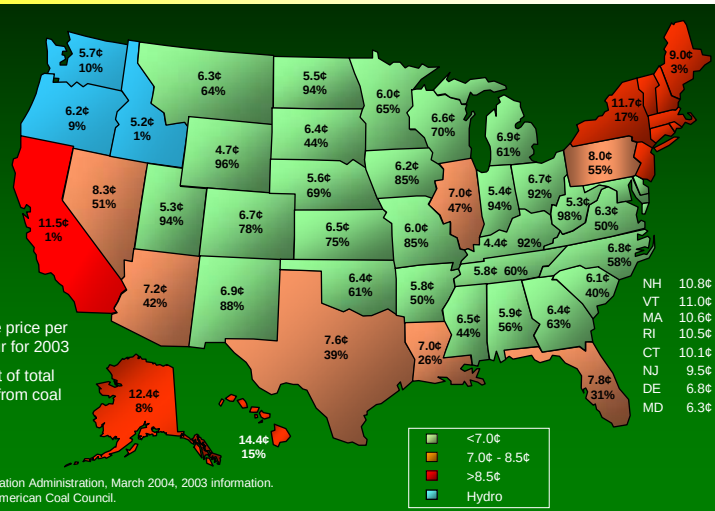
Carbon Dioxide Capture and Storage: Status Today and Outlook for the Future

NREL Seminar

Howard Herzog
MIT
July 23, 2007

Coal and the Electricity Price



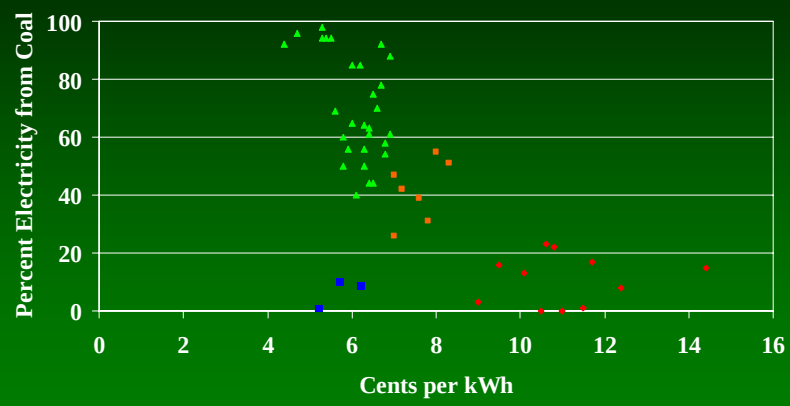
NH	10.8¢	22%
VT	11.0¢	0%
MA	10.6¢	23%
RI	10.5¢	0%
CT	10.1¢	13%
NJ	9.5¢	16%
DE	6.8¢	54%
MD	6.3¢	56%

¢ = average price per kilowatt hour for 2003

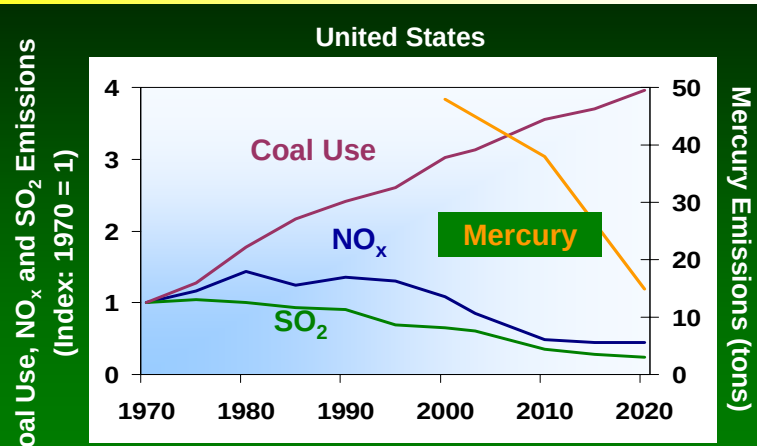
% = percent of total generation from coal for 2003

Source: Energy Information Administration, March 2004, 2003 information.
Slide courtesy of the American Coal Council.

