INDIANA CENTER FOR COAL TECHNOLOGY RESEARCH

What To Do With CO_2

CCTR Basic Facts File # 10

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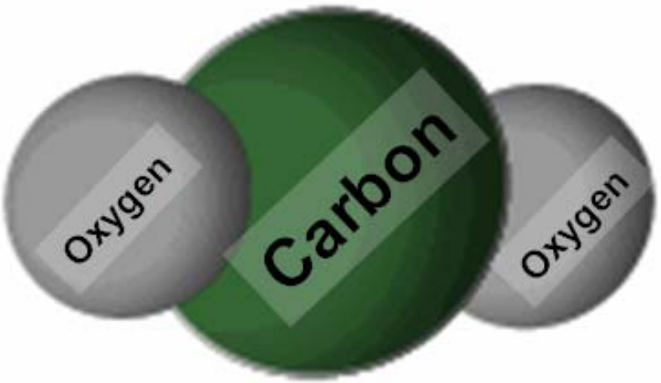
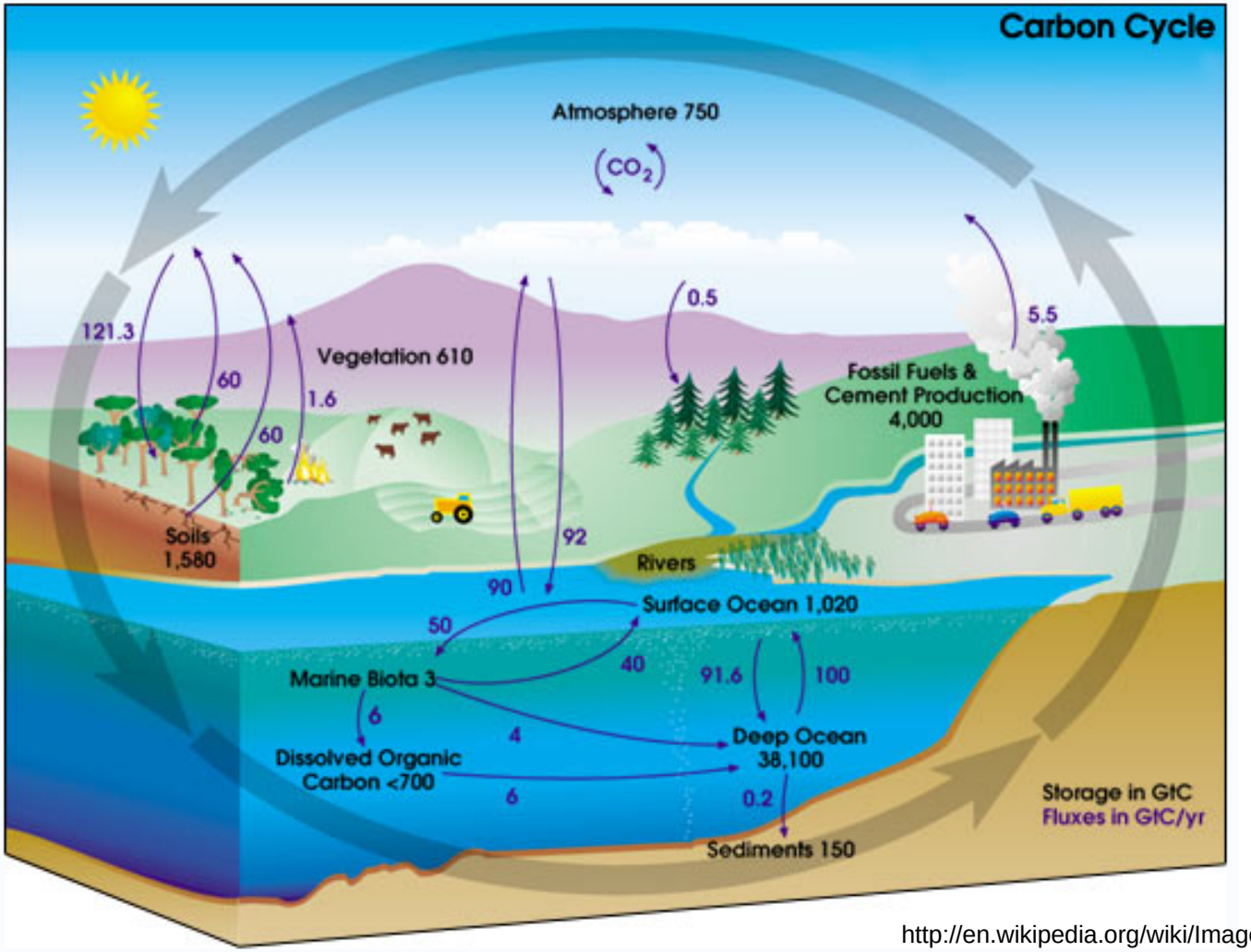


Global Carbon Cycle

Total amount of CO_2 stored
in the atmosphere is 750 Billion Tons



Storage & annual exchange of CO_2 in Billions Tons

Burning fossil fuels adds about 5.5 Billion Tons of CO_2/year into the atmosphere.

