CARBON SEQUESTRATION

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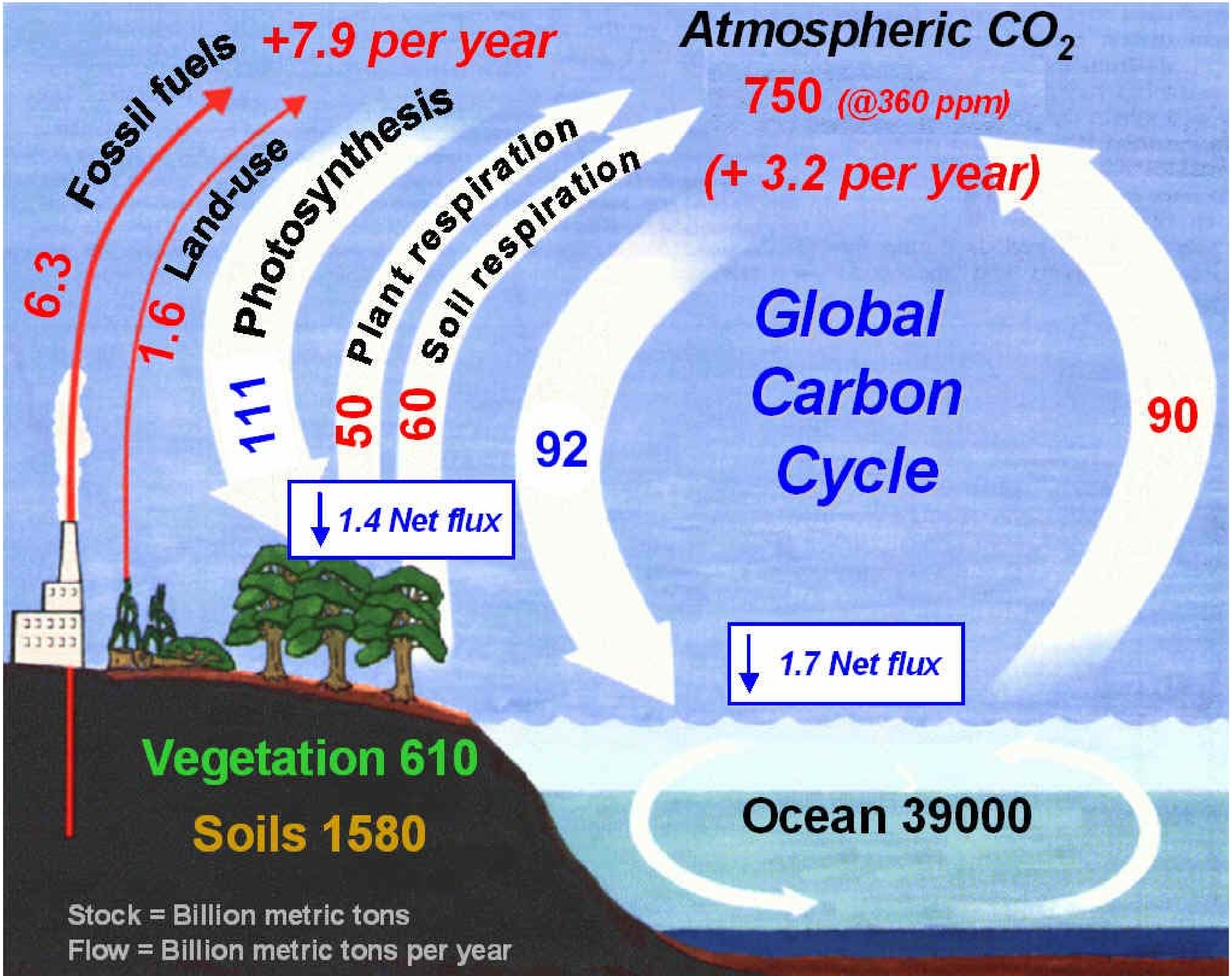
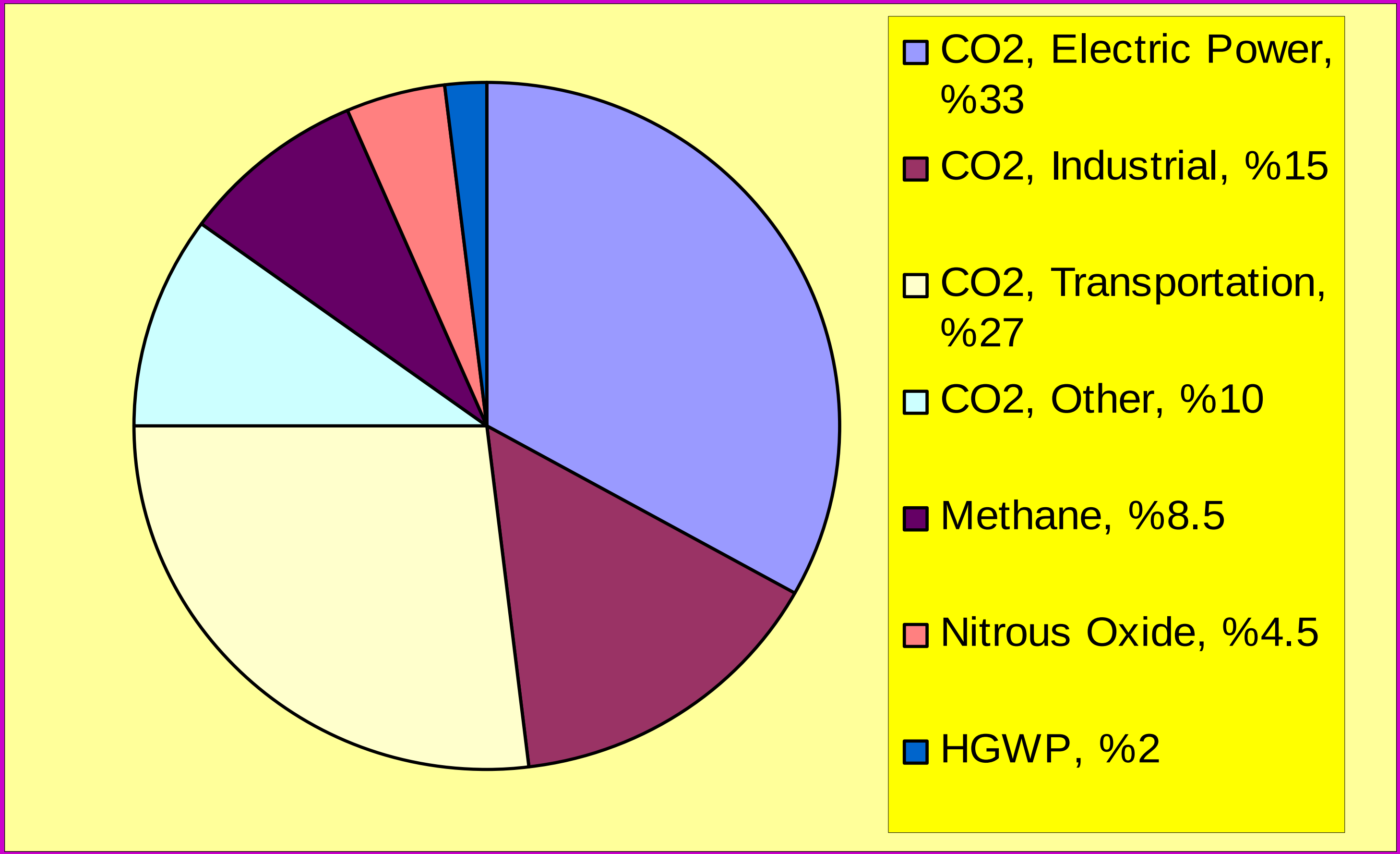