Coal and the Electricity Price

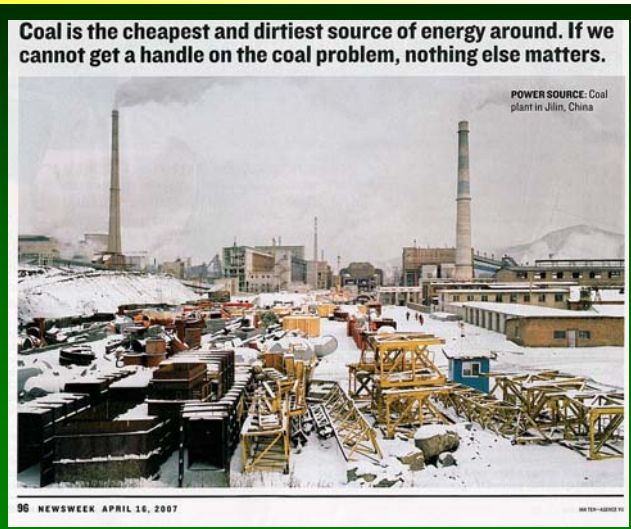


Air Emission Trends From Coal



Historical data (1970–2000): Coal consumption and electricity generation per DOE EIA, AER 2003
NO_x and SO_2 per EPA Air Trends Report: http://www.epa.gov/air/airtrends/econ-emissions.html
Projected data (2003–2020): Coal consumption and electricity generation per DOE EIA, AEO 2005
NO_x and SO_2 per EPA projections under CAIR: http://www.epa.gov/interstateairquality/charts.html
Mercury per EPA Clean Air Mercury Rule

Coal from the Climate Change Perspective



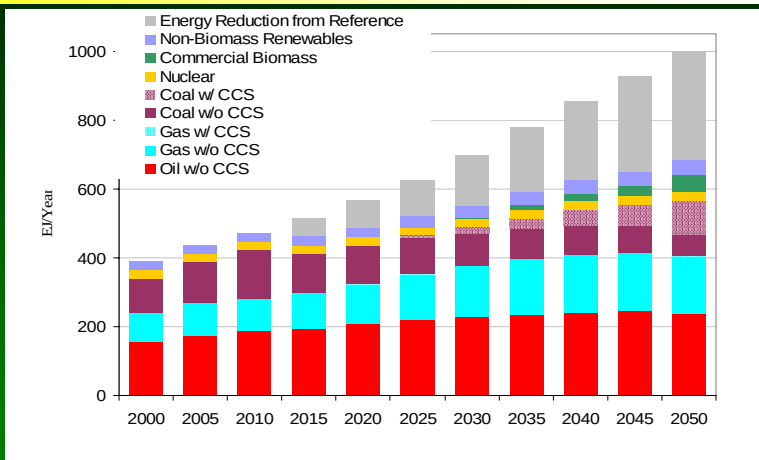
MIT Coal Study Overview

- Follow-on to *The Future of Nuclear Power*
  - On web at mit.edu/nuclearpower
- Full report released March 14
  - On web at mit.edu/coal
- Authors
  - John Deutch, Ernie Moniz (PIs)
  - Jim Katzer (Executive Director)
  - Stephen Ansolabehere, Janos Beer, Denny Ellerman, Julio Friedmann, Howard Herzog, Jake Jacoby, Paul Joskow, Lester Richard, Greg McRae, Edward Steinfeld

Key question:

What actions regarding technology do we take now to impact GHG emissions on a Gigaton scale in 2050?

