Lawrence Livermore National Laboratory

Carbon Capture and Sequestration

National Association of Clean Air Agencies
Spring Membership Meeting
May 6, 2008

Robin L. Newmark

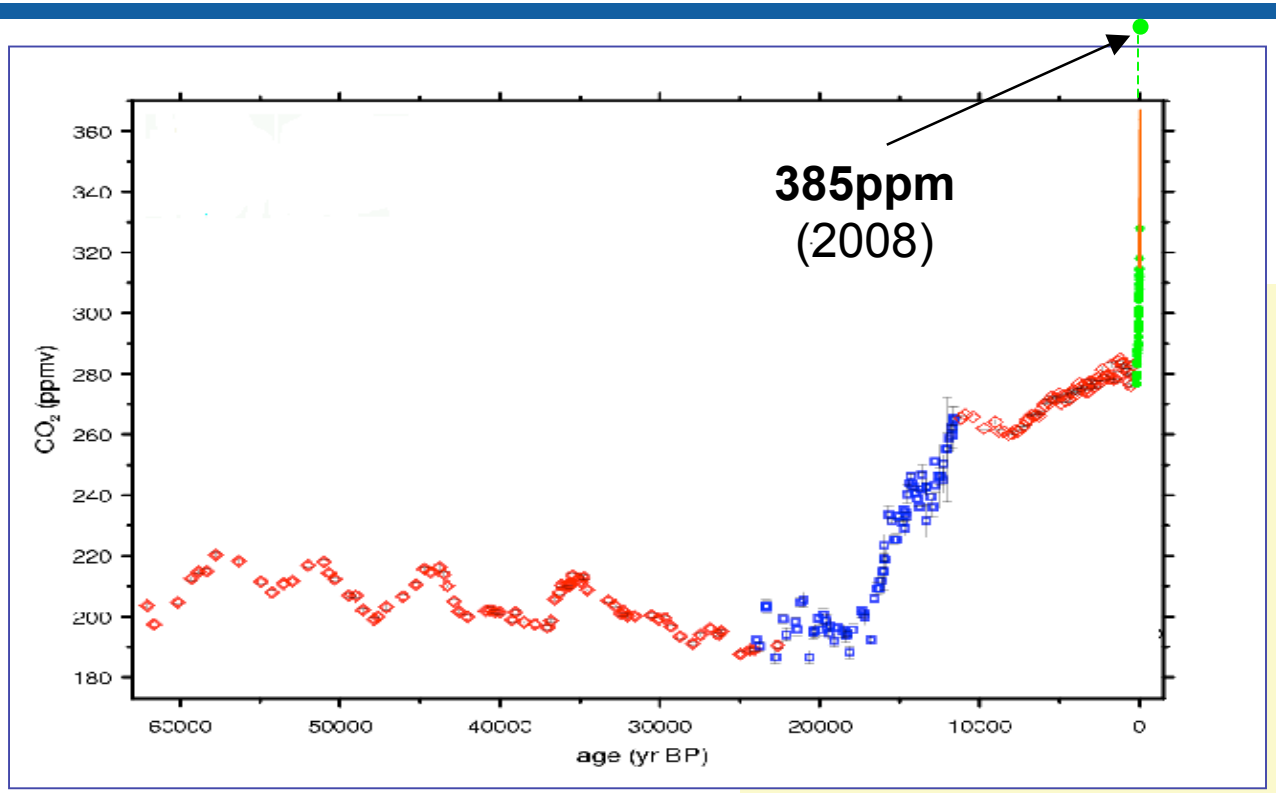
Deputy Program Director, Energy and Environmental Security

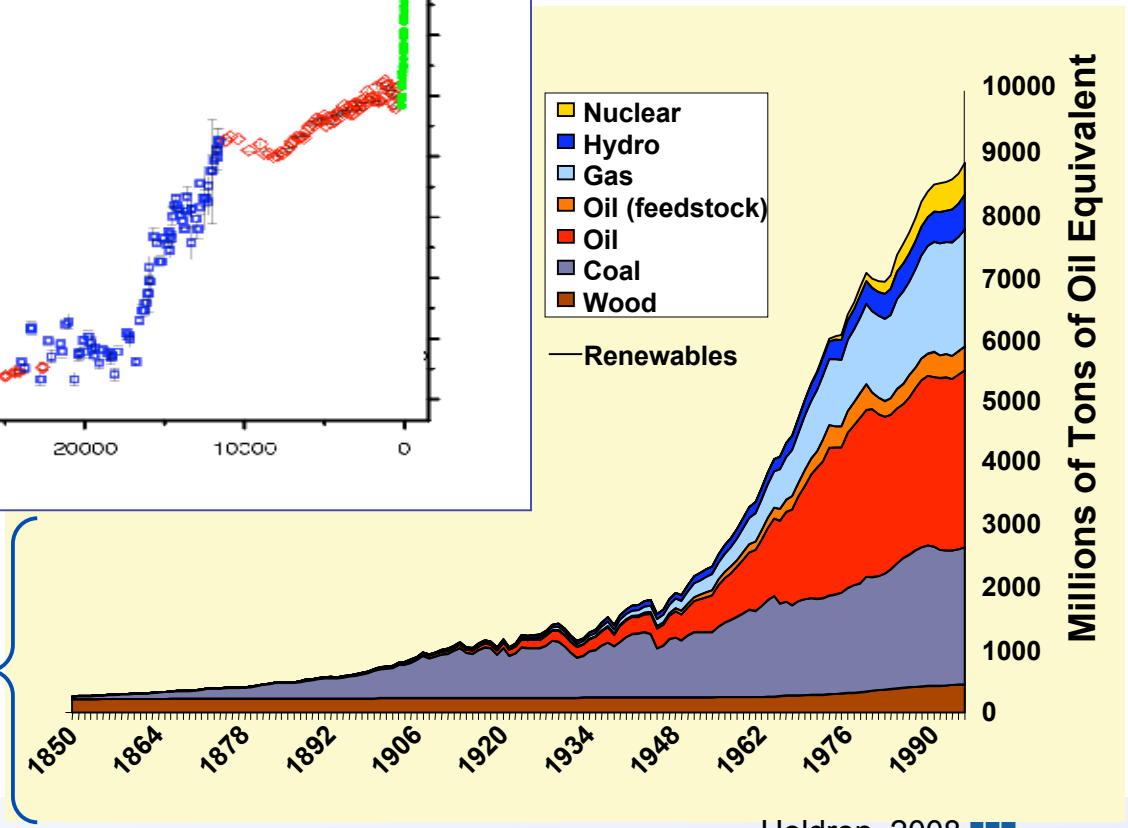
Lawrence Livermore National Laboratory, P. O. Box 808, Livermore, CA 94551

This work performed under the auspices of the U.S. Department of Energy by
Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344

