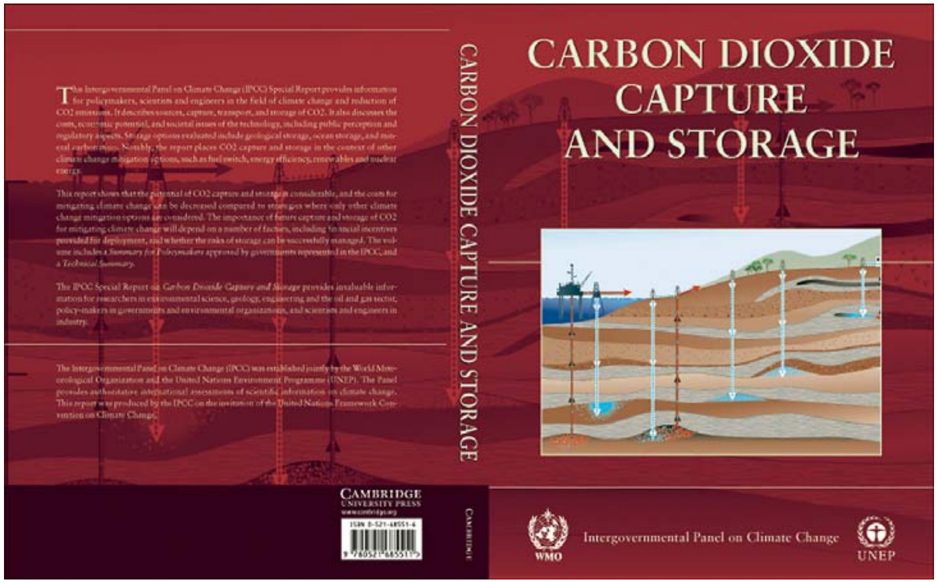
IPCC Special Report on Carbon Dioxide Capture and Storage



Edward S. Rubin

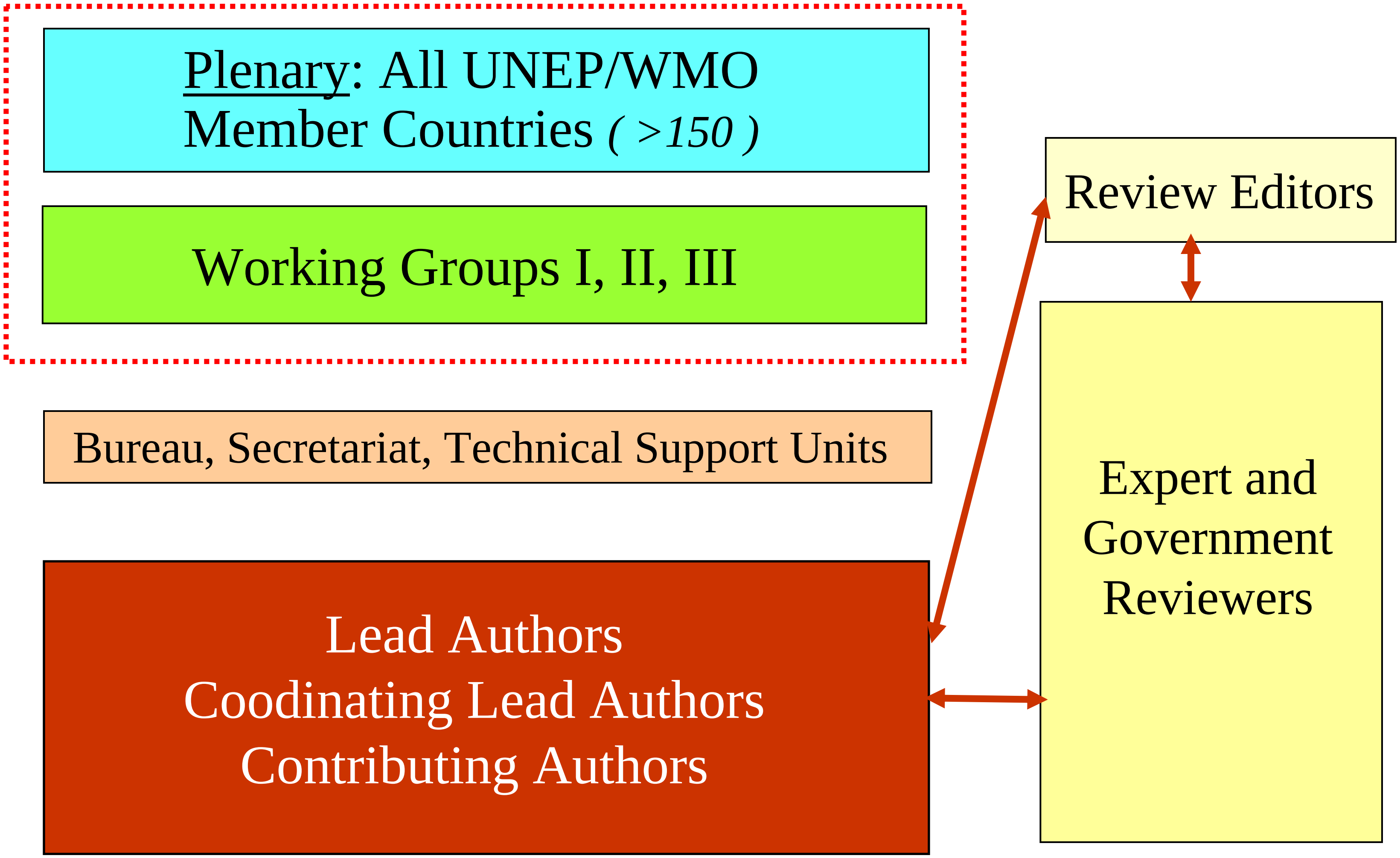
Carnegie Mellon University, Pittsburgh, PA