Oceons absorb about 2 Billion Tons & forests about 0.5 etc

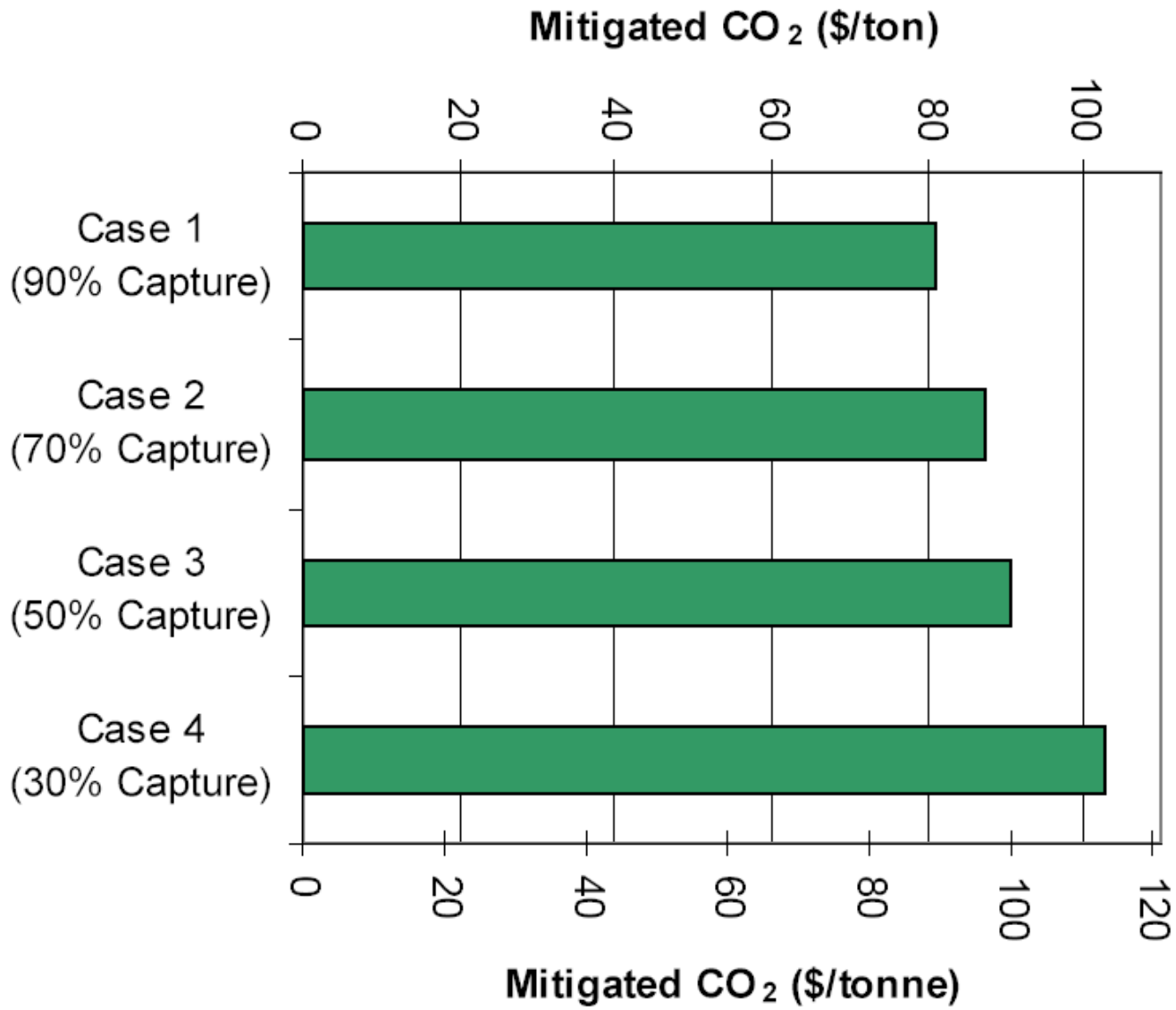
http://en.wikipedia.org/wiki/Image:Carbon_cycle-cute_diagram.jpeg

Options for CO_2 Control

- **CAPTURE & STORAGE**
- **CAPTURE & TRADE**
- **CAPTURE & REUSE**

Various approaches are possible for each of the above but **in all instances we need to first of all capture CO_2**. The economics of capture and what to do with it are huge issues that are to be assessed in the early part of the 21st century

CO_2 Capture Costs



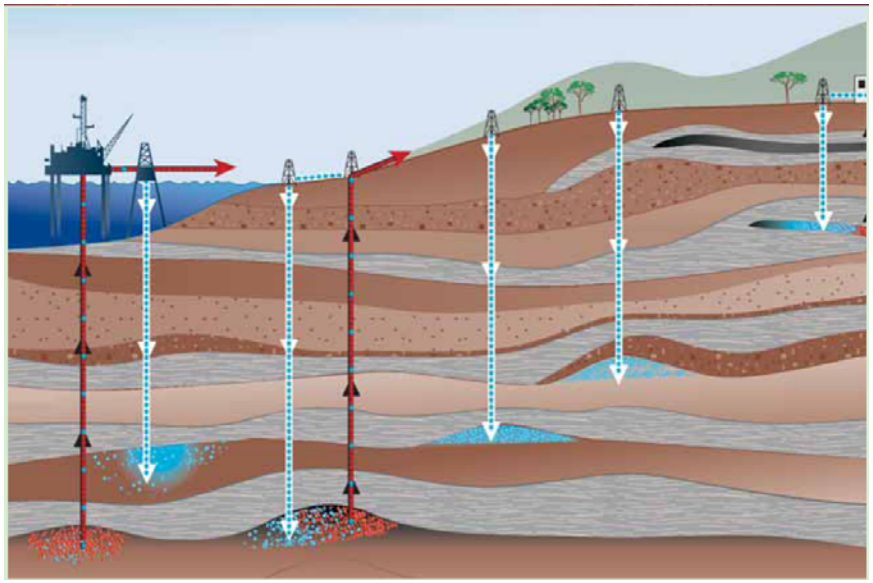
On retrofitting of existing coal-fired power plants the capture costs per Ton of CO_2 are expected to slightly decrease as the percentage capture rate is increased

90% capture = \$80/Ton CO_2

30% capture = >\$100/Ton CO_2

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

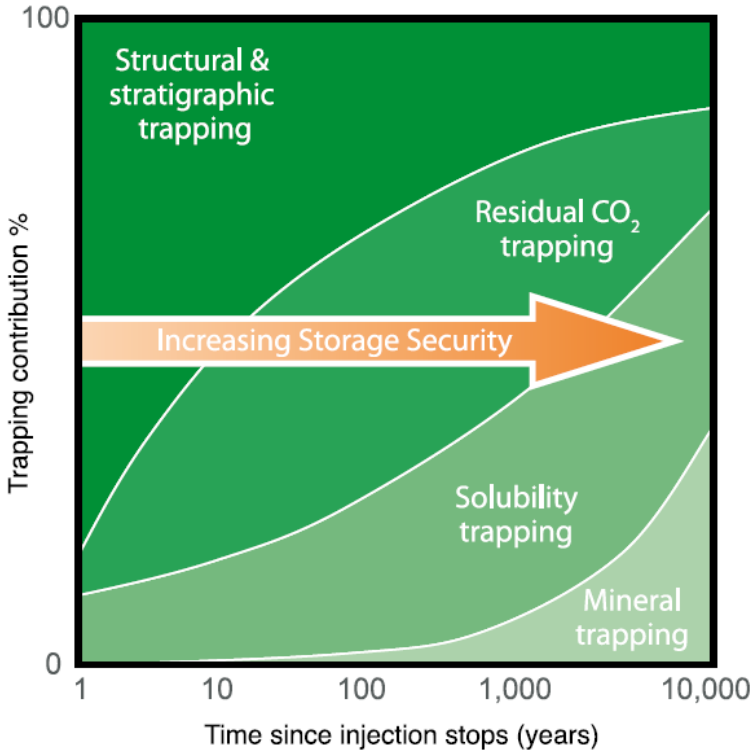
CO_2 Storage Site Selection



"Data will be required to demonstrate the **injectivity, capacity, and effectiveness** (ICE) of a given site. A firm characterization of ICE is needed to address questions regarding project life cycle, ability to certify and later close a site, site leakage risks, and economic and liability concerns."

