



Carbon Reduction Options in Power Generation

**Federal Reserve Bank of Chicago
Detroit Branch**

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Overview

- What needs to be done
- When does it need to be done
- Where does electrical generation fit
- What are the options in generation
- US Generation Fleet Characteristics
- Retrofitting Existing PC Plants
- Fleet Impact of Retrofit CO₂ Capture
- Issues Outside the Plant Gate
- Regional Considerations





What Needs to be Done about CO₂

- **UK's Stern calls on 'rich' nations for 75% cut in greenhouse gases**
 - September 27, 2007 (**Emissions Daily**) -- Sir Nicholas Stern, told US congressional staff on September 21 that the United States, EU countries and other industrialized nations should agree this year to cut emissions 75% below 1990 levels by 2050.

- What constitutes an appropriate level of GHG in the atmosphere remains open to debate, but even modest scenarios for stabilization would eventually require a reduction in worldwide GHG emissions of 50 to 90 percent below current levels. Source: “Carbon Sequestration Program Environmental Reference Document”, August 2007, DE-AT26-04NT42070 **National Energy Technology Laboratory**





When Should CO₂ Capture be Required

- **“The Future of Coal”, MIT, 2007**
 - *Recommendation #6b*: Congress should act to close this potential “grandfathering” loophole before it becomes a problem for new power plants of all types that are being planned for construction. (Page 100)
- **EPRI, “The Power to Reduce CO₂ Emissions”, 2007**
 - The technology development pathways outlined in this section are intended to achieve two key targets: first, increase the efficiency of PC and IGCC baseload plants (with CO₂ capture) to the 43-45% range by 2030; and second, ensure that all coal plants built after 2020 have the capability to capture and store 90% of the CO₂ produced.





Carbon Dioxide Sources

- US 2005: 5945 million tonnes CO₂ all sectors
- Electrical generation: 2375 million tonnes
- Transportation: 1953 million tonnes
- Electric power and transportation are roughly $\frac{3}{4}$ of the total

Source: EIA Annual Energy Review 2006





Why Electricity Generation is a Target

- Transportation and coal-fired generation have similar CO₂ emissions
 - 1953 Million tonnes – coal 2005
 - 1944 Million tonnes – transportation sector 2005
- There are about 1500 coal-fired generators, about 240 million cars and trucks
- The average coal plant emitted 1.6 million tonnes, the average vehicle emitted 8.1 tonnes

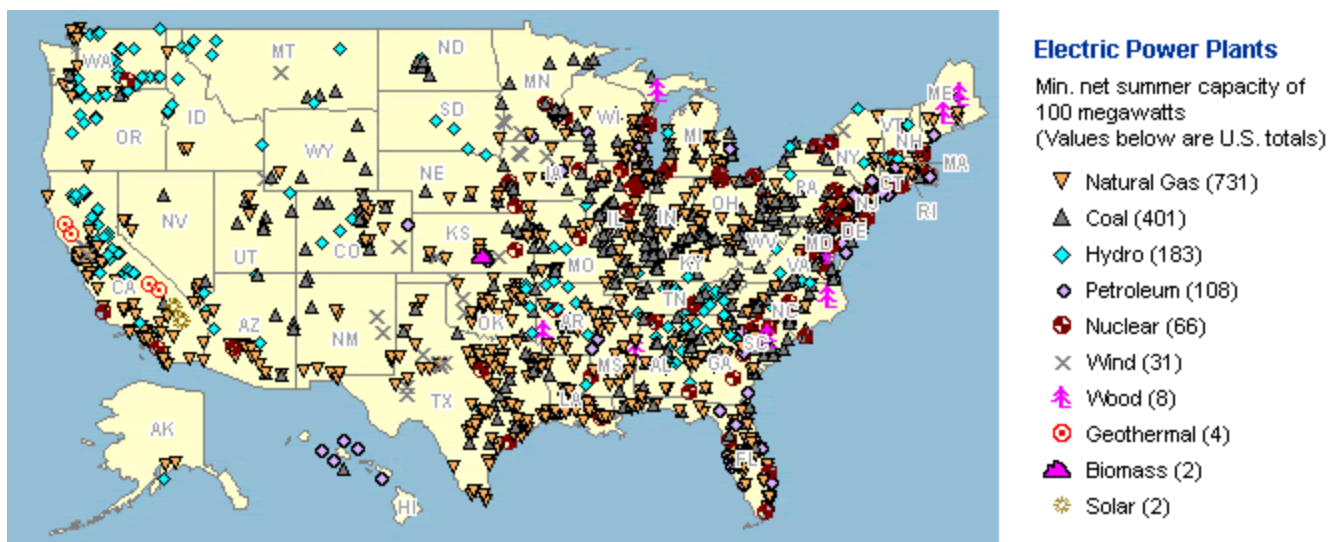
Sources: Emissions: EIA Annual Energy Review 2006

Transportation: Transportation Energy Data Book, 26th Ed., ORNL, 2007



Electricity and Transportation

■ US Power Plants > 100 MW



Source: EIA Website

1536 total power plants
greater than 100 MW





What are the Options in Electricity

- Fuel switching
 - Substituting natural gas for coal
- Post combustion capture
 - Conventional PC with amine scrubbing of flue gas
 - Oxyfuel PC with amine scrubbing of flue gas
- Pre-combustion capture
 - IGCC
 - *FutureGen prototype*
- Chemical looping and other approaches
- Nuclear and renewables
 - These are subjects of other presentations today





Fuel Switching – Coal to Natural Gas

- Existing coal fleet has 72.2% capacity factor, 32.8% thermal efficiency
- Existing gas fleet has 23.7% capacity factor, 39% thermal efficiency
- Substituting gas for coal reduces emissions about 53%, not 70-90% needed
- ***We don't have either the gas resources or deliverability to make this substitution***