Atmospheric CO_2
750 (@360 ppm)
(+ 3.2 per year)
+7.9 per year
Fossil fuels
6.3
Land-use
1.6
Photosynthesis
111
Plant respiration
50
Soil respiration
60
92
90
Global Carbon Cycle
1.4 Net flux
1.7 Net flux
Vegetation 610
Soils 1580
Ocean 39000
Stock = Billion metric tons
Flow = Billion metric tons per year

Greenhouse Gas Emissions in the United States, 2003



Source: DOE Energy Information Administration

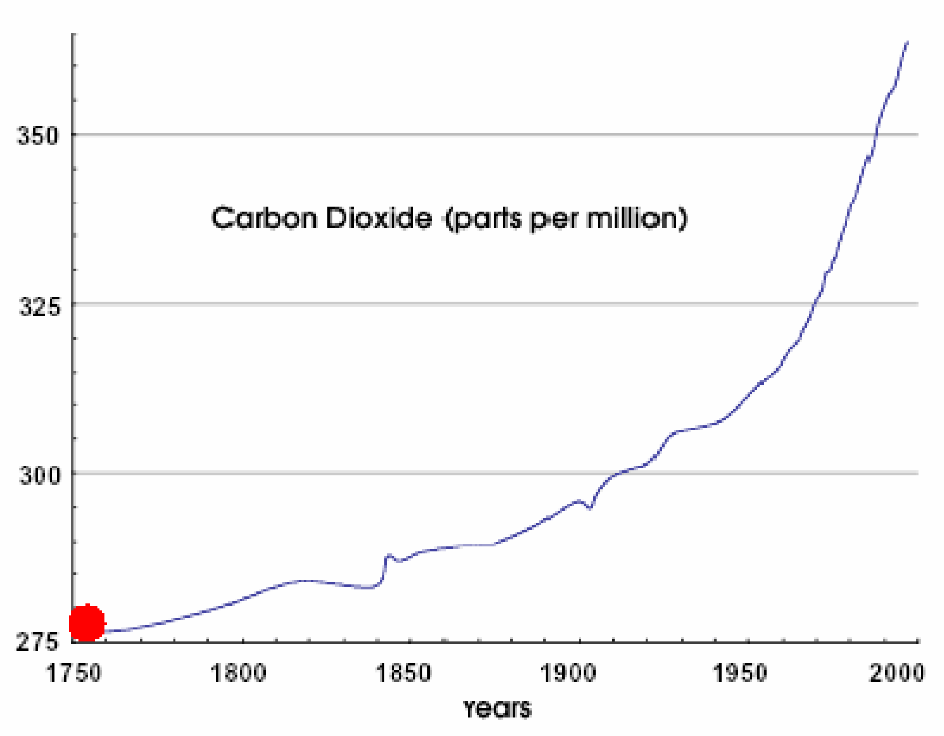
Total 2003 U.S. GHG emissions were 6,891 million metrics tons CO2 equivalent.

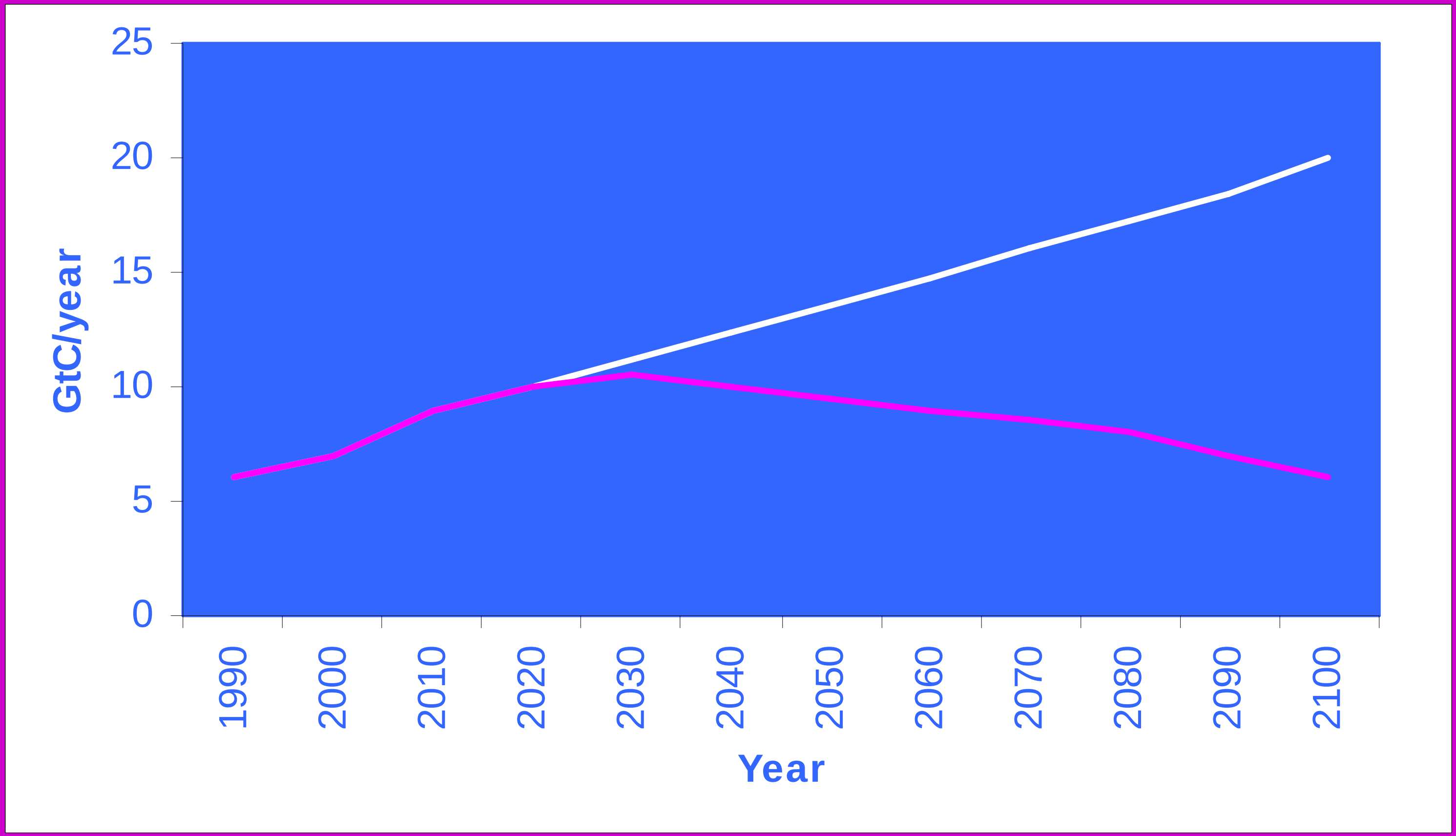
Methane, Nitrous oxide, and HGWPs reported in 100 year forcing CO2 equivalents

