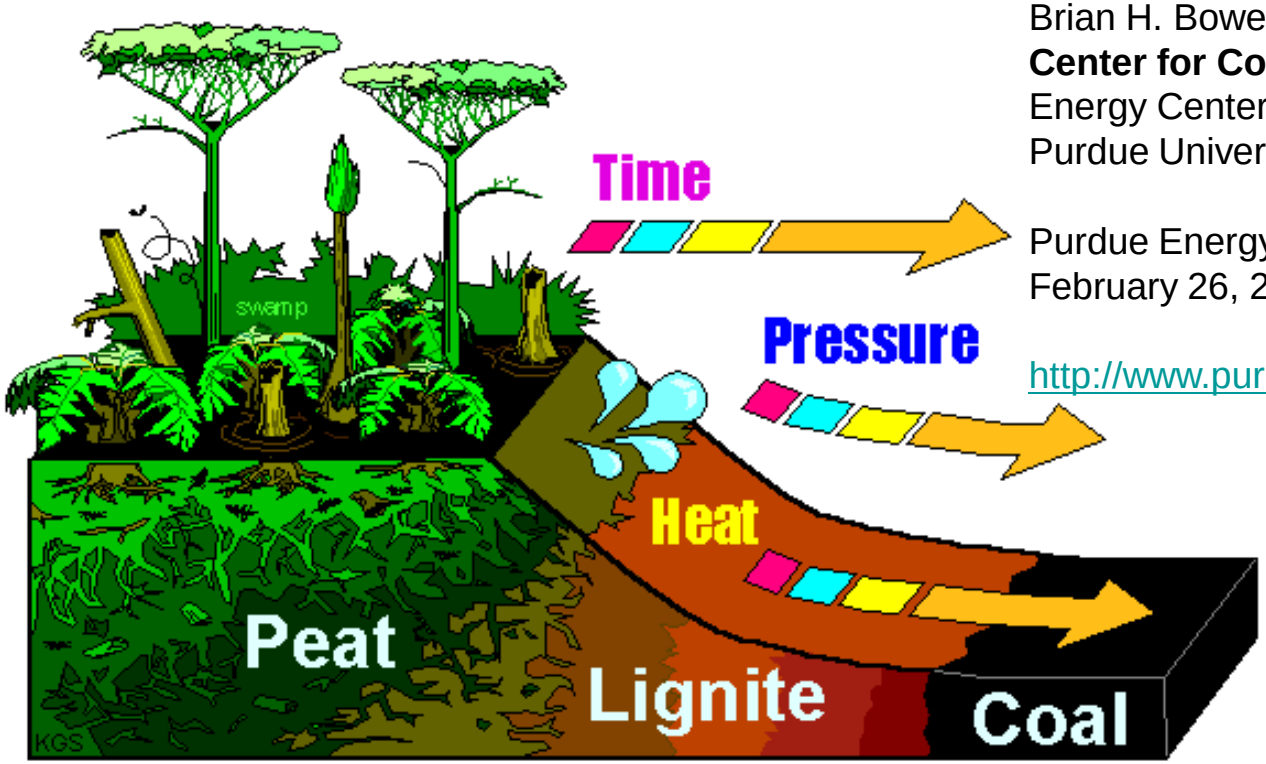
Energy Technology Efficiency, Economics & Environment



Brian H. Bowen
Center for Coal Technology Research
Energy Center at Discovery Park
Purdue University

Purdue Energy Club Meeting
February 26, 2009

http://www.purdue.edu/dp/energy/CCTR/index.php

City Water Gets Cleaner

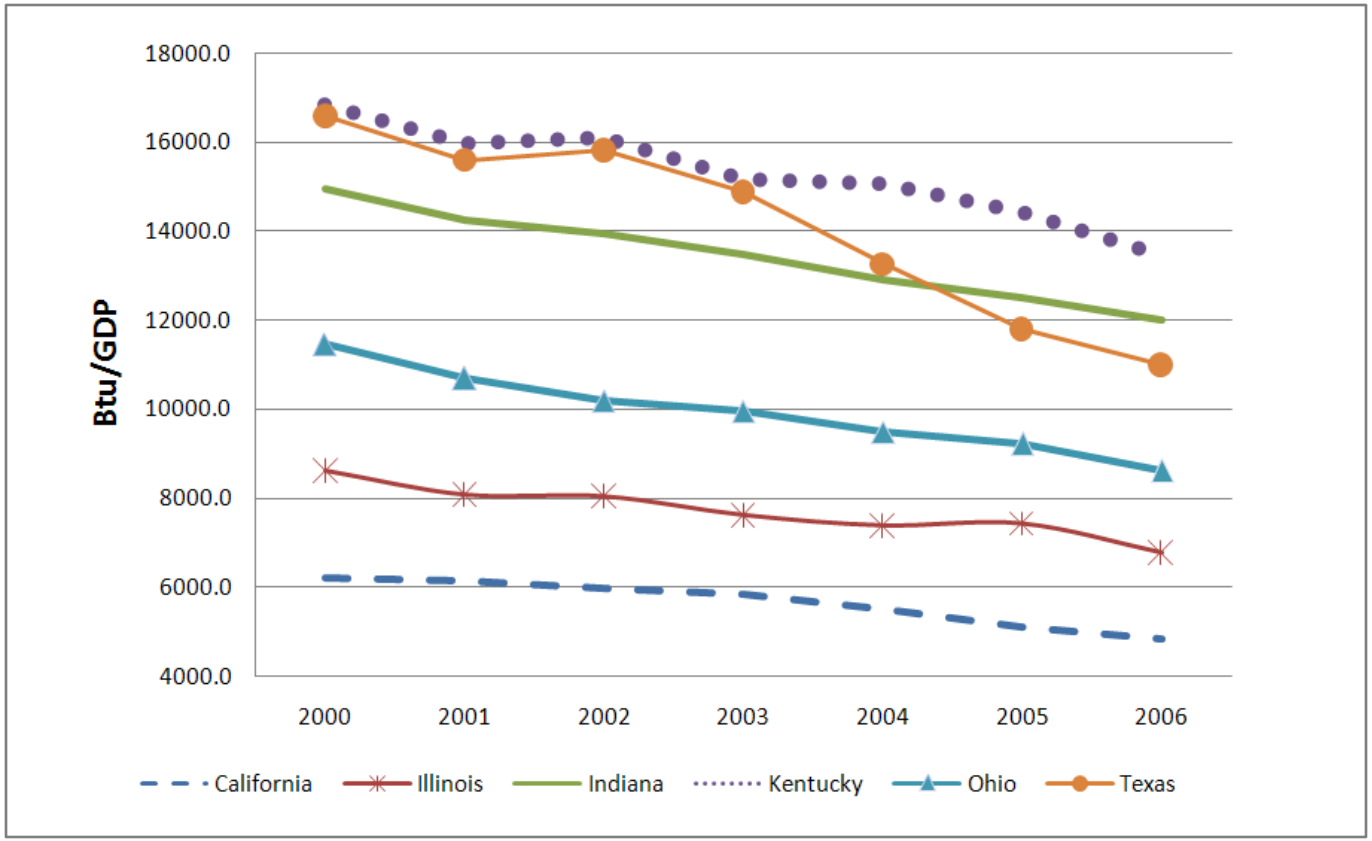
Despite government regulations, incredible advancements & **improvements over the past 50 years** in water technology, the water issuing from home taps is still quite contaminated. Chlorine has been linked to asthma & other respiratory diseases, & excessive fluoride intake can lead to yellowed teeth, dental problems, & other serious health problems for young children. The water contains disease-bearing pathogens, pesticide chemicals, & industrial sludge, to name only a few of modern water contaminants.

Proven Science or Media Perceptions
“An Inconvenient Truth”
“Slumdog Millionaire”

http://www.historyofwaterfilters.com/water-filters-present.html

Energy Intensity is Declining, Btu/GDP

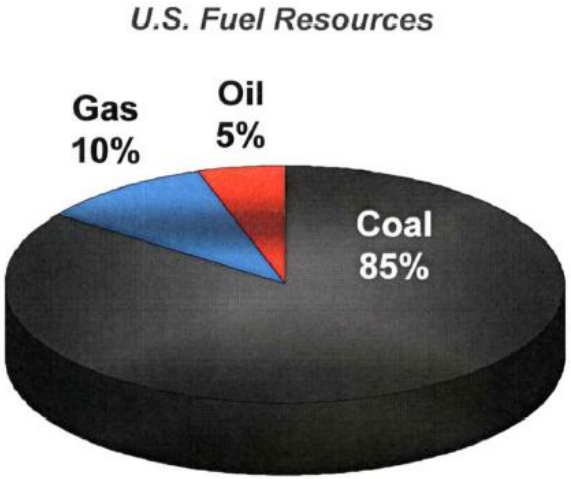
Good news: Promotion of improved energy efficiency, in US states ~ less energy is consumed per $ of GDP

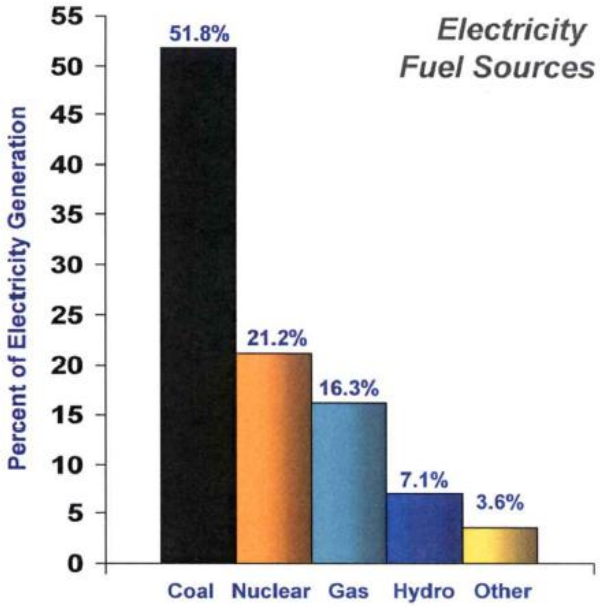


Sources: GDP Data is from :http://www.bea.gov/regional/gsp/Source: Energy Consumption Data is from EIA's webpage and GDP data is from Bureau of Economic Analysis
http://www.eia.doe.gov/emeu/states/state.html?q_state_a=il&q_state=INDIANA,
http://www.eia.doe.gov/emeu/states/state.html?q_state_a=il&q_state=ILLINOIS, etc

