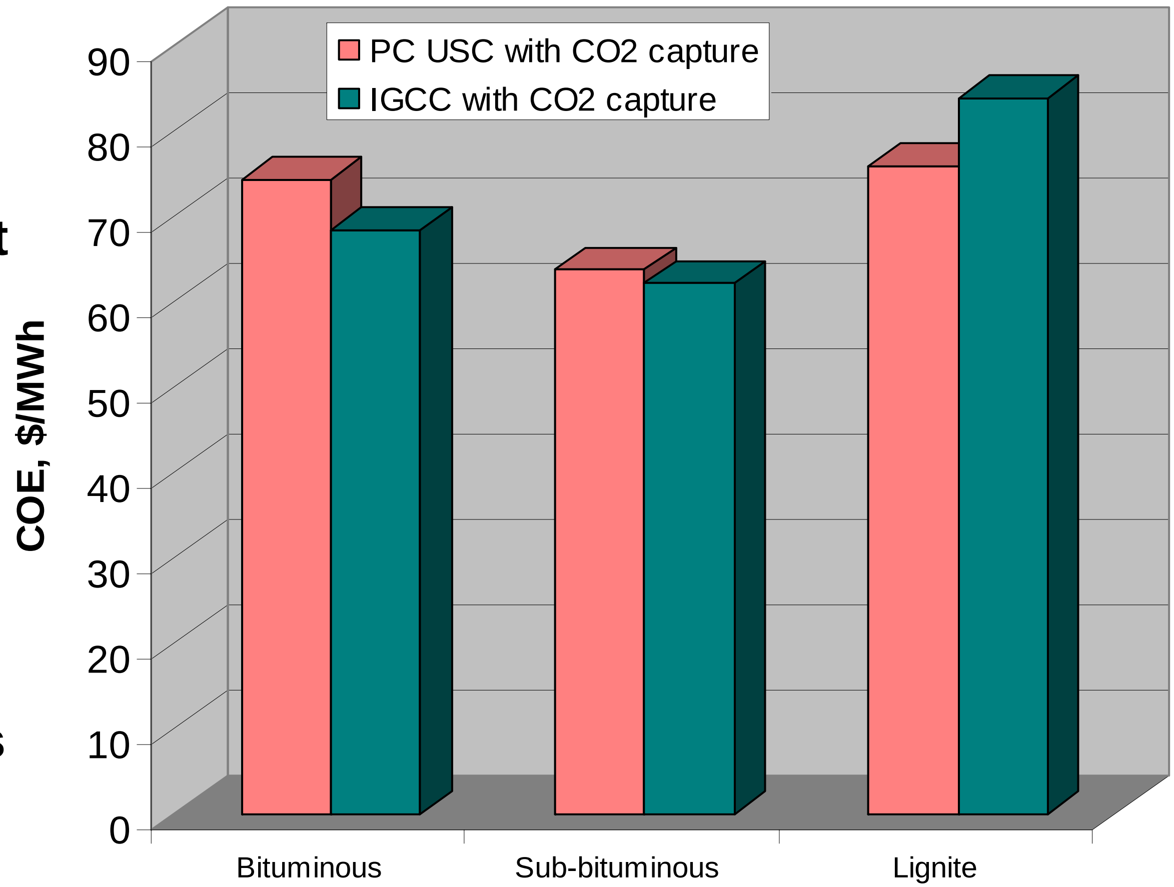
Fuel Impact on PC vs. IGCC Cost of Electricity: Canadian Study Results (first set of data)

Source
Canadian Clean
Power Coalition

- **PC: Higher cost than IGCC except for lignite**
- **Suggests that fuel choice may have an impact on technology selection**
- **Suppliers addressing the issue**
- **Canadian studies ongoing re-analysis**



See also Paper - http://uregina.ca/ghgt7/PDF/papers/nonpeer/068.pdf

Note: Coal Cost—Bit=$1.92/MBtu, SB=$0.48/MBtu, L=$0.845/MBtu; 90% Cap Factor;