* High global warming potential gases, e.g., certain refrigerants.

CARBON MANAGEMENT

In the past 60 years, the amount of anthropogenic carbon dioxide (CO_2) emitted to the atmosphere has risen from Preindustrial levels of 280 parts per million (ppm) to present levels of over 365 ppm.





One representation of the reductions in CO_2 that would be necessary to reach atmospheric stabilization compares the IS92A (business as usual) scenario with a scenario (WRE550) that leads to stabilized atmospheric CO_2 concentrations of 550 ppm (about twice preindustrial levels). The WRE550 scenario is commonly used by analysts of climate change. *Source:* Wigley, Richels, and Edmonds 1996.

Effects of CO_2

Elevated amounts of atmospheric CO_2 have two primary effects:

- CO_2 in the atmosphere exerts a greenhouse effect that traps solar energy within the earth's ecosystem.

- Increased CO_2 in the atmosphere causes an increased rate of CO_2 dissolution into ocean water which could make the oceans more acidic potentially causing damage to the ocean ecosystem.

Three Approaches to Carbon Management

- to develop and implement energy-efficient technologies to decrease the need to burn CO_2-emitting fossil fuels.

- to switch from fossil-fuel combustion to lower-carbon and carbon-free fuels and technologies for power production.

- to capture carbon emissions from energy production facilities and securely store, or sequester

Carbon Sequestration?

Carbon sequestration can be defined as the capture and secure storage of carbon that would otherwise be emitted to or remain in the atmosphere. The idea is:

(1) to keep carbon emissions produced by human activities from reaching the atmosphere by capturing and diverting them to secure storage,

(2) to remove carbon from the atmosphere by various means and store it.

Necessary Characteristics for Carbon Sequestration Systems

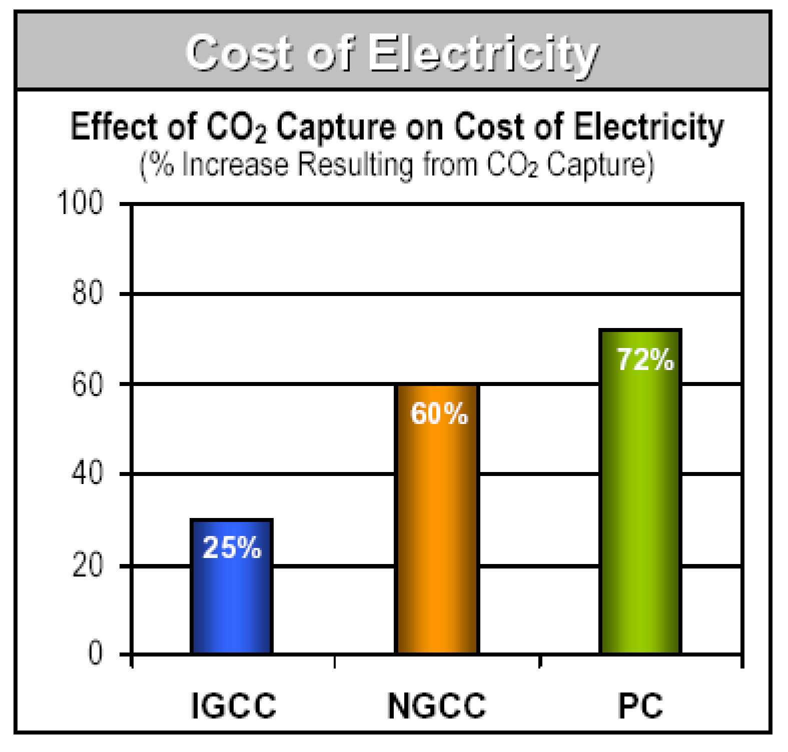
- **Capacity and price.** The technologies and practices to sequester carbon should be effective and cost competitive.