U.S. Energy Reserves – Balancing Act

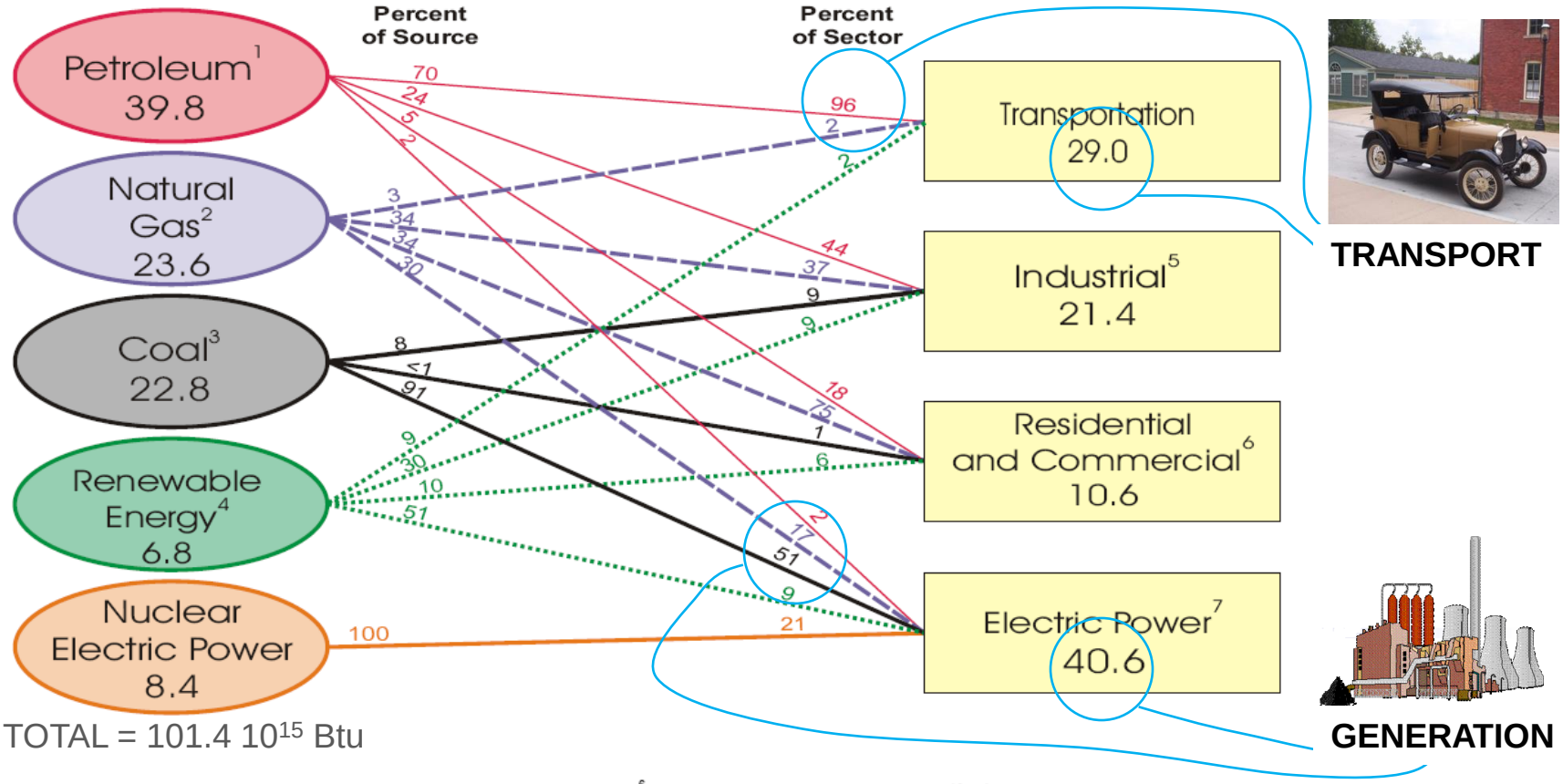
- **Importance of energy security & huge U.S. coal reserves**
- How to balance economics & the environment
- What are reasonable research time horizons for H_2 economy
- Increased dependence on Natural Gas - LNG & where from





Ultimately recoverable demonstrated reserves on Btu basis. Source: USGS, National Assessment of United States Oil and Gas Resources, U.S. Coal Reserves; Energy Information Administration Monthly Energy Review, May 2003, Table 7.2b, 2002 data.

U.S. Primary Energy Consumption, 2007 by Source & Sector (Quadrillion Btu, 10^{15} Btu)



TOTAL = 101.4 10^{15} Btu

[1]Does not include 0.6 quadrillion Btu of fuel ethanol, which is included in "Renewable Energy."
[2]Excludes supplemental gaseous fuels.
[3]Includes less than 0.1 quadrillion Btu of coal coke net imports.
[4]Conventional hydroelectric power, geothermal, solar/PV, wind, and biomass.
[5]Includes industrial combined-heat-and-power (CHP) and industrial electricity-only plants.
[6]Includes commercial combined-heat-and-power (CHP) and commercial electricity-only plants.
[7]Electricity-only and combined-heat-and-power (CHP) plants whose primary business is to sell electricity, or electricity and heat, to the public.

Note: Sum of components may not equal 100 percent due to independent rounding.
Sources: Energy Information Administration, *Annual Energy Review 2007*, Tables 1.3, 2.1b-2.1f and 10.3.

http://www.eia.doe.gov/emeu/aer/pecss_diagram.html

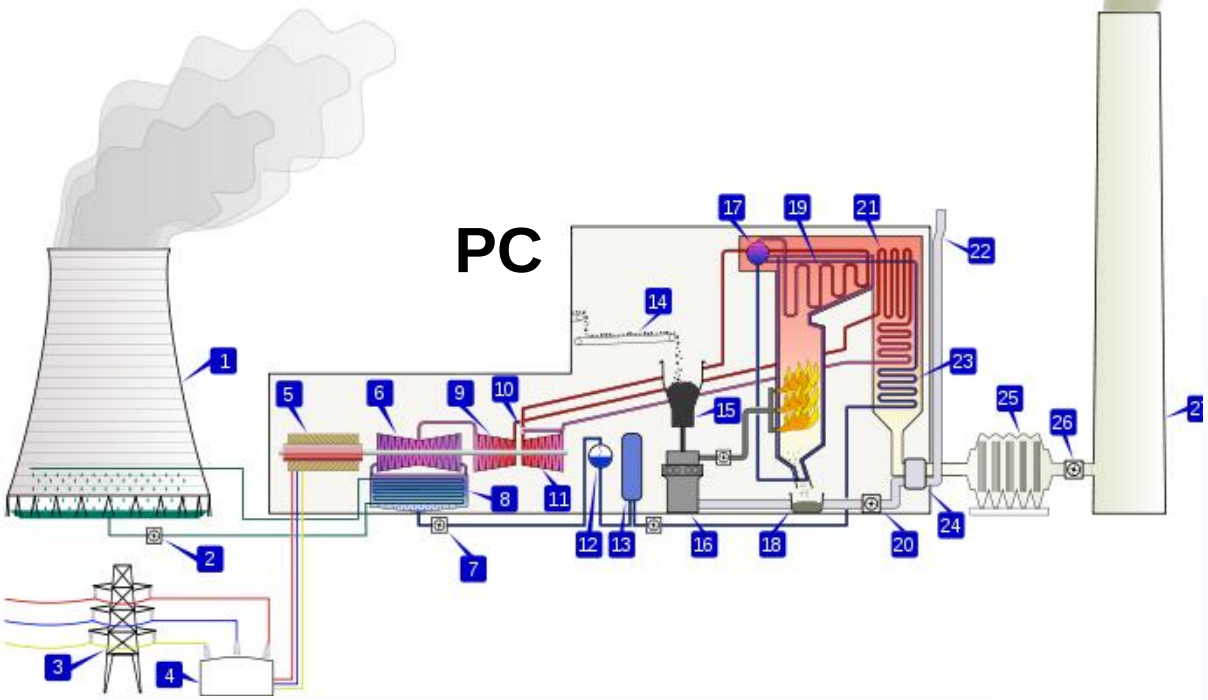
Transportation Cost Savings, & Emission Reductions From Improved Efficiency

Maximizing the use of time while forming policies & so must improve efficiencies: Transportation = distance/unit energy input

Example:
Average fuel consumption of 35 mpg compared with 25 mpg means that for any distance **there is a 29% fuel saving & also a 29% reduction in car emissions.**

For a distance of 350 miles at 25 mpg then 14 gallons of fuel are needed. At 35 mpg only 10 gallons are needed & so **there has been a 29% (4/14) fuel saving & also therefore 29% less emissions**

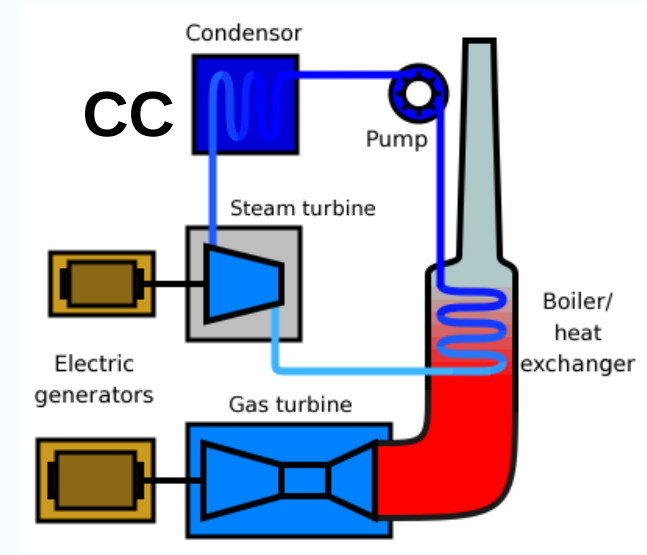
Pulverized Coal & Combined Cycle Power Plants



1. Cooling tower	10. Steam governor valve	19. Superheater
2. Cooling water pump	11. High pressure turbine	20. Forced draught fan
3. Transmission line (3-phase)	12. Deaerator	21. Reheater
4. Unit transformer (3-phase)	13. Feed heater	22. Air intake
5. Electric generator (3-phase)	14. Coal conveyor	23. Economiser
6. Low pressure turbine	15. Coal hopper	24. Air preheater
7. Condensate extraction pump	16. Pulverised fuel mill	25. Precipitator
8. Condensor	17. Boiler drum	26. Induced draught fan
9. Intermediate pressure turbine	18. Ash hopper	27. Chimney Stack

http://en.wikipedia.org/wiki/File:COGAS-diagram.png

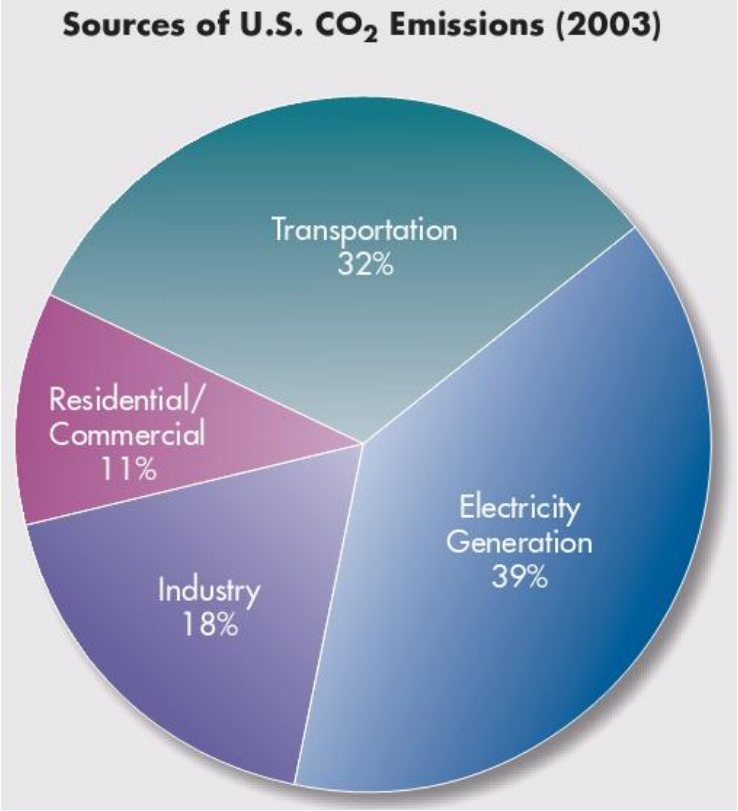
PC – Pulverized Coal
Low fuel prices, Lower %
CC - Natural Gas
High fuel prices, Higher %