Post Combustion Capture

■ **Conventional PC with Scrubbing**

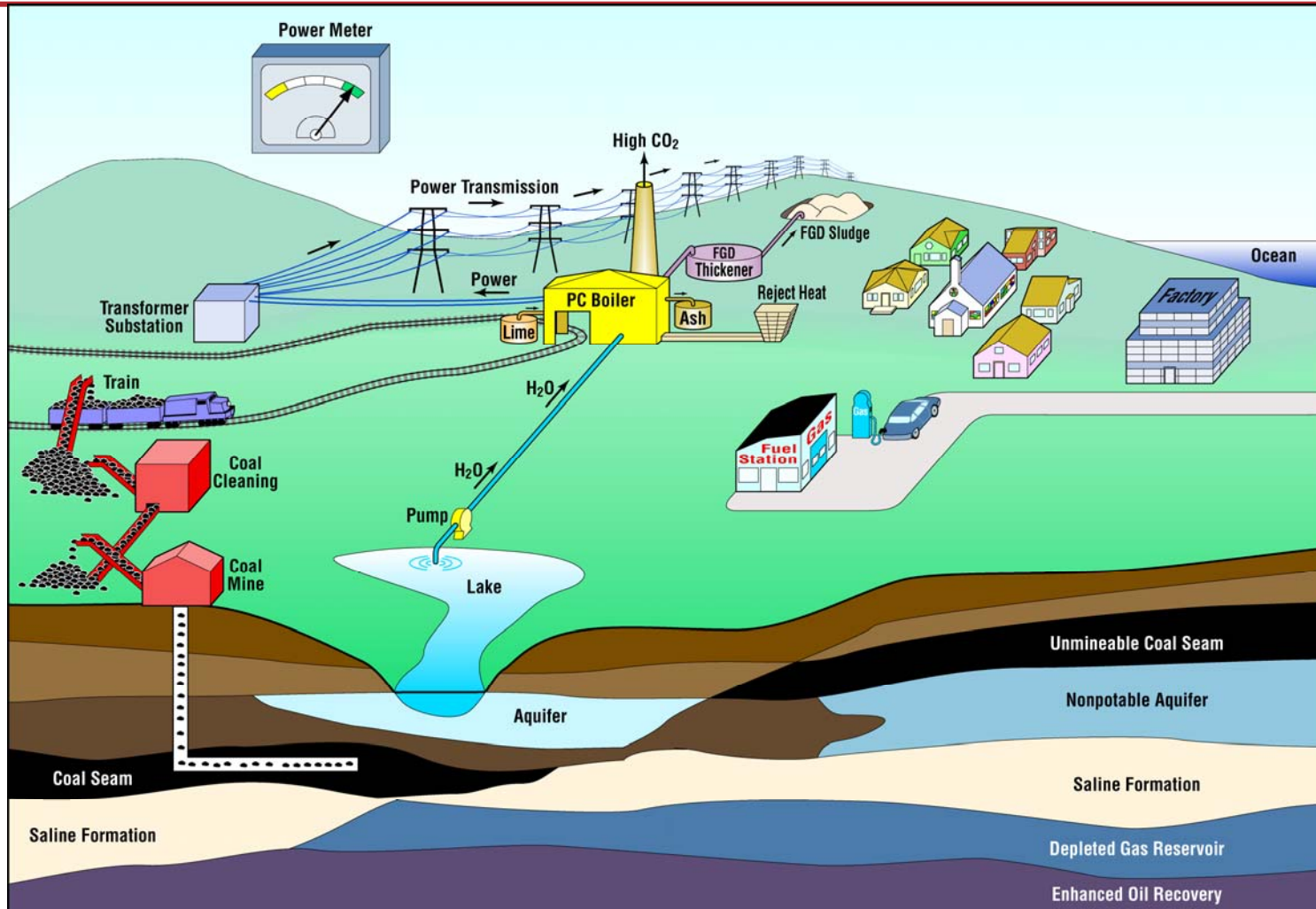
- **Costs**
- **Derating, Efficiency reduction**
- **Lack of utility-scale experience**

■ **Oxyfuel PC with Scrubbing**

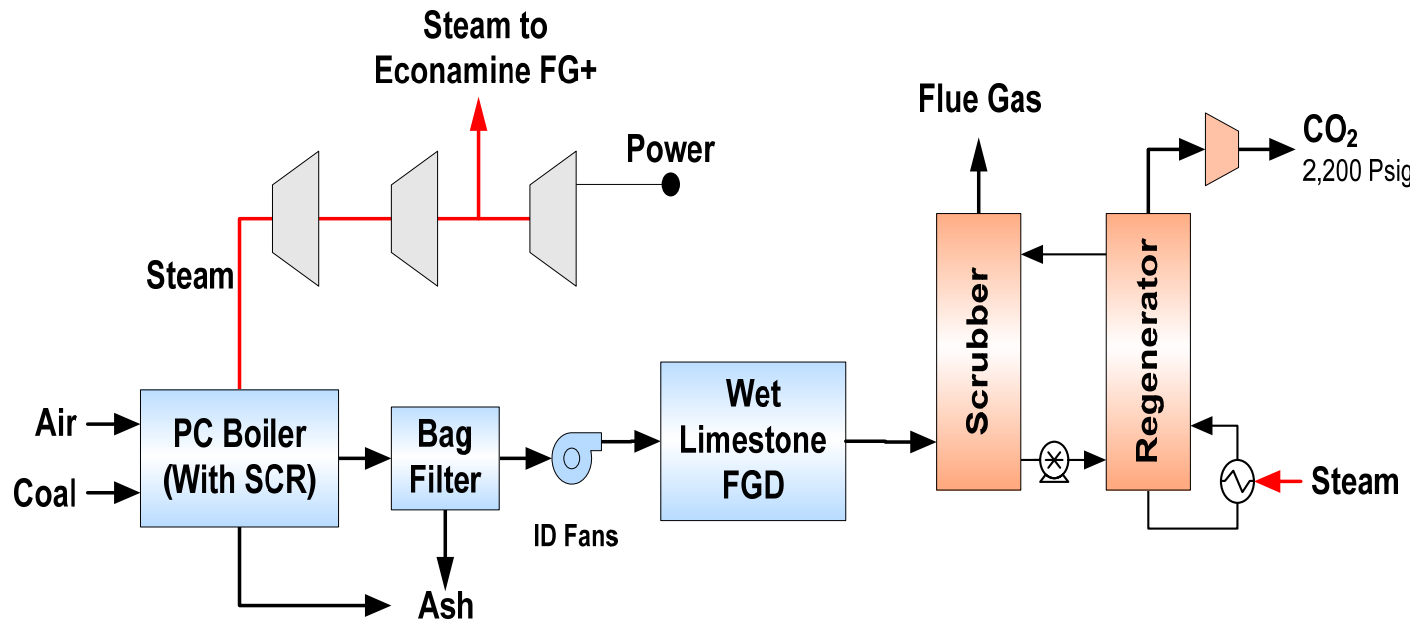
- **Cost, complexity**
- **Air separation reduces efficiency, derates output**
- **Lack of experience base**