- **Environmentally benign fate.** The sheer scale and novelty of sequestration suggests a careful look at environmental side effects.

- **Stability.** The carbon should reside in storage for a relatively long duration.

SEPARATION AND CAPTURE OF CARBON DIOXIDE

The costs of separation and capture, including compression to the required pressure for the sequestration option used, are generally estimated to make up about three-fourths of the total costs of ocean or geologic sequestration.



IGCC-integrated gas combined cycle
NGCC-natural gas combined cycle
PC-pulverized coal

Source – National Energy Technology Lab

CO_2 Storage in Geologic Formati

The storage of CO_2 in a geologic formation (geosequestration) is the injection of CO_2 into an underground formation that has the capability to contain it securely.

Oil and Gas Reservoirs:

- An oil or gas reservoir is a formation of porous rock that has held crude oil or natural gas (both of which are buoyant underground like CO_2) over geologic timeframes.
- It thus has a "demonstrated seal," and is fundamentally an ideal setting for CO_2 storage.

Oil and Gas Reservoirs (Cont'd)

- Enhanced Oil Recovery (EOR): CO_2 can be injected into depleted oil reservoirs to enhance oil recovery from the reservoir. CO_2 will dissolve into the residual oil in place, which lowers the viscosity of the oil. The lower viscosity enables the oil to flow more easily, which makes it possible to extract more oil from reservoirs.

- Enhanced Gas Recovery (EGR): As gas is removed from natural gas reservoirs, the pressure of the reservoir decreases. As the pressure within the reservoir decreases, it becomes more difficult to recover more gas. By injecting CO_2 into the natural gas reservoir, the pressure of the reservoir is increased, and more gas can be recovered.

The 5,500 tons of CO_2 from the Great Plains Synfuels Plant that is injected daily into the oil reservoir near Weyburn, Saskatchewan, is the equivalent of CO_2 emissions from 600,000 cars each day.

Deep Coal Seams

- CO_2 injected into a coal bed becomes adsorbed onto the coal's surfaces and is sequestered.
- Most coals contain adsorbed methane, and this methane can be recovered from coals that are too deep or too thin to mine economically.
- Coals preferentially adsorb CO_2 and, like enhanced oil recovery, CO_2 can be injected into an unmineable coal formation to enable recovery of residual methane not produced by depressuring.

Saline Formations

- A saline formation is a formation of porous rock that is overlain by one or more impermeable rock formations and thus has the potential to trap injected CO_2.

- Saline formations are more commonplace than oil and gas formations or coal seams and, on the basis of total pore volume, saline formations offer the potential capacity to store hundreds of years worth of CO_2 emissions.

Terrestrial Sequestration

- Terrestrial sequestration is the enhancement of CO_2 uptake by plants that grow on land and in freshwater, and carbon storage in soils. Tree-plantings, no-till farming, forest preservation and other early activities provide an opportunity for low-cost CO_2 emissions offsets.

Ocean Sequestration

- To enhance the growth of plants in the surface ocean.
- Inject CO_2 into ocean water.

