IPCC Special Report on Carbon Dioxide Capture and Storage

-- Storage in Deep Underground Geological Formations --

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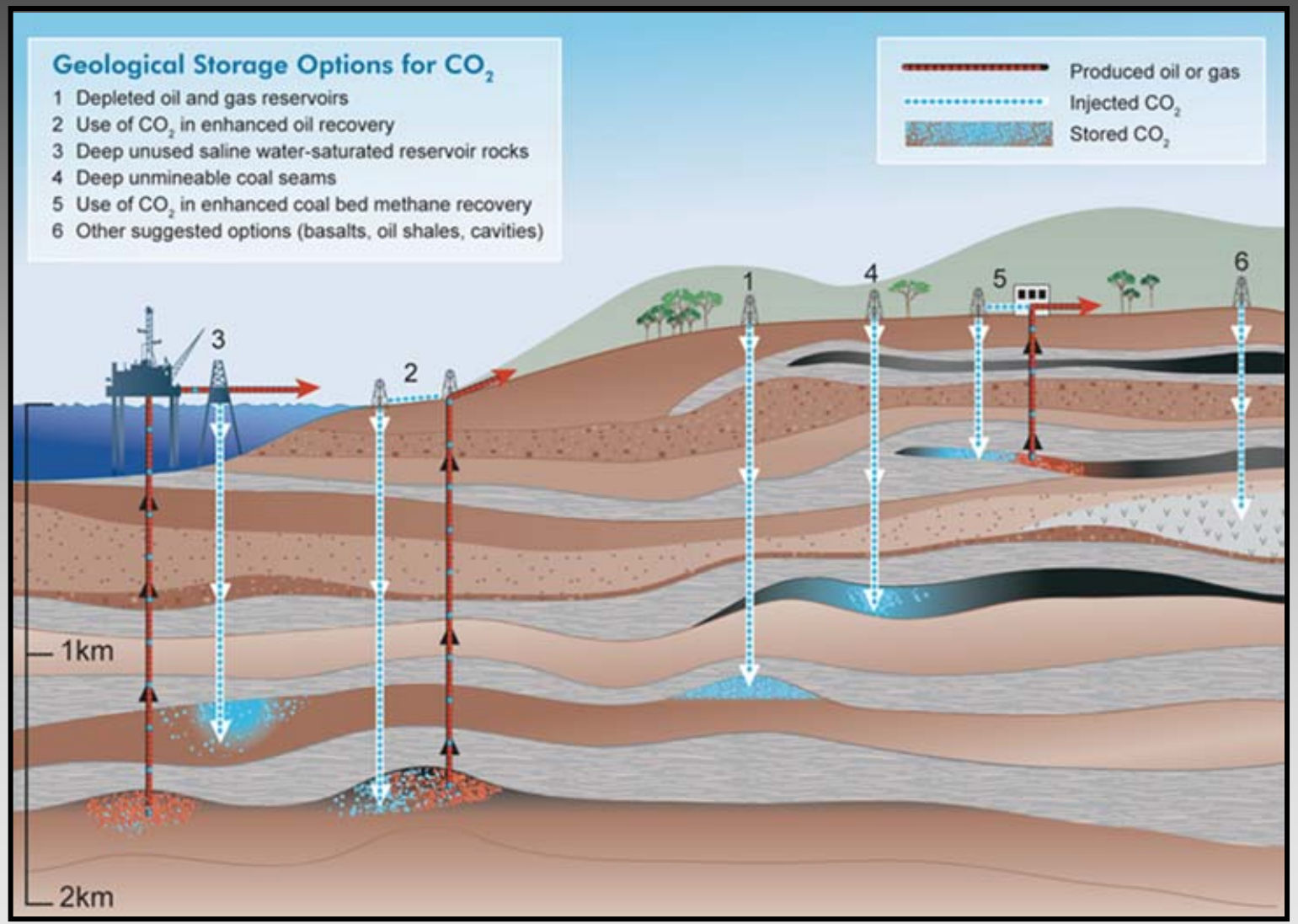
WMO INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE UNEP

Key Topics

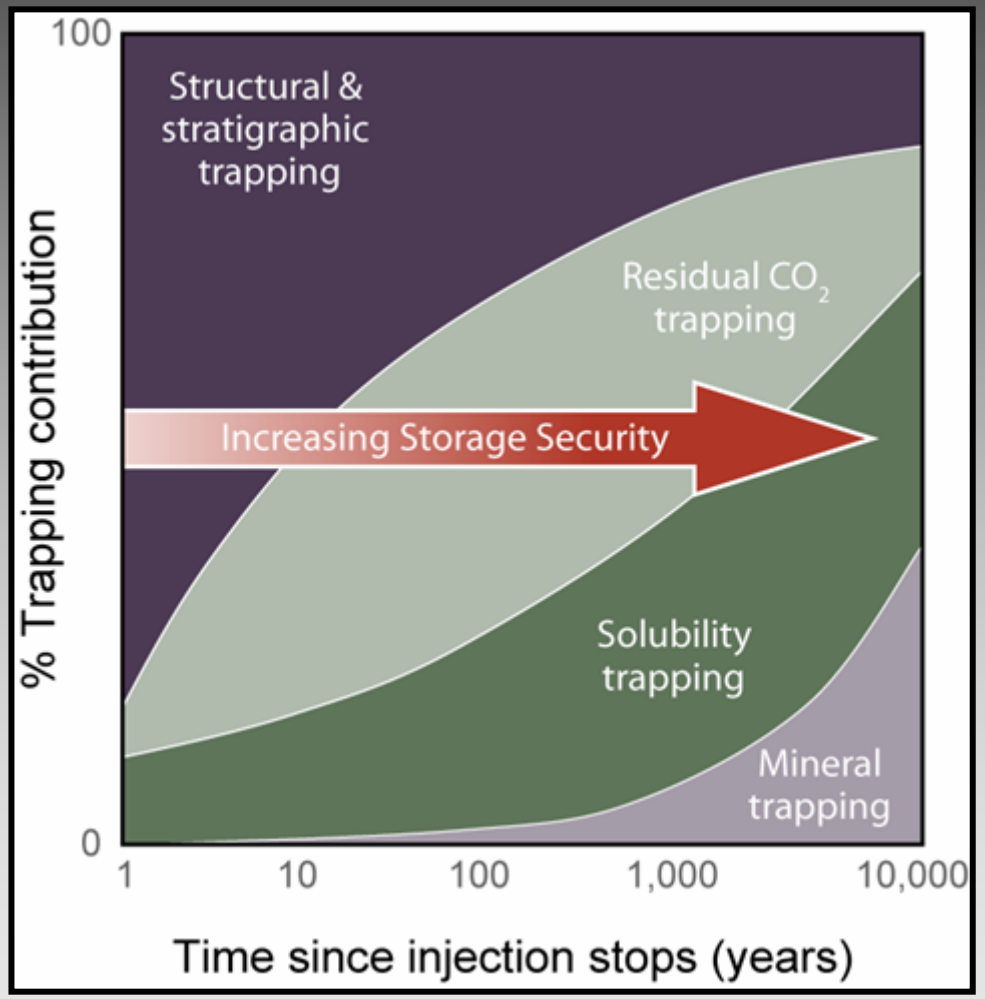
- Storage fundamentals
- Storage capacity and locations
- Storage security and major risks
- Cost
- Well selected and managed storage sites