Presentation to the

U.S. Climate Change Science Program Workshop
Washington, DC

November 14, 2005

Structure of the Intergovernmental Panel on Climate Change (IPCC)



About IPCC Reports

- Provide assessments of scientifically and technically sound published information
- No research, monitoring, or recommendations
- Authors are best experts available worldwide, reflecting experience from academia, industry, government and NGOs
- Policy relevant, but NOT policy prescriptive
- Thoroughly reviewed by other experts and governments
- Final approval of Summary by governments

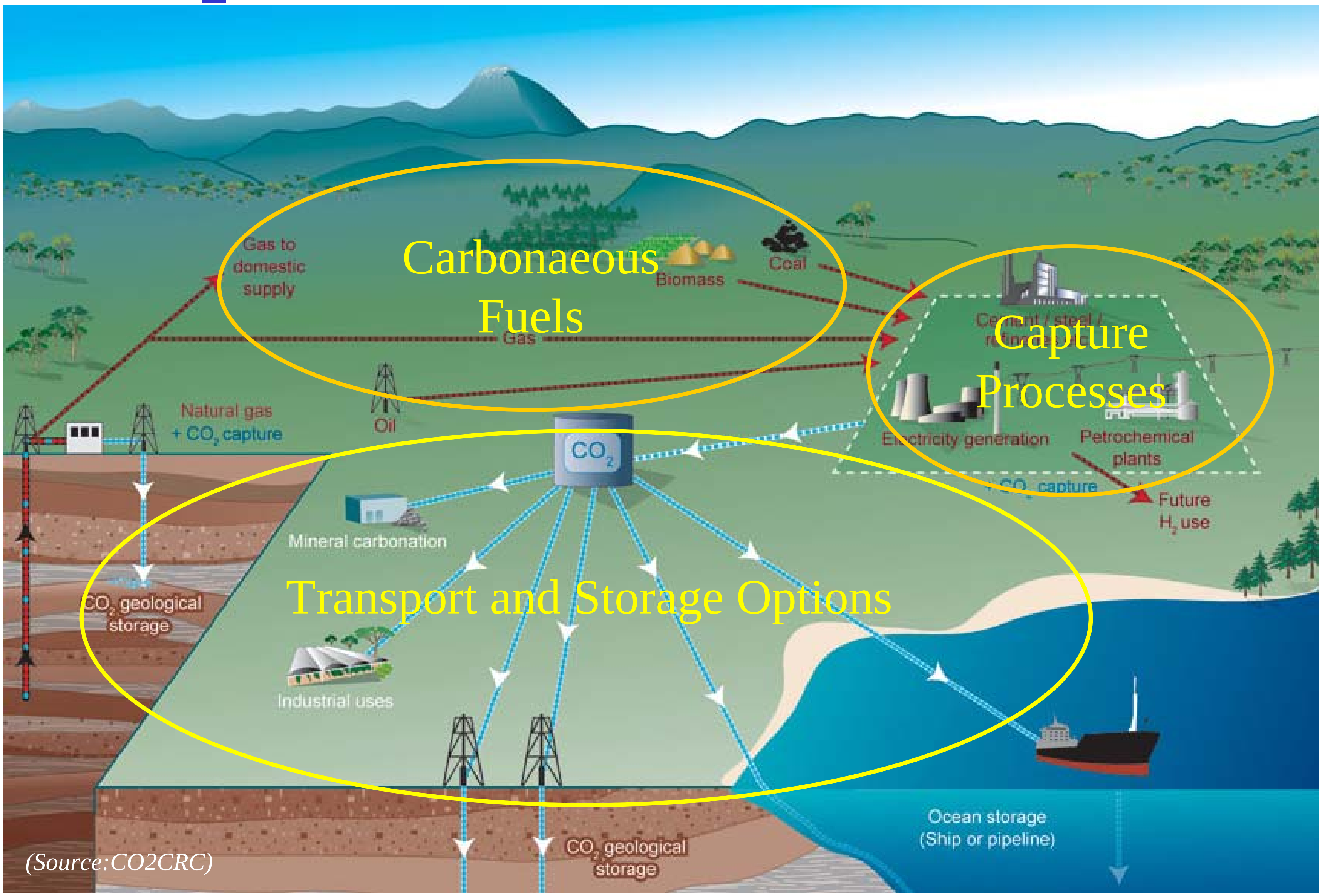
History of the Special Report

- ***<u>2001</u>***: UNFCCC (COP-7) invites IPCC to write a technical paper on geological carbon storage technologies
- ***<u>2002</u>***: IPCC authorizes a workshop (held November 2002) that proposes a Special Report on CO_2 capture and storage
- ***<u>2003</u>***: IPCC authorizes the Special Report under auspices of WG III; first meeting of authors in July
- ***<u>July 2003–June 2005</u>***: Preparation of report by ~100 Lead Authors + 25 Contributing Authors (w/100s of reviewers)
- ***<u>September 26, 2005</u>***: Final report approved by IPCC plenary
- ***<u>December 2005</u>***: Will be presented officially to UNFCCC at COP-11

Why the Interest in CCS?