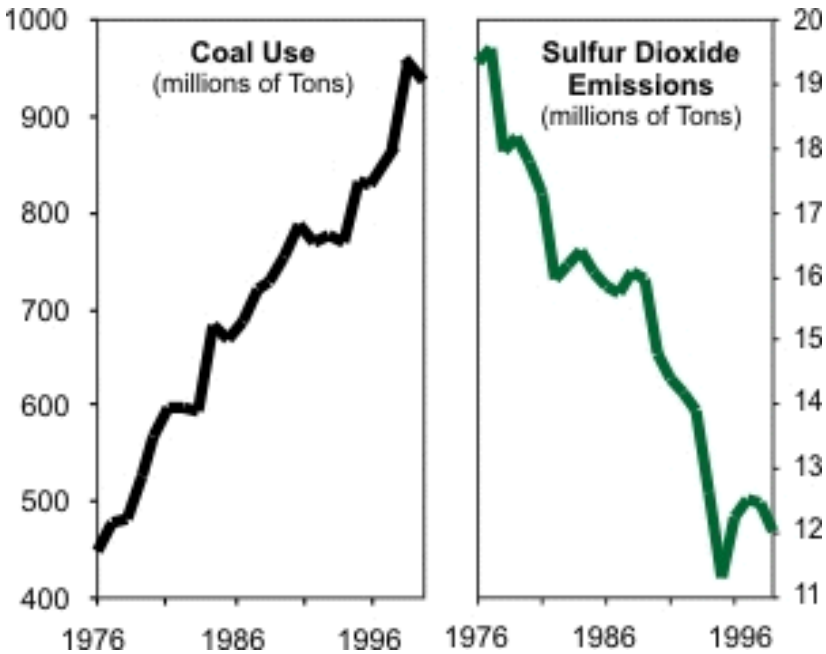


IGCC – Integrated Gasification Combined Cycle Power Plant

Emissions from Transportation & Power

CO_2 from **transportation & power plants - similar** magnitudes
Big improvements in reducing SO_2 & other emissions



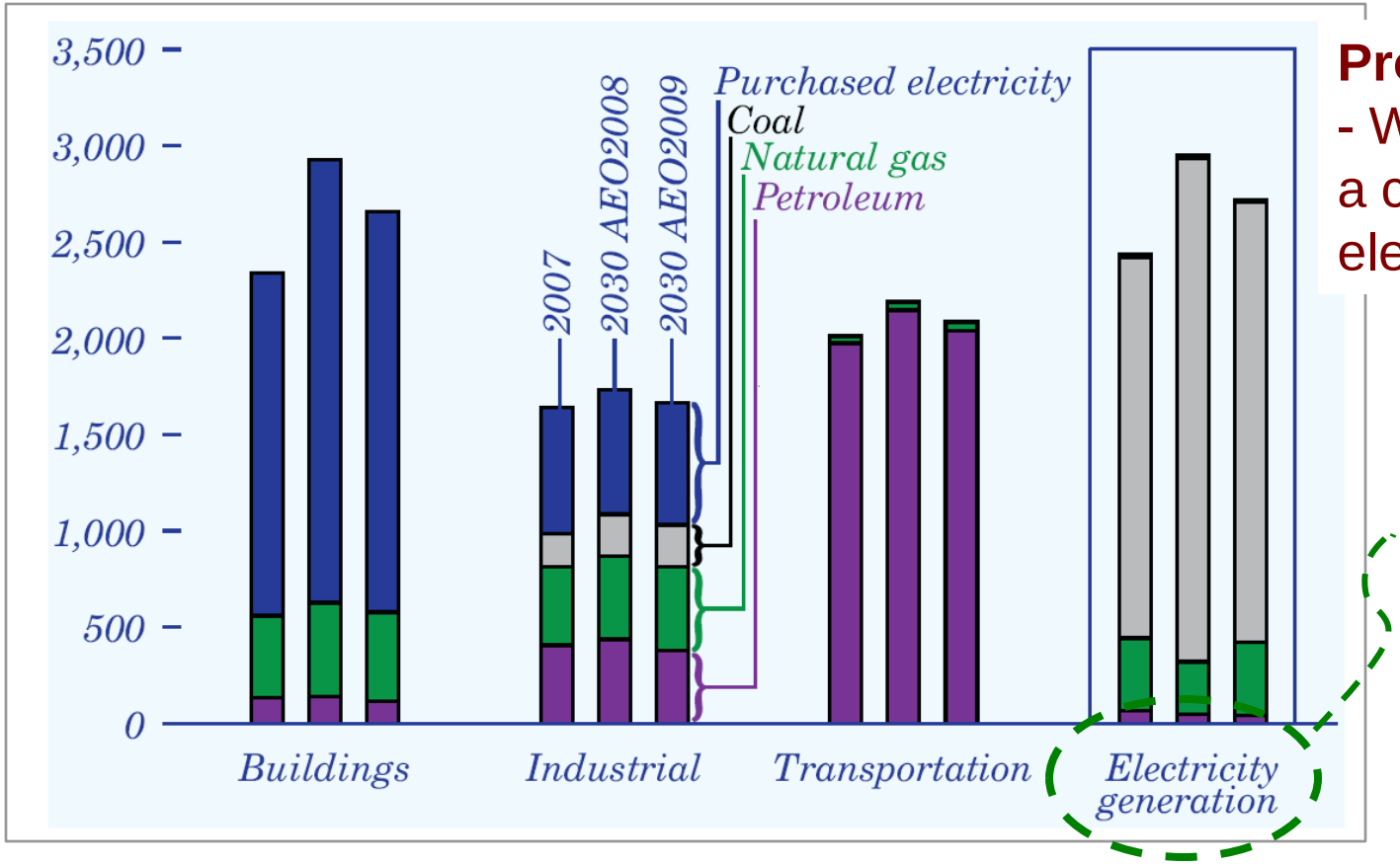


Source: EPRI 2006, http://mydocs.epri.com/docs/CorporateDocuments/EPRI_Journal/2006-Summer/1013720_ClimatePolicy.pdf

U.S. Energy Related CO_2 Emissions by Sector & Fuel, 2007 & 2030 (Million metric tons)

Emissions from transportation & electricity generation

In 2030 each continues to emit over 2 BTons/yr



Problem

- We each want a car & more electricity

Stationary objects are so much easier to control

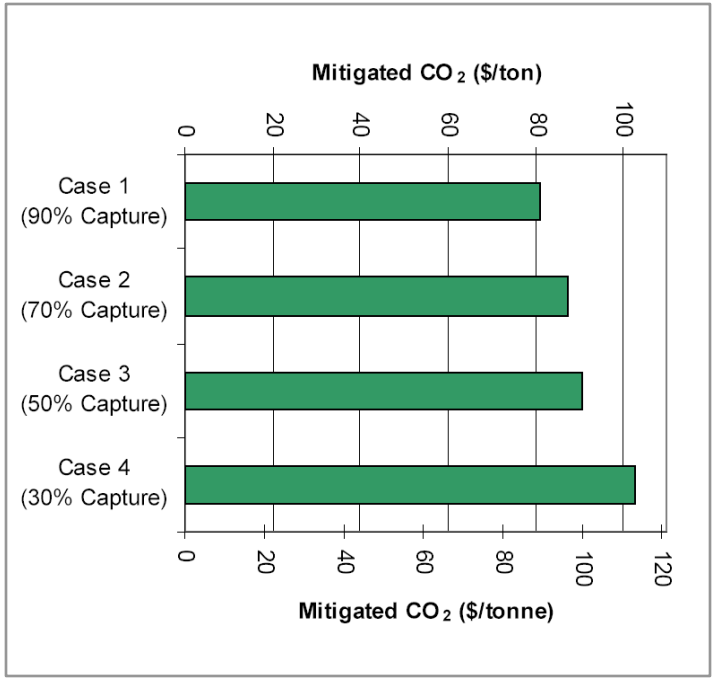
EIA, Annual Energy Outlook 2009, http://www.eia.doe.gov/oiaf/aeo/index.html