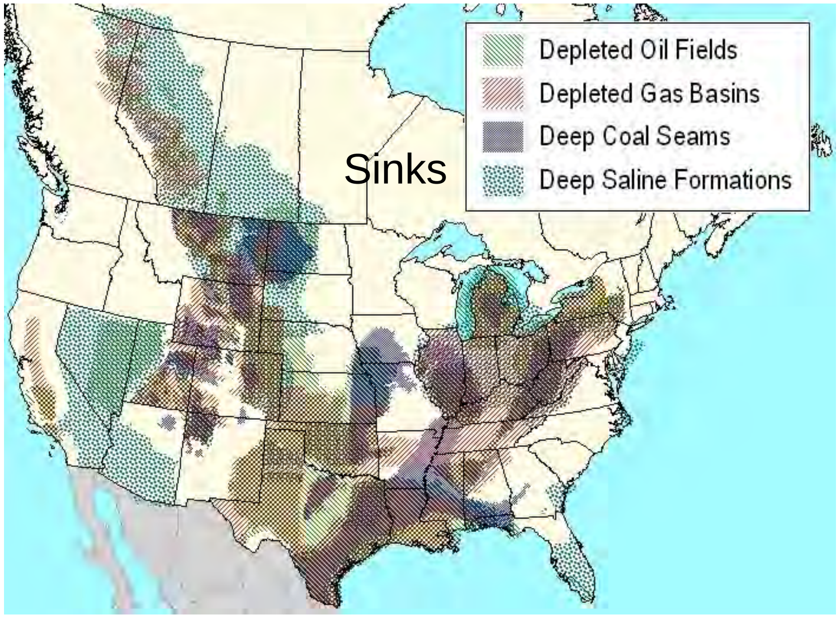
CO_2 removal—IGCC 86-89%, PC 95%

What is CO_2 Capture and Storage?

Four Basic Steps

1. **Capture** -either in flue gas at atmospheric pressure and 3-15% CO_2 or from high pressure, concentrated IGCC syngas
2. **Compress** and dehydrate the gas
3. **Transport** – usually at > 100 bar (critical point is 73 bar so it is a liquid). Long pipelines do exist > 2MTPY as individual pipelines and > 30 MTPY total
4. **Store - Inject underground** in a suitable geologic formation (e.g., saline aquifer, oil, coal and gas strata, basalt)

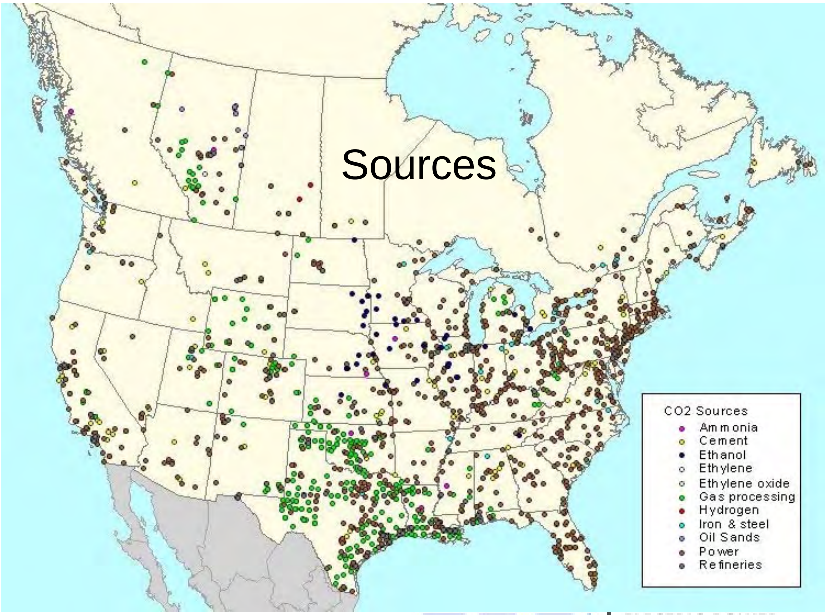
Fossil Generation and Possible Sequestration Sites