LLNL-PRES-403382

The dominant energy trends are increased fuel use and increased CO_2 emission



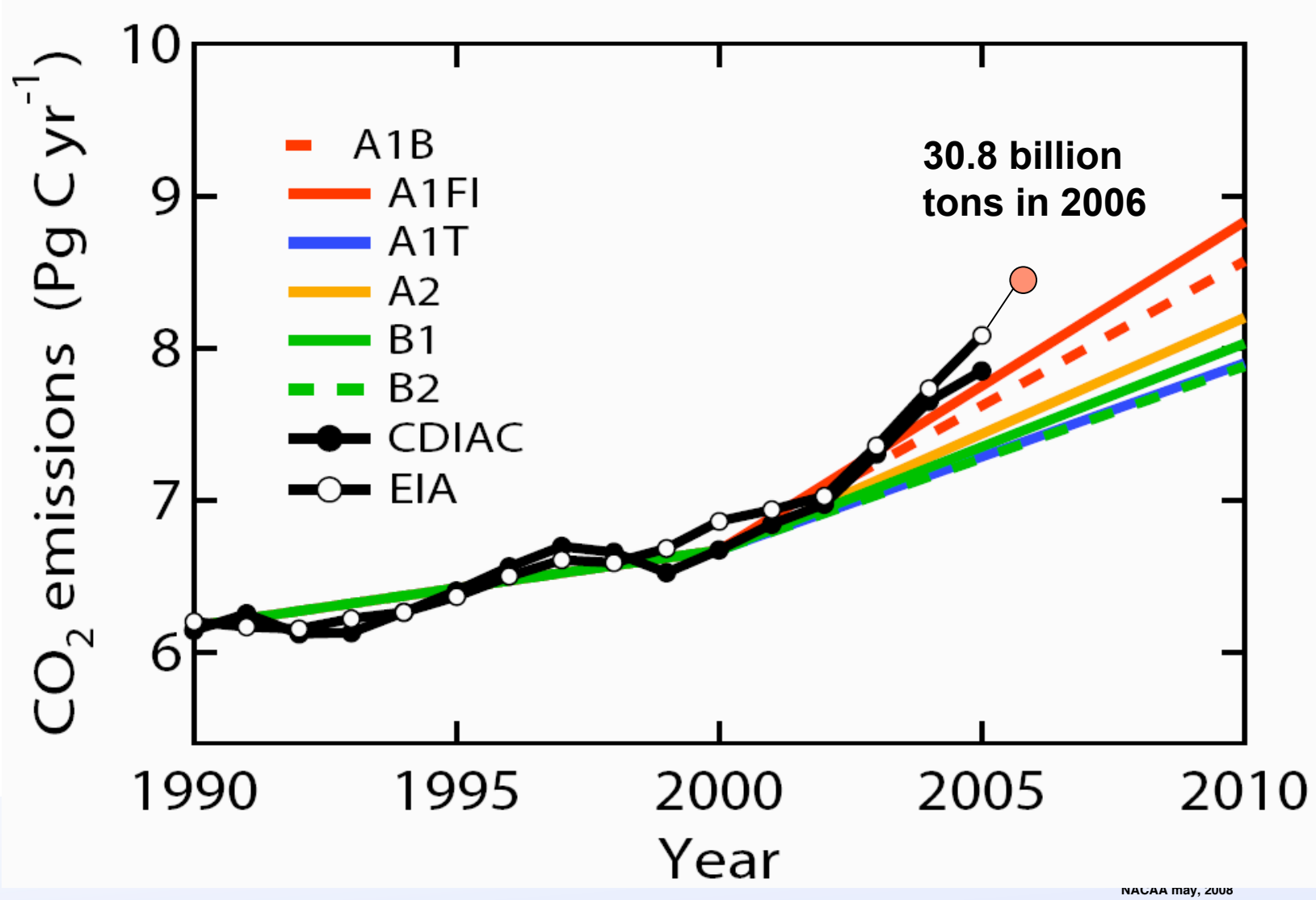


We have never used less of any fuel

If all future demand were met by zero carbon sources, we'd have the same graph

Holdren, 2008

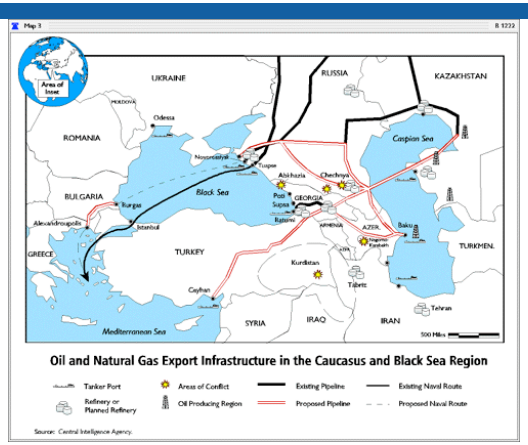
Actual emissions for 2000-2007 are well above the worst case IGCC emissions scenarios



The Times They Are a-Changing…

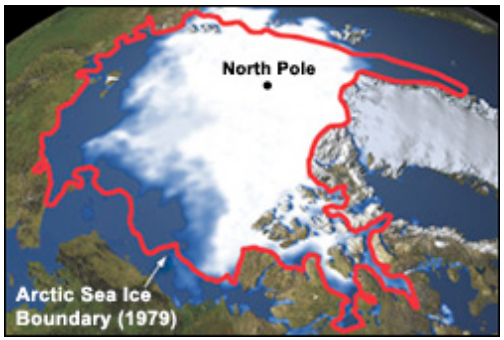
Energy resources

- Increasing global competition and volatility
- Energy import dependency risks
- New resources needed: conventional, unconventional and renewable



Climate Change

- Increasing convergence of political and public opinion
- Improved climate models and predictions
- Clearer delineation of risks, observations of changes



Industry and Government need and want action

- Major policy shifts (Kyoto in force, US acknowledges signal, State actions)
- Major generating, energy, coal companies
- Emerging CO_2 markets, finance/insurance interest
- Carbon market likely coming
- Already driving activity


Courtesy ErgoExergy

We will likely continue to use fossil fuel resources—CCS mitigates the emissions and verifies effectiveness

Proved Recoverable World Reserve

Natural Gas
More than
5,000 Tcf

Coal
984 billion tons

Oil
Just over 1
trillion barrels

Estimated World Resource

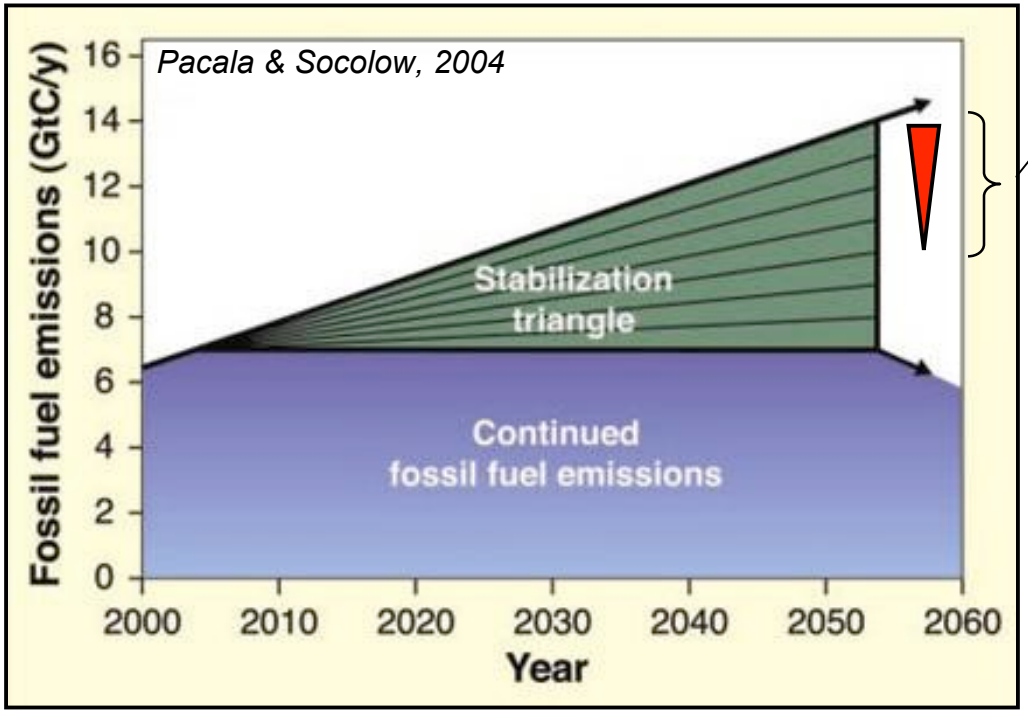
Methane Hydrates
Up to 270 Million Tcf

Proved recoverable reserves should last most of the 21st century

NETL

World Energy Council
1998 Survey of Energy Resources

CO_2 Capture & Storage (CCS) represents an attractive pathway to substantial GHG reductions