- The UNFCCC goal of stabilizing atmospheric GHG concentrations will require significant reductions in future CO_2 emissions
- CCS could be part of a portfolio of options to mitigate global climate change
- CCS could increase flexibility in achieving greenhouse gas emission reductions
- CCS has potential to reduce overall costs of mitigation

CO_2 Capture and Storage System



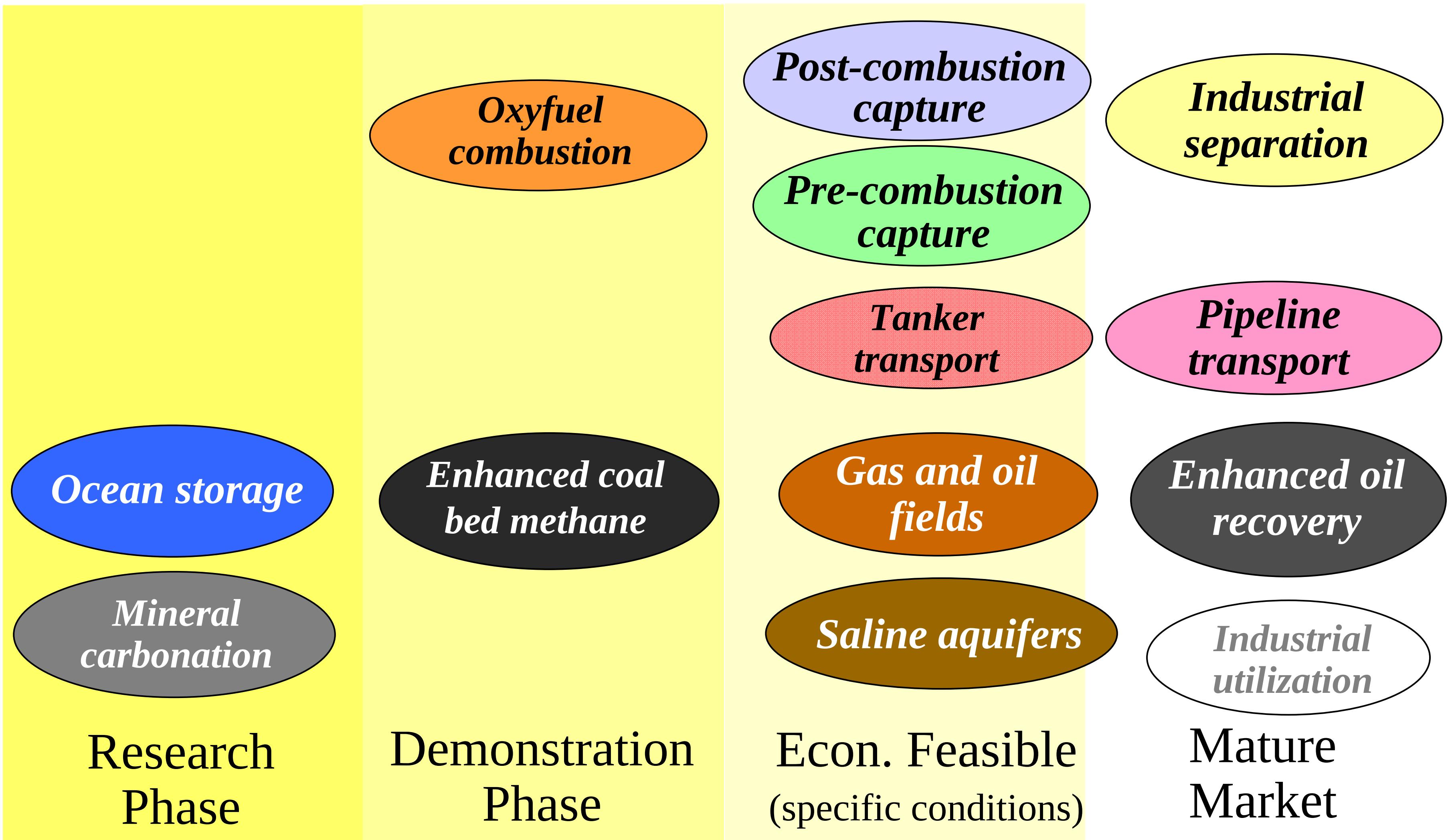
Structure of the Report

1. Introduction
2. Sources of CO_2
3. Capture of CO_2
4. Transport of CO_2
5. Geological storage
6. Ocean storage
7. Mineral carbonation and industrial uses
8. Costs and economic potential
9. Emission inventories and accounting

Key Questions for the Assessment

- Current status of CCS technology?
- Potential for capturing and storing CO_2?
- Costs of implementation?
- Health, safety and environment risks?
- Permanence of storage as a mitigation measure?
- Legal issues for implementing CO_2 storage?
- Implications for inventories and accounting?
- Public perception of CCS?
- Potential for technology diffusion and transfer?