Sources: "The Future of Coal", An Interdisciplinary MIT Study, 2007
"Carbon Dioxide Capture and Storage", Intergovernmental Panel on Climate Change, WMO, UNEP, 2005

CO_2 Storage Improves with Time



CO_2 becomes less mobile over time as a result of multiple trapping mechanisms, further lowering the prospect of leakage

Storage security depends on a combination of physical & geochemical trapping. Over time, the physical process of residual CO_2 trapping & geochemical processes of solubility trapping & mineral trapping increase

Sources: "Carbon Dioxide Capture and Storage", Intergovernmental Panel on Climate Change, WMO, UNEP, 2005

CO_2 Storage Economics

Underground storage costs are very site specific

Capital Costs include: (1) Research for identifying suitable sites, (2) Drilling, (3) Oil and gas recovery may need additional facilities

Operating Costs include: (1) Labor, (2) Fuel for pumping CO_2 (3) Maintenance of the equipment

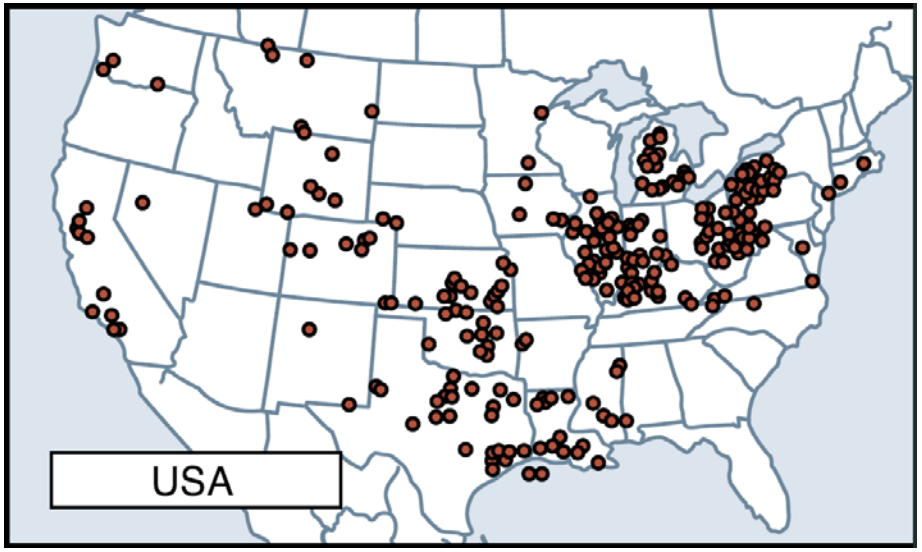
Field Parameter	Net cost	Rate of CO_2 injection
Depth	↑	
Permeability	↑	↓
Reservoir thickness	↑	↓
Effective Radius	↑	↓
Availability of Oil and gas	↓	
Oil and gas prices (if oil or gas recovered from the site)	↓	

↑ Increases with an increase in the field Parameter

↓ Decreases with a increase in the field parameter

Location of some U.S. Natural Gas Storage Sites

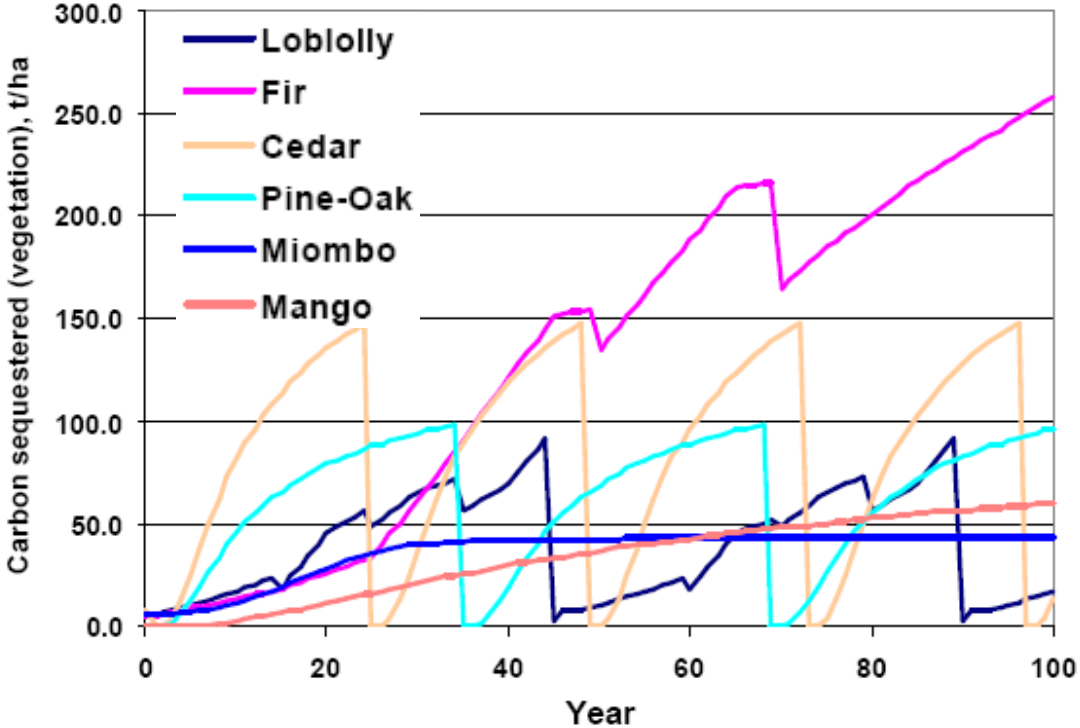
Underground natural gas storage projects offer experience relevant to CO_2 storage (operated successfully for almost 100 years). These projects provide for peak loads & balance seasonal supply & demand fluctuations. Majority of gas storage projects are in depleted oil & gas reservoirs & saline formations



Factors critical to the success of site: permeability, thickness, extent of storage reservoir, tightness of cap rock, geological structure, lithology

Sources: “Carbon Dioxide Capture and Storage”, Intergovernmental Panel on Climate Change, WMO, UNEP, 2005