Pulverized Coal – No Capture



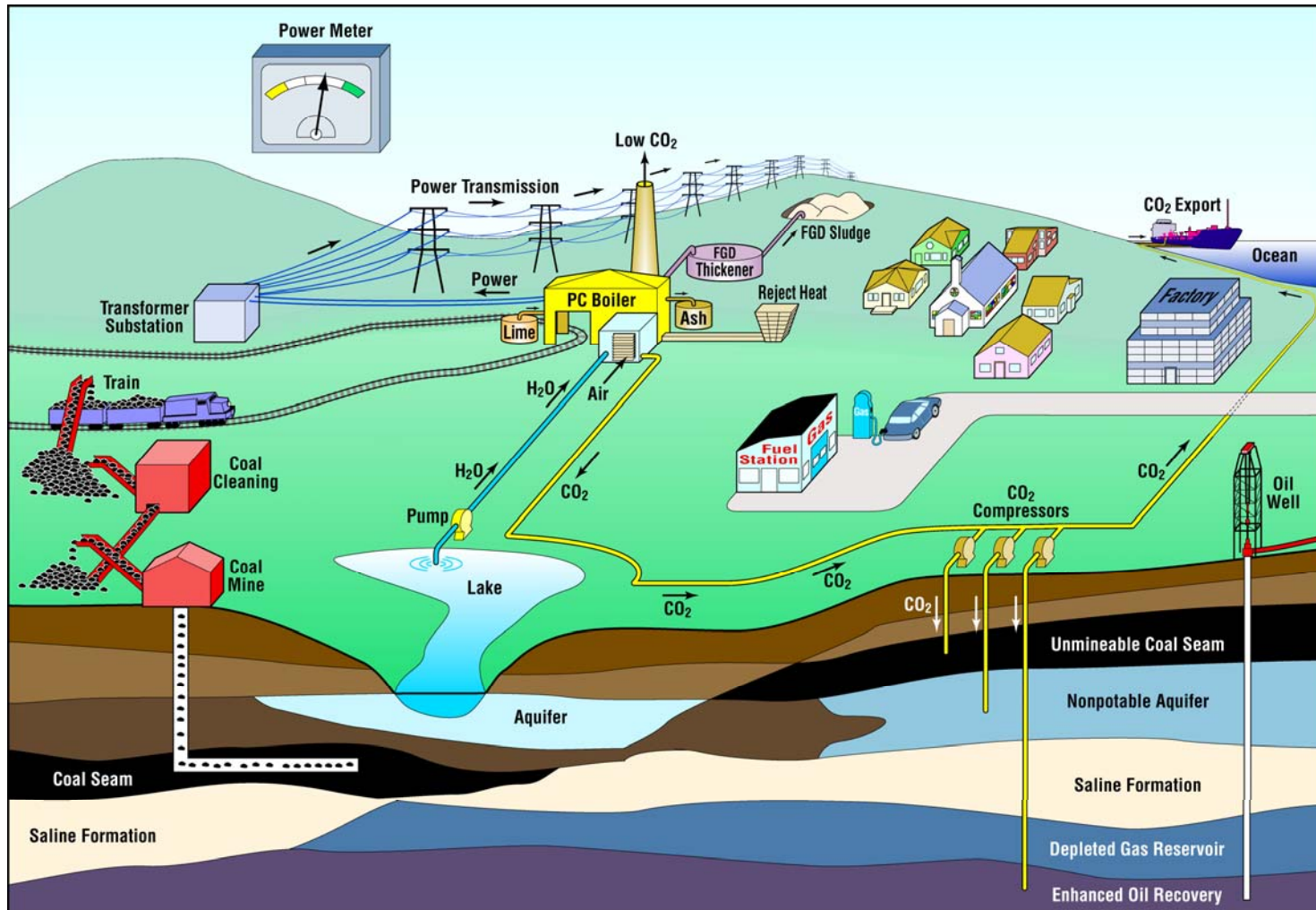
Current Technology Pulverized Coal Power Plant



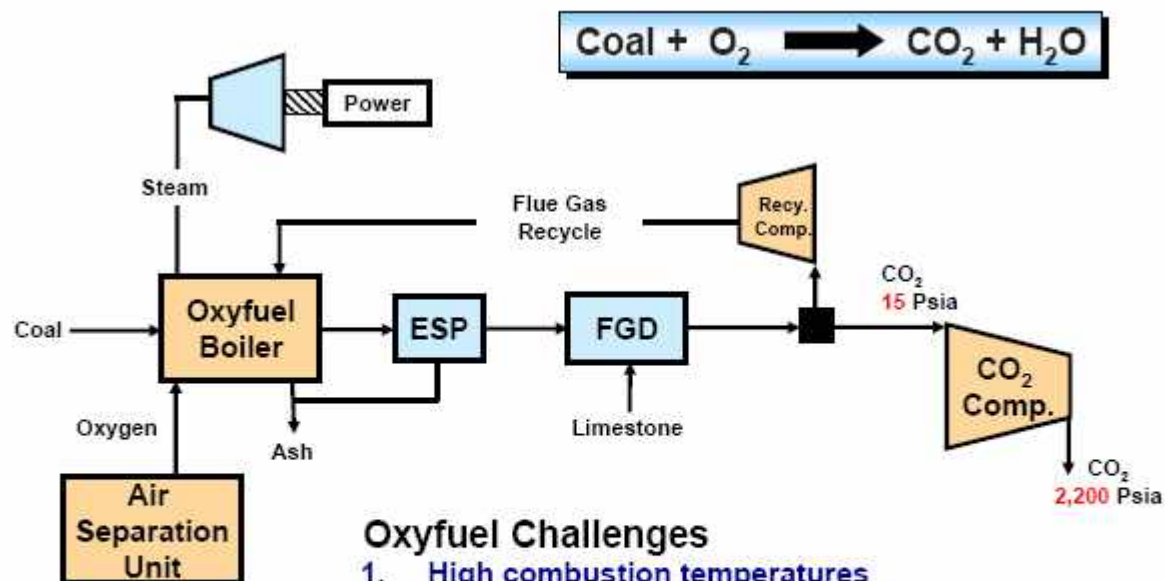
Orange blocks added for carbon capture

Source: **Cost and Performance Baseline
for Fossil Energy Plants**, National Energy Technology
Laboratory, April 10, 2007

Oxyfuel PC with CO₂ Capture



Oxyfuel Combustion



Oxyfuel Challenges

1. **High combustion temperatures**
 - *Boiler materials of construction issues
 - *Requires large amounts of flue gas recycle
2. **Cryogenic oxygen production is expensive and energy intensive**
 - *Opportunity for oxygen membranes