Using CCS, we can reach 15-50% of abatement needed for stabilization at 500 ppm

CCS

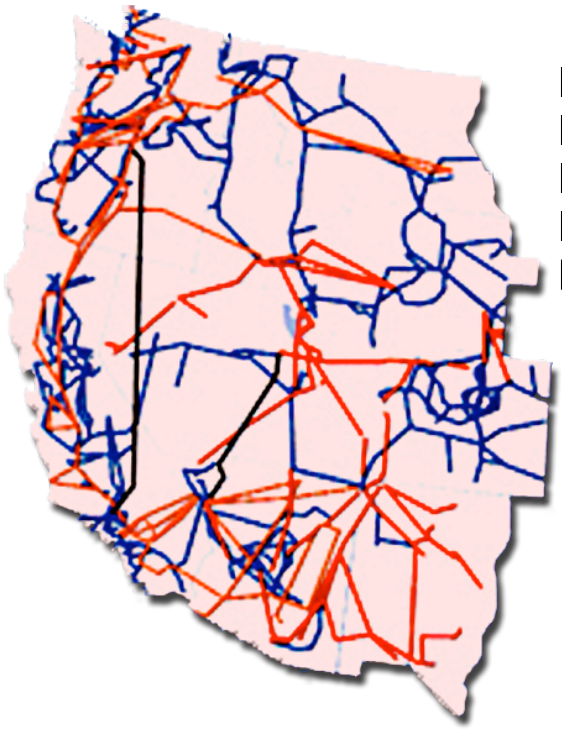
- Is a key portfolio component (with efficiency, conservation, renewables)

- Cost competitive to other carbon-free options (e.g., wind, nuclear)

- Uses existing technology

CCS appears to be an actionable, scaleable, relatively cheap, bridging technology

"Incentives" are now a reality for producers in the West: CA's SB1368 influences in the entire western United States



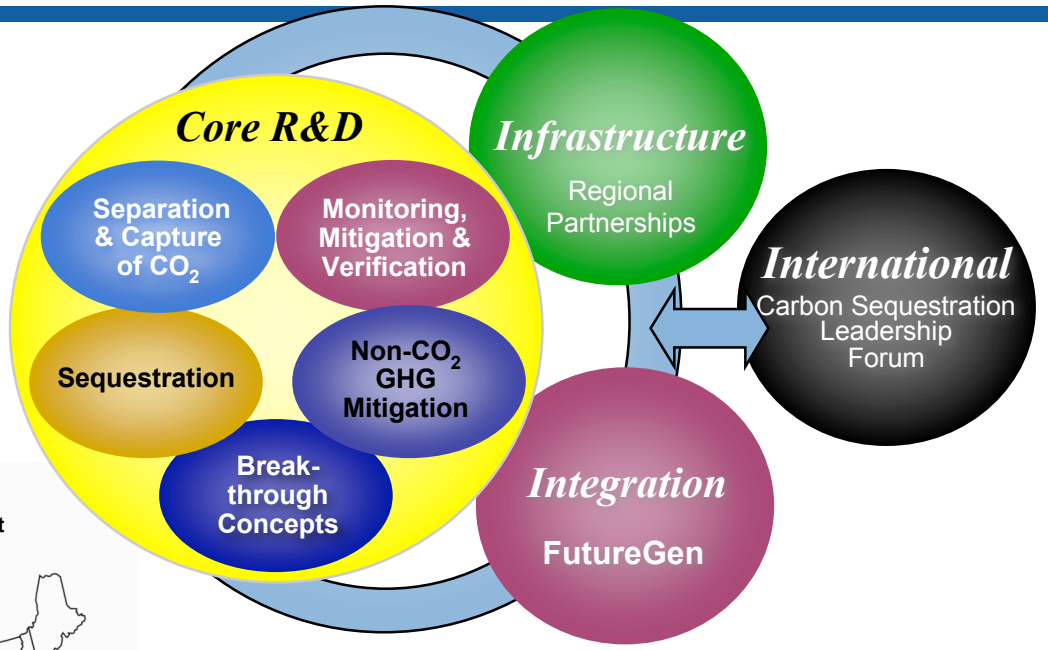
Colstrip Power Plant

- Consumes 10 million tons of coal per year
- O&M Budget—$97.6M Capital—$52.6M
- Annual CO_2 Emissions—18,255,571(Tons) (.9 ton/megawatt-hour)
- Estimate to capture 90% CO_2 by current available technology: $50/ton CO_2 removed (includes $330 Million capital)

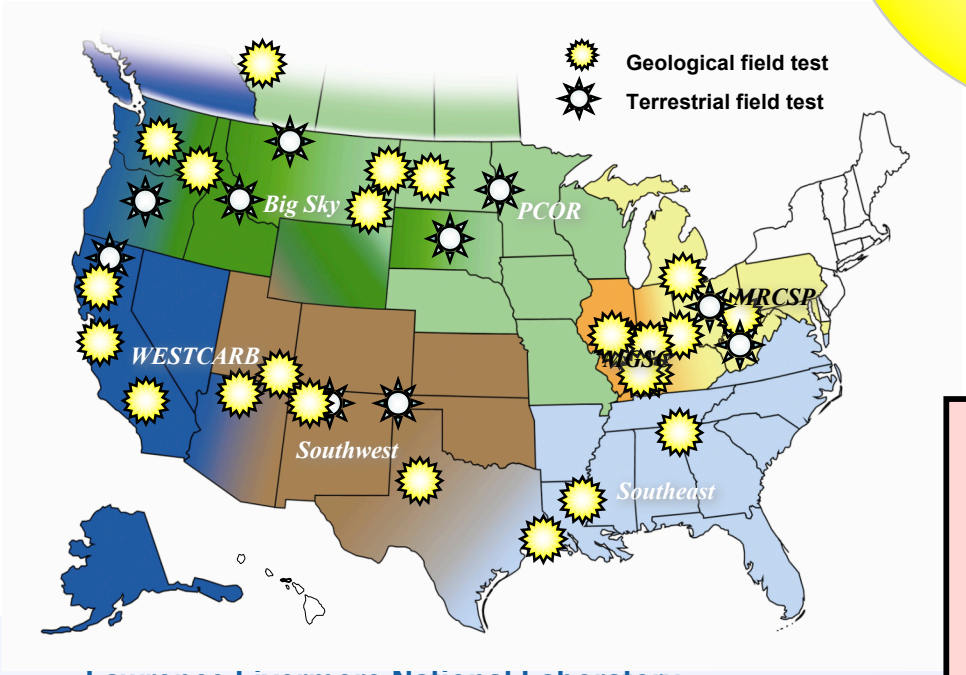
- California Law SB 1368 requires California utilities to purchase new electricity base load contracts that have emissions no greater than a combined-cycle, gas-turbine plant
- Typical coal producers like the 2,276 MW Colstrip, Montana plant will have to sequester about 1/2 of their carbon

To address CCS challenges, the DOE Clean Coal Program has a substantial research effort

The US program ($120M/y) has three main planks: FutureGen, Core R&D, and the Regional Partnerships.

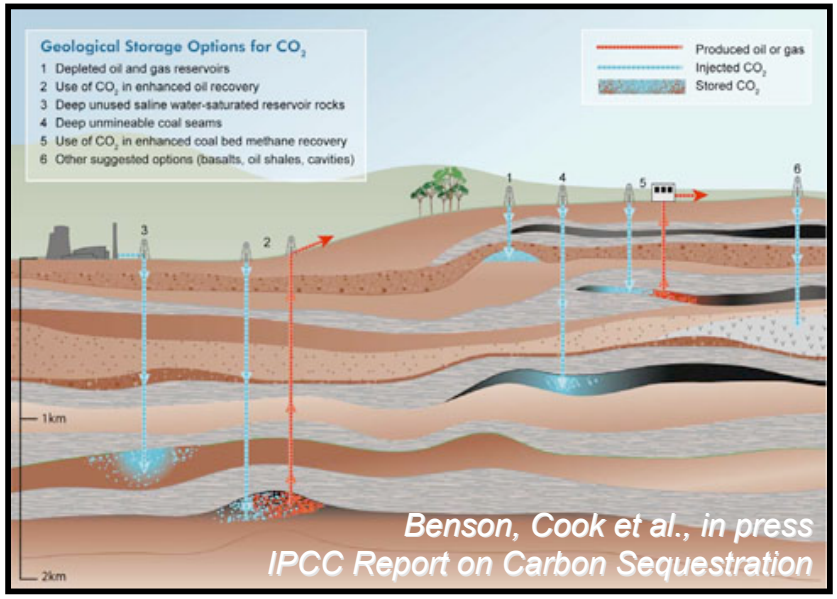


Courtesy US DOE



The partnerships work in 40 states and 4 provinces, with members from industry, government, academia, and FFRDCs