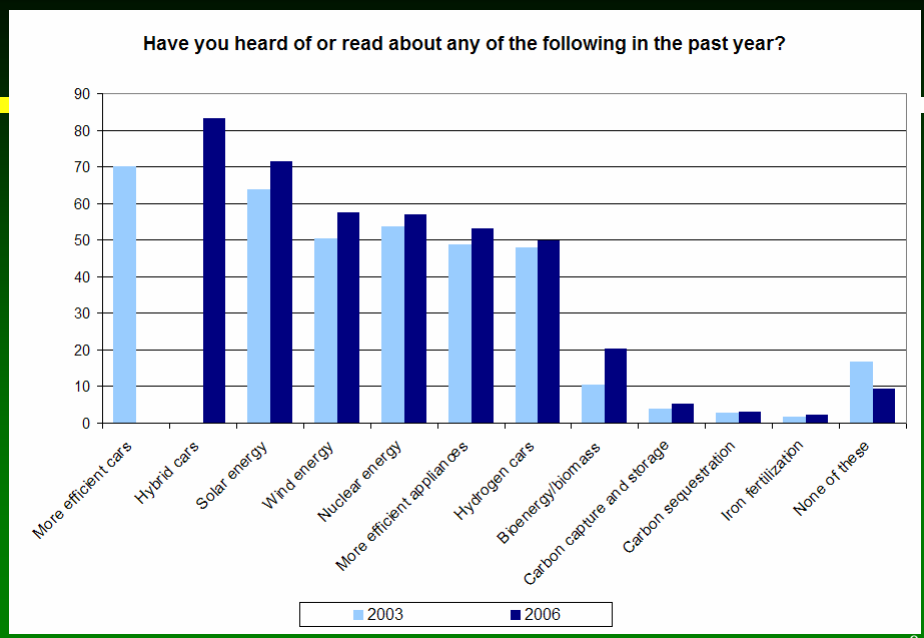
Global Primary Energy Consumption under High CO_2 Prices
Limited Nuclear Generation Case



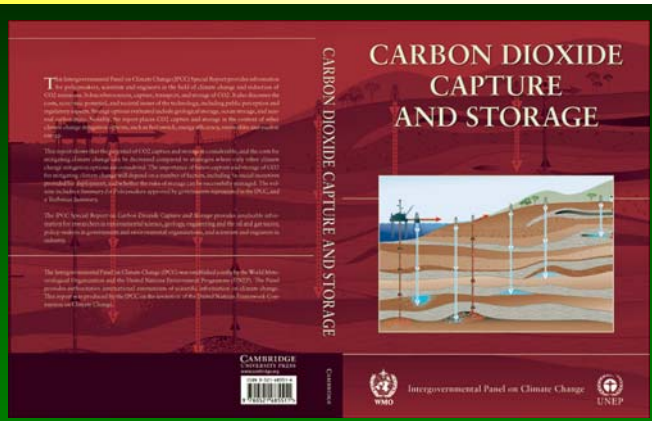
MIT Coal Study Figure 2.4
Initial CO_2 Price of \$25/tCO_2 in 2015 with 4%/yr increase

MIT Coal Study

- We conclude that CO_2 capture and sequestration (CCS) is the critical enabling technology that would reduce CO_2 emissions significantly while also allowing coal to meet the world's pressing energy needs.



Intergovernmental Panel on Climate Change (IPCC) Special Report on Carbon Dioxide Capture and Storage



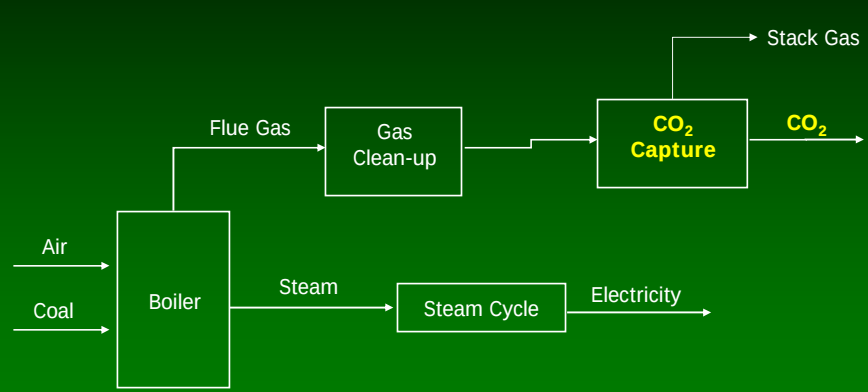
Accepted September 26, 2005 -- www.ipcc.ch