- **Significant information suggests potential**
- **Need pilot and large-scale US demonstrations to prove ability to store long-term**

Source: IEA GHG – from Battelle

- **Generation not always near storage sites**
- **EOR and ECBM have limited storage capacity but are least expensive**

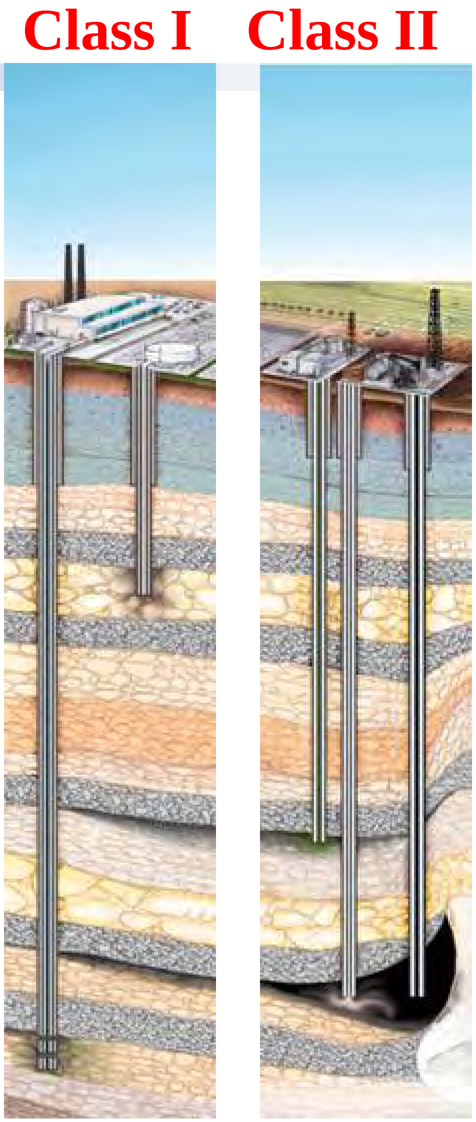


Leakage Risk

- **What do you need to understand?**
- **What is the likelihood that CO_2 placed into the ground will stay where you want it?**
  - Pathways of leaks
  - Remediation
- **What are the consequences of environmental exposures to CO_2**
  - Health
    - Human
    - Animal
  - Environmental
    - Terrestrial

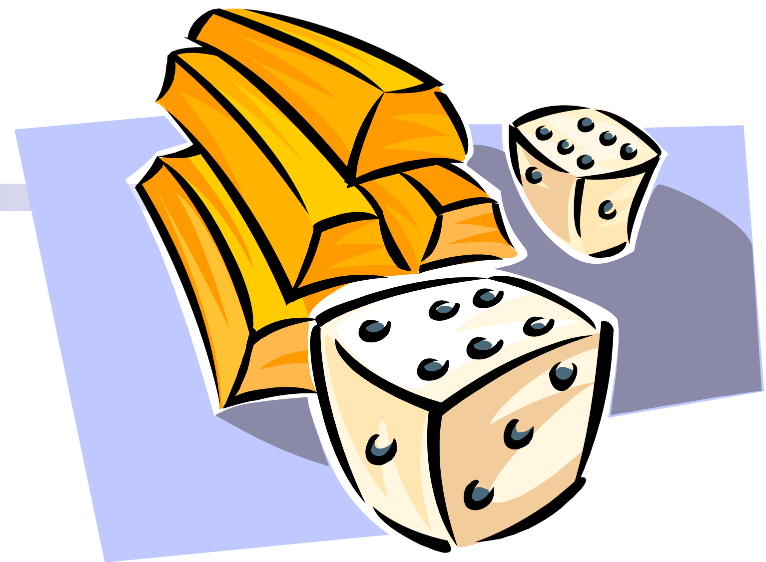
Regulatory Risk

- How CO_2 underground injection is classified can have a significant impact
  - Difficulty of permitting
  - Cost of injection
- Significant experience with CO_2 injection
  - Generally smaller amounts
  - No significant problems
- Likely controlled by the USEPA Underground Injection Control program
  - May require new injection well type