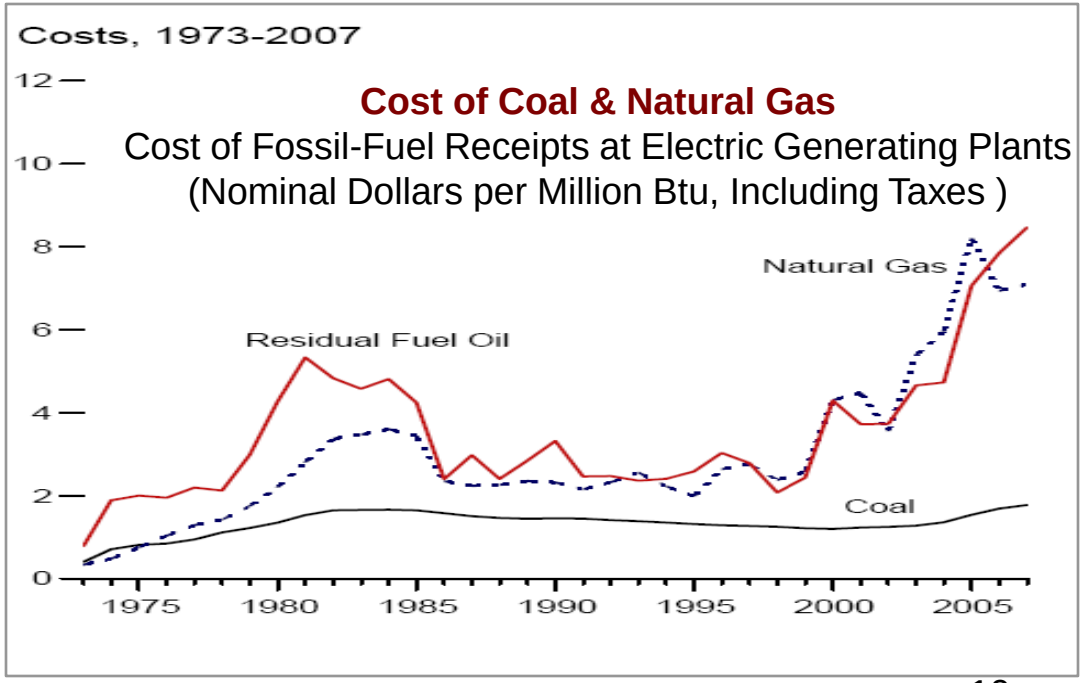
Fuel Options & CO_2 Control

Each a Huge Issue

- CO_2 Prevention
- CO_2 Capture
- CO_2 Storage
- CO_2 Usage

Coal prices are about one third of those for Natural gas





"Carbon Dioxide Capture from Existing Coal-Fired Power Plants", DOE/NETL-401/110907, November 2007

http://www.purdue.edu/dp/energy/CCTR/index.php

CCTR Funded Project Areas

- Indiana Coal Characteristics
- Indiana Coals for Coke
- Coal Transportation
- Slurry Ponds Evaluation
- Site Selection for Gasification
- Coal-To-Liquids Study, CTL
- Indiana Coal Forecasting
- UCG Gasification
- Benefits of Oxyfuel Combustion
- Economic Assessment of CTL
- Coal & the DOD
- FT Fuel & Engine Testing
- Coal & Biomass Gasification

2007 Coal Destination: Indiana

70.6 MTons Consumption, 34.7 MTons Production

State Total Consumption = 70,604 Thousand short tons

Methods of Transportation: Rail 52,441, Truck 12,935, River 813, Conveyor etc 4,415

Wyoming: 21,989 Total
21,777 Electricity Generation
Rail **Industrial** *212 River*

Montana: 1,631 Total
1,631 Electricity Generation
Rail

Utah: 197 Total
197 Industrial
Rail

Colorado: 192 Total
192 Electricity Gen,
Rail

Illinois: 5,859 Total
4,760 Electricity Generation
Rail 4,760
1,097 Industrial Plants
Rail 1,097

Kentucky: 1,716 Total
1,117 Electricity Generation
Rail 889 River 352
598 Industrial Plants
Rail 388 Truck 112

Alabama: 483 Total
483 Coke *Rail*

West Virginia: 5,481 Total
374 Electricity Generation
Rail 243 River 131
3,726 Coke Plants
Rail
1,382 Industrial Plants
Rail 1,255 Truck 127

In state: 34,770 Total
29,807 Electricity Generation
Rail 14,586 River 103
Conveyer 4,415 Truck 10,703
1,812 Industrial Plants *Truck*
166 Residential-Commercial *Truck*

Ohio: 388 Total
382 Electricity Generation
Rail 369 Truck 13
7 Industrial Plants *Truck*

Pennsylvania: 397 Total
367 Electricity Generation
Rail 341 River 26
21 Coke Plants *Rail*

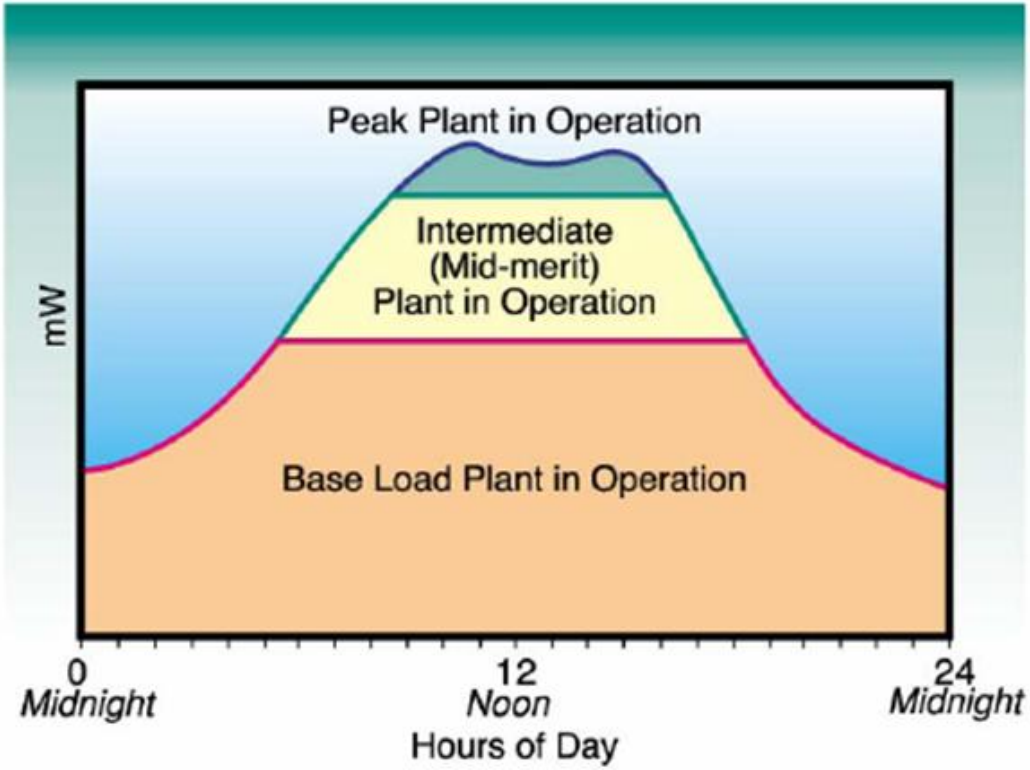
Virginia: 486 Total
486 Coke Plants *Rail*

Note:
Indiana Coal Exports
Total = 2,985
KY 1,779, WI 361,
AL 374, IL 280,
TN 97, MS 78

Source: http://www.eia.doe.gov/cneaf/coal/page/coaldistrib/coal_distributions.html

Base Load Power & Economies of Scale

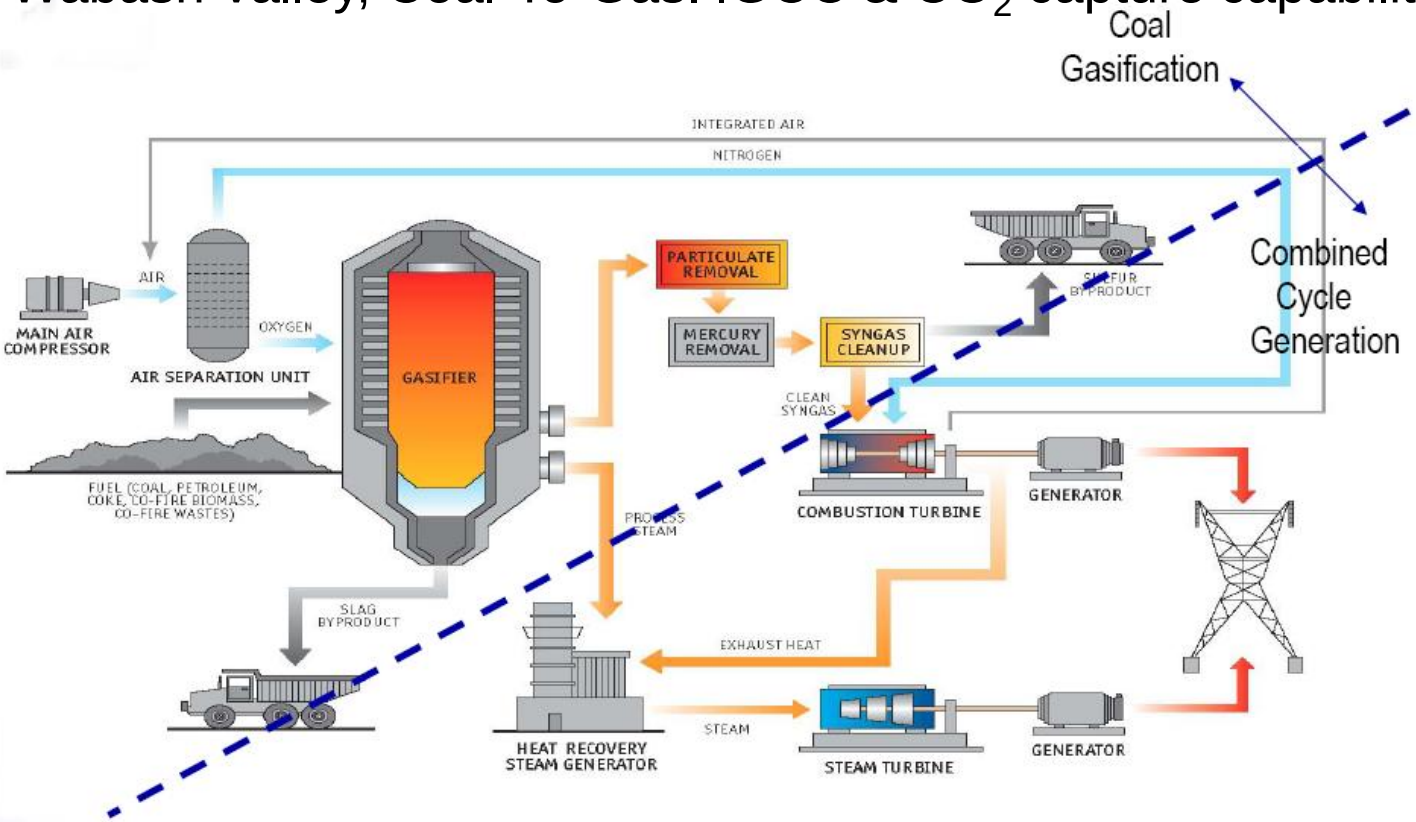
Large power plants will operate non-stop & provide most of our base-load power (coal, nuclear). Intermediate (cycling) & peaking plants are more flexible (combined cycle etc)



Technologies:
Pulverized Coal, **PC**
Super Critical PC, **SCPC**
Gas Turbines, **GT**
Combined Cycle, **CC**
Integrated Gasification Combined Cycle, **IGCC**