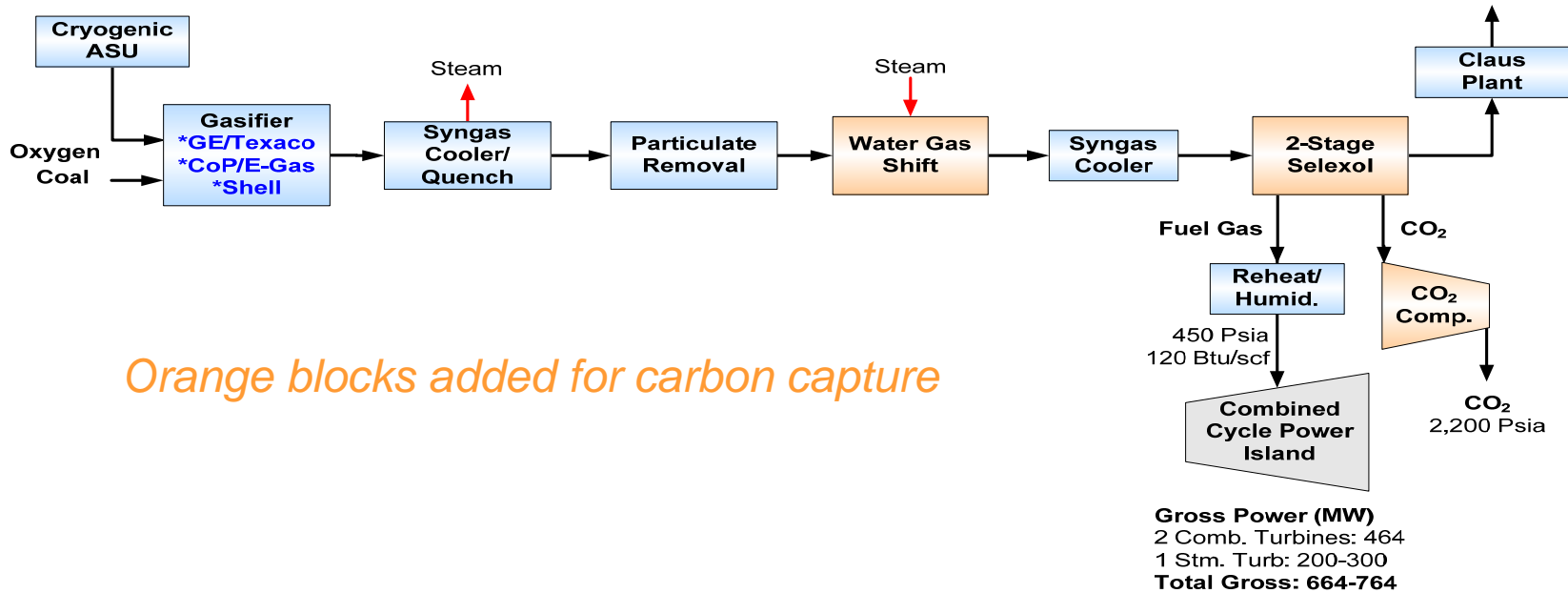


GCEP - JPC - 4/27/04

Source: NETL Carbon Sequestration Program
US Perspective on CO₂ Capture and Separation, Jared P. Ciferno,
April 27, 2004
Stanford University



IGCC with Carbon Capture



Source: **Cost and Performance Baseline for Fossil Energy Plants**, National Energy Technology Laboratory, April 10, 2007



Existing US IGCC Plants



Wabash River

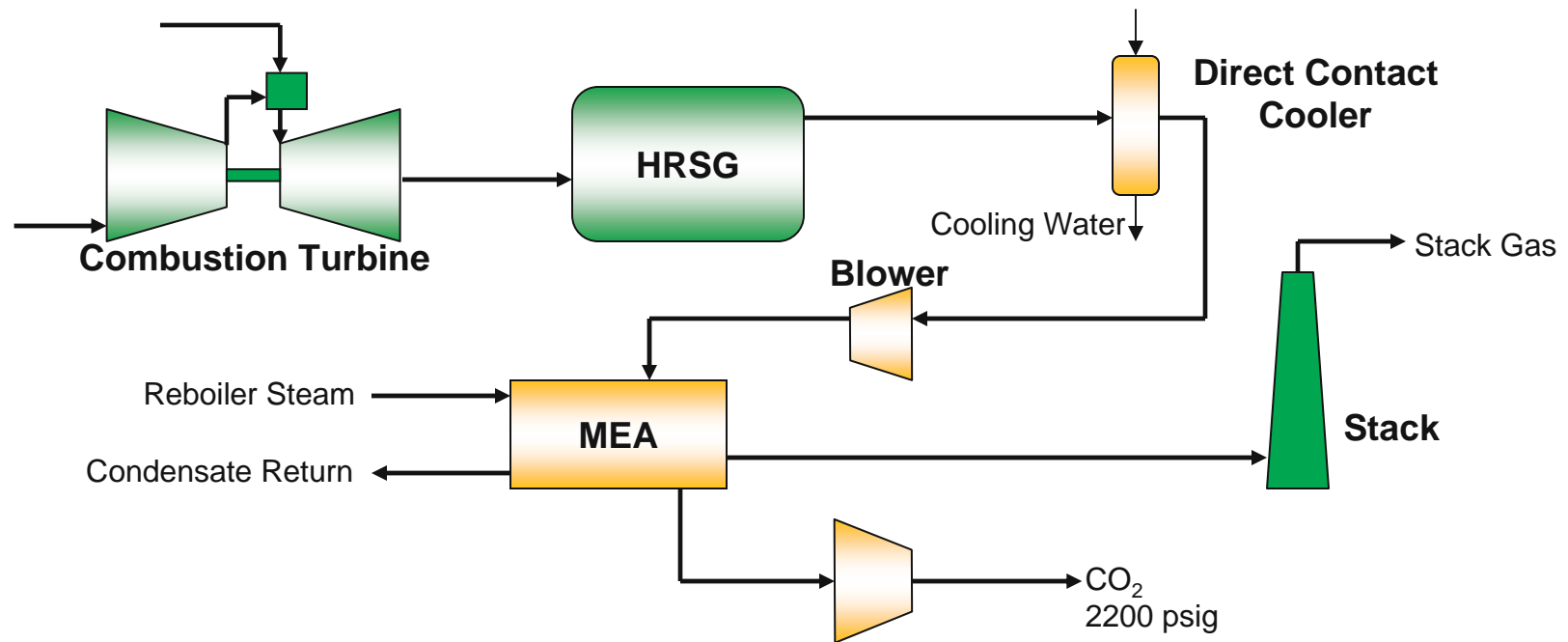
Source:
<http://www.netl.doe.gov/technologies/coalpower/gasification/pubs/photo.html>