CO_2 Biological Surface Storage

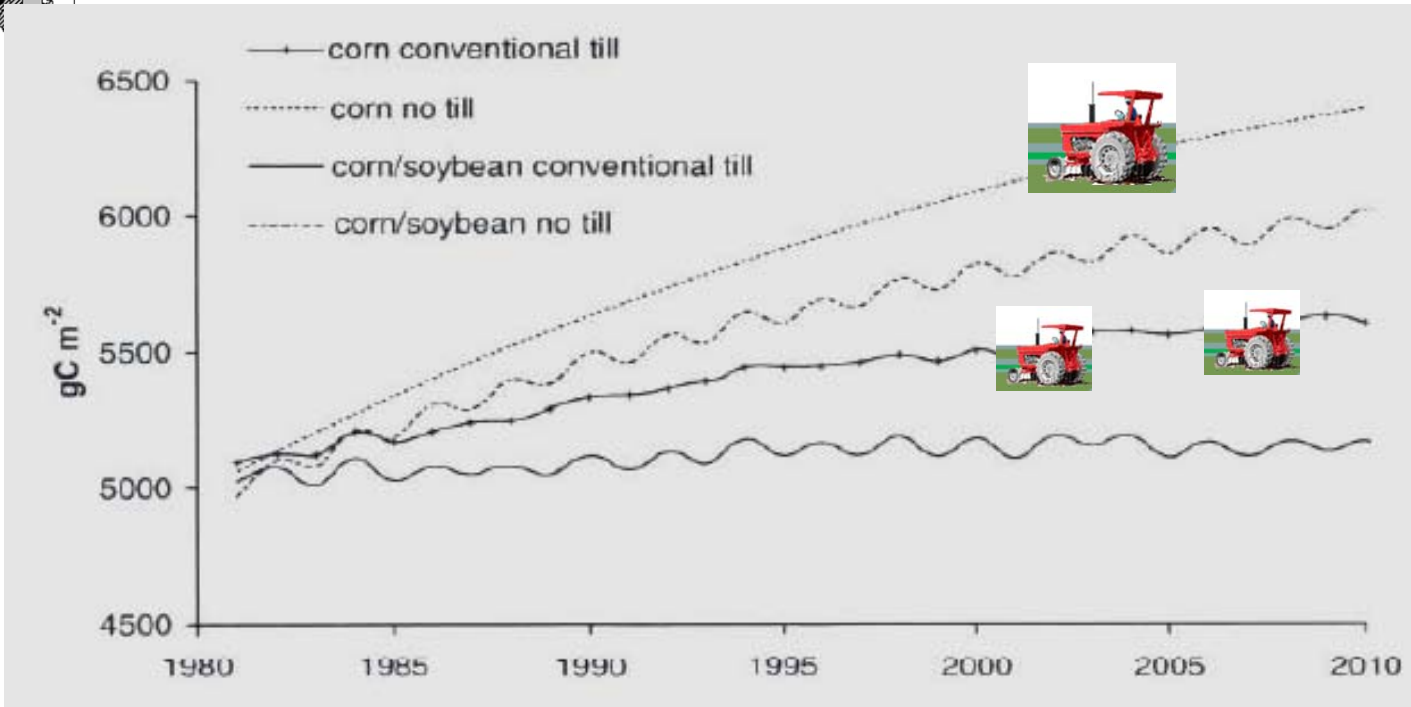


Plants convert CO_2 in the atmosphere to carbon. Trees store carbon in above ground mass, litter, roots & soil

Over time forests reach a dynamic equilibrium where the amount of CO_2 converted into carbon is equal to amount of carbon converted back into CO_2

Source: Bock, B., R. Rhudy, H. Herzog, M. Klett, J. Davison, D. De la Torre Ugarte and D. Simbeck, 2003: Economic Evaluation of CO2 Storage and Sink Options. DOE Research Report DE-FC26-00NT40937.

CO_2 Surface Storage Croplands Sink Enhancement



Reducing the amount of tillage increases the soil organic content of the soil

Conservative tillage results in an increase of equilibrium carbon storage in the soil. With careful selection of crops & tillage practices, the net equilibrium carbon content of a cropland can be increased

Source: Bock, B., R. Rhudy, H. Herzog, M. Klett, J. Davison, D. De la Torre Ugarte and D. Simbeck, 2003: Economic Evaluation of CO2 Storage and Sink Options. DOE Research Report DE-FC26-00NT40937.

CO_2 Forest Storage Costs

There are a diverse set of factors that affect the cost of forest carbon sequestration & so a broad range of estimates:

To sequester 300 MTons/year
$25-$75 per short ton of carbon

To sequester 500 MTons/year
$30 - $90 per short ton of carbon

Source: Robert Stavins, Kenneth Richards, "The Cost of U.S. Forest-Based Carbon Sequestration", 2005

Capture & Sequestration Economics

Carbon Capture & Sequestration, CCS

Cost of Electricity, COE

Percentage increases in COE with CCS:

Pulverized Coal Power Plant	44-90%
IGCC Power Plant	24-52%

Cost of Electricity 2005 Estimates US$/MWh	Pulverized Coal Power Plant	Integrated Coal Gasification Combined Cycle Power Plant, IGCC
Without CCS	**43-52**	**41-61**
With CCS	**62-99**	**51-93**

Source: "Carbon Dioxide Capture and Storage", Intergovernmental Panel on Climate Change, WMO, UNEP, 2005

Emissions Trading

REGULATORY AUTHORITY

Sets the cap
Issues allowances
Monitors and enforces allowances

Entity with emissions less than the allowance

Entity with emissions beyond the allowance

Facilitates trading of allowances, Price discovery

Emissions Trading

- Trading is seen by its proponents as a better alternative to “command-and-control” mechanism where regulatory body sets the limit and enforces it
- Conventional trading approach is used to discover the market price of emissions for a given cap
- Emissions trading approach recognizes that different polluters incur different cost of pollution abatement – if enforced properly, the one with the lowest cost of abatement ends up polluting the least

Comparison of Strategies

Command-and-control

No Option
Invest in new abatement technology

Emissions trading

Option 1
Invest in new abatement technology

Option 2
Buy Credits from other polluter

Depending on the relative costs, the firm is **expected to choose the least-cost option.**

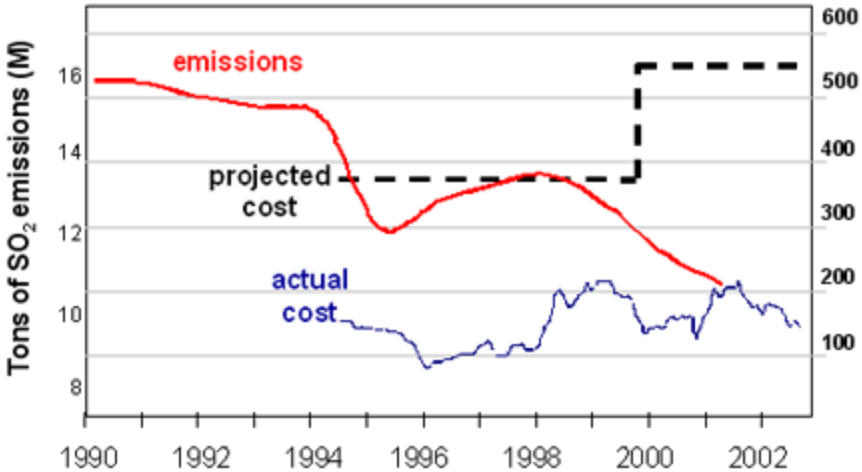
Emissions Trading in the U.S.