Maturity of CCS Technologies



Status of Capture Technology

- CO_2 capture technologies are in commercial use today, mainly in the petroleum and petrochemical industries
- Capture also applied to several gas-fired and coal-fired boilers, but at scales small compared to a power plant
- Net capture efficiencies typically 80-90%
- Integration of capture, transport and storage has been demonstrated in several industrial applications, but not yet at an electric power plant
- R&D programs are underway worldwide to develop improved, lower-cost technologies for CO_2 capture; potential to reduce costs by ~20–30% over near term, and significantly more in longer term

Industrial Capture Systems

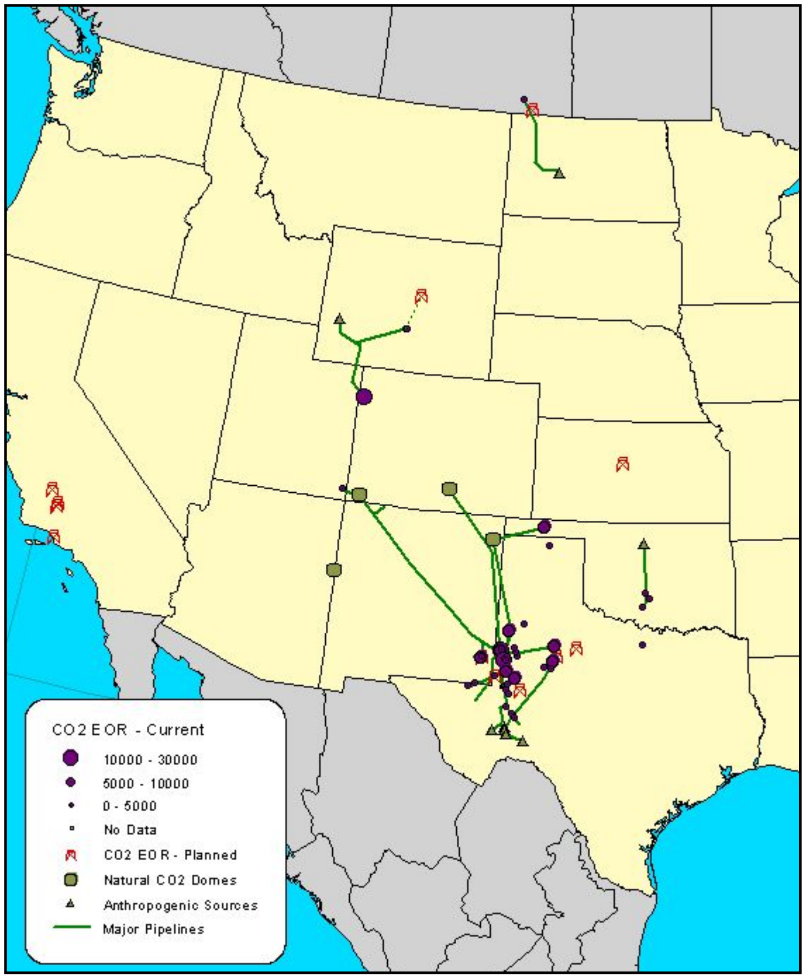
(Source: Mitsubishi Heavy Industries)

Post-Combustion Capture
(gas-fired power plant, Malaysia)

(Source: Dakota Gasification

Pre-Combustion Capture
(coal gasification plant, USA)

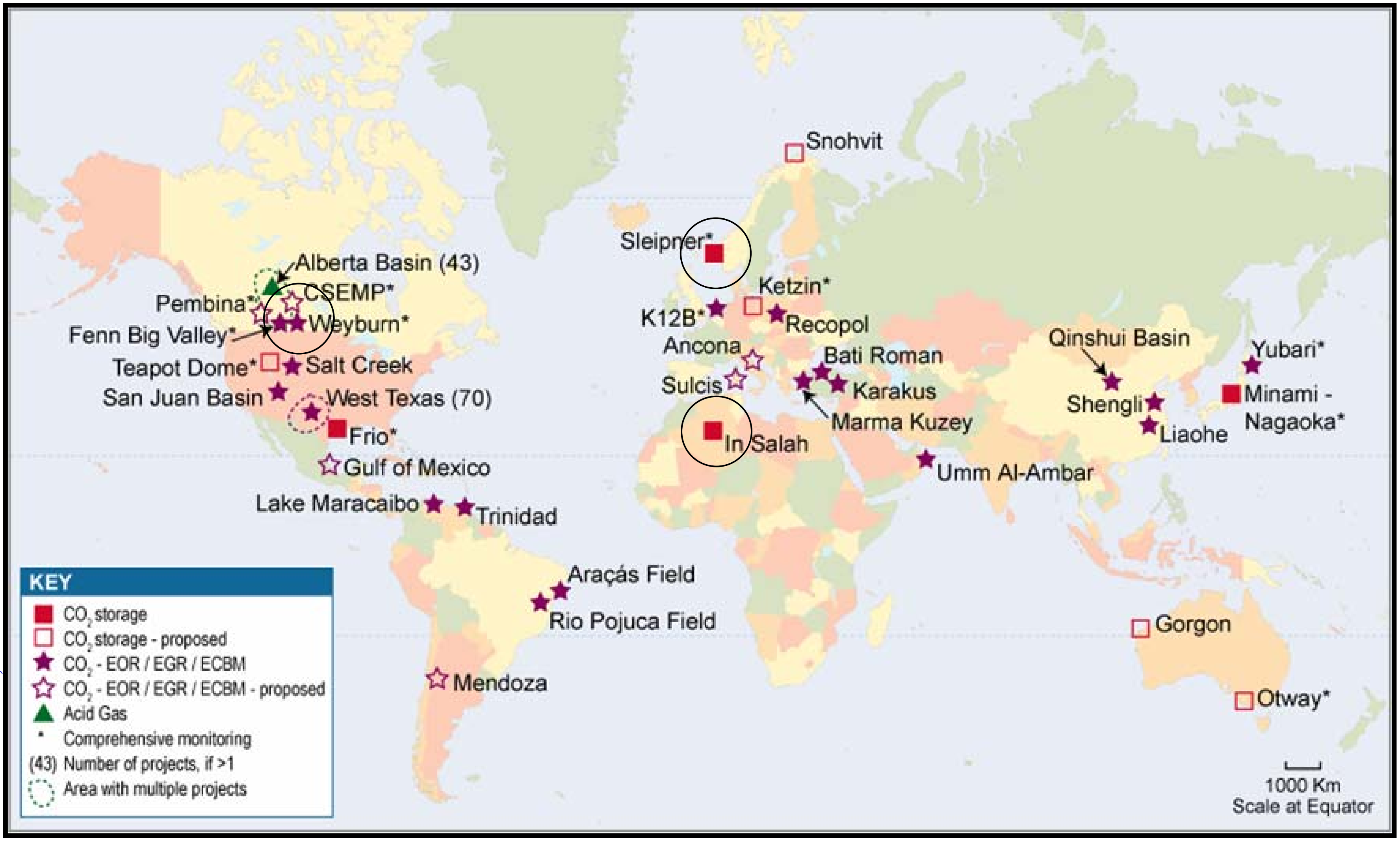
CO_2 Pipelines (for EOR Projects)