Simple guide -- www.unep.org/dec/docs/CCS_guide.pdf

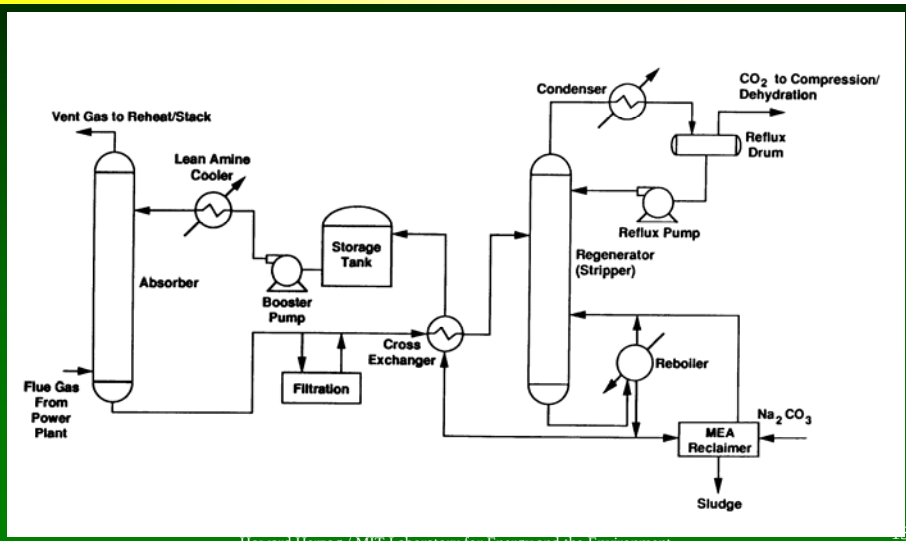
Approaches to CO_2 Capture from Coal-Fired Power Plants