IGCC - Integrated Gasification Combined Cycle

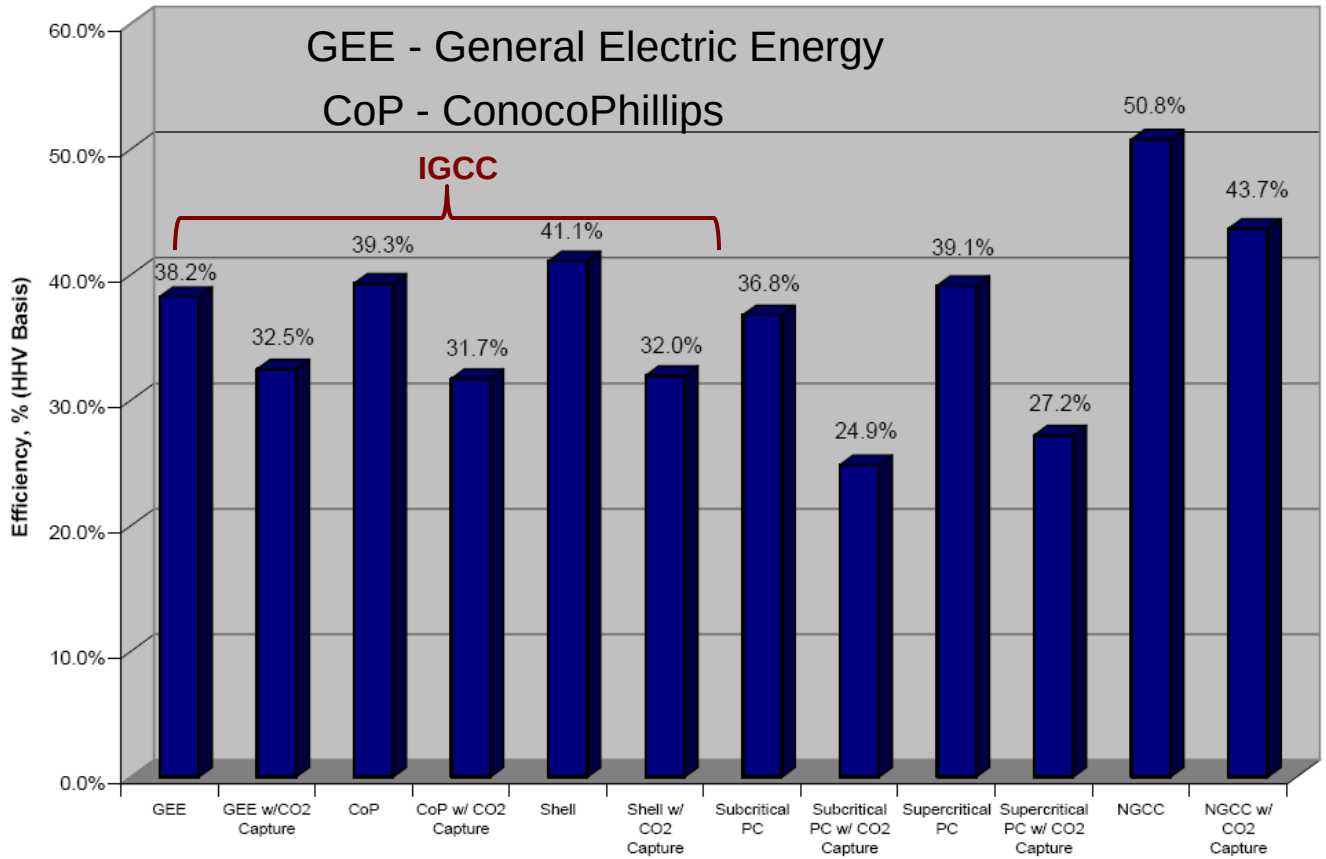
Indiana, Duke Energy, Edwardsport, Commercial first in US
Wabash Valley, Coal-To-Gas. IGCC & CO_2 capture capability



Duke Energy

Net Plant Efficiency & Fossil Energy Options

Higher efficiency means less operational expensive & reduced emissions per unit of MWh generated

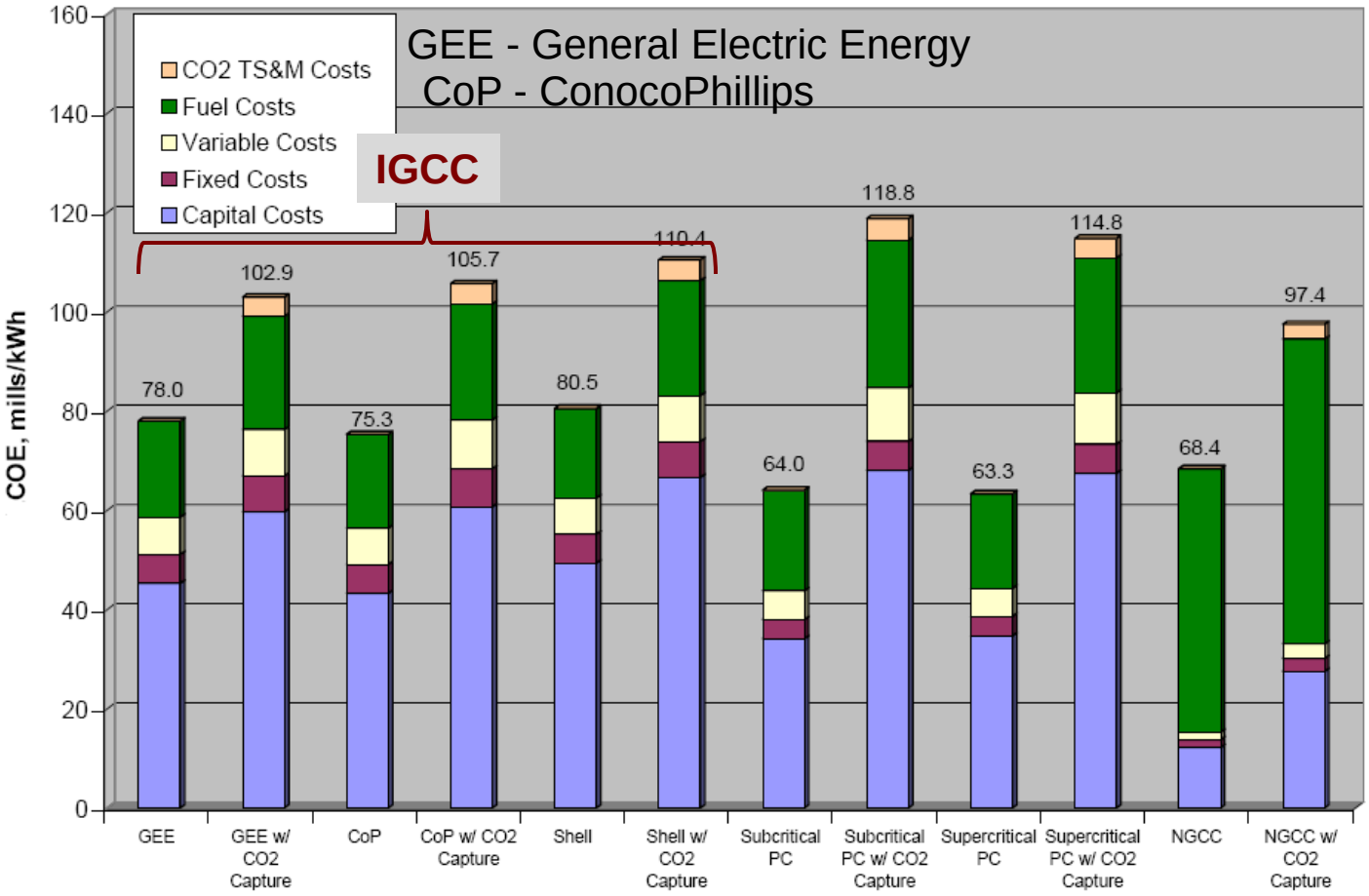


Probably the most likely U.S. base-load technologies for the next 50 years?

Life of a large power plant is 50+ years

DOE, NETL, "Cost & Performance Baseline for Fossil Energy Plants", DOE/NETL 2007/1281

Cost of Electricity & Technology Options



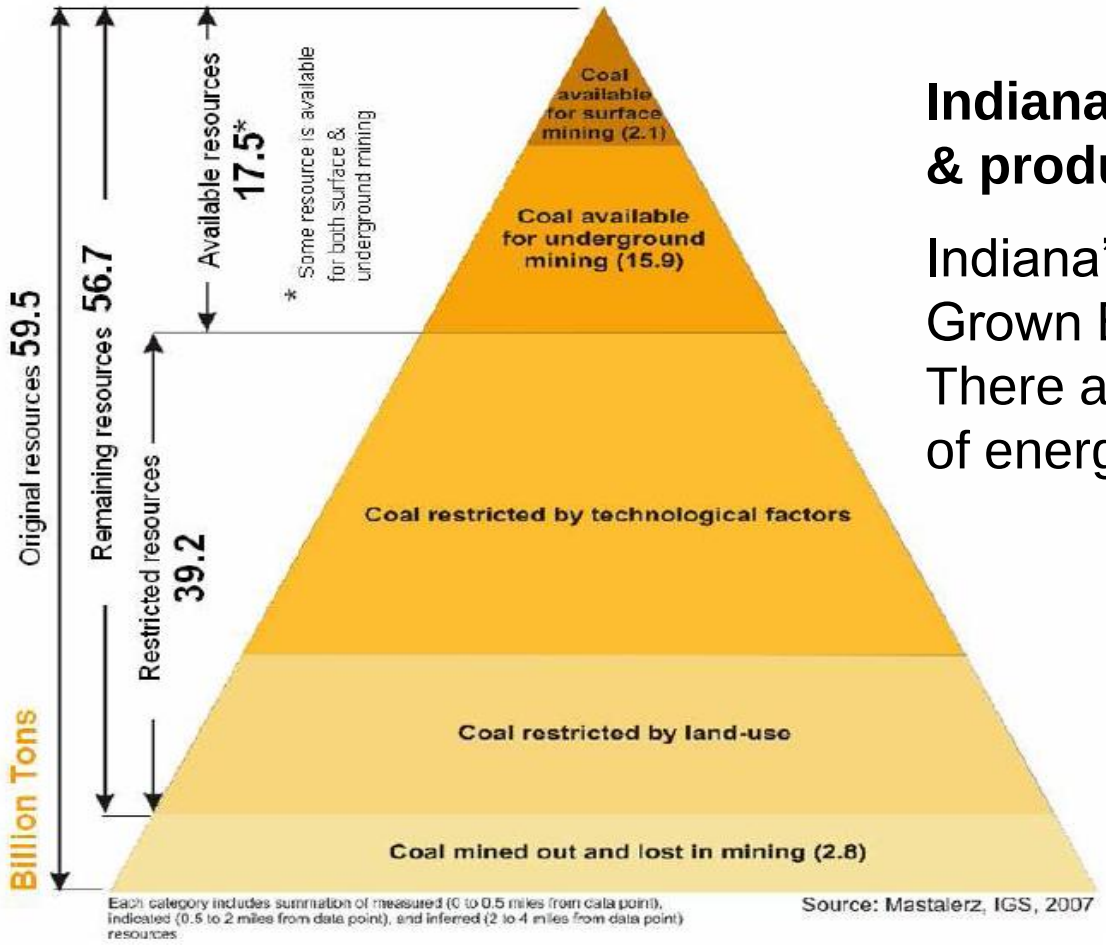
Estimated costs with capture **but no cost estimates for CO_2 storage**