Source: USDOE/Battelle

Source: NRDC

Existing/Proposed CO_2 Storage Sites

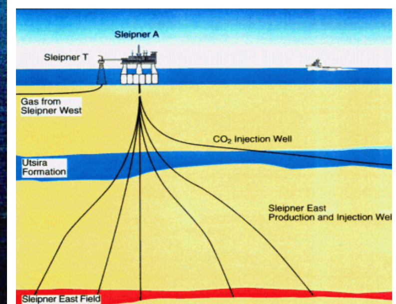


Source: S. Benson, LBNL

Geological Storage Projects

Source: Statoil

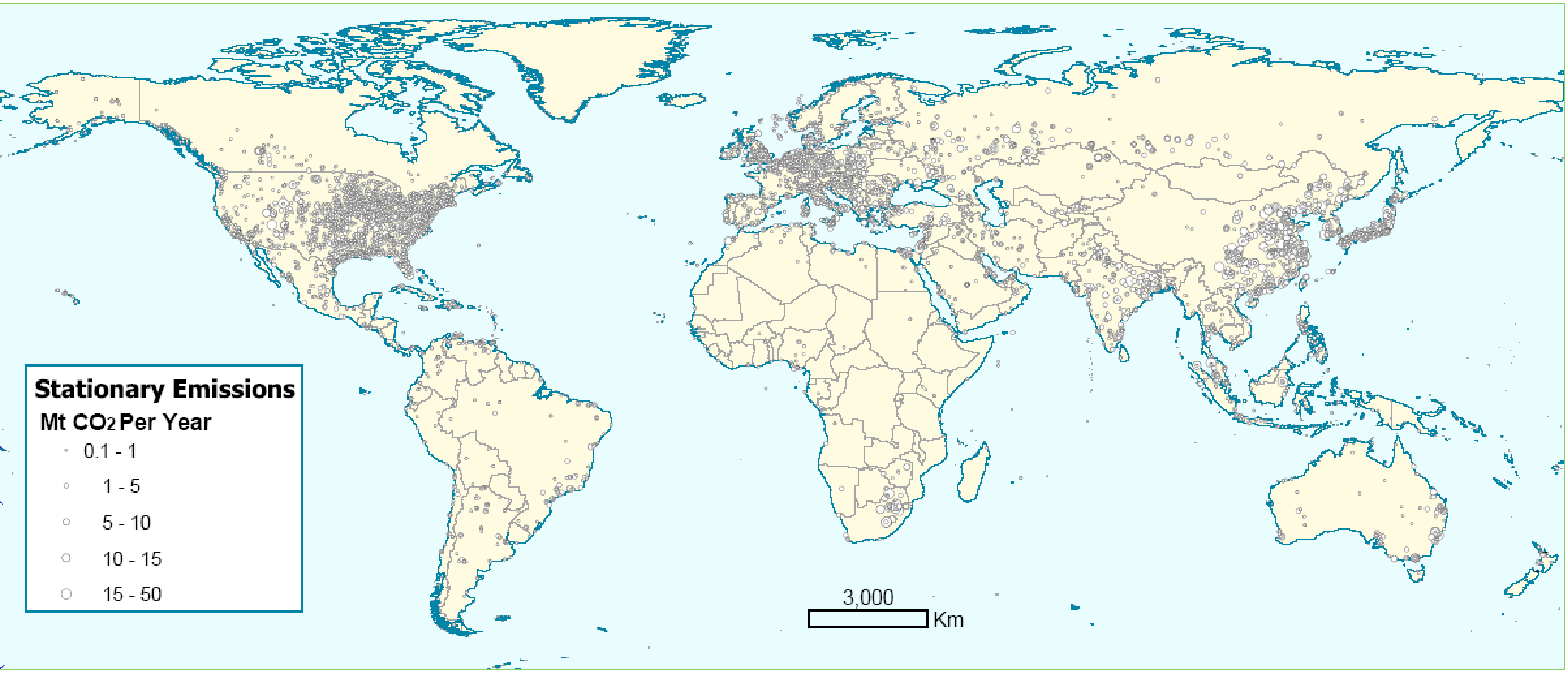
Sleipner *(Norway)*



In Salah /Krechba *(Algeria)*

Source: BP

Global Distribution of Large CO_2 Sources

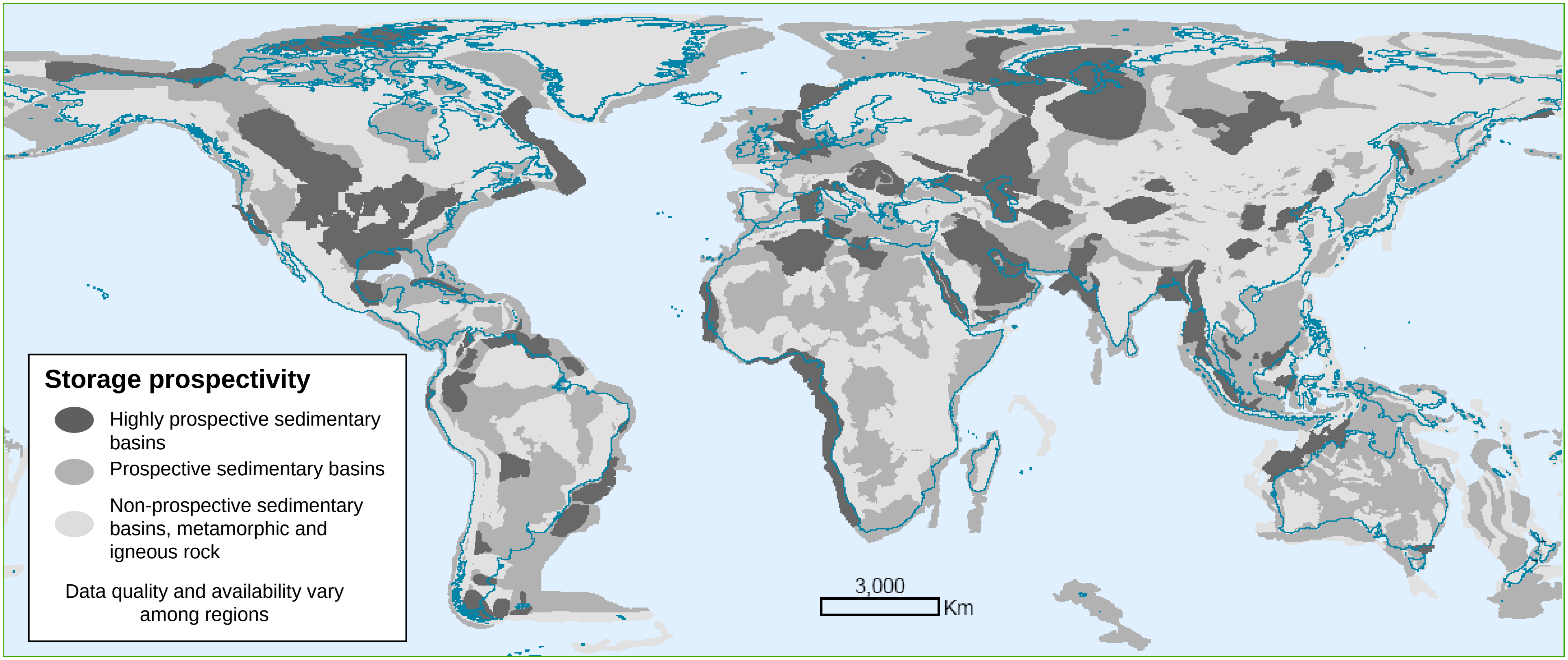


(Source:IEA GHG, 2002)

Large sources clustered in four geographical regions. Fossil fuel power plants account for 78% of emissions; industrial processes (including biomass) emit 22%.

Potential Geological Storage Areas

(Prospective areas in sedimentary basins where suitable saline formations, oil or gas fields, or coal beds may be found)



(Source: Geoscience Australia).

Good correlation between major sources and areas with potential for geological storage. More detailed regional analyses required to confirm or assess actual suitability for storage.

Leading Candidates for CCS

- Fossil fuel power plants
  - Pulverized coal combustion (PC)
  - Natural gas combined cycle (NGCC)
  - Integrated coal gasification combined cycle (IGCC)
- Other large industrial sources of CO_2 such as:
  - Refineries and petrochemical plants
  - Hydrogen production plants
  - Ammonia production plants
  - Pulp and paper plants
  - Cement plants

Estimated CCS Cost for New Power Plants Using Current Technology

(Levelized cost of electricity production in 2002 US$/kWh)

Power Plant System	**Natural Gas Combined Cycle Plant**	**Pulverized Coal Plant**	**Integrated Gasification Combined Cycle Plant**
Reference Plant Cost (without capture) ($/kWh)	*0.03–0.05*	*0.04–0.05*	*0.04–0.06*
Added cost of CCS with geological storage	**0.01–0.03**	**0.02–0.05**	**0.01–0.03**
Added cost of CCS with EOR storage	**0.01–0.02**	**0.01–0.03**	**0.00–0.01**

Variability is due mainly to differences in site-specific factors.
Added cost to consumers will depend on extent of CCS plants in the overall power generation mix