Both plants were built under the Clean Coal Technology Program of DOE

Tampa Electric



NGCC with Carbon Capture



Orange blocks added for carbon capture

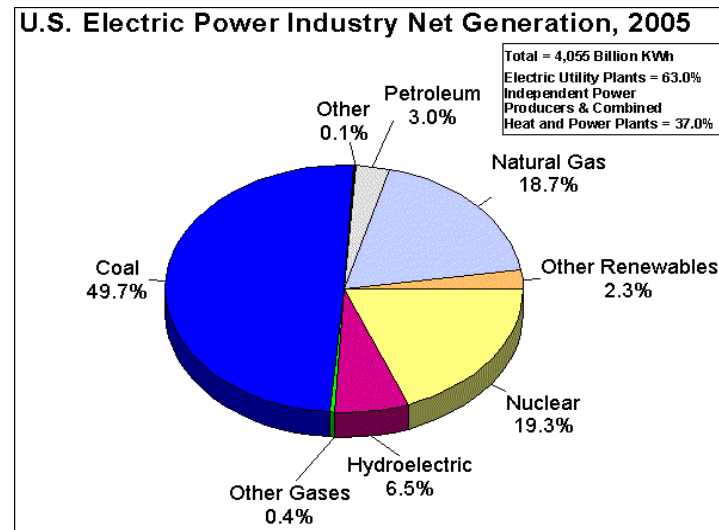
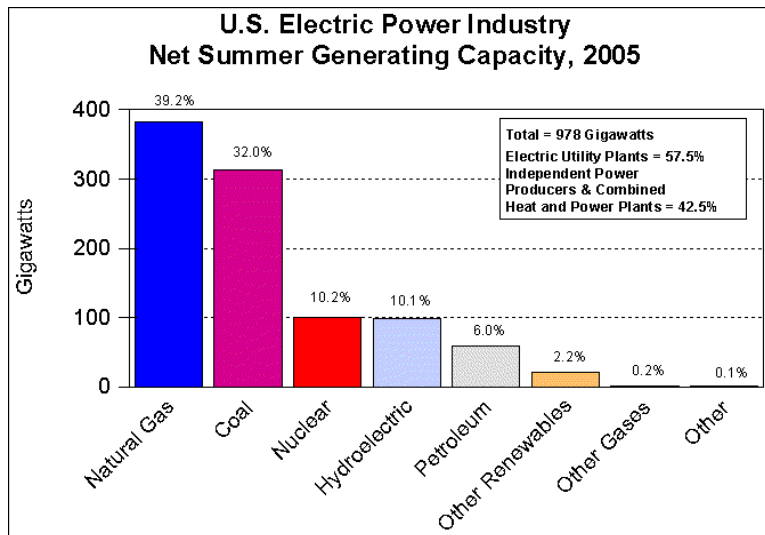
Source: **Cost and Performance Baseline for Fossil Energy Plants**, National Energy Technology Laboratory, April 10, 2007



Current Generation Capacity

- **Scale of current generation fleet**
 - 970+ GW capacity, 16,000+ units
 - 1500 >100 MW plants, 400+ are PC
 - Pre-combustion fleet very small
 - *Wabash River, IN*
 - *Tampa, FL*
- **Oxyfuel is a possible path from PC to IGCC with CCS**
 - No utility-scale currently

US Generation Fleet Characteristics

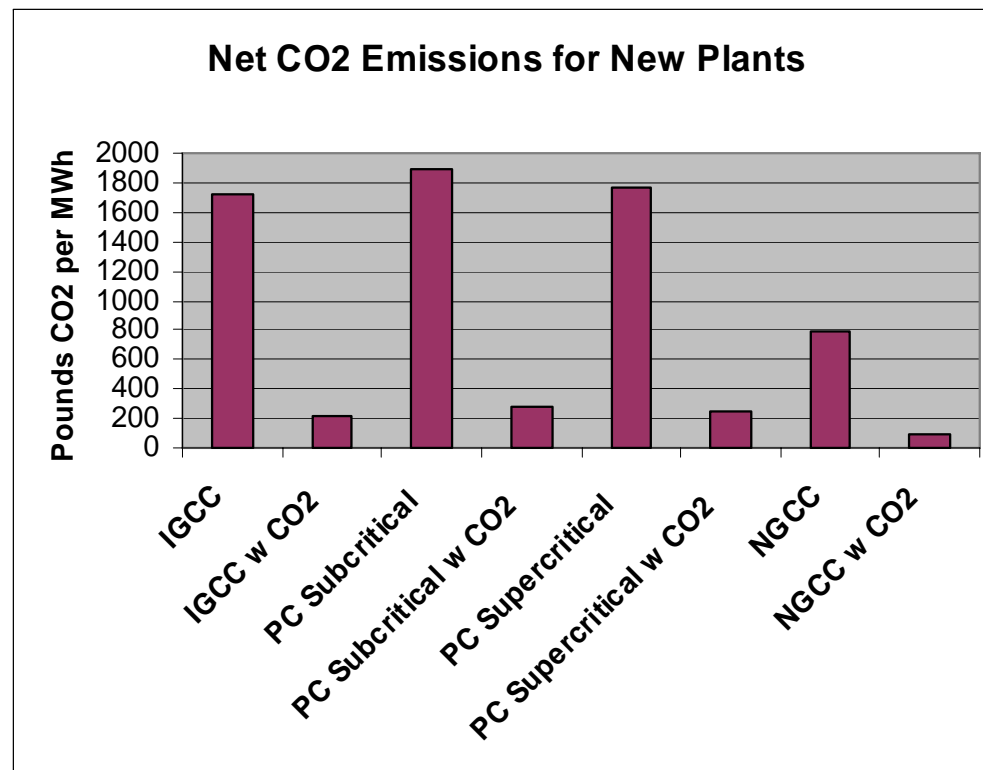


U.S. Electric Power Industry Consumption & Cost of Fossil Fuels for Electricity Generation, 2005

	Consumption	Cost (cents/million Btu)
COAL (thousand tons)	1,045,878	154
PETROLEUM (thousand barrels)	211,256	644
NATURAL GAS (million cubic feet)	6,486,761	821