- Post-combustion
- Pre-combustion
- Oxyfuel Combustion

Pulverized Coal (PC) Power Plant



Schematic of Amine Process for CO_2 Capture

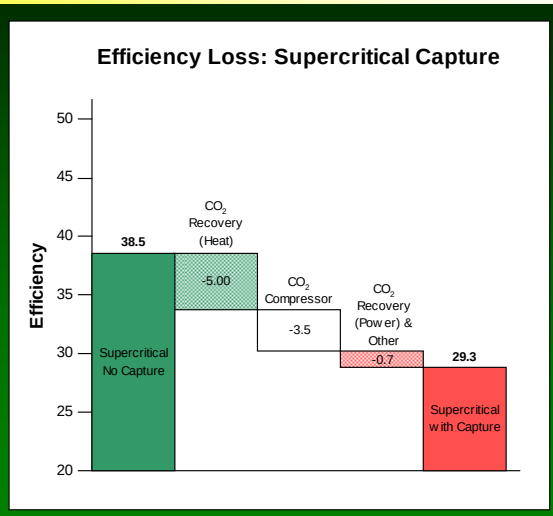


CO_2 Capture at a Coal-Fired Power Plant

Source: ABB Lummus

E.S. Rubin, Carnegie Mellon

Parasitic Energy Requirements for PC Plant with Amine Capture

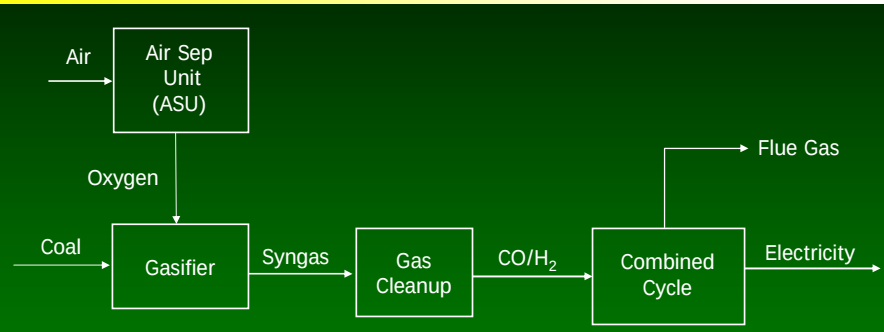


Change Power Generation Process to Facilitate CO_2 Capture

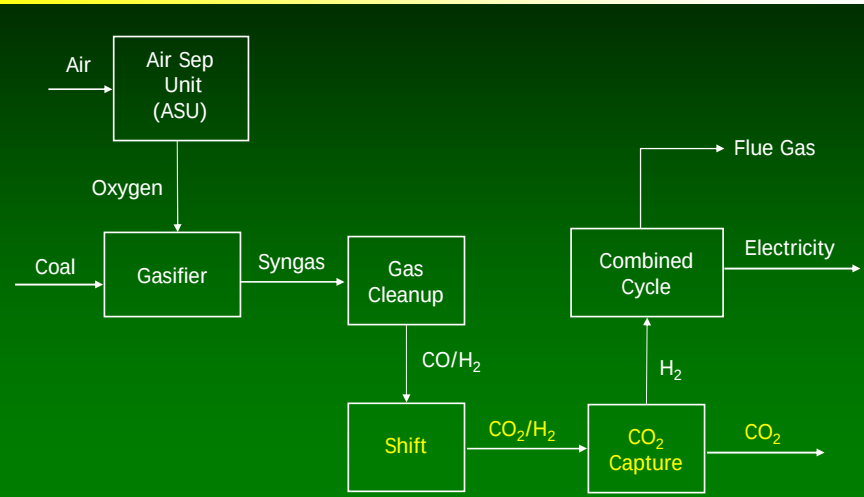
Power Plant	PC	IGCC	PC/Oxy
P (atm)	1	40	1
Fract CO_2	0.15	0.40	0.9
Capture Process	Chemical Absorption	Physical Absorption	Distillation

Two approaches:
(1) Improved capture processes
(2) Modify power plant to facilitate capture

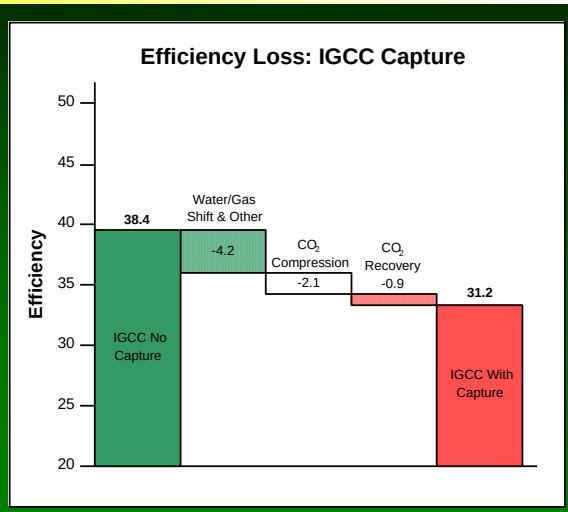
IGCC Power Plant



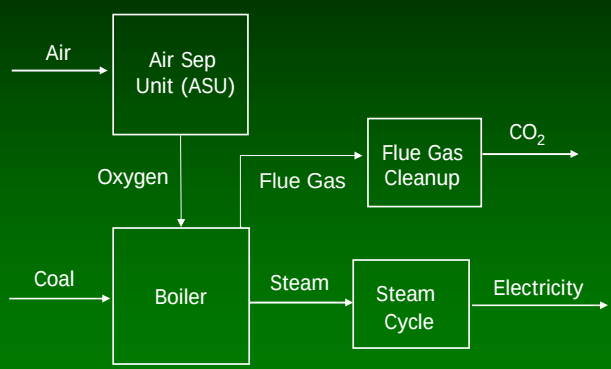
IGCC with Capture



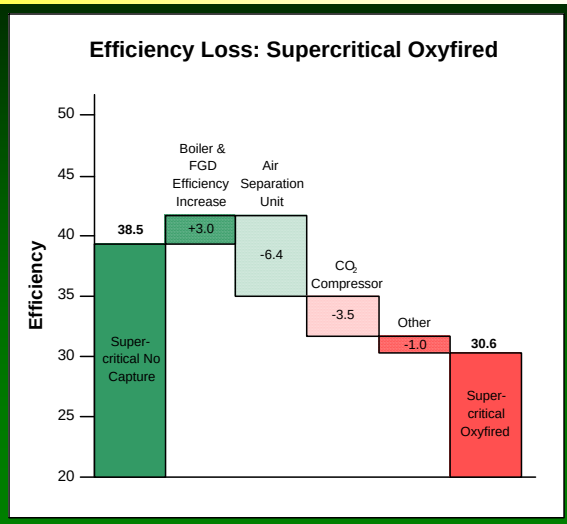
Parasitic Energy Requirements for IGCC with Capture



Oxyfuel Combustion Power Plant



Parasitic Energy Requirements for Oxyfuel Capture



Capture and Compression Costs

- Output – high purity supercritical CO_2
- The numbers that follow are representative and are used to simply compare approaches
- There is much variability in the cost
  - Process Variability – plant location, coal type, criteria emission levels, process integration, etc.
  - Economic Variability – fuel costs, cost of capital, material and labor costs, capacity factor, etc.