- **Chicago Climate Exchange (CCX** established 2000), first in North America to facilitate GHG trading
- **Voluntary participation**, commitments legally binding
- **Verification provided** through Financial Industry Regulatory Authority (formerly National Association of Securities Dealers, NASD)
- Commitments are standardized, **one Carbon Financial Instrument (CFM) represents 100 metric tons of CO_2**
- In 2006, nearly 10.3 Million tons of CO_2 was traded. Small amount compared with EU 1 Billion tons

Sources: Capoor K. and P. Ambrosi, 2007. State and Trends of the Carbon Market 2007. World Bank Carbon Finance Business an International Emissions Trading Association. World Bank: Washington DC (www.carbonfinance.org) Chicago Climate Exchange www.chicagoclimateex.com

SO_2 Emissions Trading

ACID RAIN EXPERIENCE



Acid Rain Program is a market-based initiative taken by the US EPA (Environmental Protection Agency) in an effort to reduce overall atmospheric levels of SOx and NOx, which cause acid rain

Title IV of the 1990 Clean Air Act established the **allowance market system** we know today as the Acid Rain Program. Initially targeting only sulfur dioxide, Title IV set a decreasing cap on total SO_2 emissions for each of the following several years, aiming **to reduce overall emissions to 50% of 1980 levels**. The program did not begin immediately, but was implemented in two stages: Phase I beginning January 1, 1995, and Phase II starting January 1, 2000

http://www.environmentaldefense.org/page.cfm?tagID=1085

U.S. Cap & Trade

Cap & trade argues that **property rights are more effective than employing a tax.** One allowance (emission permit) gives the right to emit one unit of pollution/year

First started in the US in the 1950s in the context of **fisheries management** to prevent overuse & collapse. Only quota holders could legally harvest fish – quotas were transferable in practice (**ITQs, Individual Transferable Quotas**) going to those who value them most

Many environmentalists recognize a level of success in the 1990 SO_2 program who originally were opposed to **"buying & selling the right to pollute**"

Cap & Trade, Carbon Tax, Auctions

With Cap & Trade the emissions **level is established** & the **market determines the emissions price**. With a carbon tax the **tax is the emissions price** & the **market determines the emissions level** (so offers relative cost certainty)

Cap & Trade relied on **giving emissions allowances away for free** as in Acid Rain Program & more recently with the EU Emissions Trading system (ETS). Government foregoes potential revenues & so **there is increased talk about selling allowances through auctions** becoming more similar to the carbon tax approach

"A Primer on Market-Based Approaches to CO2 Emissions Reductions", L.Raymond, G. Shively, Purdue Climate Change Research Center

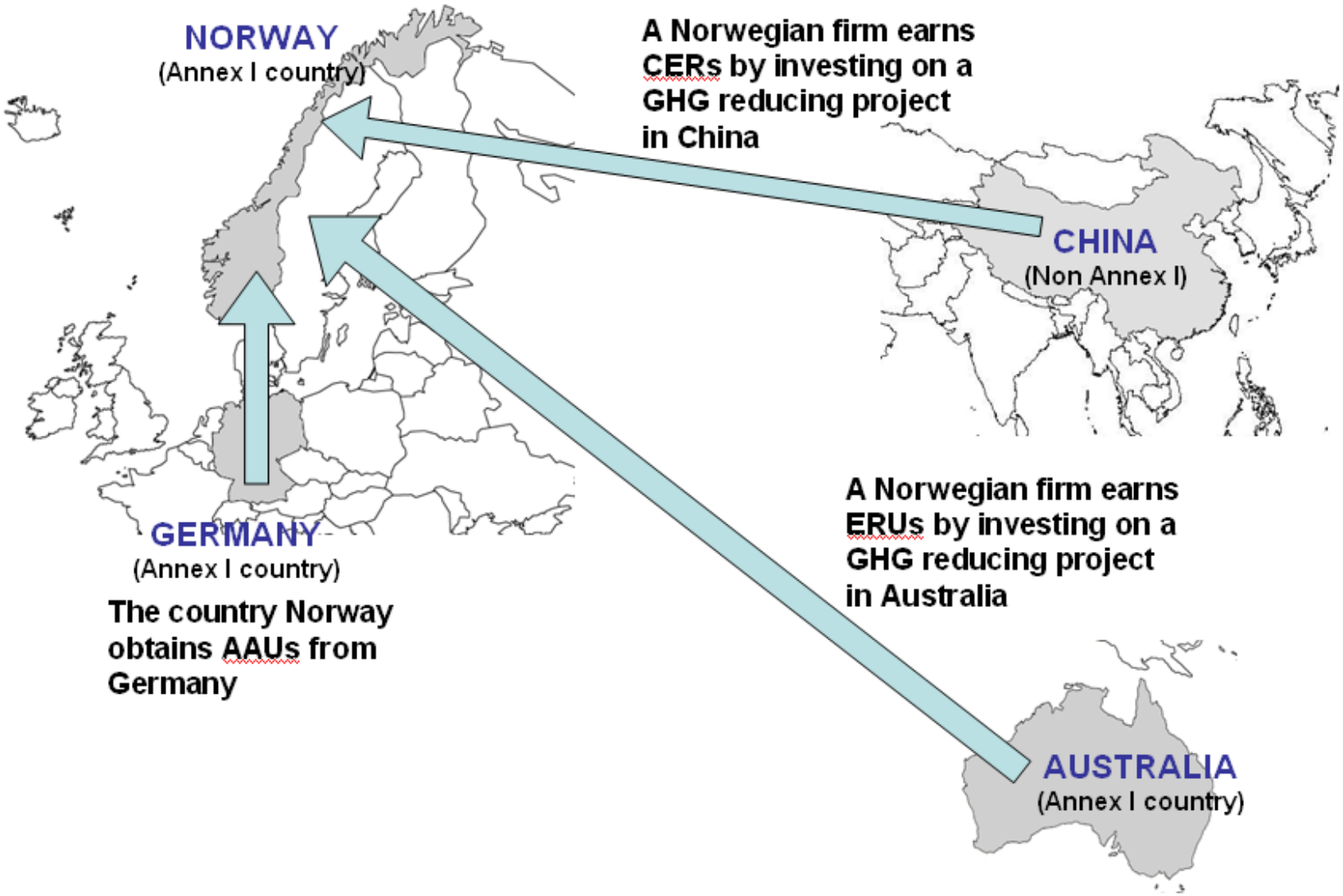
CO_2 Kyoto Reduction Options

Creation of emission trading systems to provide incentives to firms & increase their efficiency or switch to lower GHG production processes

Purchase emission credits from investing in GHG reduction projects abroad

- Clean Development Mechanism (CDM): investing in emission reduction projects in non-Annex-I countries earn **Certified Emission Reductions (CERs)**
- Joint Implementation: investing in emission reduction projects in Annex-I countries generates **Emission Reduction Units (ERUs)**
- Each Annex-I country receives **Assigned Amount Units (AAUs)** & trading of these is allowed

EU CO_2 Trading Example



CO_2 European Union Emission Trading Scheme, ETS

- The first phase, 2005-2007, of the European Union **Emission Trading Scheme, ETS**, was launched on January 1st, 2005
- The 25 member states have issued allowances to emitters located in their countries. The cap for each member state is defined in their National Allocation Plan
- The total cap was set at 6,600 MTons of CO_2 for 2005-07 with Germany accounting for a quarter of the allowances
- During 2005, 322 MTons of CO_2 was traded under ETS
- It has been criticized that the cap was too generous & that the initial allowances have been **issued freely by the government instead of auctioning them**

Sources: Climate Action Network Europe: National Allocation Plans 2005-7: Do They Deliver Key Lessons for Phase II of the EU ETS. Summary for policy-makers
Capoor K. and P. Ambrosi, 2006. State and Trends of the Carbon Market 2006. World Bank Carbon Finance Business an International Emissions Trading Association. World Bank: Washington DC (www.carbonfinance.org)

CO_2 Trading Lessons for the U.S.