Options for Storing CO_2 in Deep Underground Formations

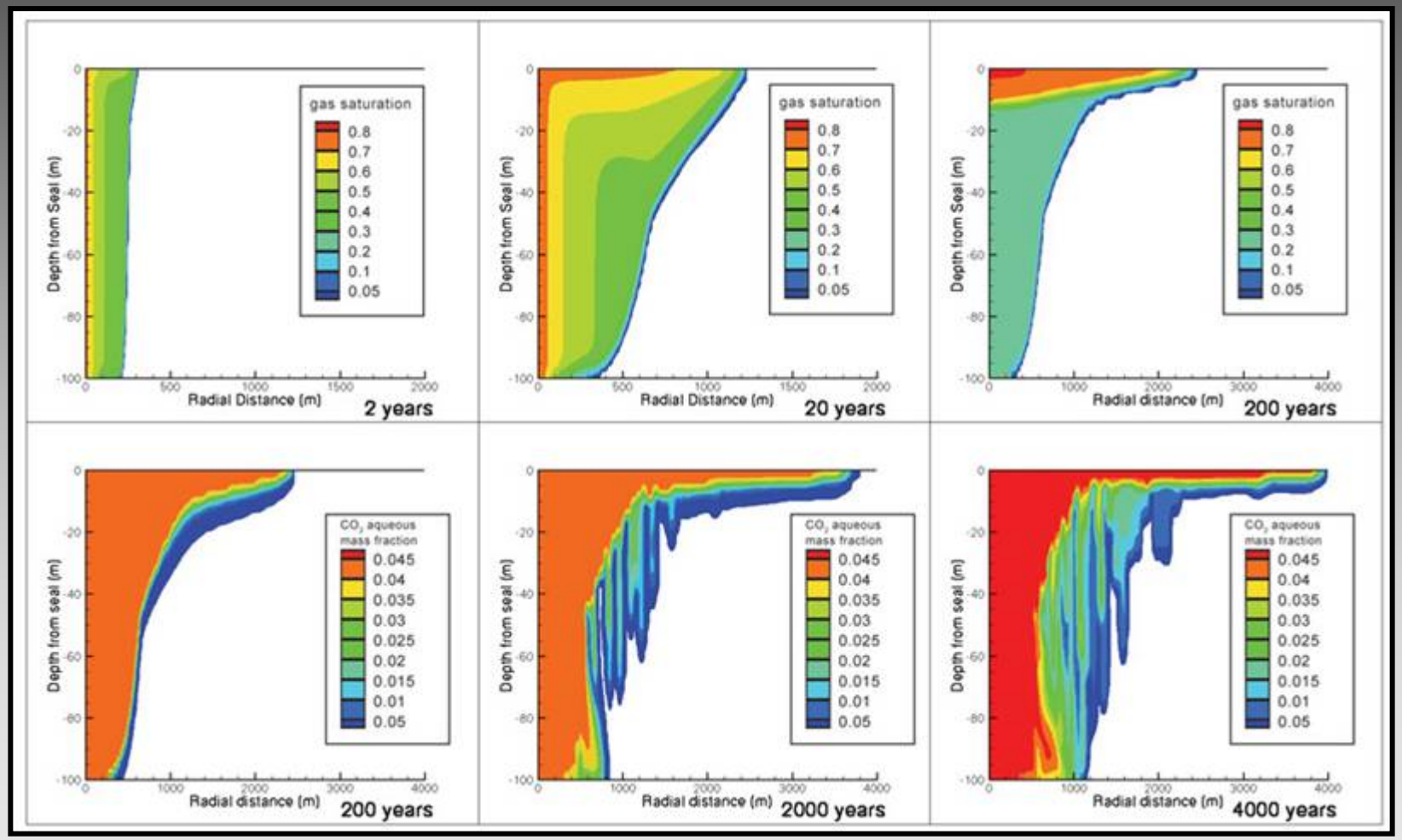


Trapping Mechanisms and Increasing Storage Security with Time

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

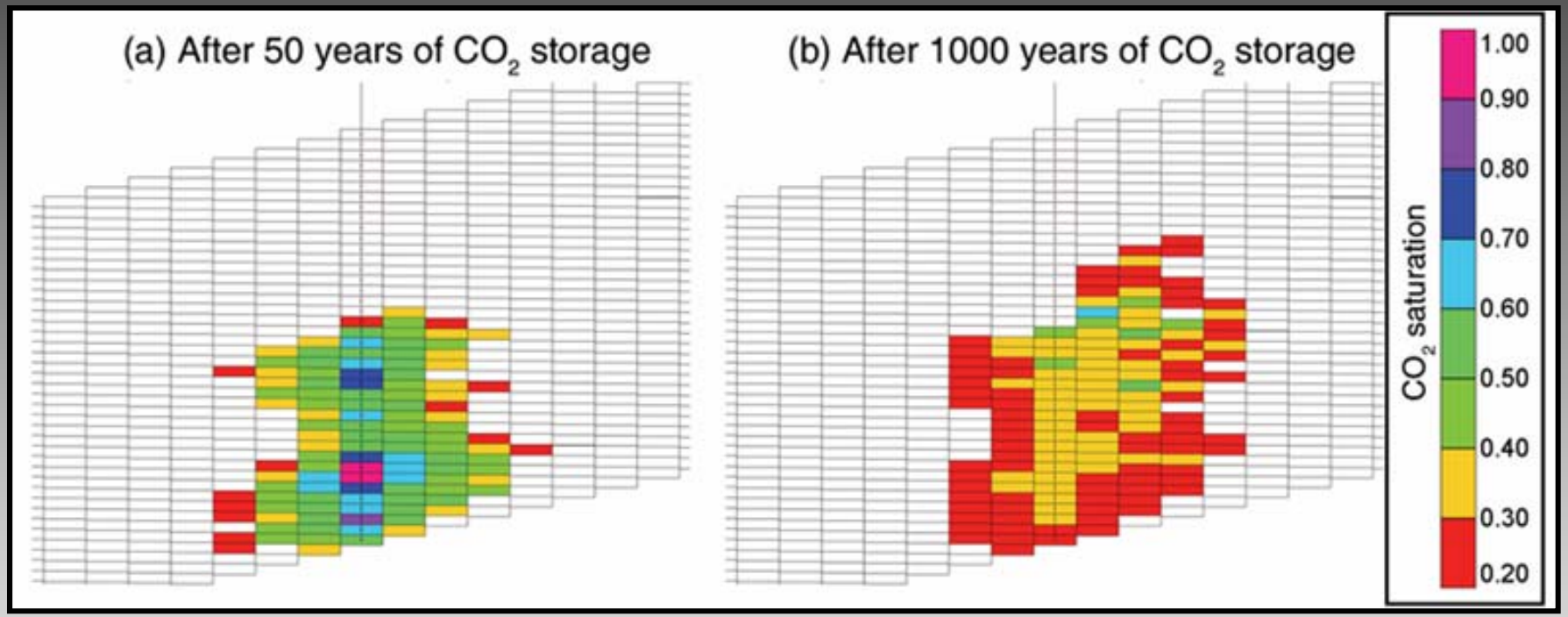


Simulations of CO_2 Injection Show Convective Mixing is Possible



After Ennis-King, 2002

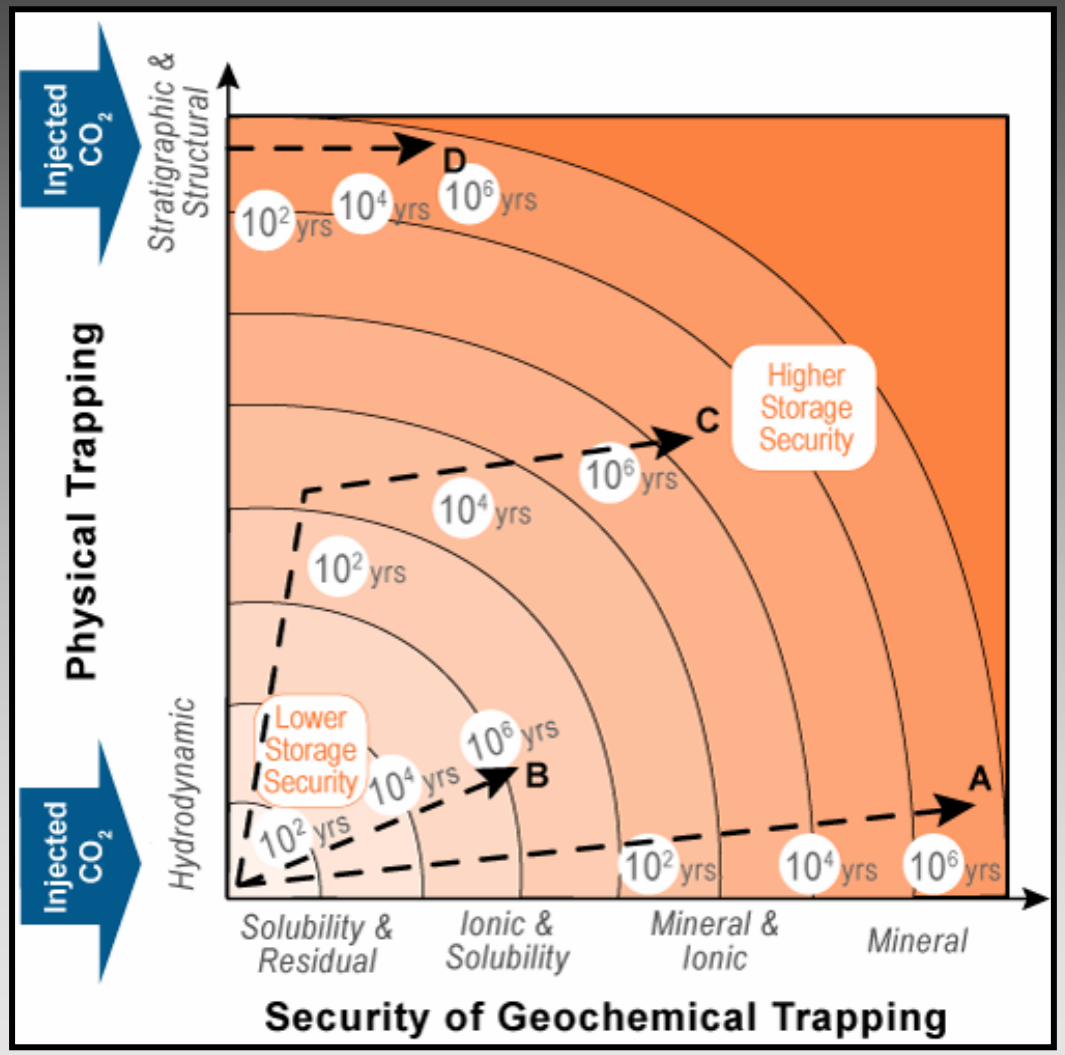
Capillary Trapping Immobilizes CO_2



After Kumar et al, 2005

- After 50-year injection period is over most CO_2 is still mobile, driven upwards by buoyancy forces