Carbon dioxide can be stored in multiple geological targets, usually as a supercritical phase



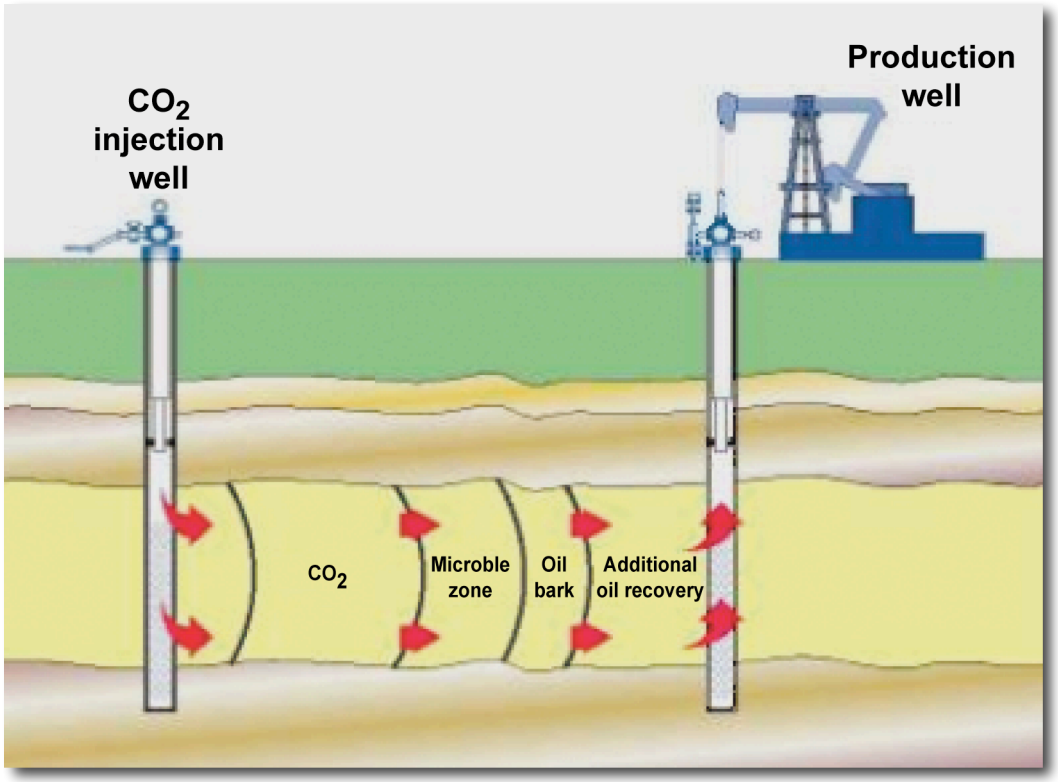
Saline Formations: *largest capacity (>2,200 Gt for N. America)*

Depleted Oil & Gas fields: *potential for enhanced oil and natural gas recovery*

Unmineable Coal Seams: *potential for enhanced gas recovery as well*

EOR/Depleted Oil & Gas fields are early actors
Saline aquifers hold the largest storage capacity
There is both overlap and distinctiveness between them

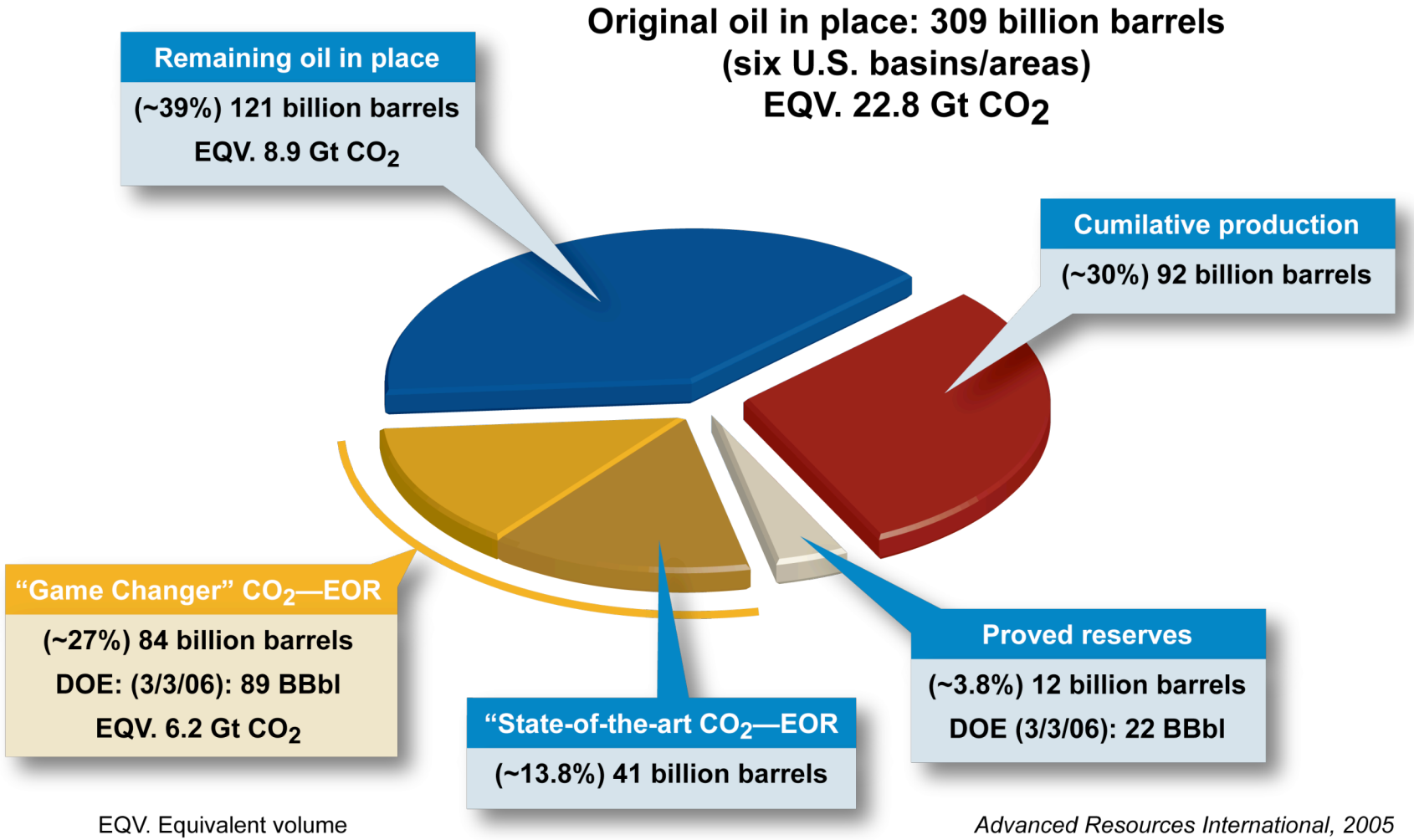
CO_2 capture's first beneficiary: enhanced oil recovery (EOR)



At the right temperature and pressure, CO_2 will dissolve in oil through multiple-contact miscibility. This decreases in-situ viscosity and increases oil volume, improving recovery of oil in place.

Although some CO_2 is co-produced, much remains dissolved in subsurface oil, where it is effectively sequestered.