- Credible regulatory authority is essential
- Centralized authority to set a cap at the national level
- Frequent appraisals on actual emissions to avoid extreme price fluctuations (as it was in Europe)
- Banking of contracts should be allowed to ensure continuity (EU-ETS, Phase II has this provision)
- Longer time horizon may provide greater incentive to invest in capital intensive long-term technologies

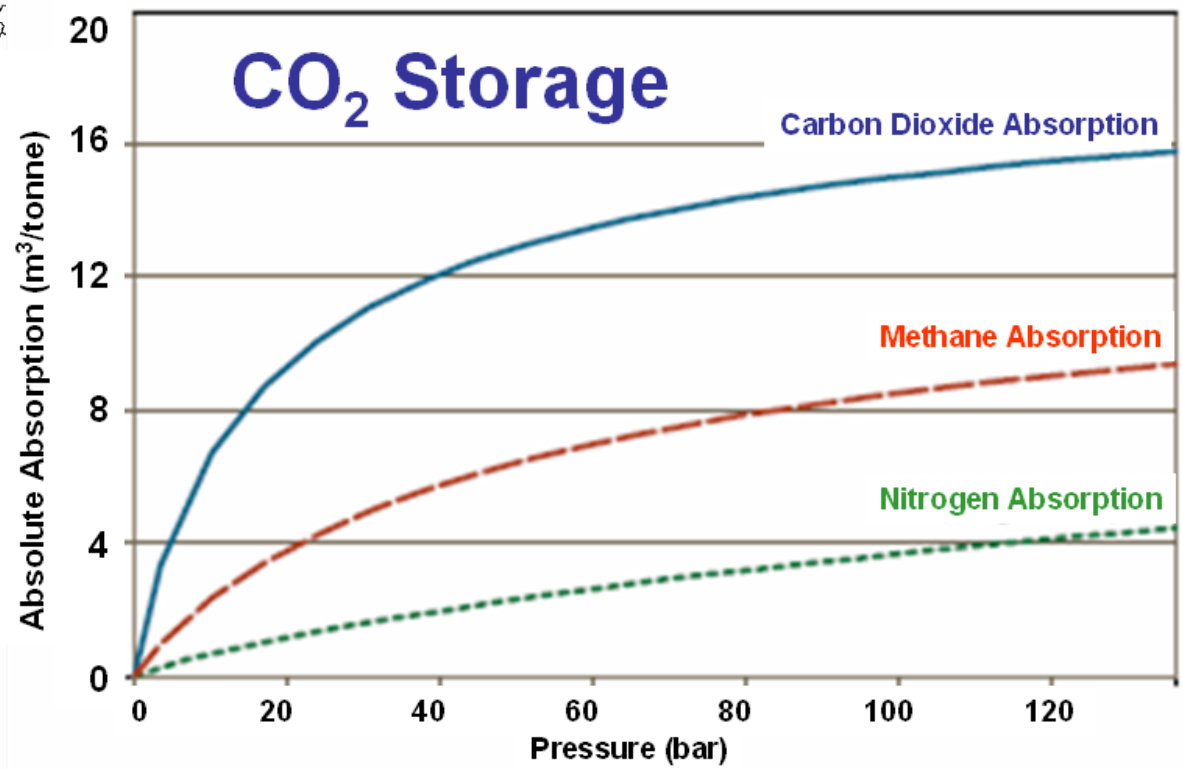
Midwest Geological Sequestration Consortium (MGSC)

New Albany Shale

Injection of CO_2 into the organic shale may result in CO_2 absorption & possibly the enhanced production of CH_4, (**Shale Gas**) just as in coal beds (**Coal Bed Methane, CBM**)

Source: "Carbon Sequestration of the United States and Canada", NETL, DOE

Enhanced Coal Bed Methane



Coal has very large number of micro pores & can absorb many gases, the most common among them being methane. Absorption refers to binding of gaseous or liquids to solid surfaces

One ton of Coal may contain up to 25 m^3 of methane. CO_2 has higher affinity to coal than methane. This property is exploited to extract methane from coal seams by injecting CO_2

Source: IPCC, 2005: Special Report on Carbon Dioxide Capture and Storage, Special Report of the Intergovernmental Panel on Climate Change [Metz, Bert, Davidson, Ogunlade, de Coninck, Heleen, Loos, Manuela, and Meyer, Leo (Eds.)].

Enhanced Coal Bed Methane Economics

Methane Recovery: It is estimated that 1.5-10.0 m^3 of CO_2 is needed to extract 1 m^3 of methane

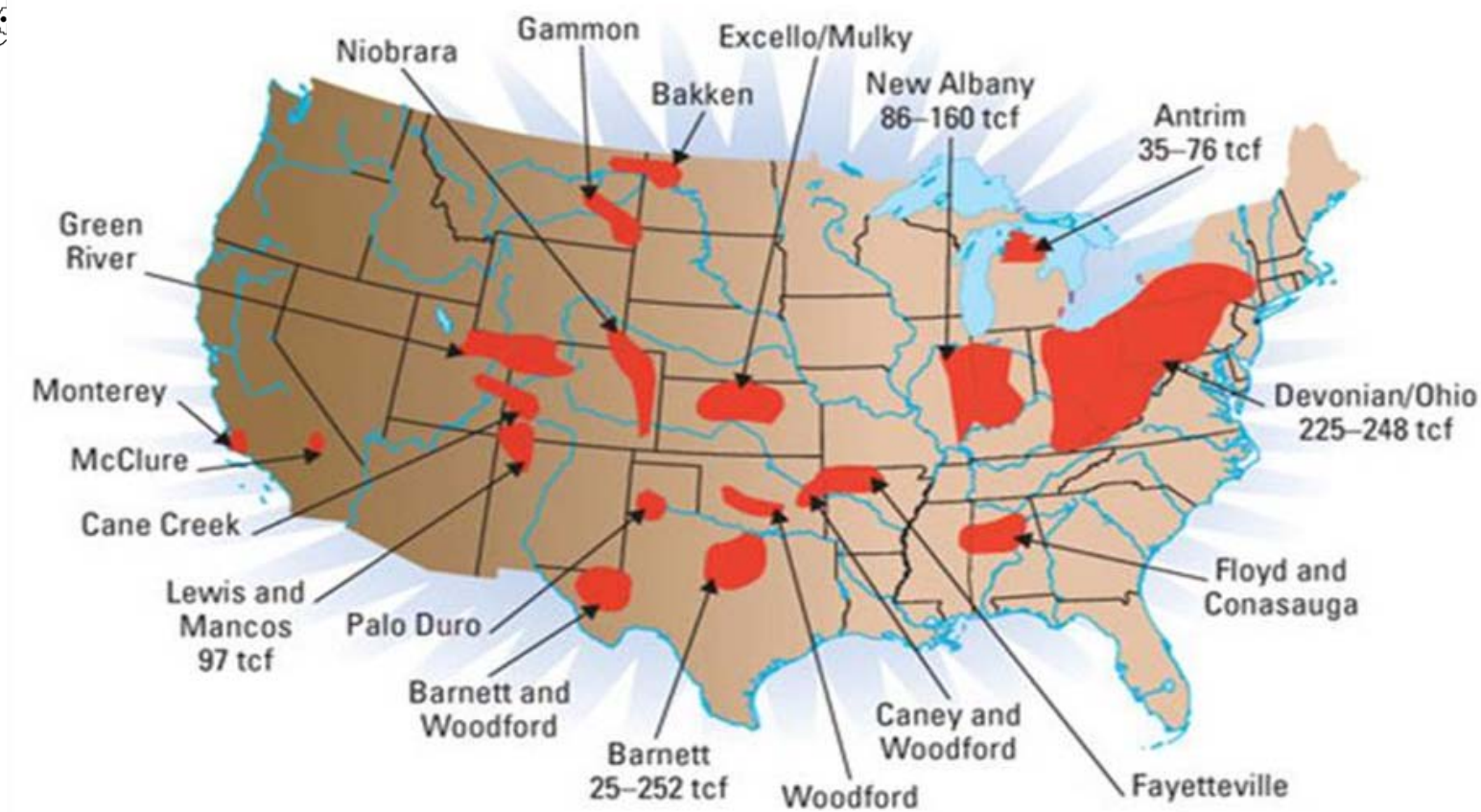
Cost: The profitability depends of the price of gas