- After 1000 years, buoyancy-driven flow has expanded the volume affected by CO_2, and much is trapped as residual CO_2 saturation or dissolved in brine (not shown). Little CO_2 is mobile and all CO_2 is contained within the saline formation.

Physical and Chemical Trapping Pathways are Site Specific

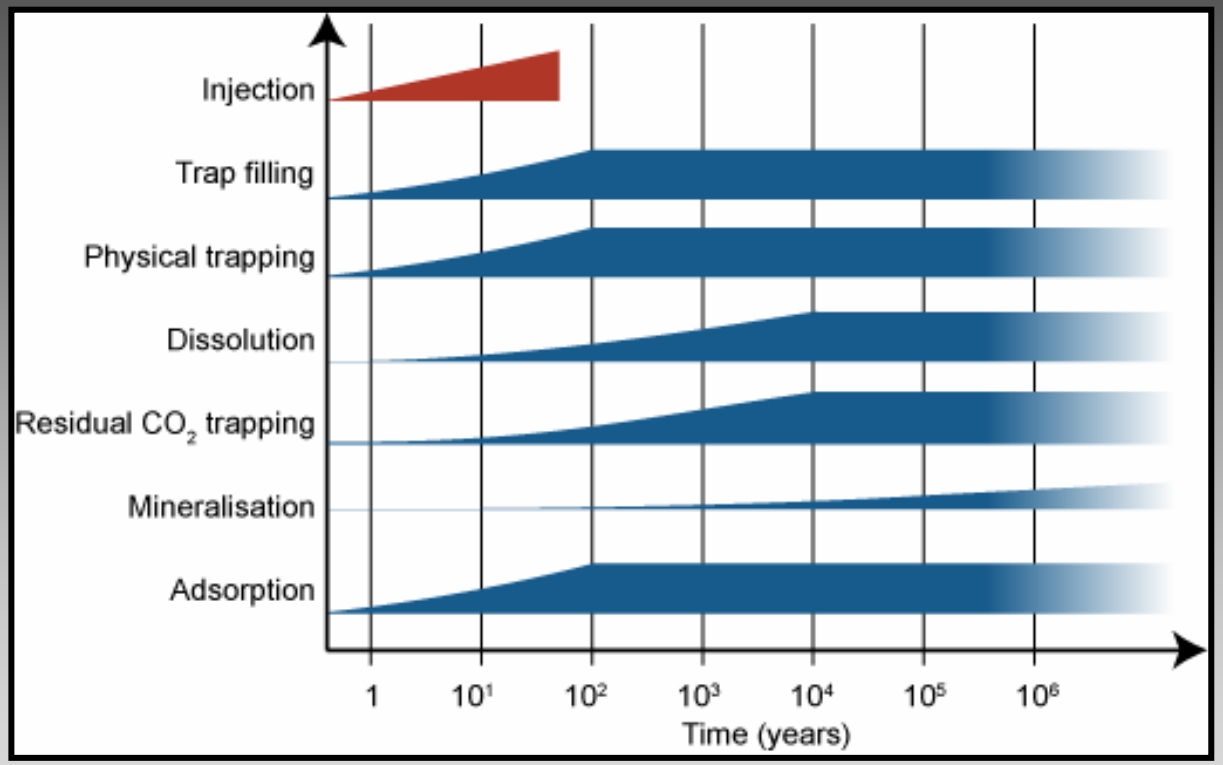


Dashed lines are examples of million year pathways

Storage Capacity and Locations

- Methodology
- Oil and gas reservoirs
- Saline formations
- Coal
- Distribution of storage locations