Probably at least 10+ years before there are any forms of commercial CSS

DOE, NETL, "Cost & Performance Baseline for Fossil Energy Plants", DOE/NETL 2007/1281

Indiana Coal Characteristics & Resources

Indiana Geological Survey, IU Bloomington



Indiana consumes 70 MTons/yr & produces 35 MTons/yr

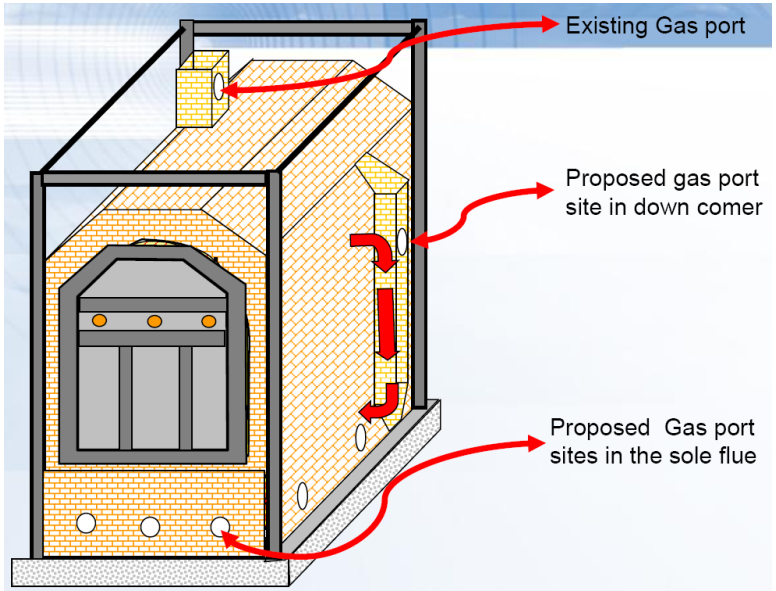
Indiana's 17.5 BTons of "Home Grown Energy" in reserves. There are hundreds of years of energy supply in the state

http://www.purdue.edu/dp/energy/CCTR/byTopic.php

Indiana's Coke & Rail Network

CCTR & **Purdue Calumet**

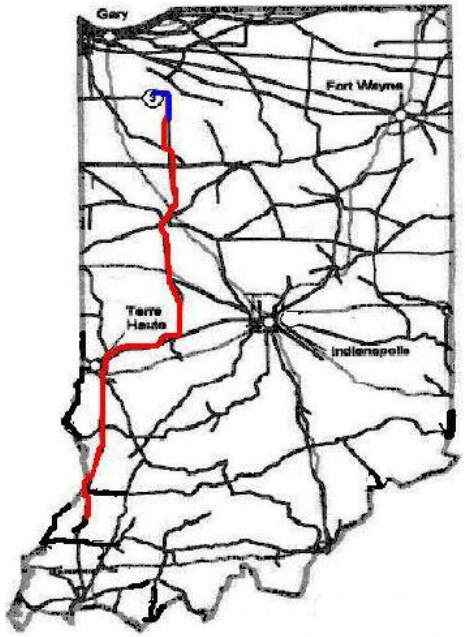
How to replace the 6 Million tons (+) of imported metallurgical coal with Indiana coal



http://www.purdue.edu/dp/energy/CCTR/byTopic.php

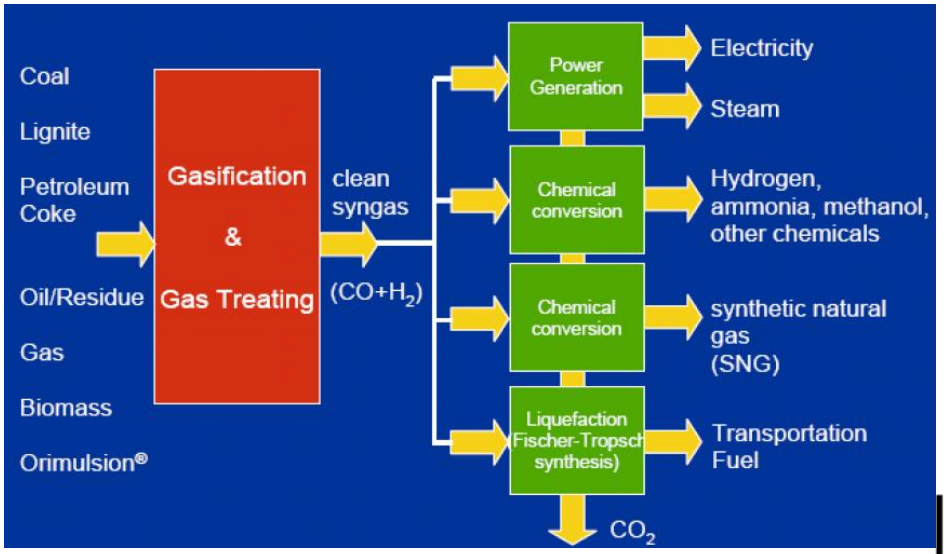
CCTR & **Purdue North Central**

Software modeling of optional expansion and operational plans of the railroad network in Indiana

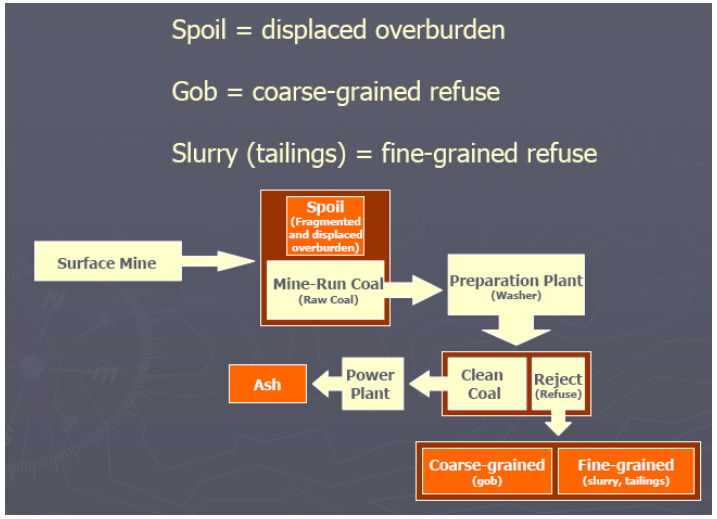


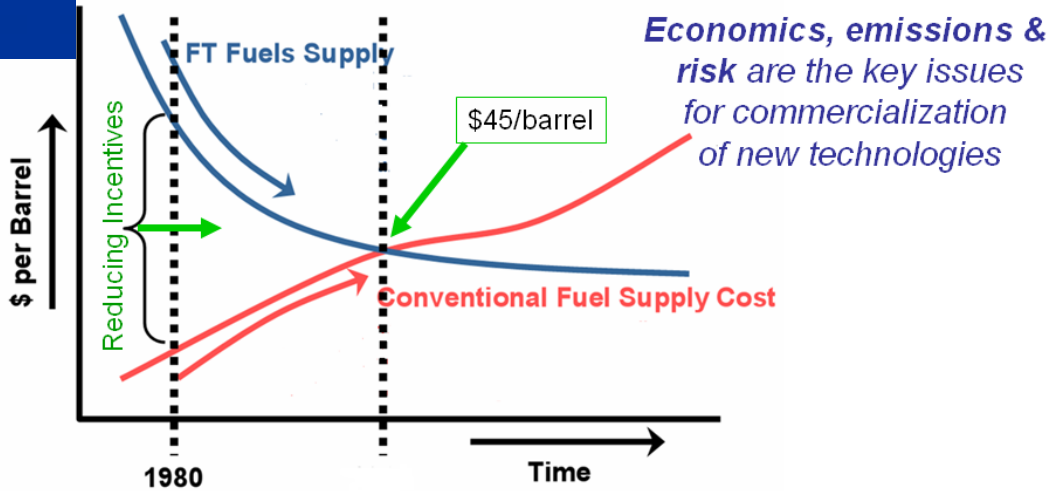
Scenario 6: Prosperity to Schahfer vis West link with North link

Syngas, Transportation Fuels, Slurry Reuse



CCTR: Industry & Academia
Coal-To-Liquids, CTL
Fuel Security
Indiana Geological Survey
Reuse of coal slurry ponds





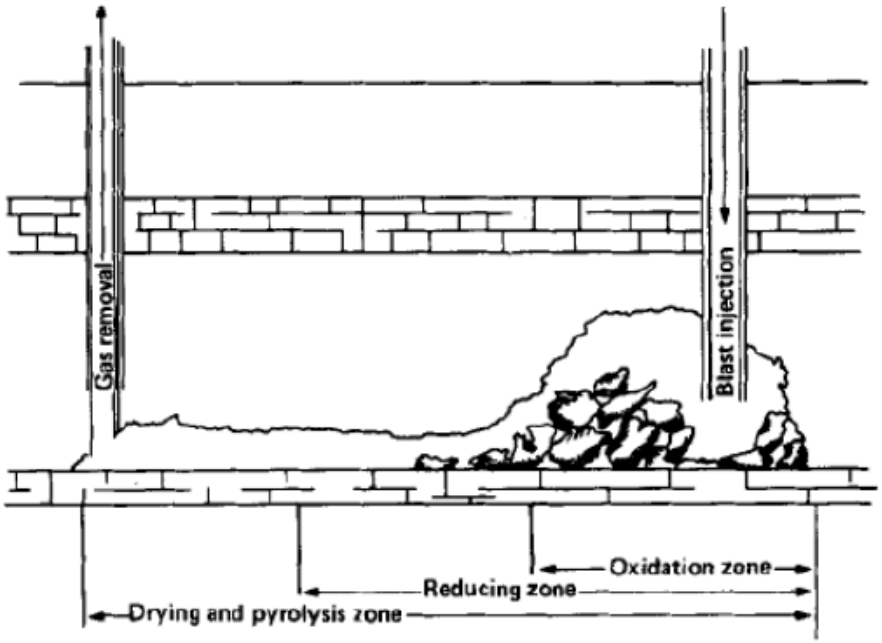
Variable incentive starts at $45/barrel & no losses/risks occur