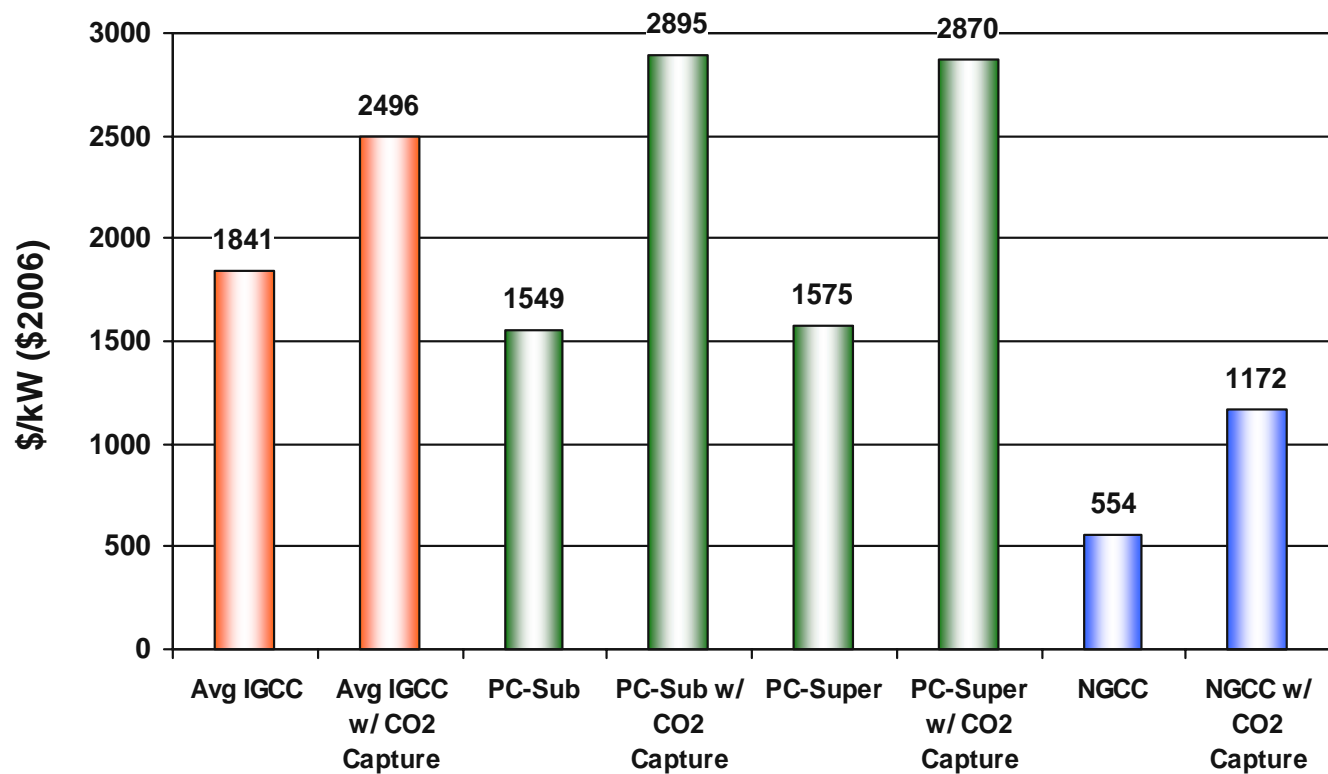
Source: EIA Electricity Website,
<http://www.eia.doe.gov/neic/brochure/elecinfocard.html>

CO₂ Emission from Generation Plants



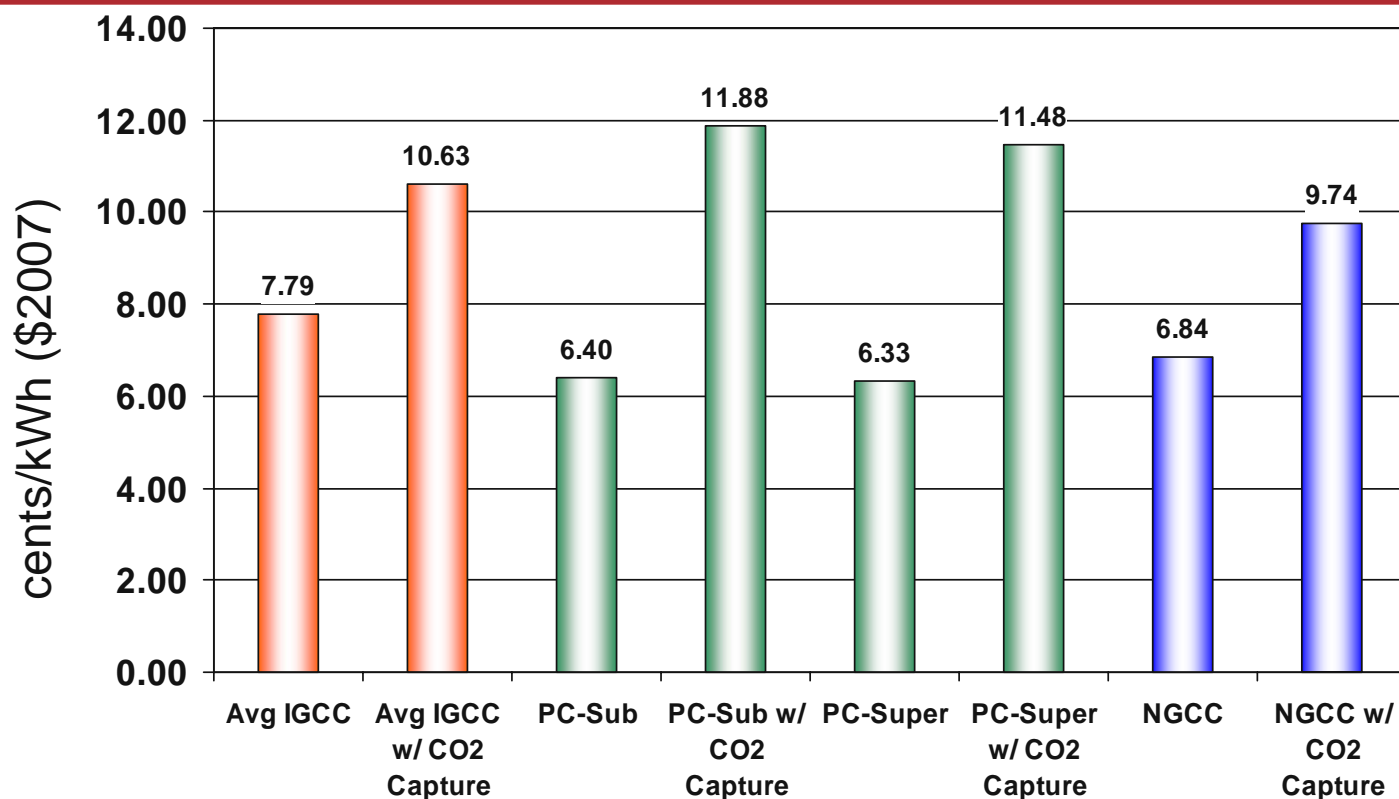
Data Source: Exhibit ES-2, Cost and Performance Baseline for Fossil Energy Plants, Volume 1: Bituminous Coal and Natural Gas to Electricity Final Report, May 2007, National Energy Technology Laboratory, DOE/NETL-2007/1281

Plant Cost Comparison



Source: **Cost and Performance Baseline
for Fossil Energy Plants, May 15, 2007**
Revised August 2007, National Energy Technology
Laboratory