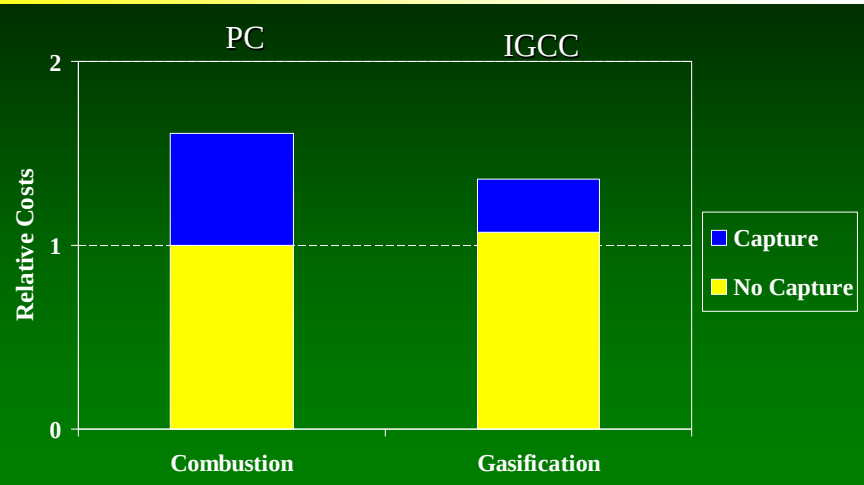
Capture and Compression Capital Costs

Power Plant	Capture Technology	Capital Investment	Power Output	$/kW
SCPC	Post-Combustion	+23%	-24%	+62%
SCPC	Oxyfuel-Combustion	+14%	-20%	+42%
IGCC	Pre-Combustion	+7%	-19%	+32%

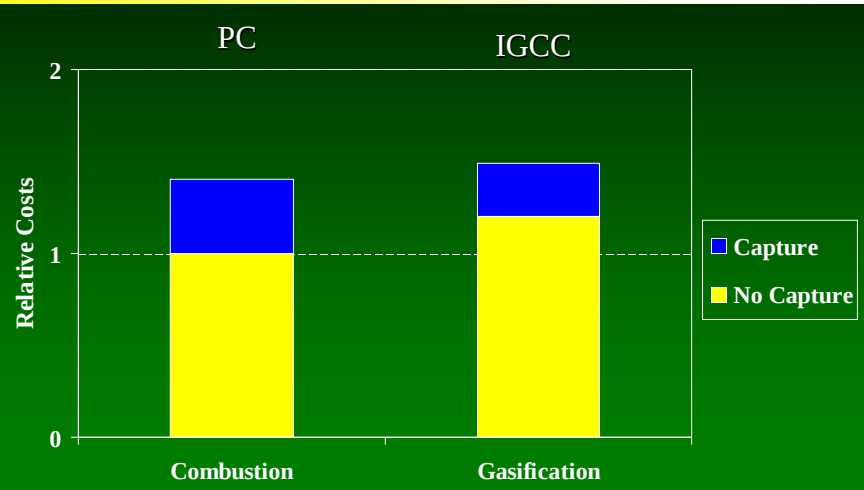
Relative Cost of Electricity

	Without Capture	With Capture
Post-Combustion	1	1.61
Oxyfuel-Combustion		1.46
Pre-Combustion	1.07	1.36