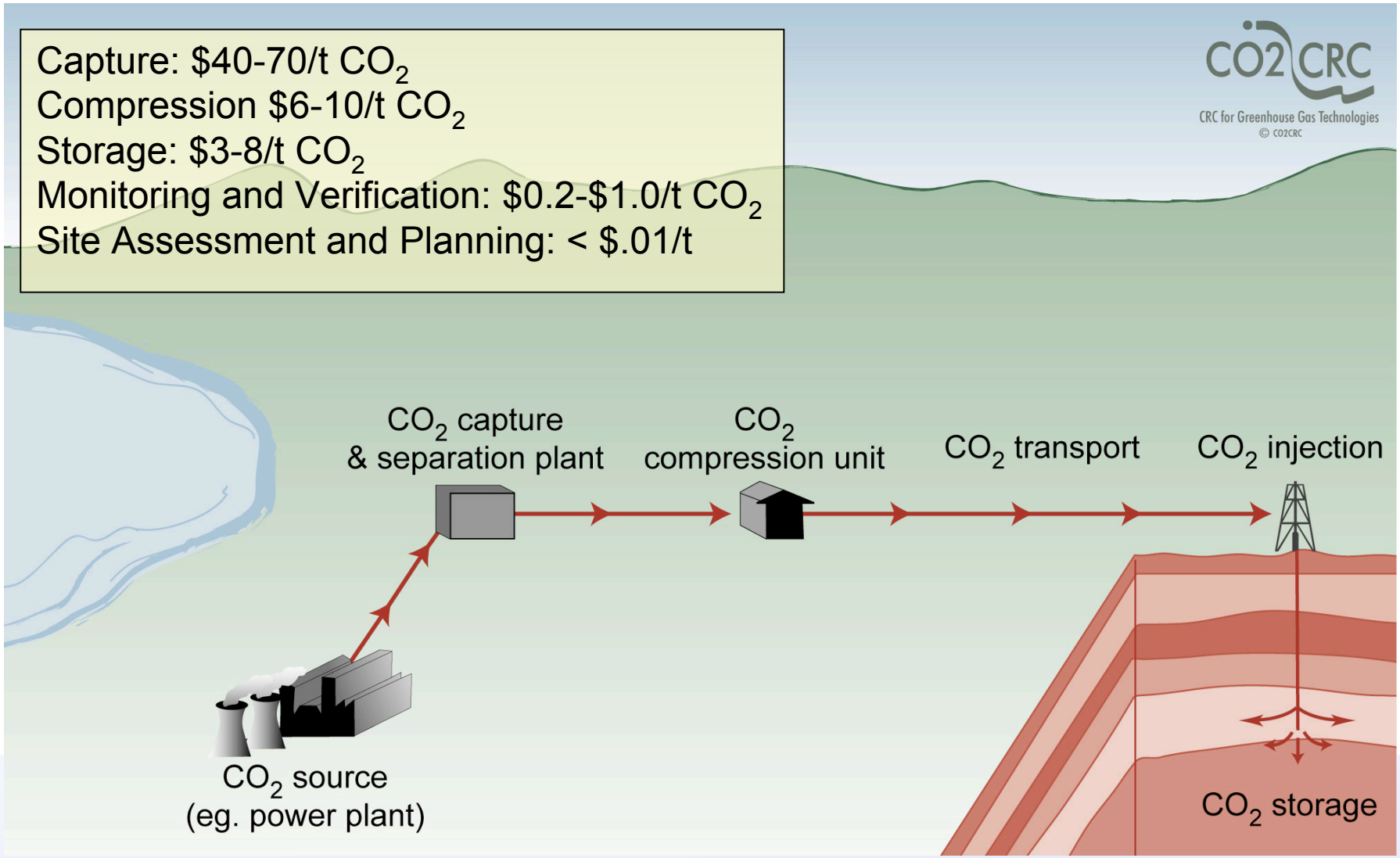
Available CO_2 will dramatically increase U.S. oil production before going into permanent "storage"



EQV. Equivalent volume

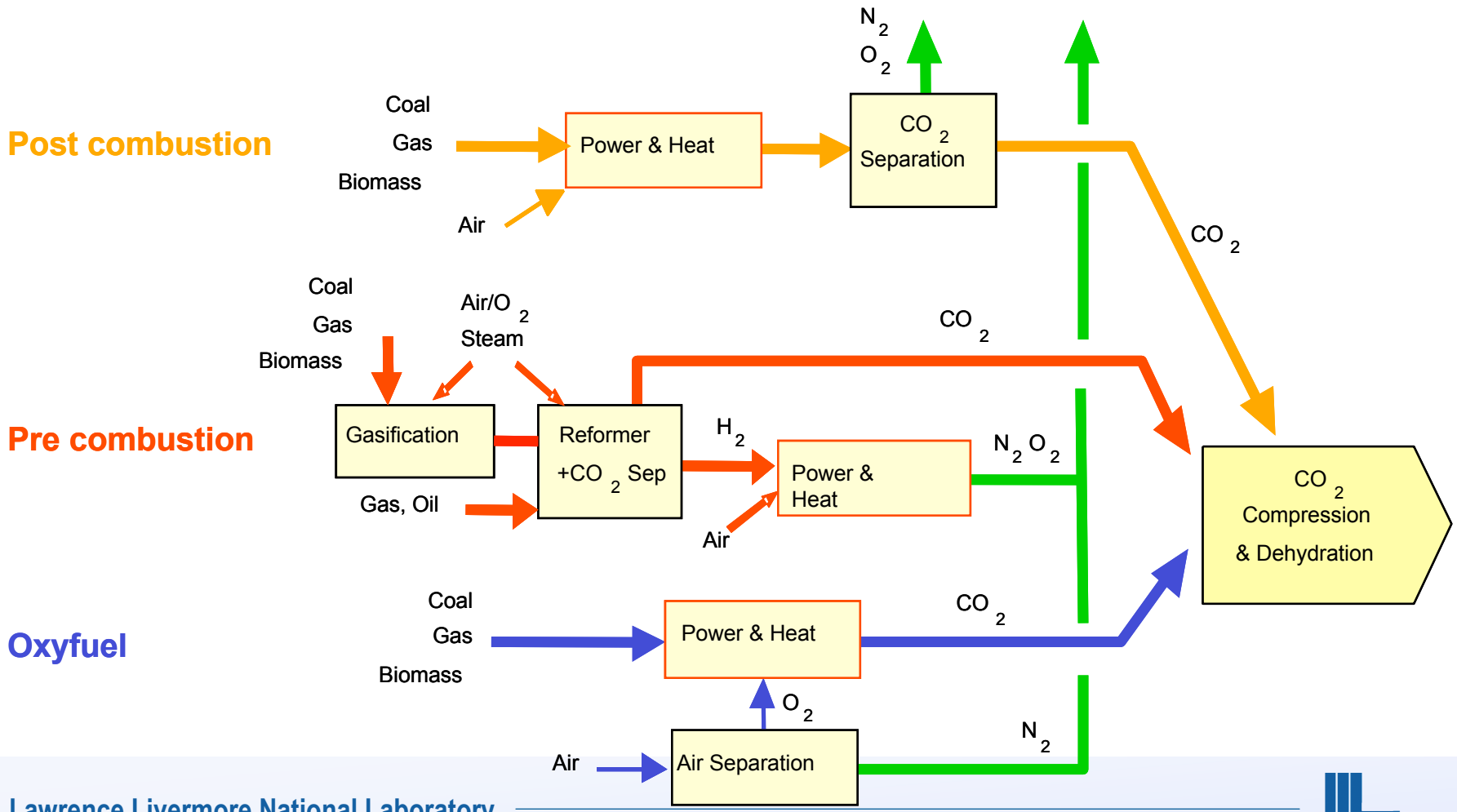
Advanced Resources International, 2005

Most of the cost is in separation - putting CO_2 in the earth is relatively cheap