According to Schreurs, 2002, capital costs are:

Production well:	US$ 750,000 per well
In seam drilling:	US$ 1,500 per meter
Injection well:	US$ 430,000 per well

Source: Schreurs, H.C.E., 2002: Potential for geological storage of CO2 in the Netherlands. Proceedings of the 6th International Conference on Greenhouse Gas Control Technologies (GHGT-6), J. Gale and Y. Kaya (eds.), 1–4 October 2002, Kyoto, Japan, Pergamon, v.I,303–308.

CO_2 for Extracting Shale Gas



There are enormous amounts of shale gas in Indiana.
How economically can CO_2 be used to extract shale gas?

Source: Baseline Oil & Gas, Inc.

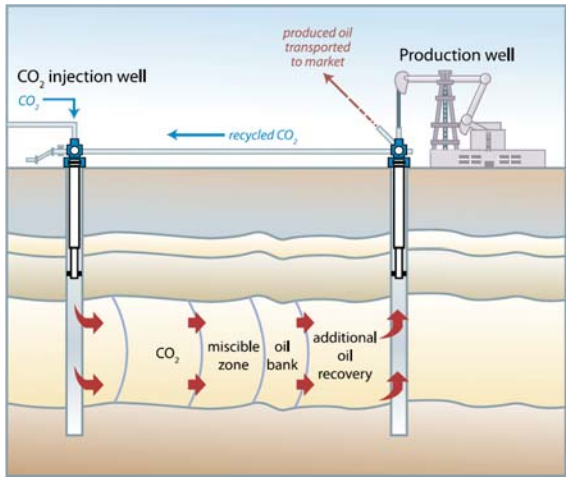
CO_2 Capture & Sequestration (CCS) & then used in Oil & Gas Reservoirs

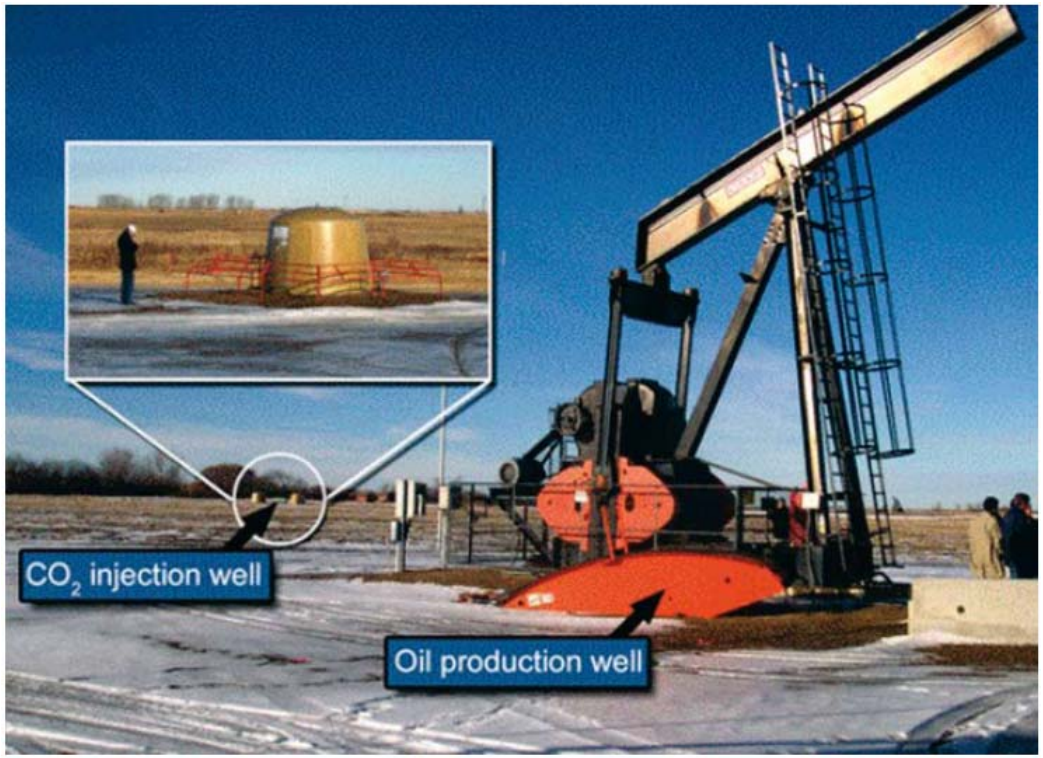
Injecting CO_2 into a mature oil reservoir can enable incremental oil to be recovered. Typical oil recovery produces 30-40% of original oil in place (OOIP). 5-40% is usually recovered by conventional primary production & an additional 10-20% of OOIP is produced by secondary recovery that uses water flooding.

A CO_2 flood allows recovery of an additional 10-15% of the OOIP. A price of $25 per ton of CO_2 is significant as this approaches levels that makes CCS economical

Sources: "Carbon Sequestration" Atlas of the United States and Canada", NETL, DOE
"The Future of Coal", MIT Study, 2007
"Carbon Dioxide Capture and Storage", Intergovernmental Panel on Climate Change, WMO, UNEP, 2005