Relative Cost of Electricity



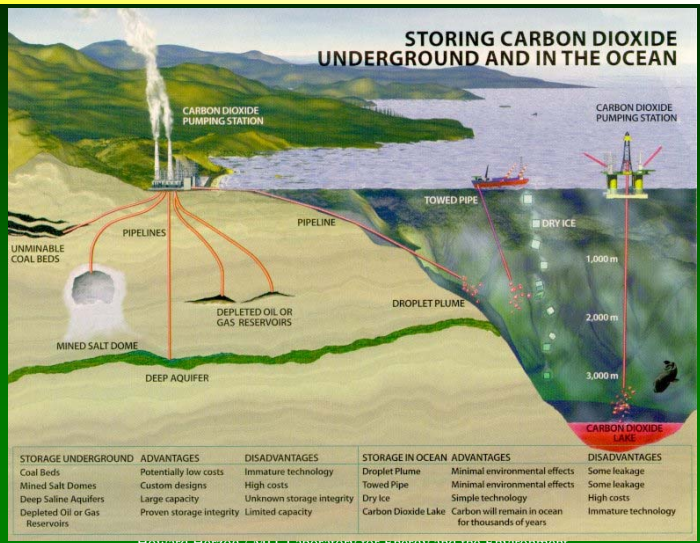
Relative Cost of Electricity



MIT Coal Study
Finding #6

- It is premature to select one coal conversion technology as the preferred route for cost-effective electricity generation combined with CCS.
  - Variability in location, coal type, etc.
  - Uncertainty in technological progress

CCS - Sinks



Geologic Carbon Sequestration Uncertainties

- Subsurface issues:
  - Is there enough capacity to store CO_2 where needed?
  - Do we understand storage mechanisms well enough?
  - Could we establish a process to certify injection sites with our current level of understanding?
  - Once injected, can we monitor and verify the movement of subsurface CO_2?
- Near surface issues:
  - How might the siting of new coal plants be influenced by the distribution of storage sites?
  - What is the probability of CO_2 escaping from injection sites? What are the attendant risks? Can we detect leakage if it occurs?
  - Will surface leakage negate or reduce the benefits of CCS?

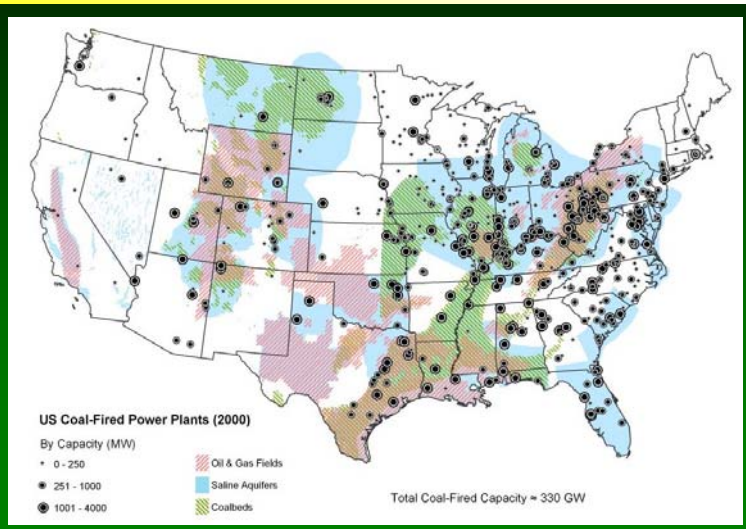
US Storage Capacity is Potentially Large

Formation Type	**DOE Regional Partnerships**
Oil & Gas Reservoirs	~25 GtC
Unmineable Coal Seams	~50 GtC
Deep Brine Formations	250-1000 GtC

Total Global carbon emissions = ~7 GtC/year

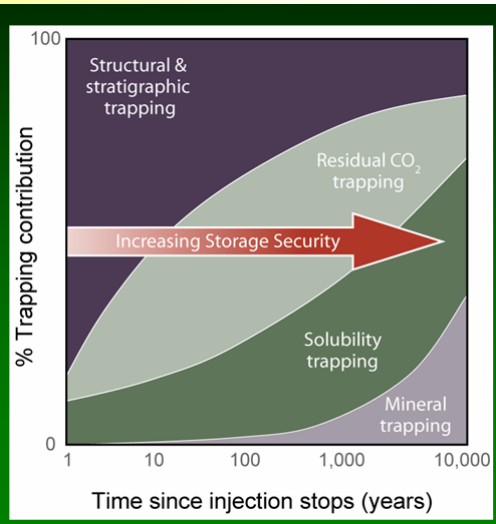
Total US power plant carbon emissions = >~.6 GtC/year

Matching Coal Plants to Potential Geologic Storage Sites



Trapping Mechanisms and Increasing Storage Security with Time

- Storage security depends on a combination of physical and geochemical trapping
- Over time, residual CO_2 trapping, solubility trapping and mineral trapping increase