Storage requires high purity (>95%) CO_2 streams

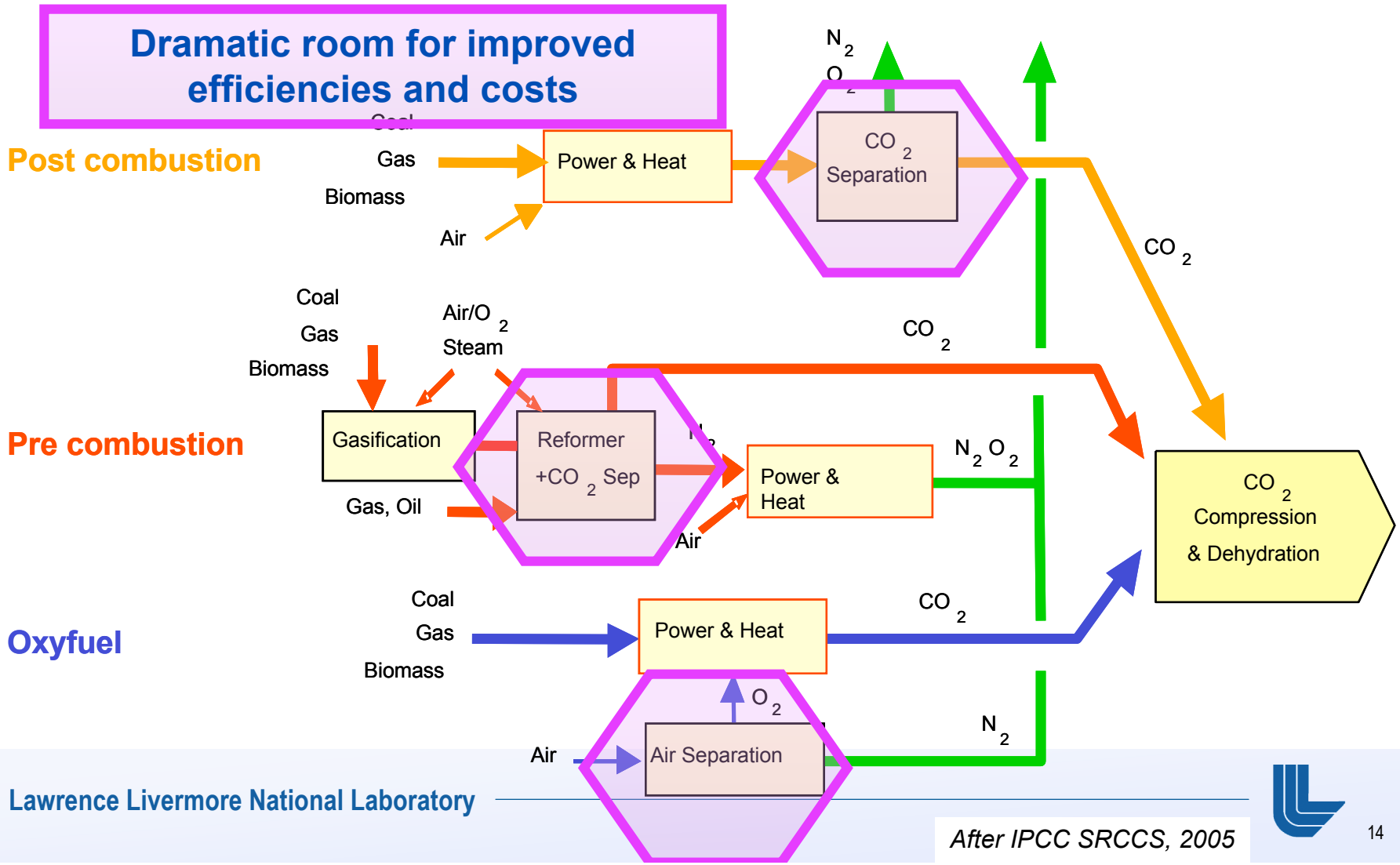
Three technology pathways can capture and separate large volumes of CO_2



After IPCC SRCCS, 2005

Storage requires high purity (>95%) CO_2 streams

Three technology pathways can capture and separate large volumes of CO_2



After IPCC SRCCS, 2005

Pre-combustion separation converts carbon to CO_2 before burning

Coal, pet-coke, or biomass can be gasified, creating "syngas"

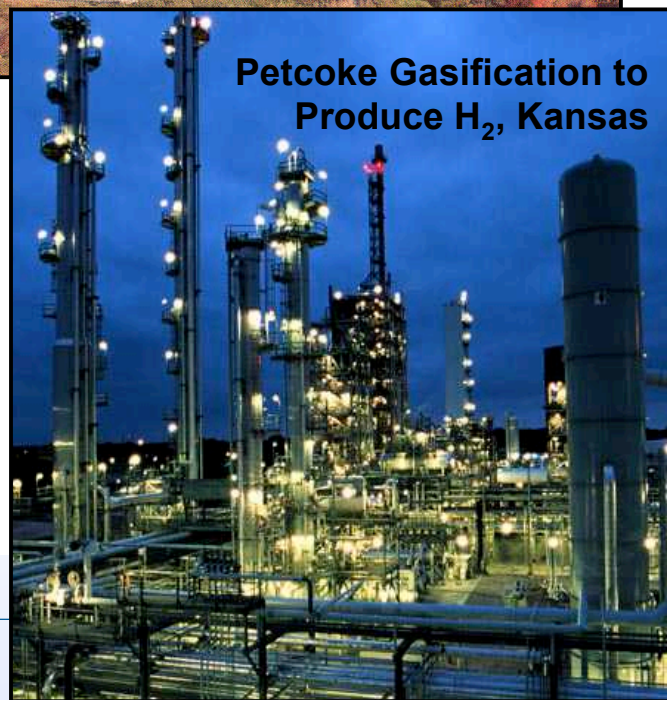
$$C + H_2O \longrightarrow H_2 + CO$$

Syngas or natural gas can be added to water and chemically shifted

$$H_2 + CO + H_2O \longrightarrow 2H_2 + CO_2$$

Hydrogen and CO_2 can be separated using physical sorbents (e.g., Selexol)

Hydrogen can be burned, and CO_2 sequestered



This technology has been well-tested at industrial scale for >50 years

Cost ~$35-50/ton CO_2

Post-combustion capture separates CO_2 from nitrogen for storage

Chemical sorbents such as amines currently present the lowest cost options for industrial applications

Novel sorbents, such as chilled ammonia, and novel technologies hold out the promise of substantial costs reductions

This technology has been well-tested at industrial scale for >70 years

Cost ~$40-60/ton CO_2

Burning coal or natural gas in pure oxygen produces CO_2

Oxygen is separated from the air and fed into the boiler or reactor.

CO_2 is usually recycled into the boiler to moderate temperature

The product is CO_2 and steam, which can be easily removed by compression

Issues:

- Oxygen separation is expensive

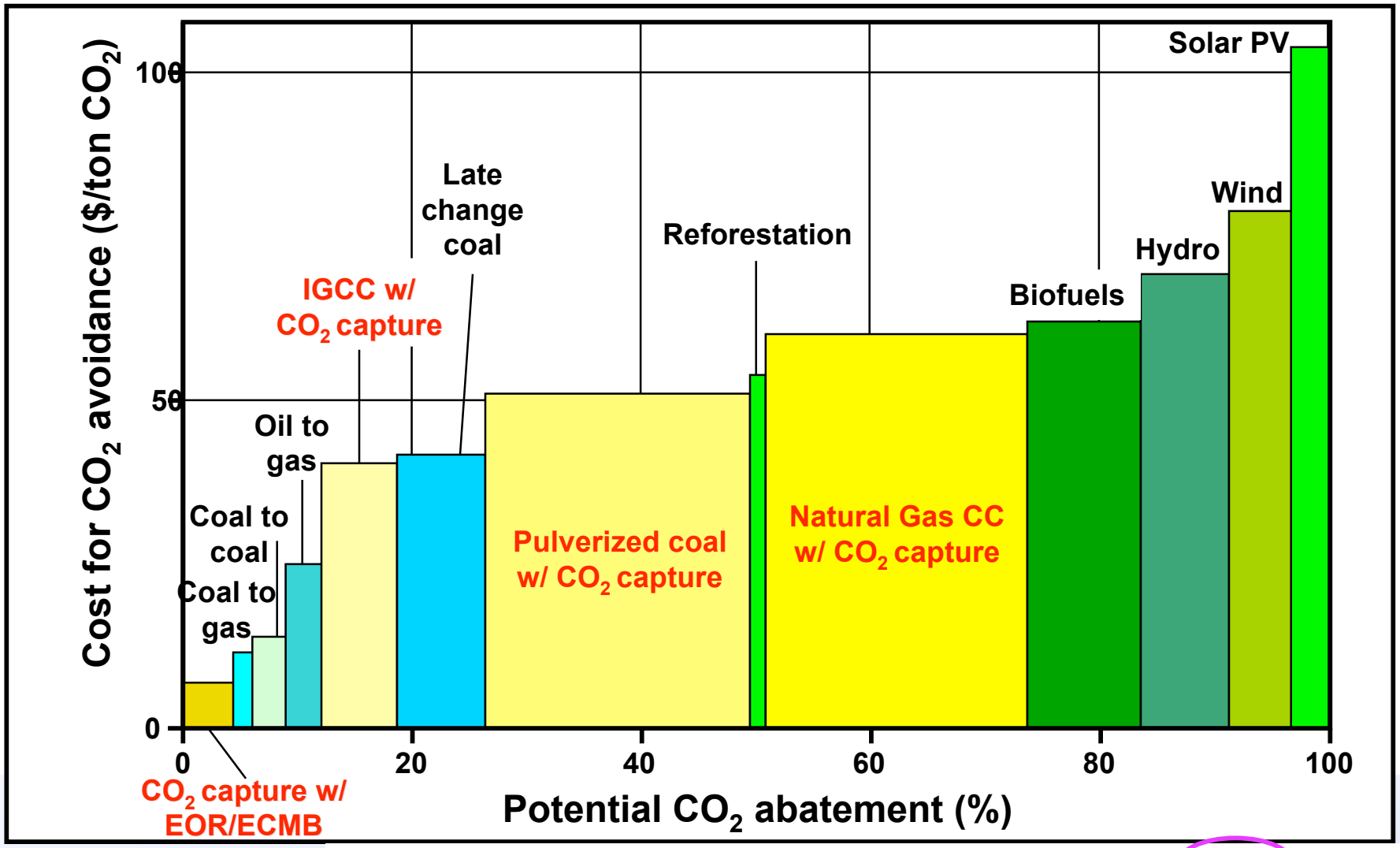
- Best efficiency achieved with high temperature combustion: requires novel materials and designs

This technology is not tested commercially, but holds great promise for retro-fit and new plants

Estimated Cost ~$25-40/ton CO_2

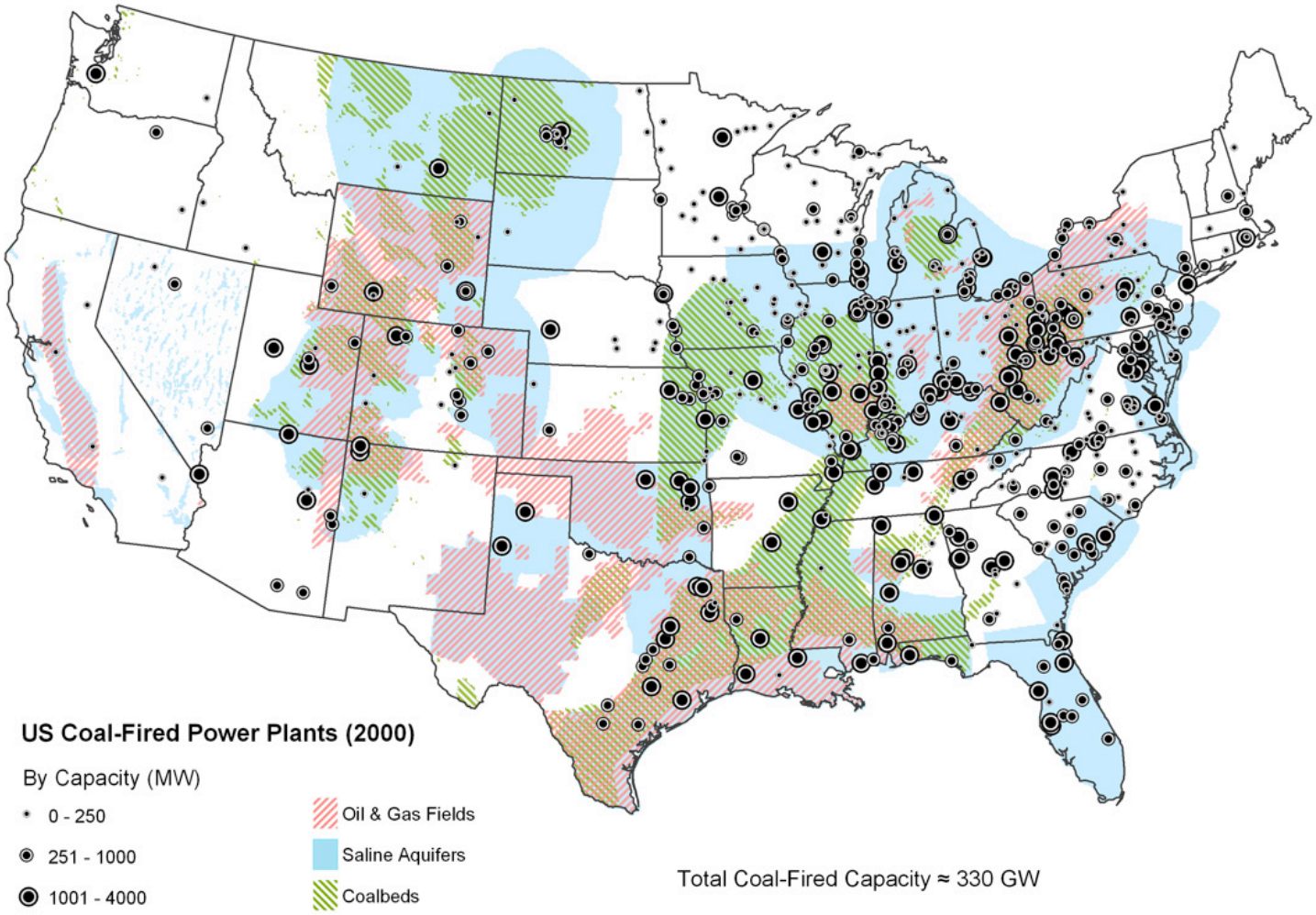
CCS Costs today appear competitive

Opportunities for dramatic cost reductions are substantial



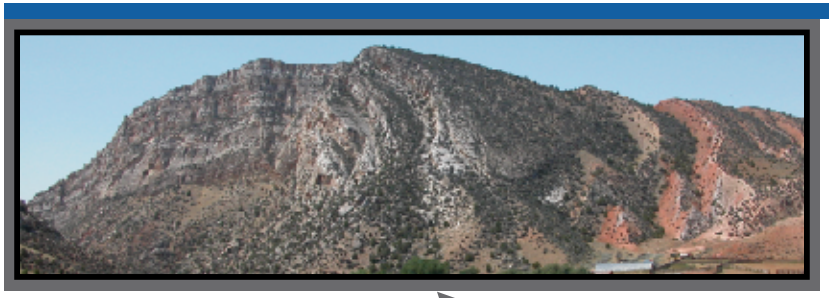
Adapted from Lars Stromberg, Vattenfall AB, Electricity Generation, Sweden, 2001; SPA Pacific

