Energy Technology Efficiency, Economics & Environment

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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](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=INDIANA), [http://www.eia.doe.gov/emeu/states/state.html?q_state_a=il&q_state=ILLINOIS](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 H₂ economy
- Increased dependence on Natural Gas - LNG & where from
U.S. Primary Energy Consumption, 2007
by Source & Sector (Quadrillion Btu, $10^{15}$ Btu)

TOTAL = 101.4 $10^{15}$ Btu

1. Petroleum 39.8
2. Natural Gas 23.6
3. Coal 22.8
4. Renewable Energy 6.8
5. Nuclear Electric Power 8.4

TRANSPORT
Transportation 29.0
Industrial 21.4
Residential and Commercial 10.6

GENERATION
Electric Power 40.6

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.
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

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

CO₂ from transportation & power plants - similar magnitudes
Big improvements in reducing SO₂ & other emissions

U.S. Energy Related CO₂ 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

Fuel Options & CO₂ Control

Each a Huge Issue
• CO₂ Prevention
• CO₂ Capture
• CO₂ Storage
• CO₂ Usage

Coal prices are about one third of those for Natural gas

Cost of Coal & Natural Gas
Cost of Fossil-Fuel Receipts at Electric Generating Plants
(Nominal Dollars per Million Btu, Including Taxes)
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 197 Industrial
Rail 212 River

**Montana:** 1,631 Total
1,631 Electricity Generation
Rail 197 Industrial

**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

**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

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

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

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
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
Cost of Electricity & Technology Options

Estimated costs with capture but no cost estimates for CO₂ storage

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

CCTR & Purdue North Central
Software modeling of optional expansion and operational plans of the railroad network in Indiana

http://www.purdue.edu/dp/energy/CCTR/byTopic.php
Syngas, Transportation Fuels, Slurry Reuse

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

Economics, emissions & risk are the key issues for commercialization of new technologies

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. CO₂ 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

Future Capacity Requirements 2008-2027

Reference Wind Mandate = 12,600 MW
Coal Retirement = 6844 MW
Demand Response = 1,235 MW
*Behind the Meter Generation = 1,425 MW

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?

<table>
<thead>
<tr>
<th></th>
<th>CO$_2$</th>
<th>Coal (Weight Units)</th>
<th>Natural Gas (Weight Units)</th>
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</thead>
<tbody>
<tr>
<td>(1) Per Unit of Primary Energy</td>
<td></td>
<td>25</td>
<td>15</td>
</tr>
<tr>
<td>(2) Per Unit of Electricity</td>
<td></td>
<td>78</td>
<td>25</td>
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http://www.purdue.edu/dp/energy/SUFG/

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2 Corporate Strategic Research, ExxonMobil Research and Engineering Company, Annandale, NJ 08801, USA.
**CO₂ Use, Gas Pipelines, Carbon Highways**

**CO₂ use has +ve cash flow compared with storage**

Midwest Consortium starting to pump 1 MTons of CO₂ 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 CO₂

- Emissions of CO₂ are much greater than any other type of emission – a much greater controls challenge
- Problematic modeling of cloud movement vs modeling of global warming

<table>
<thead>
<tr>
<th>2002 U.S. Emissions (MTons)</th>
<th>SO₂</th>
<th>NOₓ</th>
<th>CO₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>Utilities</td>
<td>10.6</td>
<td>4.4</td>
<td>2,449.6</td>
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<tr>
<td>Transportation</td>
<td>0.7</td>
<td>12.6</td>
<td>1,657.5</td>
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<tr>
<td>Other</td>
<td>5.1</td>
<td>5.6</td>
<td>1,688.9</td>
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<tr>
<td>Total</td>
<td>16.3</td>
<td>22.6</td>
<td>5,796.0</td>
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Is there Significant Investment for Energy R&D

20th Century

1942 Manhattan 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

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 CO₂ emissions. Expect soon to hear more about costs.

• Cutting back CO₂ emissions is very costly
• Cost for CO₂ zero emission policy - $5 Trillion
• Kyoto Protocol costs at least $150 Billion/year
• European Union – carbon emission policies (20% reduction in CO₂ 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

China consumes more than three times as much energy than the U.S. per $GDP

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](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](http://ddp-ext.worldbank.org/ext/DDPQQ/member.do?method=getMembers&userid=1&queryId=135)