Time Evolution of CO_2 Storage Mechanisms



- Schematic showing the time evolution of various CO_2 storage mechanisms operating in deep saline formations, during and following injection
- Assessing storage capacity is complicated by the different time and spatial scales over which these processes occur

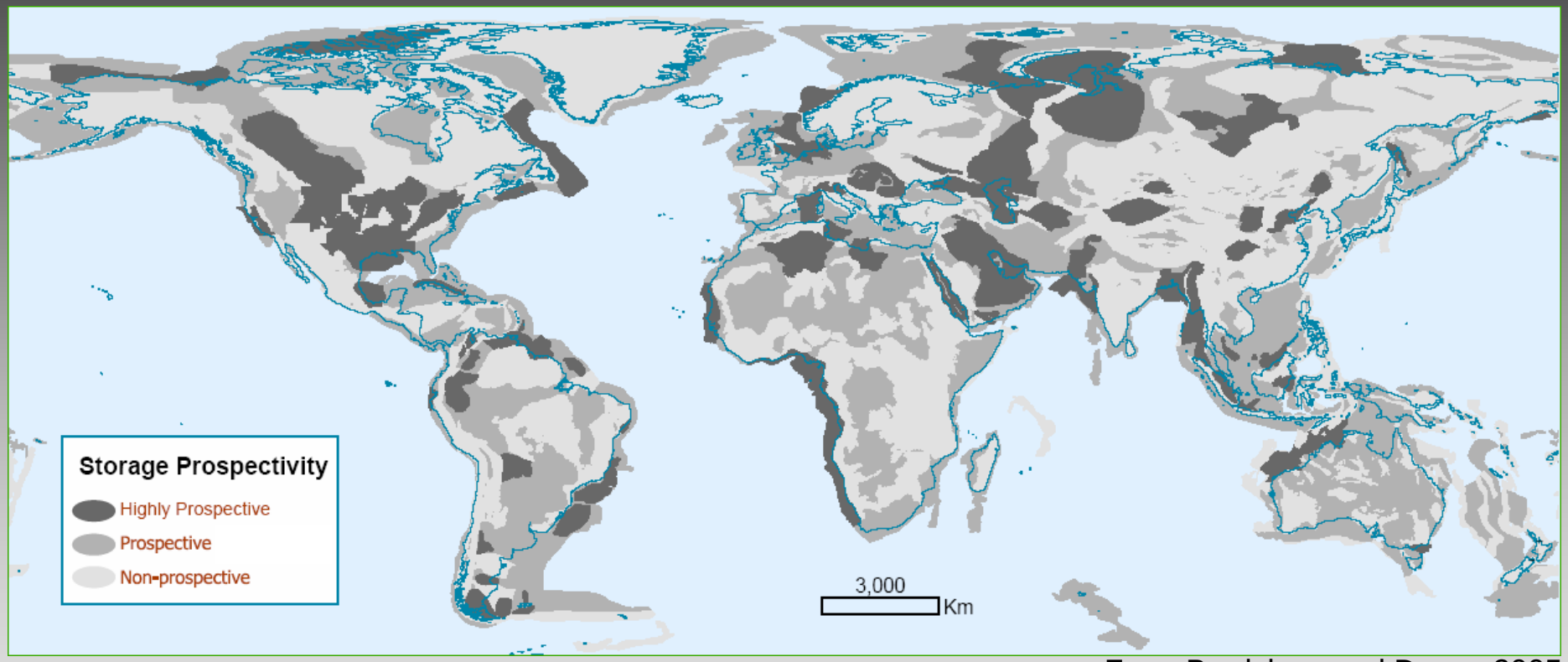
Capacity of Storage Formations

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

a. Estimates would be 25% larger if undiscovered reserves were included.

"Available evidence suggests that worldwide, it is likely that there is a technical potential of at least about 2,000 GtCO-2 (545 GtC) of storage capacity in geological formations."

Prospectivity for Storage Around the World



From Bradshaw and Dance 2005

"It is likely that the technical potential for geological storage is sufficient to cover the high end of the economic potential range (2200 $GtCO_2$), but for specific regions, this may not be true."