Cost of CO_2 Avoided

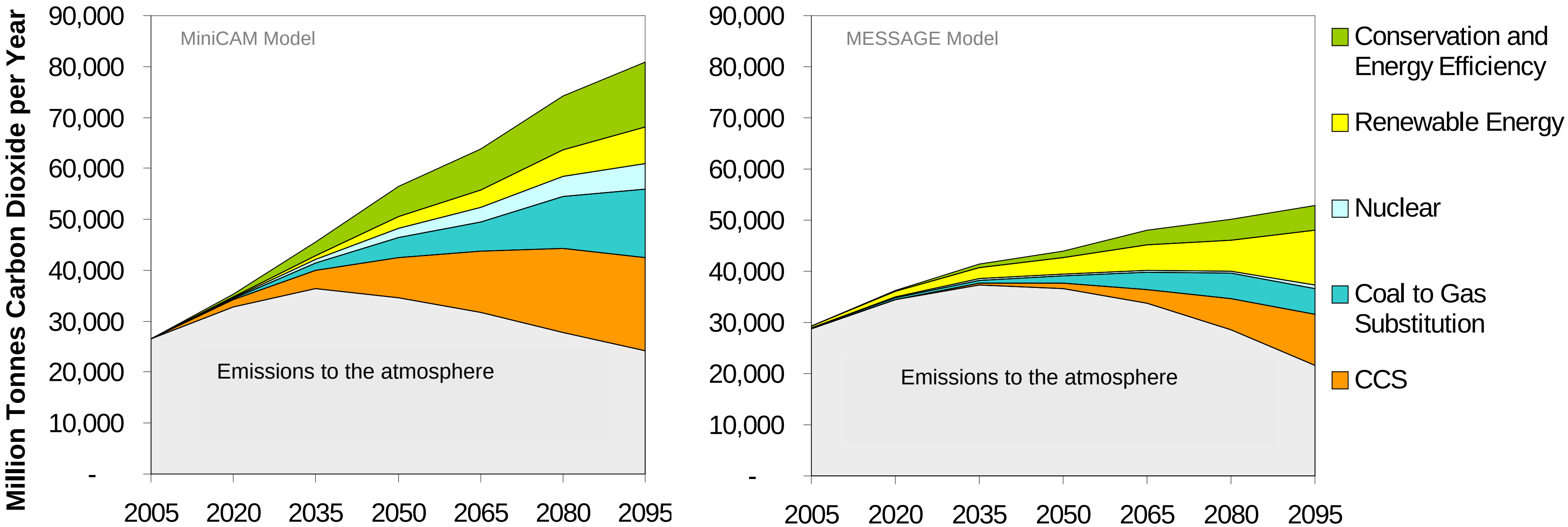
(2002 US$ per tonne CO_2 avoided)

Power Plant System	Natural Gas Combined Cycle Plant	Pulverized Coal Plant	Integrated Gasification Combined Cycle Plant
Same plant with CCS (geological storage)	40–90	30–70	15–55
Same plant with CCS (EOR storage)	20–70	10–45	(-5)–30

Other industrial processes have roughly similar costs

Different combinations of reference plant and CCS plant types have avoidance costs ranging from \$0–270/tCO_2 avoided; site-specific context is important

Economic Potential of CCS



- Across a range of stabilization and baseline scenarios, models estimate cumulative storage of 220–2200 $GtCO_2$ via CCS to the year 2100
- This is 15–55% of the cumulative worldwide mitigation required to achieve stabilization
- Cost is reduced by 30% or more with CCS in the portfolio

Geological Storage Capacity

Reservoir Type	Lower Estimate ($GtCO_2$)	Upper Estimate ($GtCO_2$)
Oil and gas fields	675*	900*
Unminable coal seams	3–15	200
Deep saline formations	1000	Uncertain, but possibly ~10^4

* Estimates are 25% larger if “undiscovered reserves” are included.

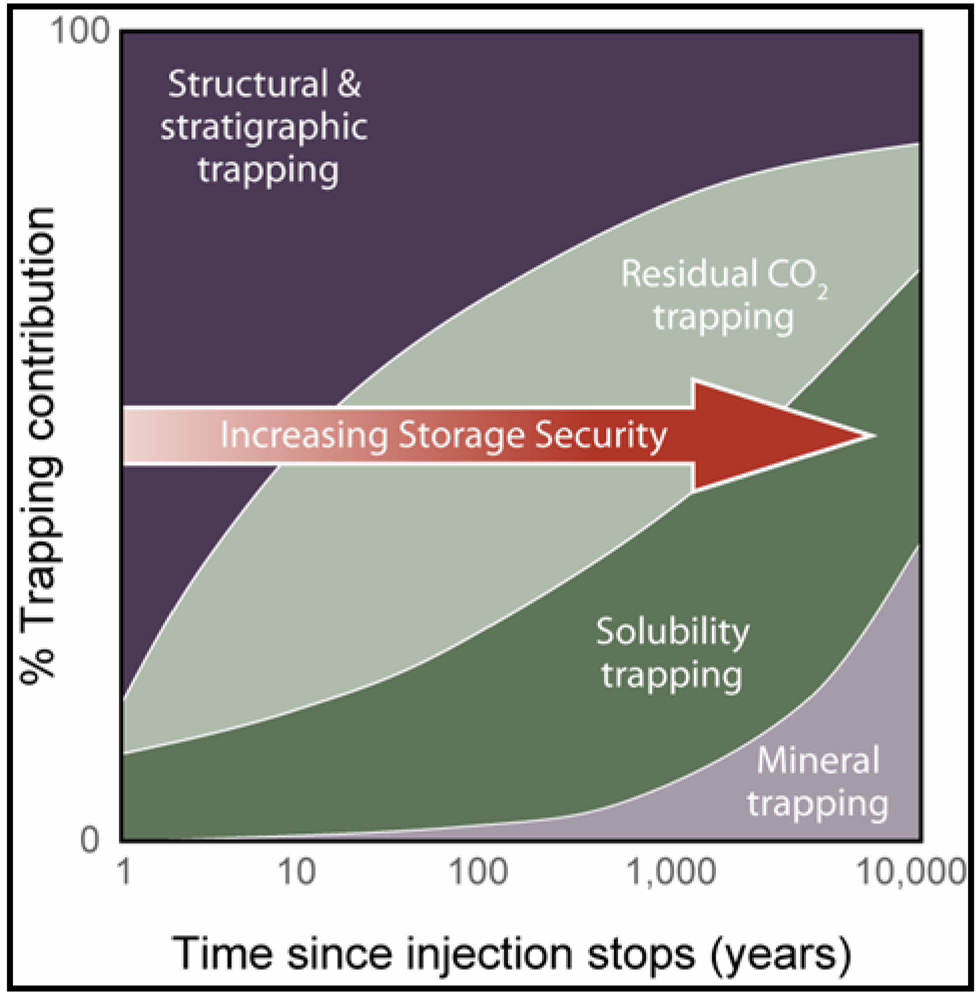
Available evidence suggests that worldwide, it is likely that there is a technical potential of at least about 2000 $GtCO_2$ (545 GtC) of storage capacity in geological formations. Globally, this would be sufficient to cover the high end of the economic potential range, but for specific regions, this may not be true.