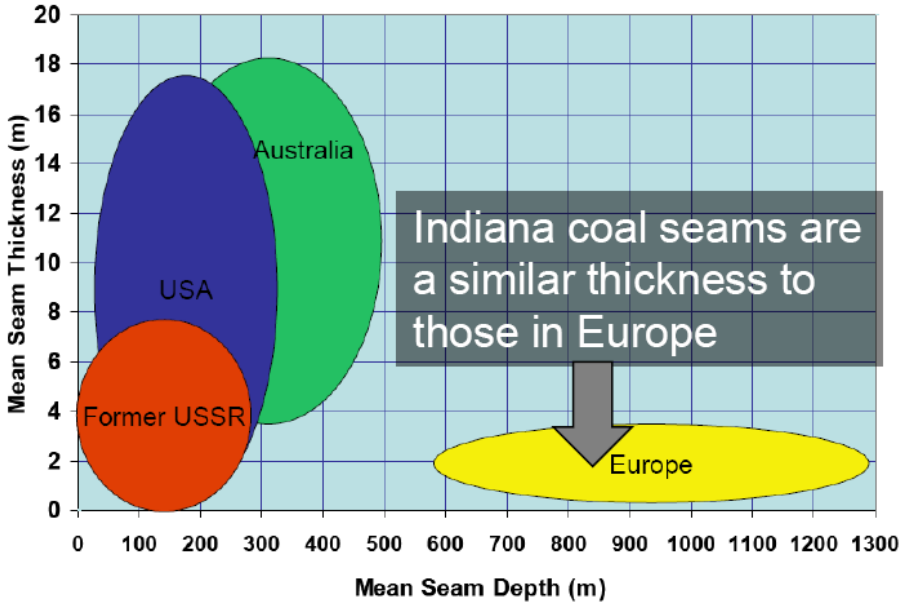
http://www.purdue.edu/dp/energy/CCTR/byTopic.php

Underground Coal Gasification, UCG

CCTR & Purdue School of Chemical Engineering

UCG reduces capital expenditure & stores CO_2



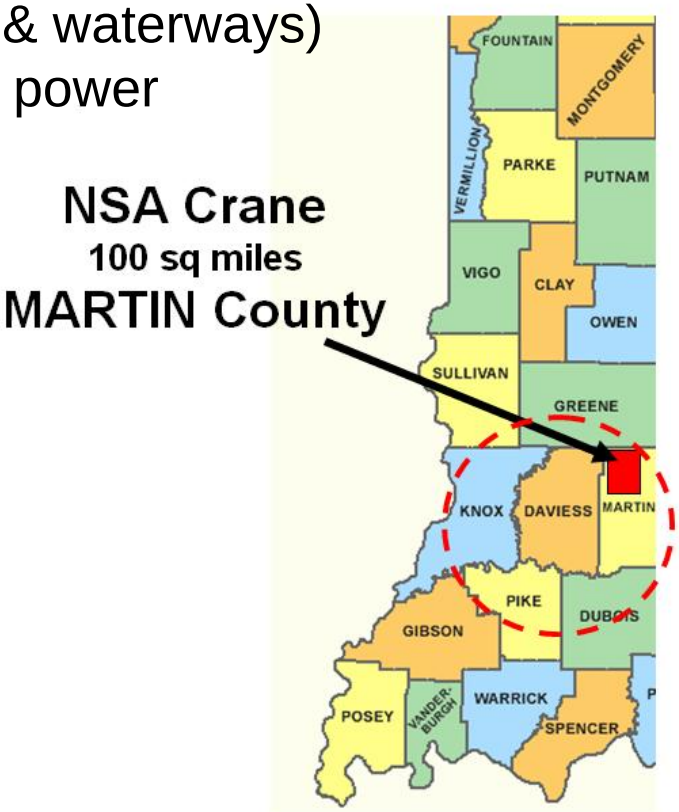


http://www.purdue.edu/dp/energy/CCTR/byTopic.php

CCTR Investigations into CTL Site Selection

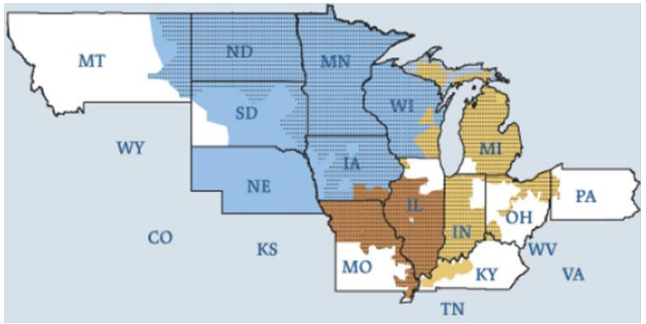
10 Criteria

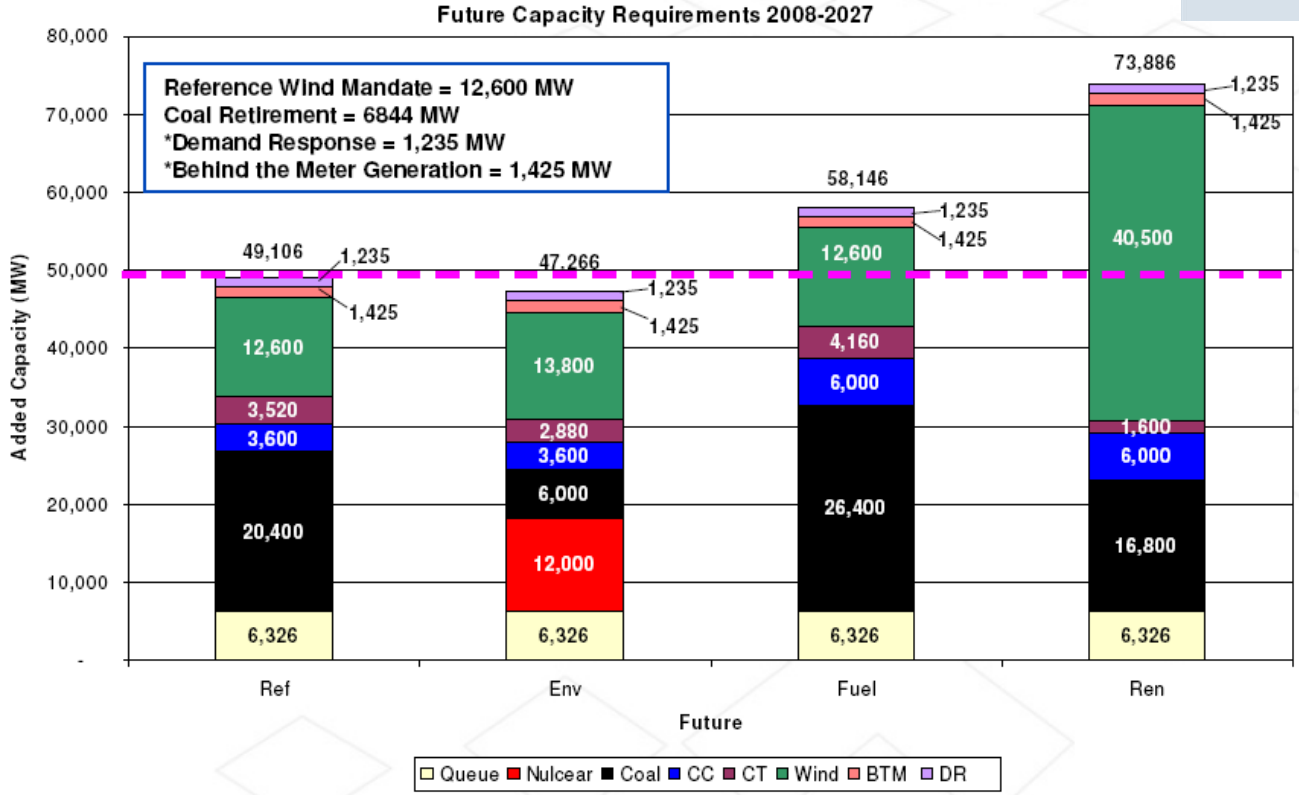
1. Coal & natural gas availability for 10,000 B/D FT fuel
2. CO_2 sequestration potential
3. Land/real-estate requirements
4. Transportation infrastructure (rail, roads & waterways)
5. Electricity transmission lines & available power
6. Gas & oil pipelines
7. Water requirements & resources
8. Waste disposal/environmental issues
9. Labor force requirements/availability
10. Economic impact



Transmission, Coal & Wind

MISO = Midwest Independent System Operator
New 765 kV line costs **$5 Million per mile**
MISO & Indiana implementing wind
Nuclear only under environmental scenario





Investment in transmission is vital for success of wind expansion

Consider the option of **coal by wire**

http://www.purdue.edu/dp/energy/CCTR/byTopic.php

Wind & CO_2; Coal & Natural Gas

- **Natural Gas emits CO_2** but less than coal
- Wind could use CC for backup power & so **wind is not emissions free**
- Suggesting **100 MW of wind includes 50 MW from gas turbine** (synfuel) for 60 MW of constant base load?

CO_2	Coal (Weight Units)	Natural Gas (Weight Units)
(1) Per Unit of Primary Energy	**25**	**15**
(2) Per Unit of Electricity	**78**	**25**

http://www.purdue.edu/dp/energy/SUFG/

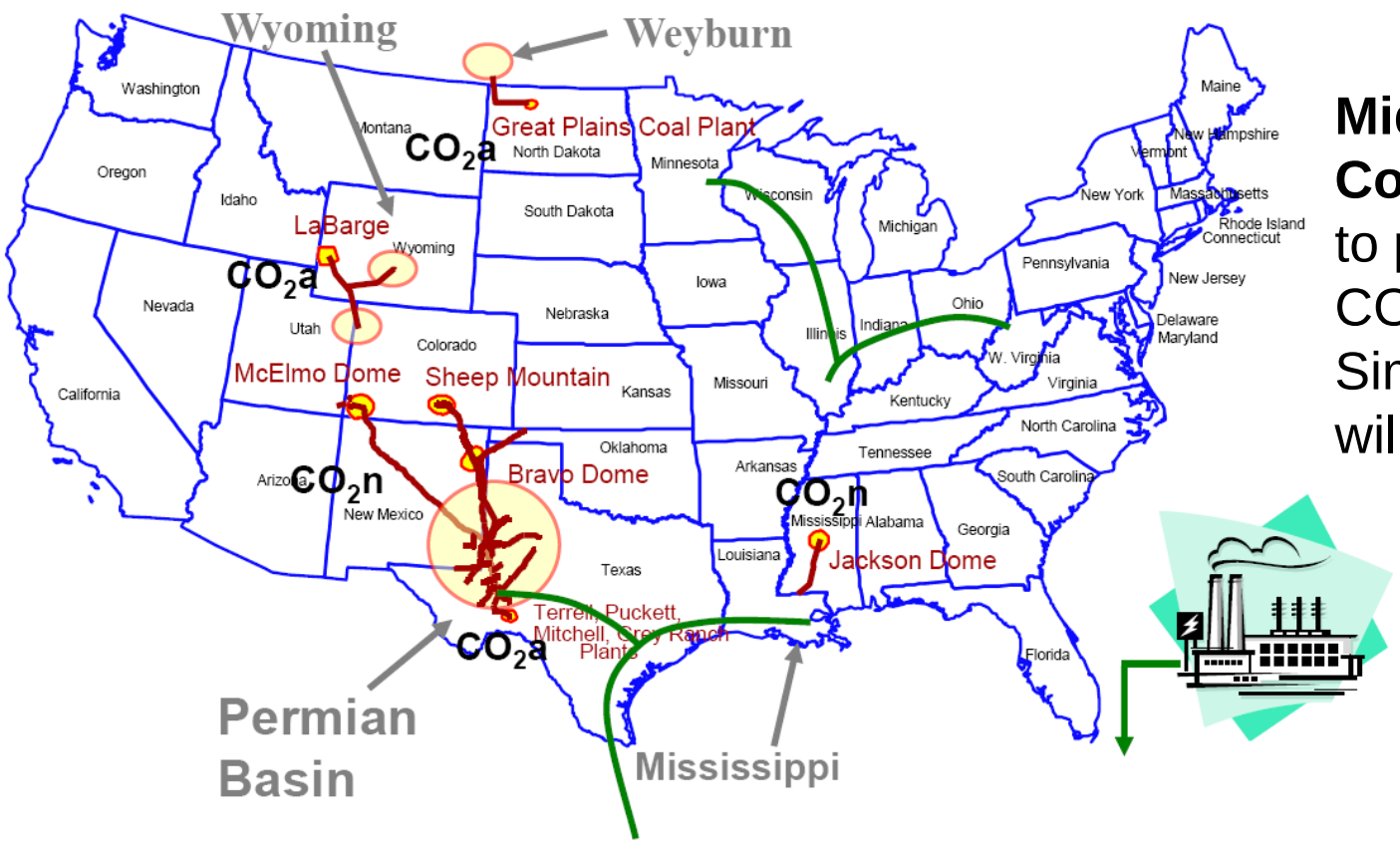
SUBSTITUTION OF NATURAL GAS FOR COAL: CLIMATIC EFFECTS OF UTILITY SECTOR EMISSIONS