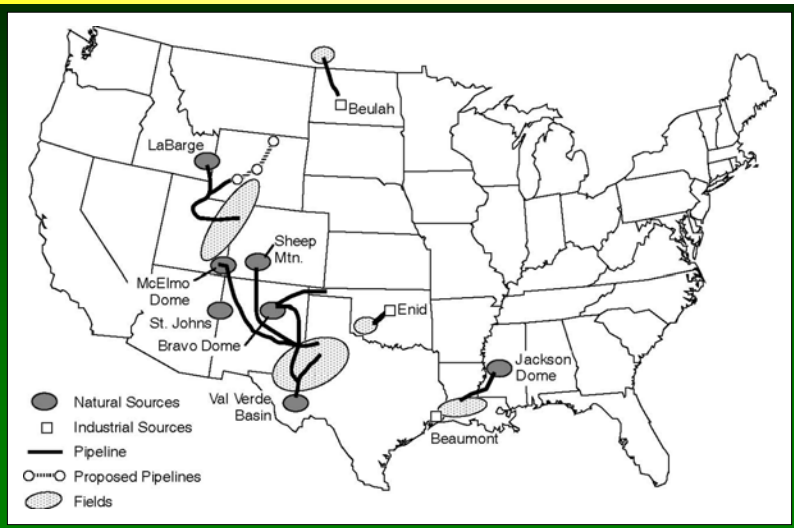


Courtesy Sally Benson, LBNL

We Transport and Inject CO_2 Today

- Acid Gas Injection
- Enhanced Oil Recovery (EOR)
- Natural Gas Storage
- CO_2 Transport

National CO_2 Network



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CO_2 Injection Projects in Operation 1 Mt/yr Scale

Project	Leader	Location	CO_2 Source	CO_2 Sink
Sleipner (1996)	Statoil	North Sea Norway	Gas Processing	Deep Brine Formation
Weyburn (2000)	Pan Canadian	Saskatchewan Canada	Coal Gasification	EOR
In Salah (2004)	BP	Algeria	Gas Processing	Depleted Gas Reservoir

In pipeline:

Snovit (Norway), Gorgon (Australia), Otway Basin (Australia)

National Regulations

- Underground Injection Control Program
  - Created under Safe Drinking Water Act
  - Creates five injection well classes
  - Generally regulated by states (as authorized by EPA)
  - Not clear how carbon dioxide injection will be interpreted

Sequestration
Institutional and Regulatory Issues

- Industrial Organization
- Impurities with CO_2
- Pipeline transport – issues at scale (e.g., common carriers)
- Ownership of storage reservoir
- Long-term stewardship
  - Accounting for CO_2
  - Monitoring and verification program
  - Ownership and liability

Although there are some gaps in the current regulatory system as applied to CCS, many of the currently identifiable issues have been successfully resolved in other contexts.

MIT Coal Study
Finding #5

- Current evidence indicates that it is scientifically feasible to store large quantities of CO_2 in saline aquifers
- In order to:
  - Address outstanding technical issues that need to be resolved to confirm CCS as a major mitigation option
  - Establish public confidence that large scale sequestration is practical and safe

  it is urgent to undertake a number of large scale (on the order of 1 Mt/yr injection) experimental projects in reservoirs that are instrumented, monitored, and analyzed to verify the practical reliability and implementation of sequestration.

None of the current sequestration projects worldwide meets all of these criteria

Costs

- CCS (all components) will add $20-30 per MWh to cost of electricity. This cost assumes:
  - 2005$
  - n^{th} plant
  - Today's technology (i.e., no technological breakthroughs required)
  - Regulatory issues resolved without imposing significant new burdens
  - Operations at scale (i.e., transition costs not included)

MIT Coal Study Key Takeaways

- Technology readiness is critical – there are myriad of options to pursue
- Don't preclude options by anointing technology winners prematurely
- We need to drastically increase R&D to bring CO_2 capture technologies to fruition. There is urgency to move ahead now if we are to reach gigaton (Gt) scale by 2050. Large scale demonstration projects are key
- No showstoppers, but moving from the megaton (Mt) scale to the Gt scale is a major challenge

Contact Information

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