The US is well endowed with sequestration resources

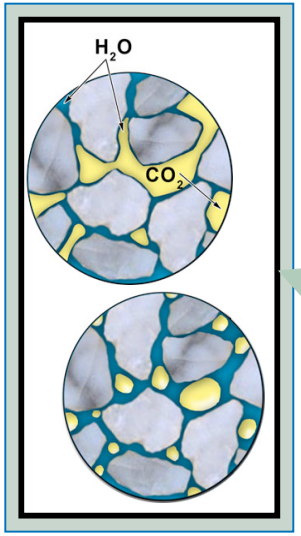


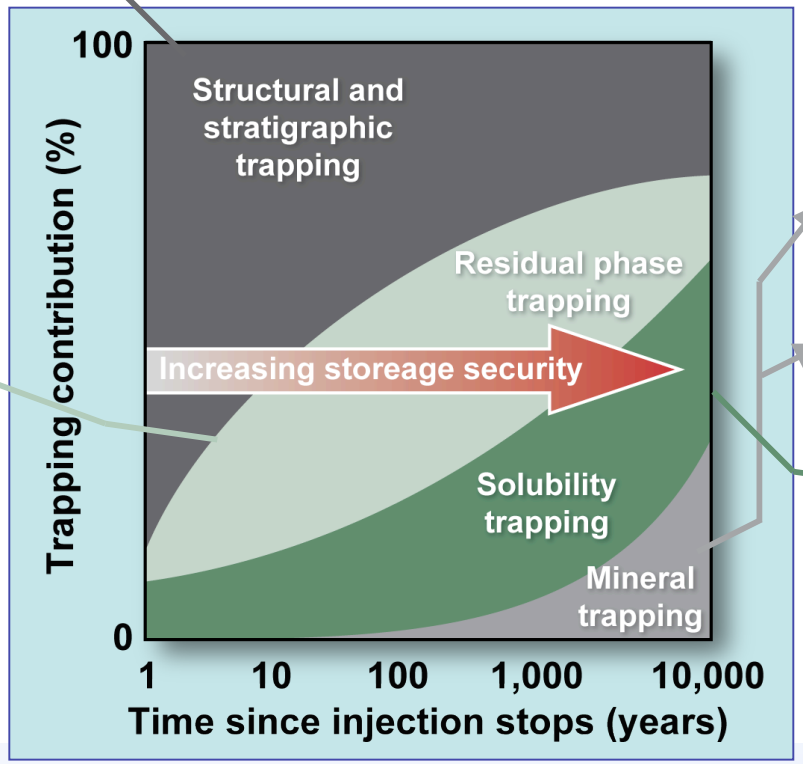
Future of Coal Report (MIT, 2007)

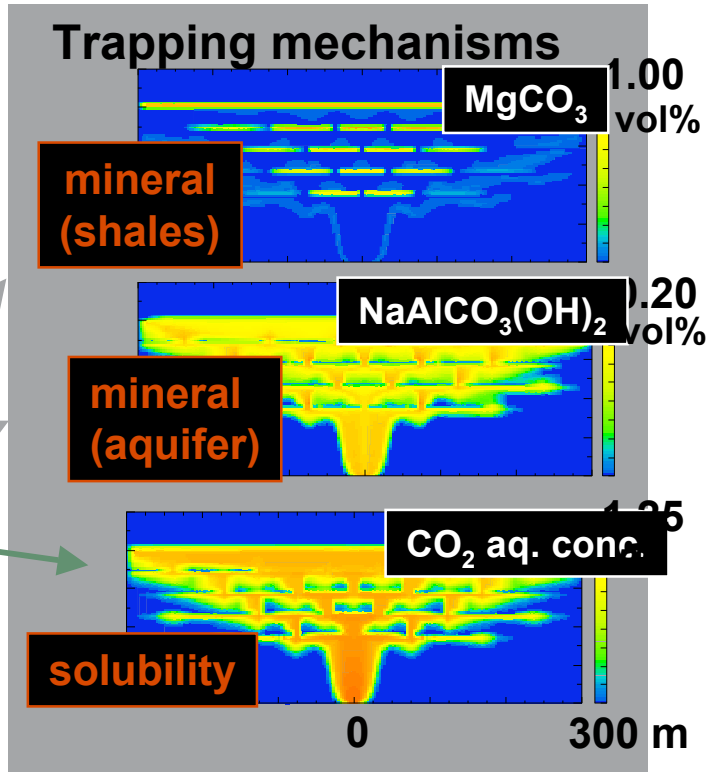
The Earth's crust is well configured to trap large CO_2 volumes indefinitely



Multiple storage mechanisms work at multiple length and time scales





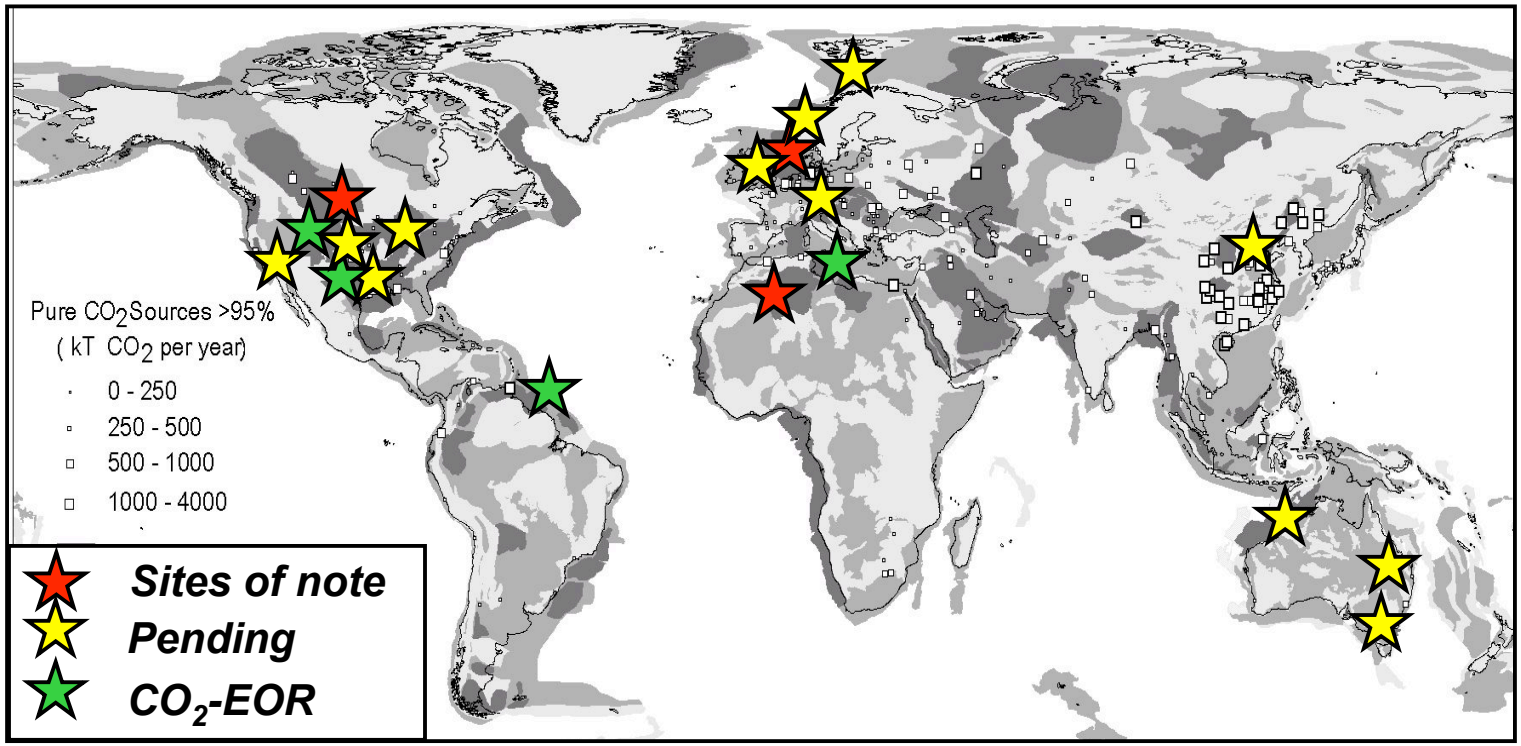


Johnson et al (2004, 2005)

Over time, risks decrease, permanence increases

Several large projects exist, with many pending

They demonstrate the high chance of success for CCS



These studies are still not sufficient to provide answers to all key technical questions or to create a regulatory structure