Storage Security and Fraction Retained

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

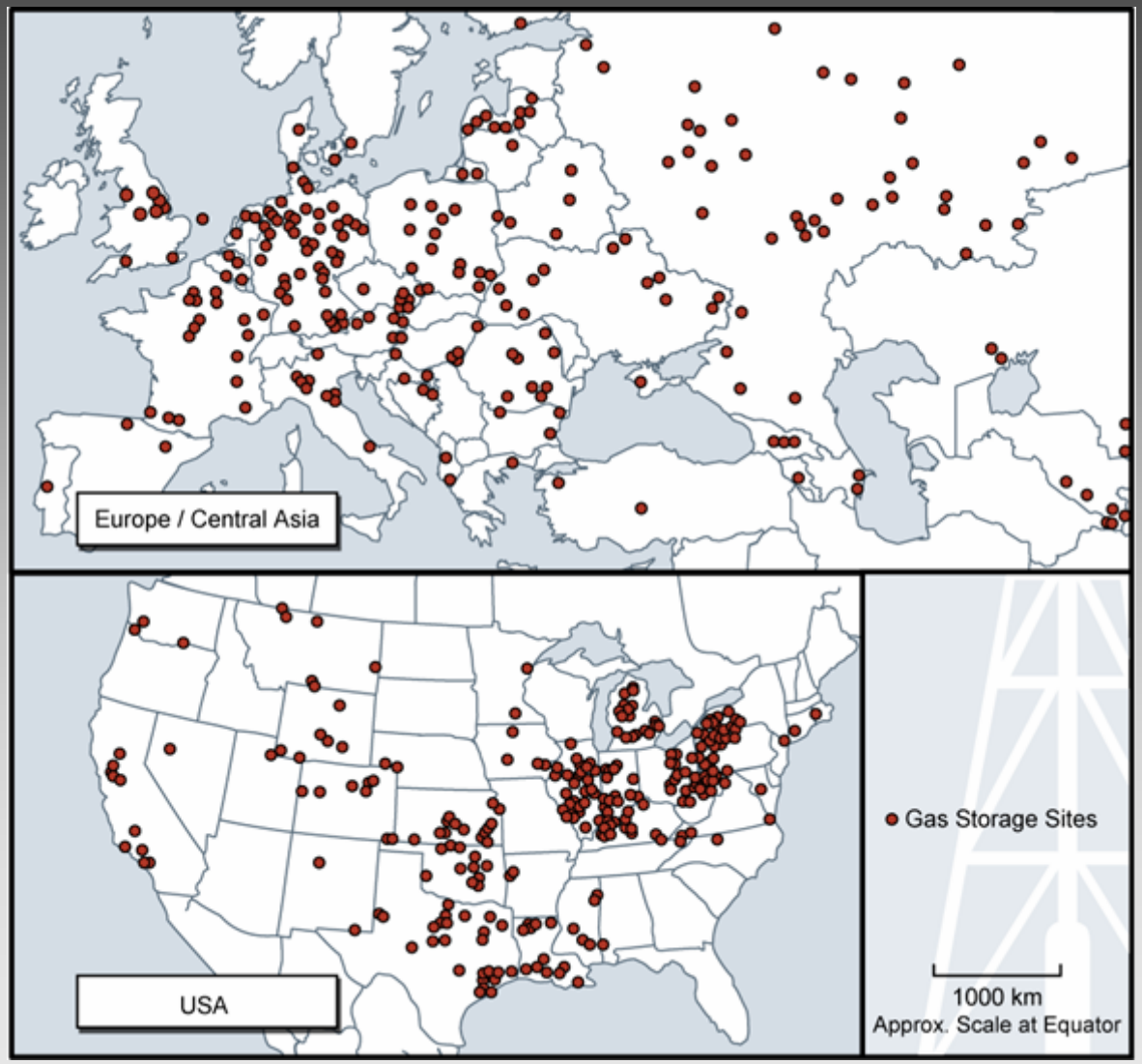
- Fraction retained estimates

  Fraction retained = % of injected CO_2 remaining after X years

Natural Accumulations of CO_2 around the World

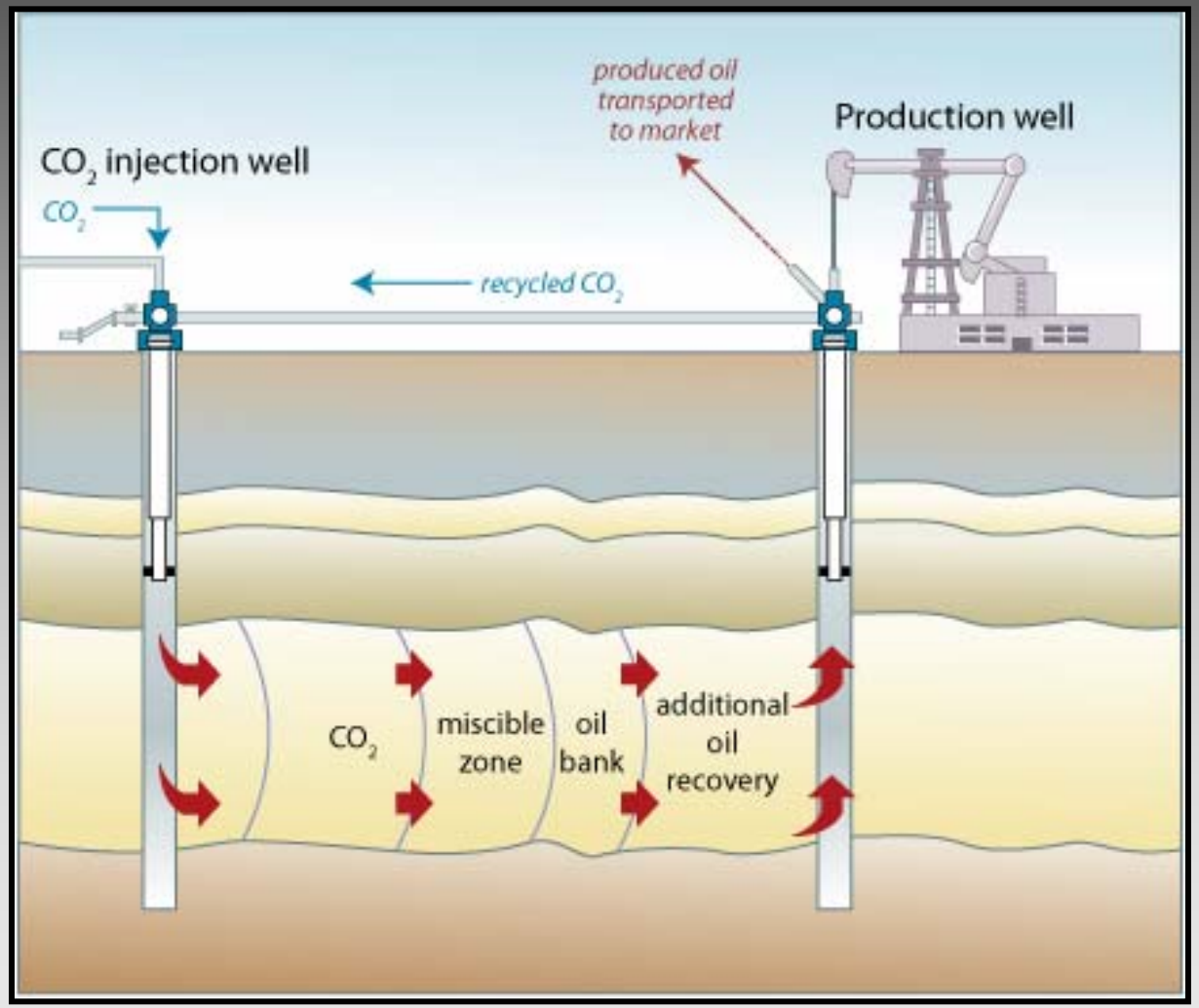
Release rates less than 10^{-7}/year

Natural Gas Storage Projects



- >10,000 facility-years of operations
- Release rates < 10^{-4} to 10^{-6}/yr