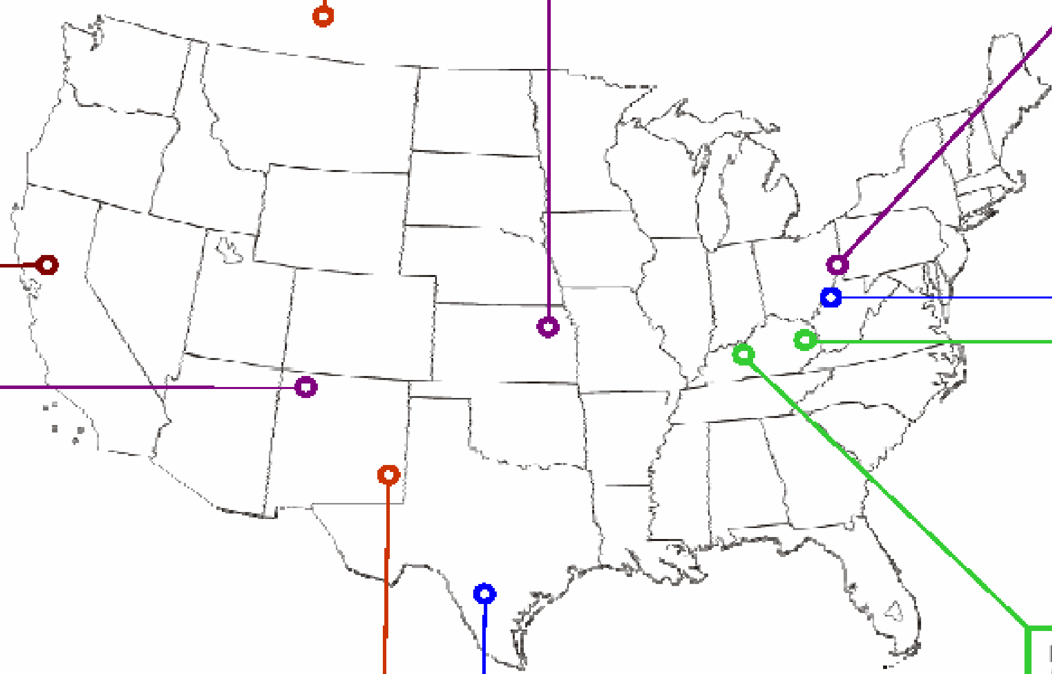
Carbon Sequestration Field Projects

WEYBURN, CANADA
Lead: ENCANA
Type: Geologic, Depleting oil reservoir
Phase: Injection began in 2001
Scale: 20 MM tons CO_2 over 15 yrs
Highlights: Demonstrate use of time lapse (3D) seismic and other technologies to monitor CO_2.
http://www.netl.doe.gov/publications/factsheets/project/Proj282.pdf
http://www.encana.com/operations/upstream/ca_weyburn.html

JOHNSON COUNTY, KS
Lead: Kansas Geologic Survey
Type: Geologic, coal seam
Phase: Pre-injection
Scale: TBD
Highlights: Will explore the possibility of injecting untreated landfill gas (50/50 CO_2/CH_4) into a coal bed for both enhanced CBM recovery and landfill gas purification.
http://www.netl.doe.gov/publications/factsheets/project/Proj324.pdf

MARSHALL COUNTY, WV
Lead: Consol Energy
Type: Geologic, coal seam
Phase: Pre-injection, 2005 injection planned
Scale: 26,000 tons CO_2 over 1 year
Highlights: Plan to demonstrate horizontal CO_2 injection wells with up to 3,000 feet of horizontal length.
http://www.consolenergy.com/content.asp?c=GreenhouseGasManagement_20030613113634

YOLO COUNTY, CA
Lead: Yolo County Planning and Public Works Dept.
Type: Non-CO_2, LFG
Phase: Construction of test cells completed
Scale: 12 acres
Highlights: Seek to demonstrate LFG generation over 5-10 years as opposed to typical 10-30 years for more economical recovery.
http://www.netl.doe.gov/publications/factsheets/project/Proj199.pdf



NEW HAVEN, WV
Lead: American Electric Power
Type: Geologic, Saline formation
Phase: Pre-injection
Scale: TBD
Highlights: Injection well revealed low permeability in target zone; evaluating potential storage capacity in shallower formations.

SAN JUAN BASIN, NM
Lead: Burlington Resources, Advanced Resources International
Type: Geologic, coal seam
Phase: Post-injection
Scale: 280,000 tons CO_2 over 6 years
Highlights: Developed improved understanding of coal swelling and ability to predict CO_2 storage capacity.
http://www.netl.doe.gov/publications/factsheets/project/Proj228.pdf

HAZARD, KY
Lead: University of Kentucky
Type: Terrestrial, tree planting
Phase: Third year of planting
Scale: 500 acres
Highlights: Demonstrated increase site indices and sequestration while increasing water infiltration and reducing sediment runoff with tree planting in uncompacted or ripped mineland.

WEST PEARL QUEEN, NM
Lead: Strata Production
Type: Geologic, Depleting oil reservoir
Phase: Post-injection
Scale: 2,200 tons CO_2 over 42 days
Highlights: Tested tracer and seismic MM&V; examined alternative CO_2 trapping mechanisms.

FRIO, TX
Lead: University of Texas Bureau of Economic Geology
Type: Geologic, Saline formation
Phase: Post-injection
Scale: 1,800 tons CO_2 over 3 weeks
Highlights: Developed a thorough Environmental Assessment under NEPA.
http://www.beg.utexas.edu/environqlty/co2seq/fieldexperiment.htm

PARADISE, KY
Lead: Tennessee Valley Authority
Type: Terrestrial, tree planting
Phase: Post-planting, second growing season
Scale: 100 acres
Highlights: Achieved 80% survival rate for maple poplar, sweet gums, and sycamore using FGD sludge as amendment and irrigating with FGD settling pond water.
http://www.netl.doe.gov/publications/factsheets/project/proj134.pdf

Worldwide Capacity of Carbon Reservoirs

Carbon sequestration reservoir	Capacity, GtC
Oceans*	1,400 - $2x10^7$
Geologic structures*	300 - 3,200
Terrestrial systems (forestation and soil)	>100
Fixation and/or re-use (advanced concepts)	??
1990 Global Anthropogenic Emissions, GtC/yr	6.0

*Source: *Carbon Dioxide Disposal from Power Stations*, IEA Greenhouse Gas R&D Programme, 1998; Carbon Management, Assessment of Fundamental Research Needs, DOE Office of Science.