Source: USEPA

Legal Risk

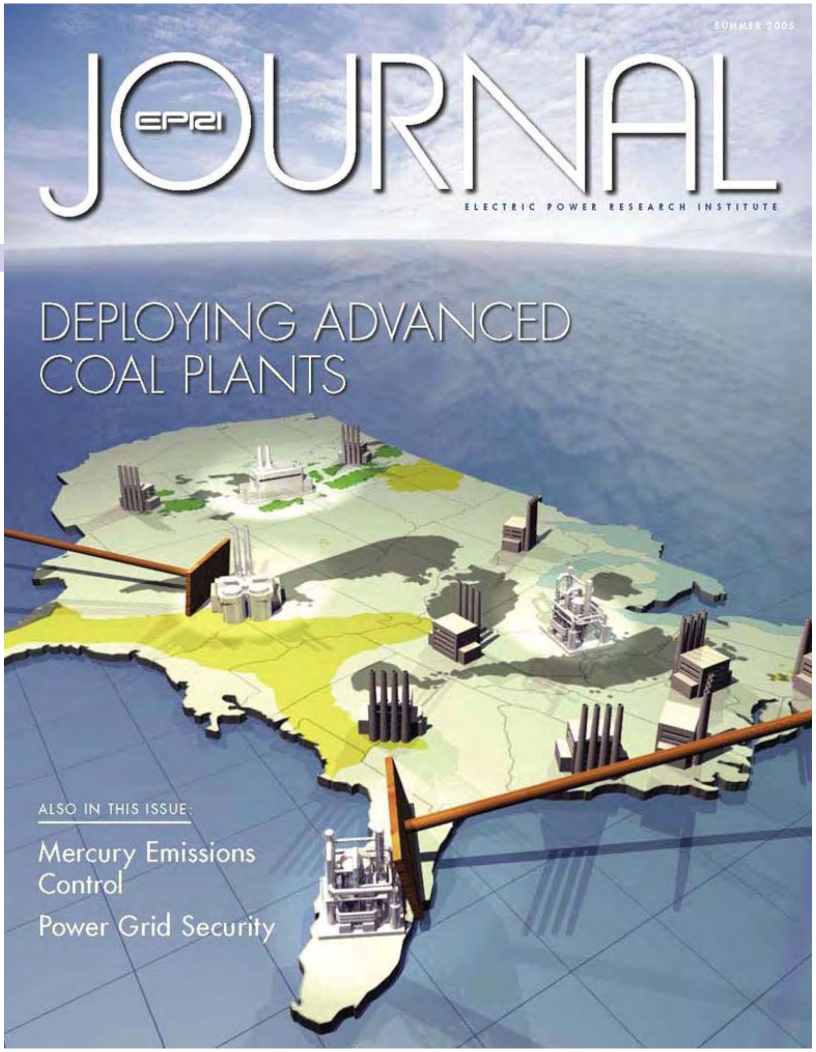


- Negligence
  - Not abnormally dangerous
  - Common law from precedents
  - Requires proof of negligence
  - Example--natural gas pipeline
- Implied Warranty & Product liability
  - More strict common law
  - Property and health damages
  - Example--radon
- Strict Liability--Joint and several liability
  - No requirement of negligence, abnormally dangerous
  - Retroactive liability
  - Any party may be liable for whole amount
  - Example--superfund

Source: MIT

CoalFleet for Tomorrow
Can it help?

- An Industry Initiative to Accelerate the Deployment of Advanced Coal-Based Power Plants
- Billion Dollar Plus Investments in an Emission-Limited World
- 2006 focus on combustion as well as IGCC
- Risks and questions for new technology
  - Is it reliable?
  - What designs are best?
  - How can it be licensed?
  - How much will the new technology cost?
  - How can it be financed?
  - Can it be “CO2 Capture Ready”



Summer 2005 EPRI Journal article available at www.EPRI.COM

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Questions From Overview?