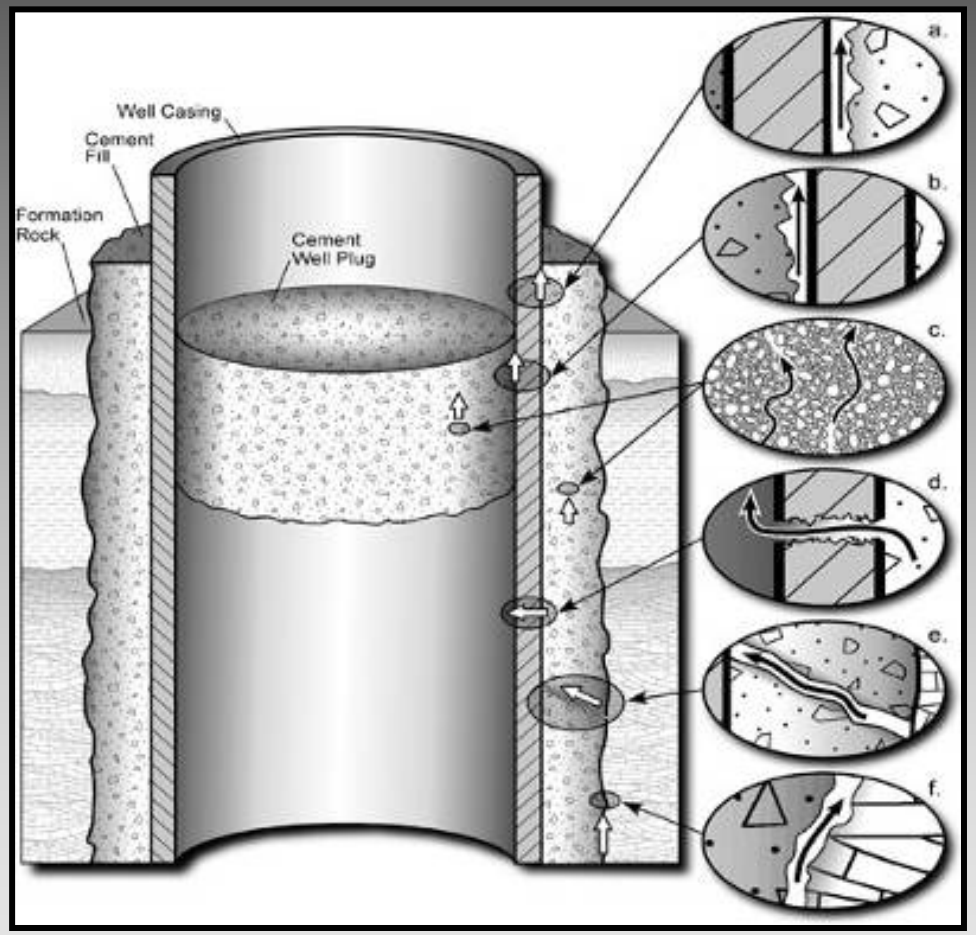
Injection of CO_2 for Enhanced Oil Recovery (EOR)



- >100 Mt injected
- Limited data show flux near zero

Leakage Pathways in Abandoned Well

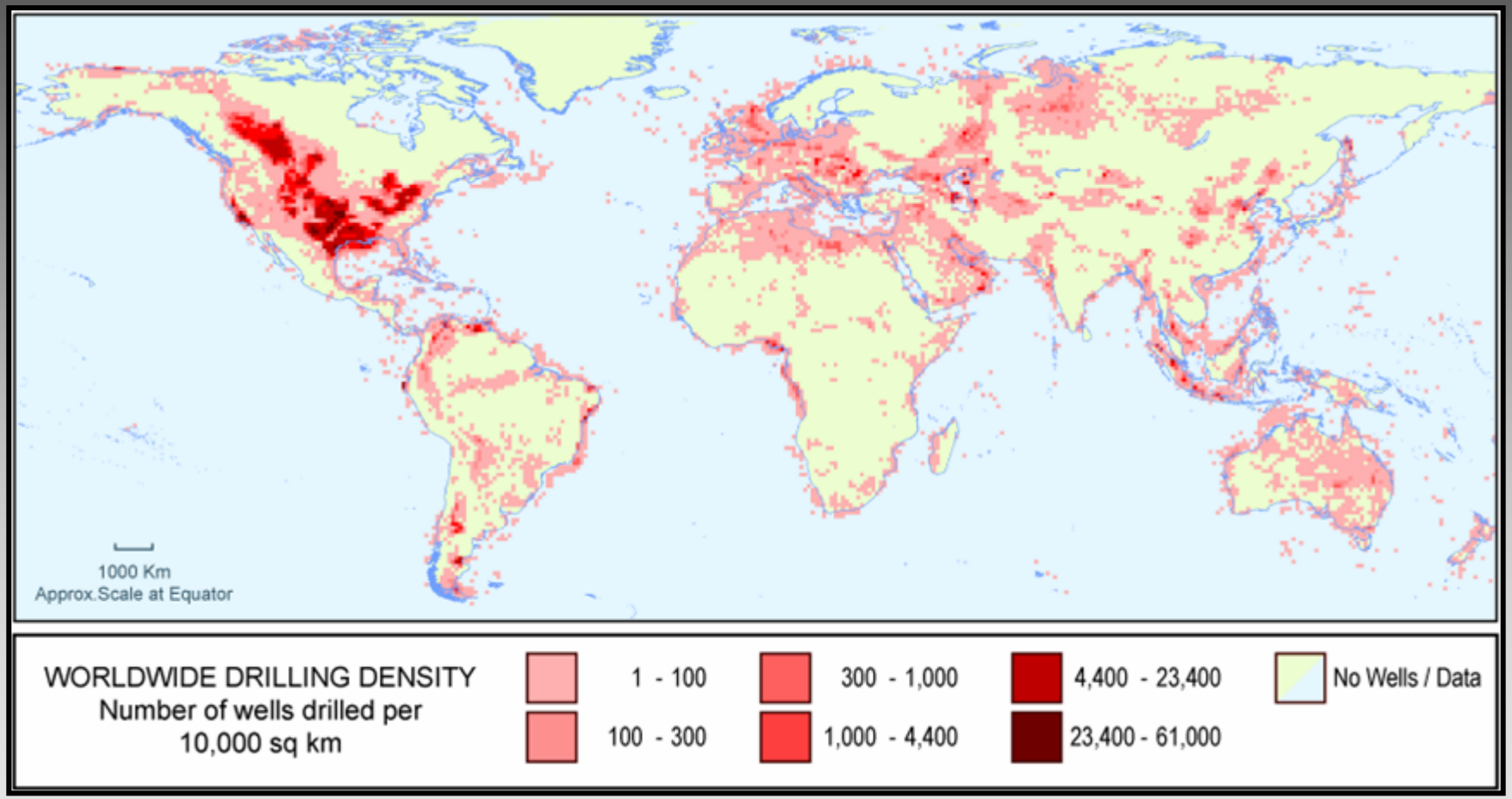
- Between casing and cement wall and plug, respectively
- Through cement plugs
- Through casing
- Through cement wall
- Between the cement wall and rock



Release rates of >10^{-2}/year for leaking wells, but remediation is likely for such large releases