Range Estimates for CO2 Sequestration in U. S. Geologic Formations

Geologic formation	Capacity estimate (GtC)	Source
Deep saline aquifers	1-130	Bergman and Winter 1995
Natural gas reservoirs in the United States	25[a] 10[b]	R. C. Burruss 1977
Active gas fields in the United States	0.3/year[c]	Baes et al. 1980
Enhanced coal-bed methane production in the United States	10	Stevens, Kuuskraa, and Spector 1998

[a]Accuming all gas capacity in the U. S. is used for sequestration
[b]Accuming cumulative production of natural gas is replaced by CO_2
[c]Accuming that produced natural gas is replaced by CO_2 at the original reservoir pressure

CO_2 Sequestration Projects at The Energy Institute

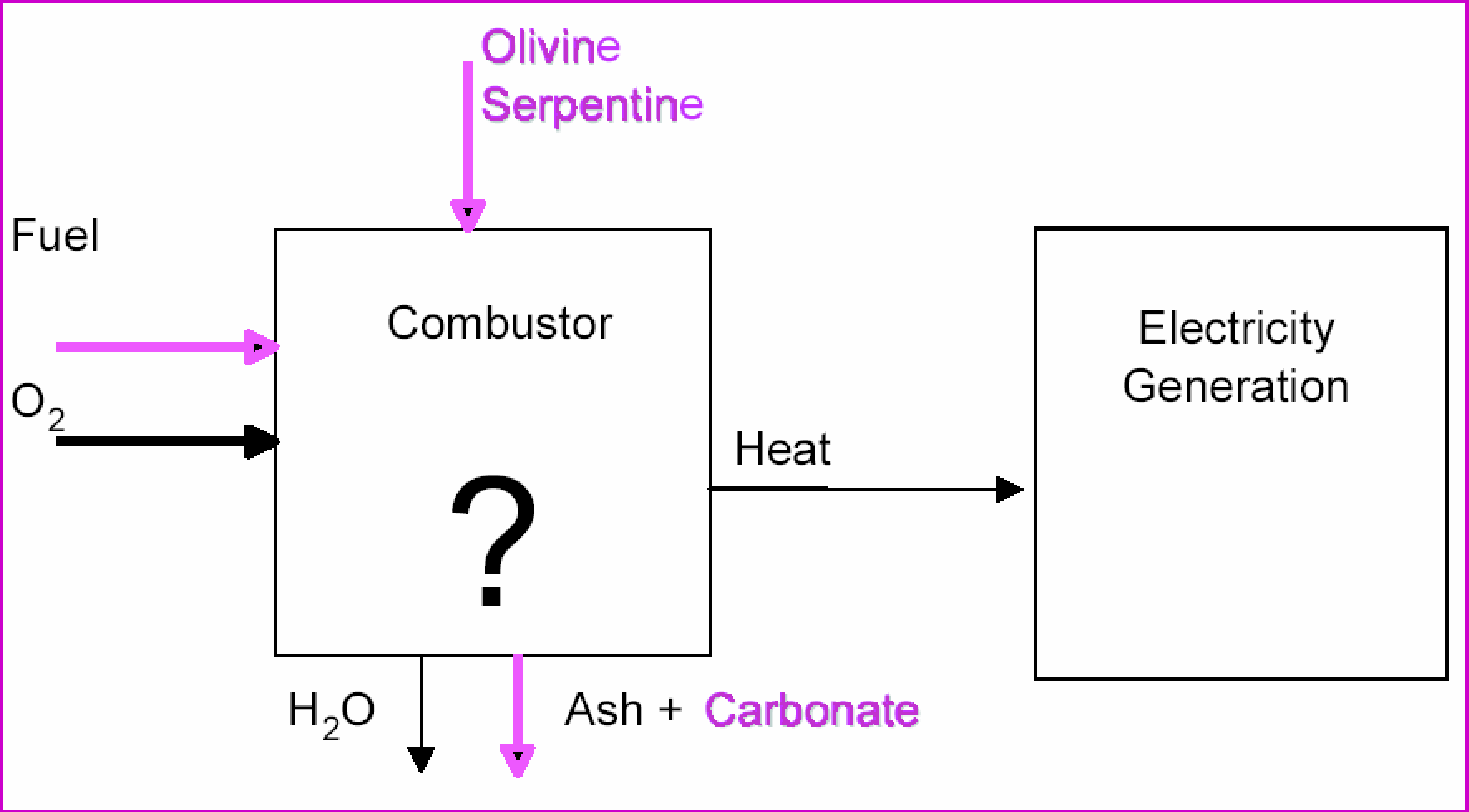
1. Mineral Carbonation

The conversion of natural silicate minerals by CO_2 to produce geologically stable carbonate minerals and silica,

$$Mg_3Si_2O_5(OH)_4 + 3\ CO_2 \Rightarrow 3\ MgCO_3 + 2\ SiO_2 + 2\ H_2O$$

+63,6 kJ per kmo

CO_2 Sequestration Projects at The Energy Institute