Cost of Electricity Impacts



January 2007 Dollars, Coal cost \$1.80/106Btu. Gas cost \$6.75/106Btu

Source: **Cost and Performance Baseline
for Fossil Energy Plants, May 15, 2007**

Revised August 2007, National Energy Technology
Laboratory

Retrofitting an Existing PC Plant

**Conesville Unit #5
studied**

Subcritical steam cycle

**463 MW gross, 430 MW
net**

Bituminous coal

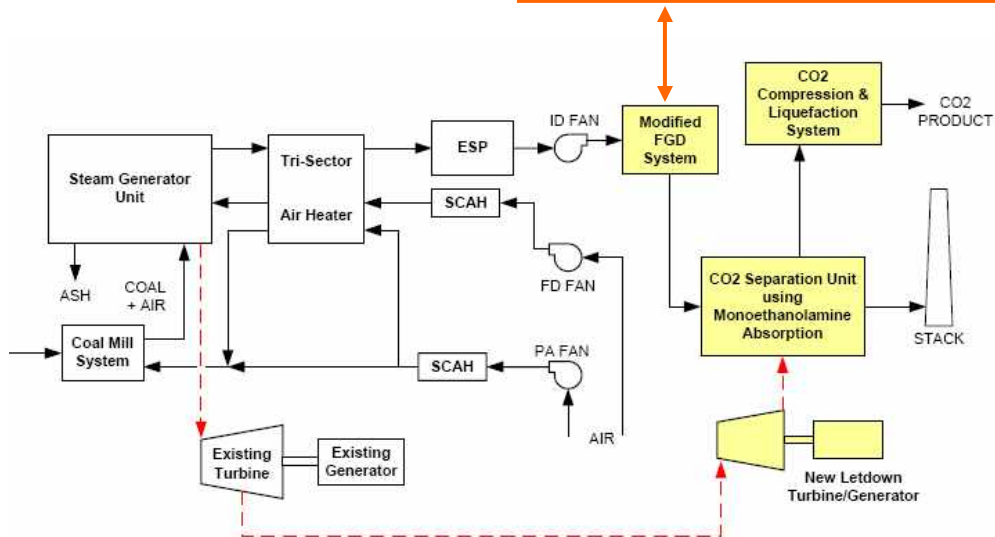
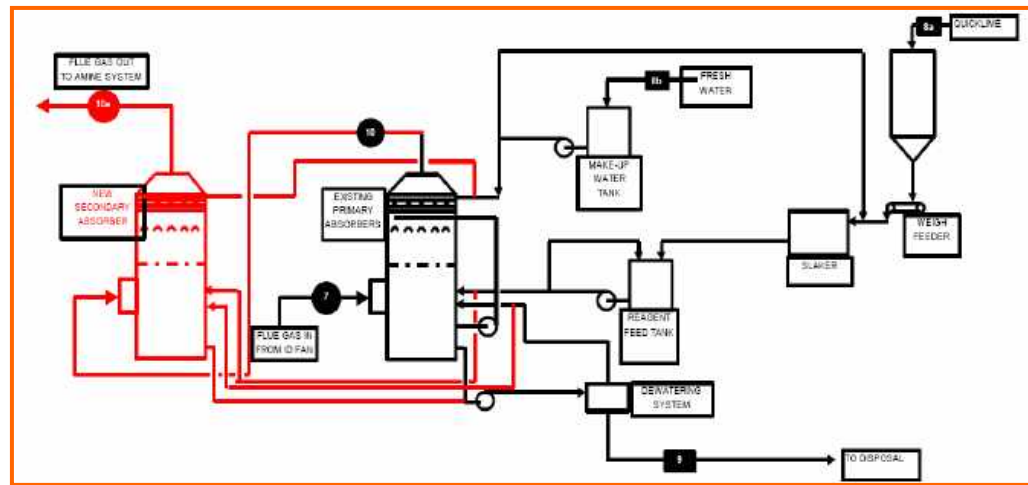
ESP and wet lime FGD

**Source: CO₂Capture From *Existing Coal-Fired*
Power Plants,
Jared P. Ciferno -National Energy Technology
Laboratory, *April 2007***



Schematic of Plant Modifications

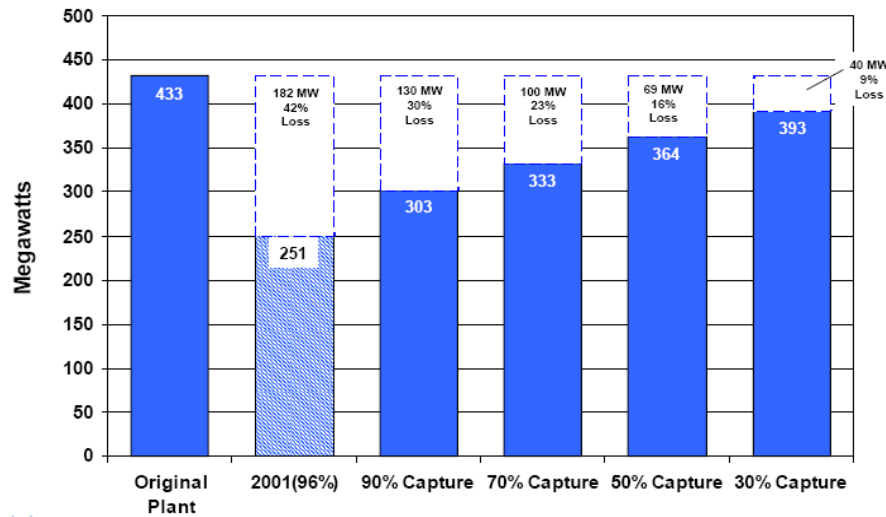
This type of FGD would be needed for most coals, retrofit or new



Source: CO₂ Capture From *Existing Coal-Fired Power Plants*,
 Jared P. Ciferno -National Energy Technology
 Laboratory, April 2007

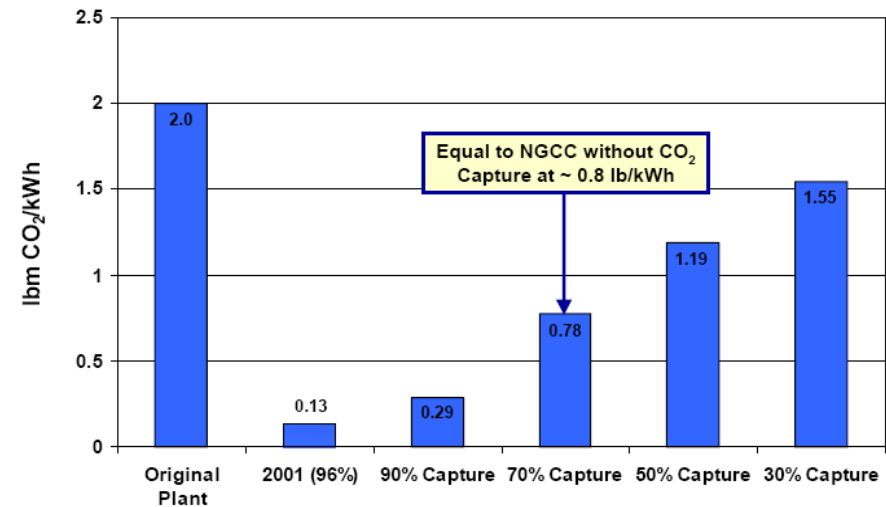


Impacts on Net Output and CO₂ Emissions



Capital costs ranged from 417 \$/kW at 30% capture to 1010 \$/kW at 90% capture

Source: CO₂ Capture From *Existing* Coal-Fired Power Plants,
 Jared P. Ciferno -National Energy Technology Laboratory,
 April 2007