Gasda et al., 2004

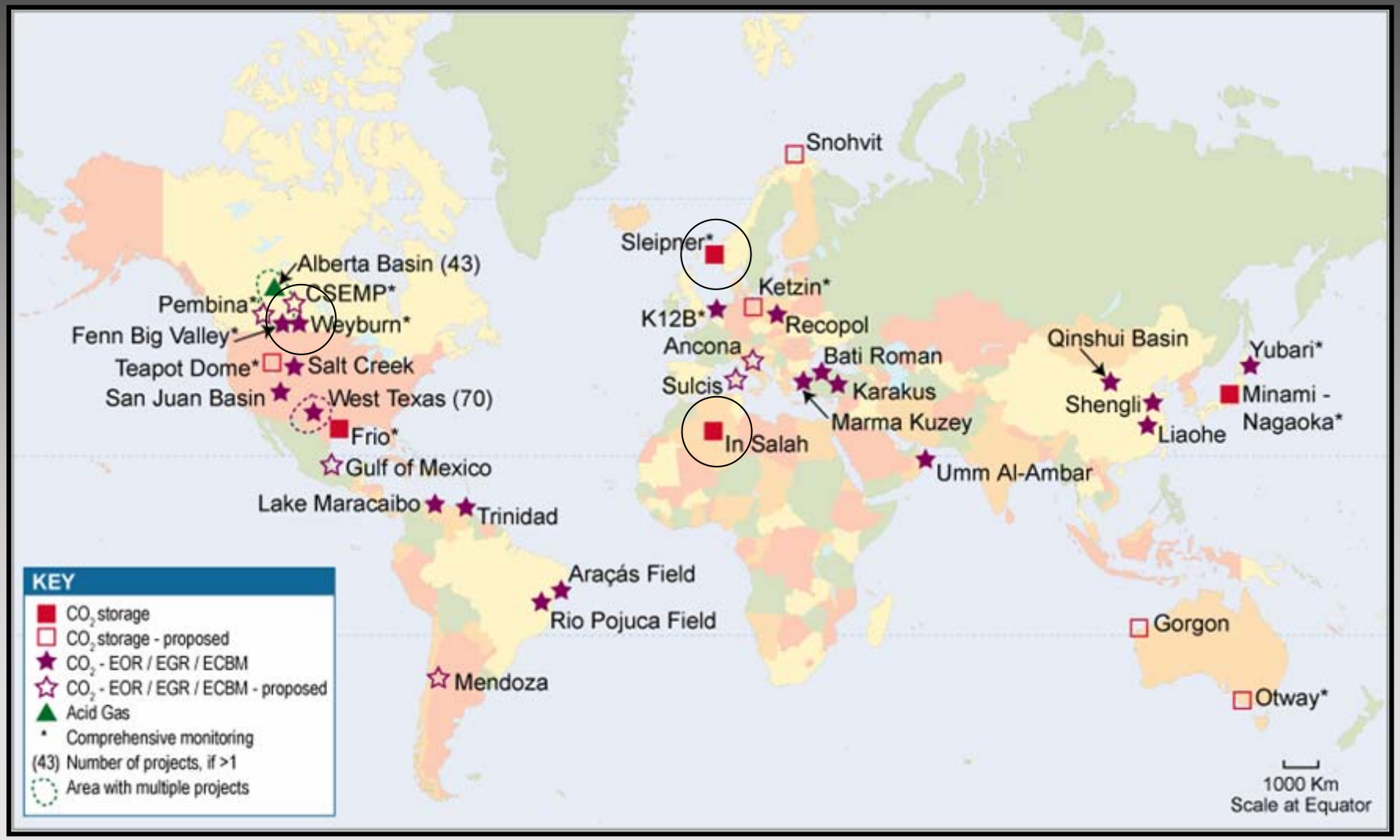
World Oil and Gas Well Distribution and Density