First Step: Sulfuric Acid Treatment

$Mg_3Si_2O_5(OH)_4$ + 3 H_2SO_4 $\Rightarrow$ 3 Mg^{2+} + $SO4^{2-}$ + 2 SiO_2 + 5 H_2O

Second Step: Titration

Mg^{2+} + $SO4^{2-}$ + 2NaOH $\Rightarrow$ $Mg(OH)_2$ +Na_2SO_4

Third Step: Carbonation Reaction

$Mg(OH)_2$ + CO_2 $\Rightarrow$ Mg_2CO_3 + H_2O

2. CO_2-Brine-Mineral Interactions

- ❖ For geological sequestration, brine sequestration, mineral sequestration
- ❖ The gas
- ❖ The rock
- ❖ The brine
- ❖ The interactions

BRINEFIELD SEQUESTRATION
Sleipner Project

Hydrodynamic trapping: traps the CO_2 into flow systems for geological periods of time

? main concern : CO_2 leakage through imperfect sealing

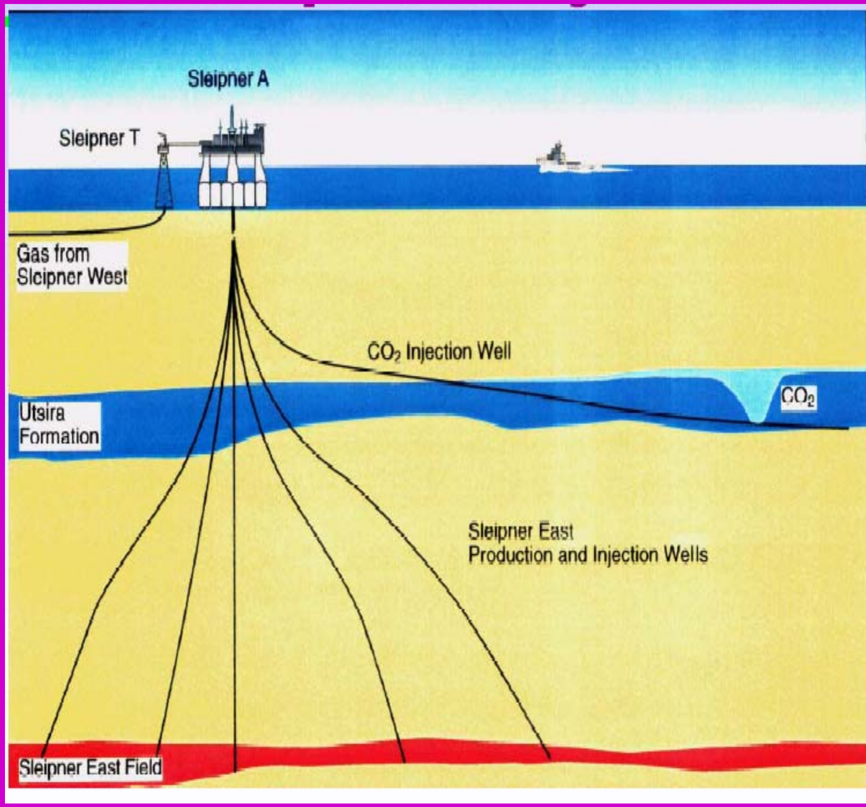
Solubility trapping: traps the CO_2 in the saline solutions

? Main concern: solubility limit and salt out effects

Mineral trapping: react with brine and rock matrix to mineralize and immobilize CO_2 (e.g., calcite, dolomite, siderite)

? main question: fast enough

? time frame for performance assessment



THANK YOU!!!