CO_2 Sequestration & EOR



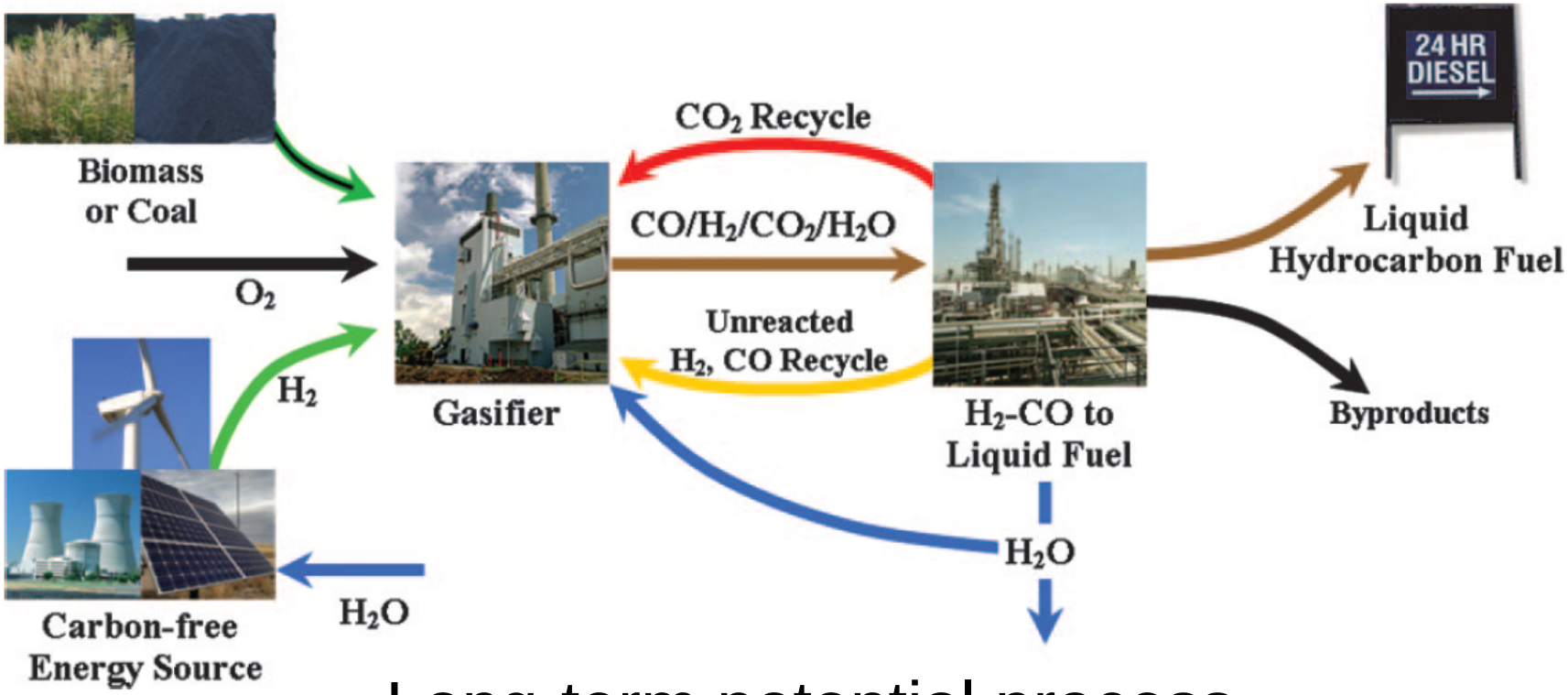


Small amounts of CO_2 dissolve in the oil, increasing the bulk volume & decreasing the viscosity, so facilitating flow

Average of 13% of the original oil in place, OOIP, is produced from **Enriched Oil Recovery, EOR**

Sources: "Carbon Dioxide Capture and Storage", Intergovernmental Panel on Climate Change, WMO, UNEP, 2005

Possible Configuration of the Purdue Proposed Hydrogen Carbon H2CAR Process

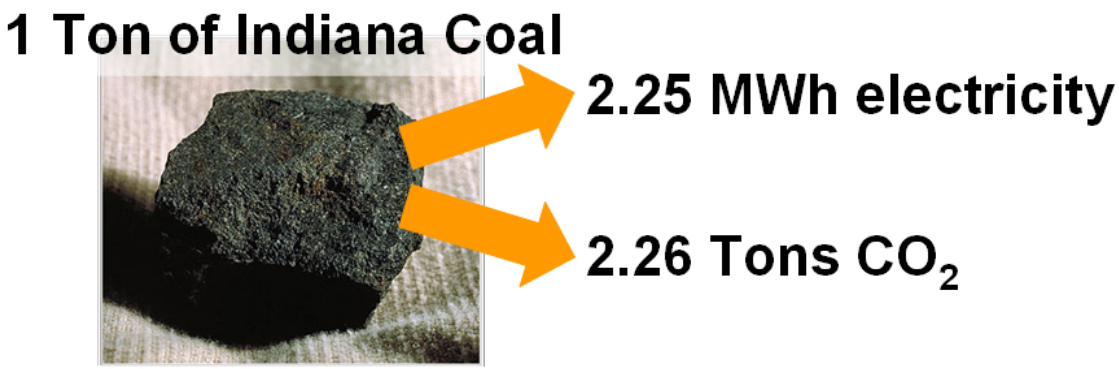


Long-term potential process to recycle CO_2 emissions

Source: Rakesh Agrawal, Navneet R. Singh, Fabio H. Ribeiro, and W. Nicholas Delgass, "Sustainable fuel for the transportation sector", *PNAS*, Mar 14, 2007

Indiana's Average CO_2 & Power Production from 1 Ton of Coal

- 1 Ton of Coal produces 2.26 Tons CO_2
- 1 Ton of Coal produces 2.25 MWh Electricity
- 1MWh of power ≈ 1 Ton of CO_2 produced



Source: CCTR Basic Facts File # 4

Indiana's CO_2 Storage

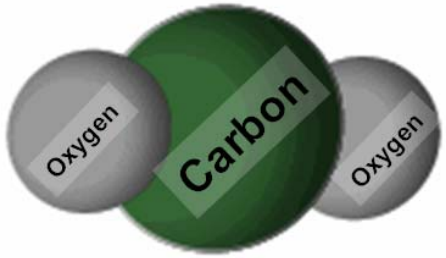
"The majority of estimates support the contention that sufficient capacity exists to store many 100's to many 1000's of GTons CO_2, but this range is too large to inform sensible policy." (MIT study)

Indiana produces nearly 0.32 Billion tons of CO_2 annually of which **0.15 BTons (47%) come from utilities.** The U.S. produces about 6.0 Billion Tons of CO_2 annually of which 2.5 BTons (42%) comes from utilities

Initial estimates from the Indiana Geological Survey indicate that there are 38.0 BTons of CO_2 storage capacity under Indiana's Mt Simon Sandstone & 7.8 BTons under the New Albany Shale

Sources: "The Future of Coal", An Interdisciplinary MIT Study, 2007
"Challenges of U.S. Energy Goals Determinism, Stewardship, Technology", The Richard G. Lugar Symposium for Tomorrow's Leaders, 2006

Summary



The future use or storage of CO_2 from coal-fired power plants will have a **major impact on the economy**

The Midwest Regional Carbon Sequestration Partnership, MRCSP is the **most comprehensive regional U.S. Midwest CO_2 study taking place**

Extensive debates on carbon capture and what to do with the captured carbon will be taking place during the next few years

This topic has **major impact on Indiana's cost of electricity** with over 95% of the state's power supply coming from coal

Source: "Carbon Sequestration of the United States and Canada", NETL, DOE