Security of Geological Storage

- Lines of evidence for duration of storage:
  - Natural CO_2 reservoirs
  - Oil and gas reservoirs
  - Natural gas storage
  - CO_2 EOR projects
  - Numerical simulation of geological systems
  - Models of flow through leaking wells
  - Current CO_2 storage projects

Trapping Mechanisms Provide 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
- Appropriate site selection and management are the key to secure storage



Source: S..Benson, LBNL

Estimates of Fraction Retained

- Storage security defined as fraction retained = percent of injected CO_2 remaining after $\underline{x}$ years
- "Observations from engineered and natural analogues as well as models suggest that the fraction retained in appropriately selected and managed geological reservoirs is very likely* to exceed 99% over 100 years and is likely** to exceed 99% over 1,000 years."

---

* "Very likely" is a probability between 90 and 99%.

** "Likely" is a probability between 66 and 90%.

Would Leakage Compromise CCS as a Climate Change Mitigation Option?

- Studies have addressed non-permanent storage from a variety of perspectives
- Results vary with methods and assumptions made
- Outcomes suggest that a fraction retained on the order of 90–99% for 100 yrs, or 60–95% for 500 yrs, could still make non-permanent storage valuable for mitigating climate change
- All studies imply an upper limit on amount of leakage that can take place

Local Health, Safety and Environmental Risks

- ***CO_2 Capture*:** Large energy requirements of CCS (10–40% increase per unit of product, depending on system) can increase plant-level resource requirements and some environmental emissions; site-specific assessments are required
- ***CO_2 Pipelines*:** Risks similar to or lower than those posed by hydrocarbon pipelines
- ***Geological Storage*:** Risks comparable to current activities such as natural gas storage, EOR, and deep underground disposal of acid gas, provided there is:
  - appropriate site selection (informed by subsurface data)
  - a regulatory system
  - a monitoring program to detect problems
  - appropriate use of remediation methods, if needed

Other Storage Options

- Oceans
  - Storage potential on the order of 1000s GtCO_2, depending on environmental constraints. Gradual release over hundreds of years (65–100% retained at 100 yrs, 30–85% at 500 yrs)
  - CO_2 effects on marine organisms will have ecosystem consequences; chronic effects of direct injection not known.
- Mineral Carbonation
  - Storage potential cannot currently be determined, but large quantities of natural minerals are available
  - Environmental impacts from mining and waste disposal
  - High cost and energy reqmt of best current processes
- Industrial Utilization
  - Little net reduction of CO_2 emissions

Legal and Regulatory Issues

- Onshore: National Regulations
  - Some existing regulations apply, but few specific legal or regulatory frameworks for long-term CO_2 storage
  - Liability issues largely unresolved
- Offshore: International Treaties
  - OSPAR, London Convention
  - Sub-seabed geological storage and ocean storage: unclear whether, or under what conditions, CO_2 injection is compatible with international law
  - Discussions on-going

Inventory and Accounting Issues

- Current IPCC guidelines do not include methods specific to estimating emissions associated with CCS
- 2006 guidelines are expected to address this issue
- Methods may be required for net capture and storage, physical leakage, fugitive emissions, and negative emissions associated with biomass applications of CCS
- Cross-border issues associated with CCS accounting (e.g., capture in one country and storage in another country with different committments) also need to be addressed; these issues are not unique to CCS

Gaps in Knowledge

- ***Technologies***—CCS demonstrations for large-scale power plant and other applications to reliably establish cost and performance; R&D to develop new technology concepts
- ***Source–storage relationships***—more detailed regional and local assessments
- ***Geological storage***—improved estimates of capacity and effectiveness
- ***Ocean storage***—assessments of ecological impacts
- ***Legal and regulatory issues***—clear frameworks for CCS
- ***Global contribution of CCS***—better understanding of transfer and diffusion potential, interactions with other mitigation measures, and other issues to improve future decision-making about CCS