Fleet Impact of Retrofit CO₂ Capture

- **Roughly 250 MW of incremental capacity needed for every 1000 MW of capacity retrofitted at 70% carbon capture**
- **NETL and Argonne are beginning a joint study to better understand the grid-level implications of retrofitting significant levels of generation capacity with CO₂ capture**
 - **Midwest will be initial focus**
 - **Least-cost replacement power sources and impacts will be examined**



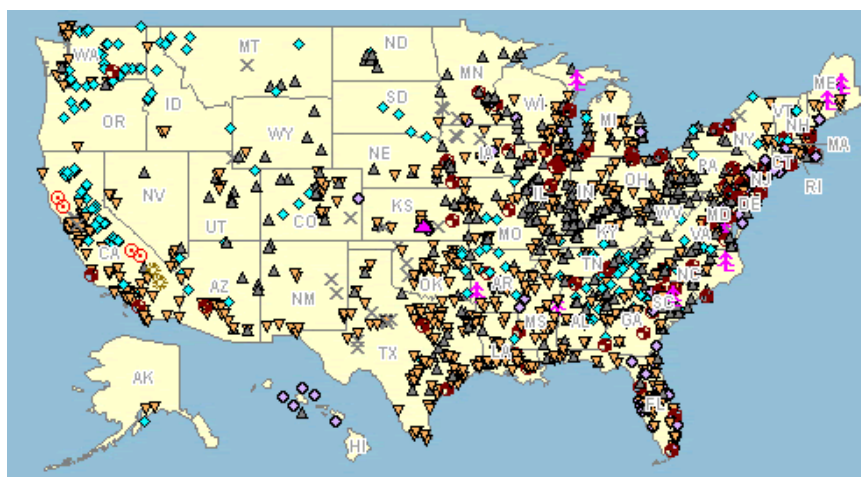


Issues Outside the Plant Gate

- Pipeline costs, rights-of-ways, regulations
- Availability of adequate storage (sequestration) capacity
- Unsettled legal and regulatory issues
 - Who owns the CO₂
 - *Is the CO₂ a 'waste' or a product*
 - Who owns the mineral rights and/or property rights at the sequestration site
 - What will the monitoring requirements be
 - How long will they run
 - If cap and trade, how will the trading regimen work
 - Who owns the short-term and long-term liabilities



US Power Plants and CO₂ Pipelines



Top map from EIA website
 Bottom map from “Prospects for Early Deployment of Power Plants Employing Carbon Capture”,
 Electric Utilities Environmental Conference
 Tucson, AZ January 22-25, 2002, National Energy
 Technology Laboratory,

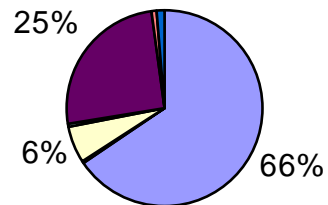




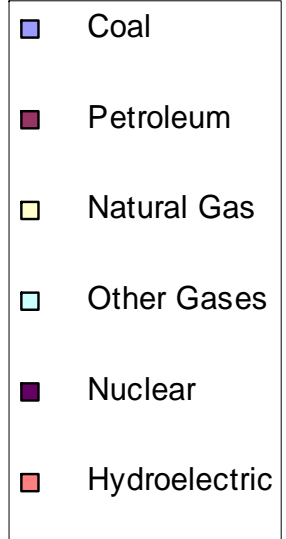
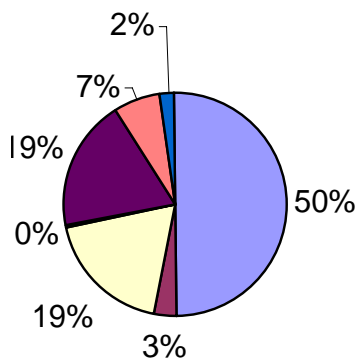
How does the Chicago FRB Region Compare to US

- States of Illinois, Indiana, Iowa, Michigan, and Wisconsin taken as surrogate for FRB region

Illinois, Indiana, Iowa, Michigan, Wisconsin

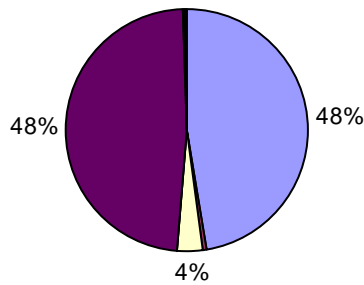


US Total

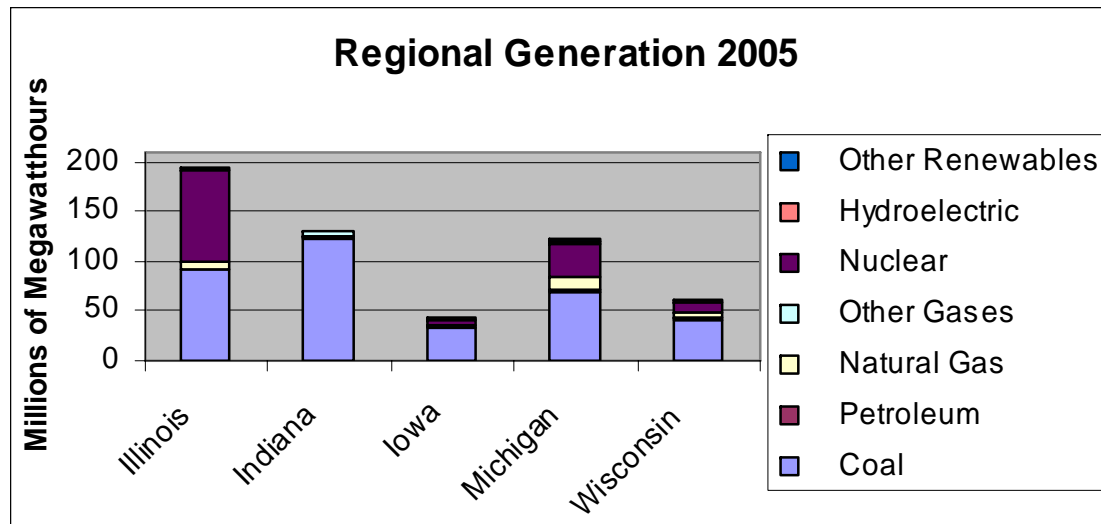
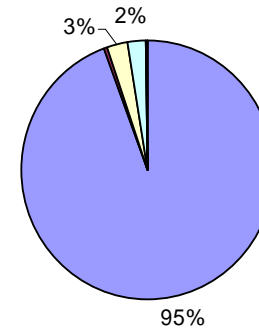


Regional Capacity and Generation

Illinois



Indiana





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Thank you for your attention