KATHARINE HAYHOE[1], HAROON S. KHESHGI[2], ATUL K. JAIN[1] and DONALD J. WUEBBLES[1]

[1]*Department of Atmospheric Sciences, University of Illinois, 105 S. Gregory St., Urbana, IL 61801, U.S.A.*
E-mail: hayhoe@atmos.uiuc.edu
[2]*Corporate Strategic Research, ExxonMobil Research and Engineering Company, Annandale, NJ 08801, U.S.A.*

CO_2 Use, Gas Pipelines, Carbon Highways

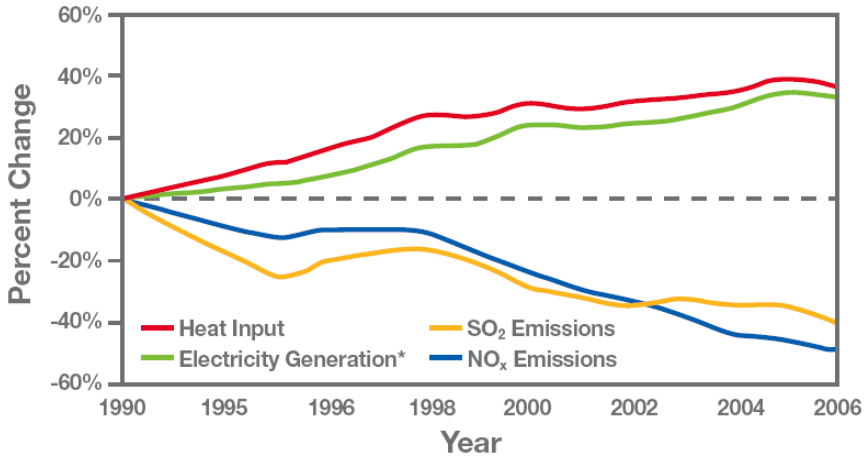
CO_2 use has +ve cash flow compared with storage



Midwest Consortium starting to pump 1 MTons of CO_2 under Mount Simon Sandstone & will take 3 years

http://www.purdue.edu/dp/energy/CCTR/byTopic.php

Improving Emissions Standards



Emission standards are improving.

As yet **no legislation for CO_2**

- Emissions of CO_2 are much greater than any other type of emission – **a much greater controls challenge**
- Problematic modeling of cloud movement **vs** modeling of global warming

2002 U.S. Emissions (MTons)	SO_2	NOx	CO_2
Utilities	10.6	4.4	**2,449.6**
Transportation	0.7	12.6	**1,657.5**
Other	5.1	5.6	**1,688.9**
Total	16.3	22.6	**5,796.0**

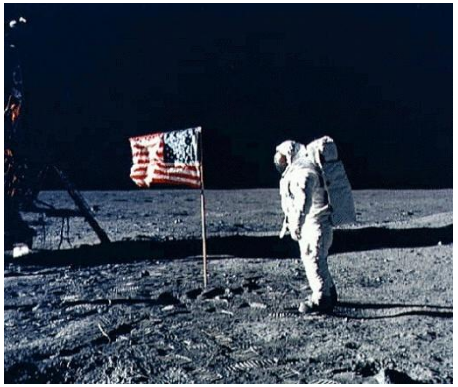
http://www.apx.com/environmental/emissions-cap-and-trade.asp

DOE, EPRI, CURC, http://www.netl.doe.gov/technologies/coalpower/cctc/ccpi/pubs/CCT-Roadmap.pdf

Is there Significant Investment for Energy R&D

20th Century

1942 Manhatton Project, $32 Billion ($2006)
1961 To put "a man on the moon by end of decade," $180 Billion ($2006)

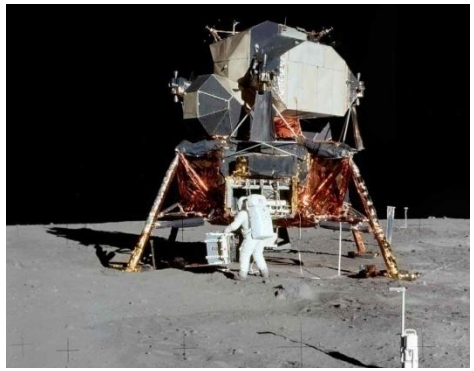


21st Century

National expenditures

- War in Iraq = $350B
- 2005 NASA space shuttle = $145B
- Energy Policy Act of 2005 = $14B

2007 U.S. GDP = $13.8 Trillion
$350B = 2.53%, $145B = 1.05%, $14B = 0.10%
2009 Stimulus Bill, $1 Trillion = 7%



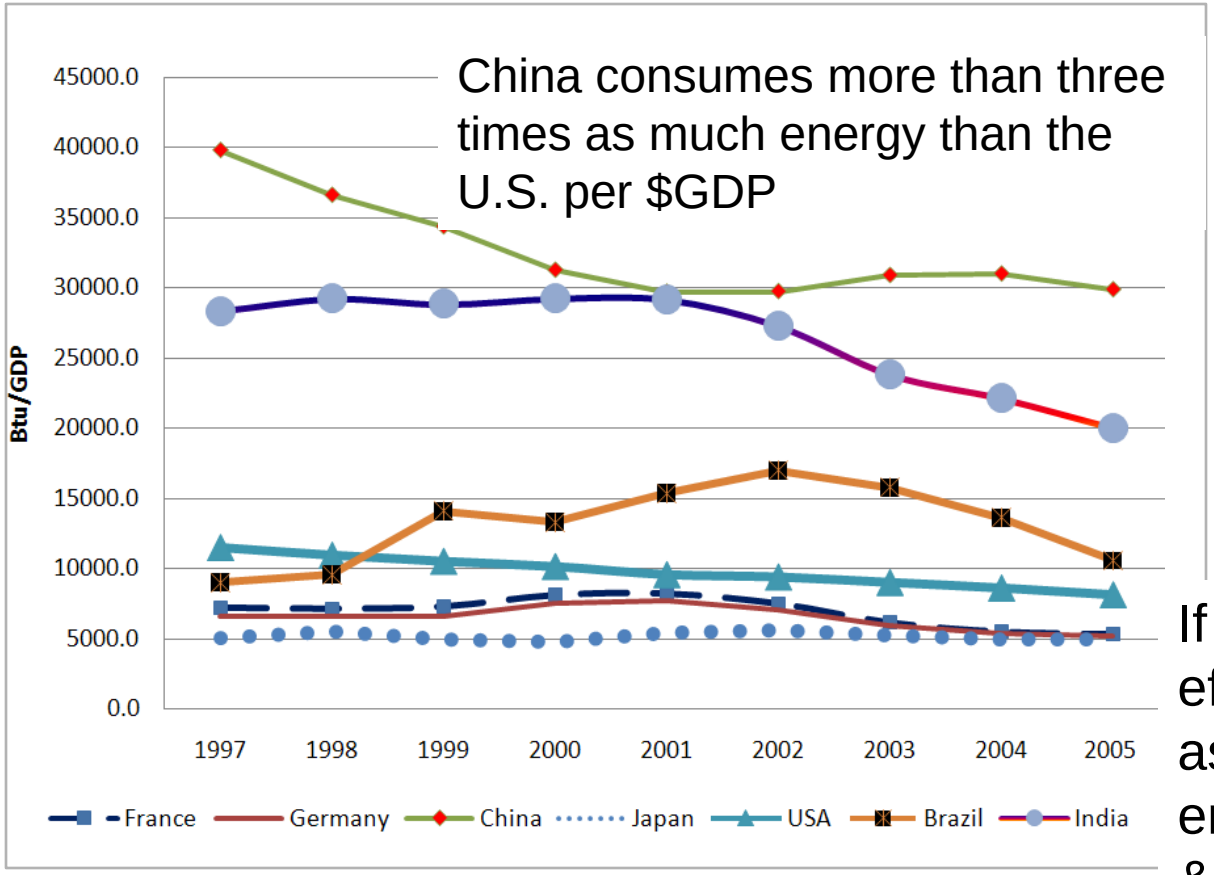
Future Energy Planning Options
Optimism & Pessimism, Fear & Facts

Great resources of coal in U.S. Enormous costs for reducing CO_2 emissions. Expect soon to hear more about costs.

- Cutting back CO_2 emissions is very costly
- Cost for CO_2 zero emission policy - $5 Trillion
- Kyoto Protocol costs at least $150 Billion/year
- European Union – carbon emission policies (20% reduction in CO_2 by 2020) gives nuclear energy added appeal
- Improving reduction in emissions but waiting to see costs
- Invest in R&D - 300yrs, 50yrs, 25yrs improve efficiencies
- $70 to $80 Billion/year could give developing world access to basics of water, sanitation, education
- 42,000 mortalities each year on U.S. roads, 20,00 cancer deaths from radon (2008), & 29 in U.S. coal mines (2008)
- What are benefits from investment options & who to believe

Bjorn Lomborg, “The Skeptical Environmentalist, Measuring the Real State of the World”, 2001

Energy & Environment are Global Issues



GDPs

U.S. $13.8 Trillion

China $3.3 T

If China has the same energy efficiency (energy intensity) as the U.S. then there are enormous energy savings & a cleaner environment

Source: Energy Consumption Data is from EIA's web page: http://www.eia.doe.gov/emeu/aer/inter.html.
Data on GDP is from World Development Indicators, World Bank, Online at:
http://ddp-ext.worldbank.org/ext/DDPQQ/member.do?method=getMembers&userid=1&queryId=135