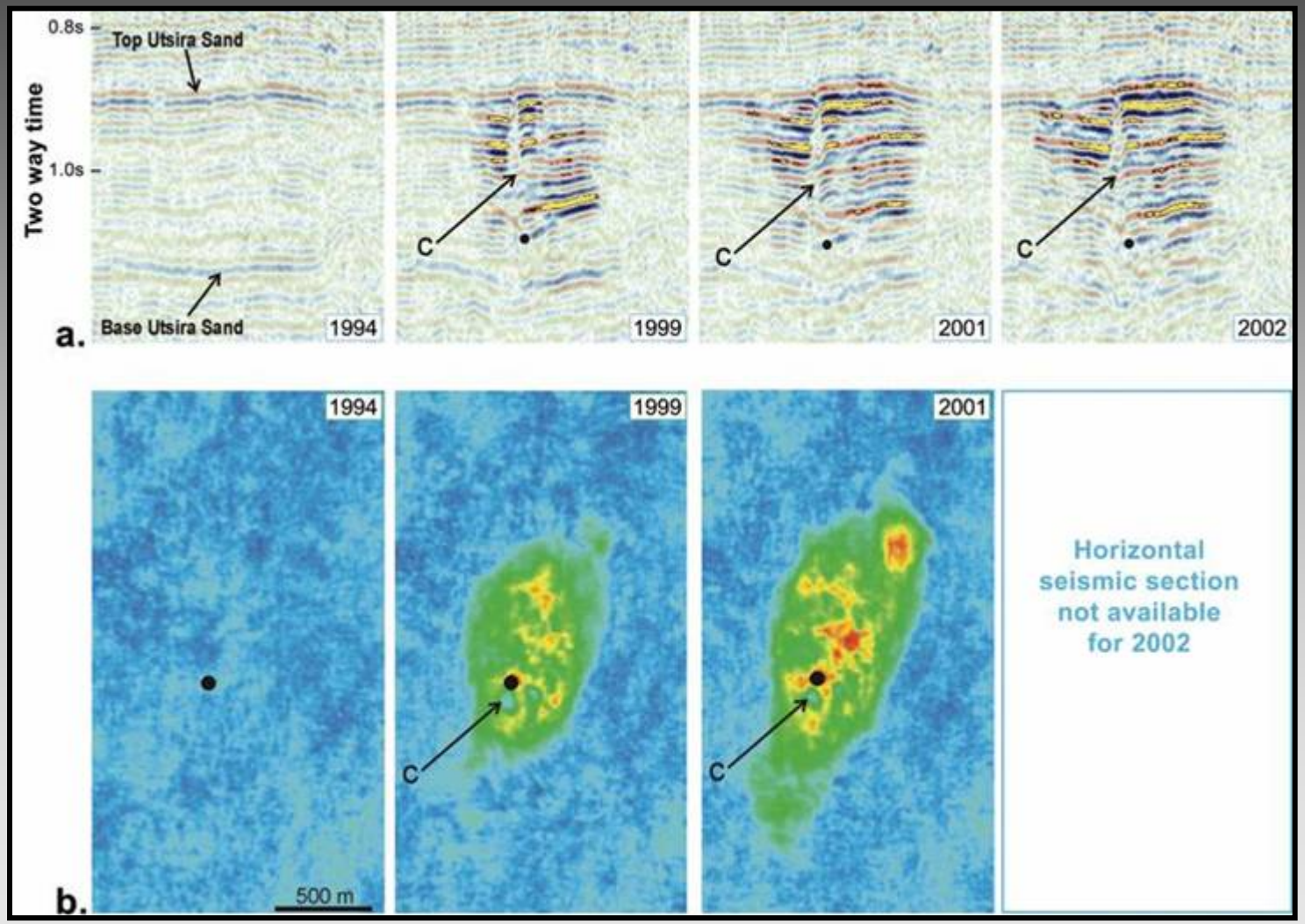
From IHS Energy

Well density and risks from abandoned wells depends on location

Existing Storage Sites



Seismic Data Collected at Sleipner Indicates Secure Storage



From Chadwich et al., 2005

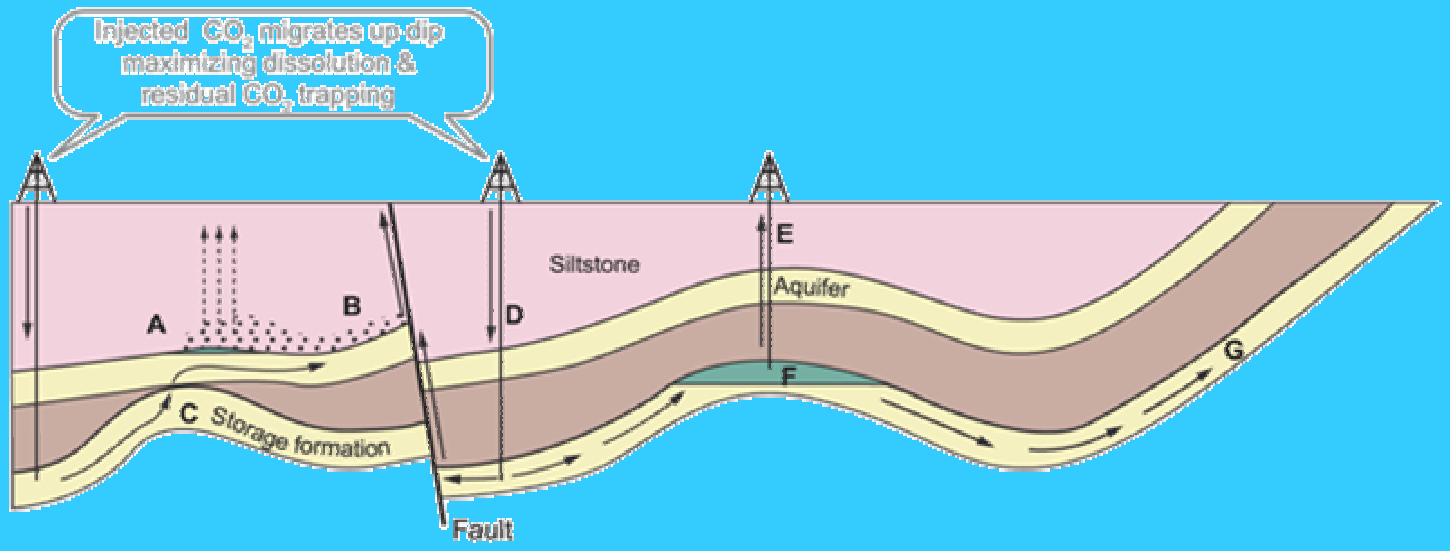
Fraction Retained

“ 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 60 and 90%.

Potential Release Pathways and Remediation Measures



Potential Escape Mechanisms

A. CO_2 gas pressure exceeds capillary pressure & passes through siltstone	**B.** Free CO_2 leaks from A into upper aquifer up fault	**C.** CO_2 escapes through 'gap' in cap rock into higher aquifer	**D.** Injected CO_2 migrates up dip, increases reservoir pressure & permeability of fault	**E.** CO_2 escapes via poorly plugged old abandoned well	**F.** Natural flow dissolves CO_2 at CO_2 / water interface & transports it out of closure	**G.** Dissolved CO_2 escapes to atmosphere or ocean

Remedial Measures

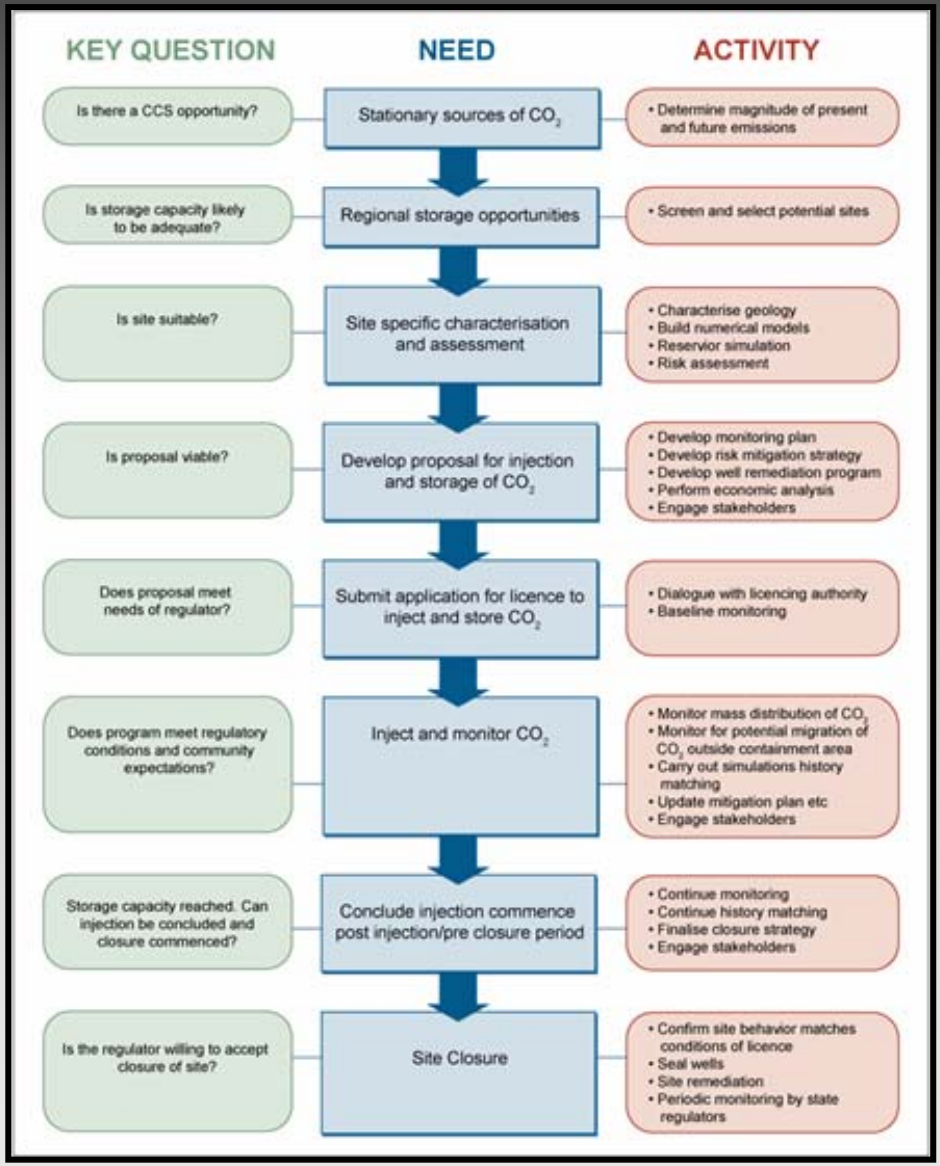
A. *Extract & purify ground-water*	***B.*** *Extract & purify ground-water*	***C.*** *Remove CO_2 & reinject elsewhere*	***D.*** *Lower injection rates or pressures*	***E.*** *Re-plug well with cement*	***F.*** *Intercept & reinject CO_2*	***G.*** *Intercept & reinject CO_2*

Storage Cost Estimates

			US$/t$CO_2$ stored		
Option type	**On or offshore**	**Location**	**Low**	**Mid**	**High**
Saline formation	Onshore	Australia	0.2	**0.5**	5.1
Saline formation	Onshore	Europe	1.9	**2.8**	6.2
Saline formation	Onshore	USA	0.4	**0.5**	4.5
Saline formation	Offshore	Australia	0.5	**3.4**	30.2
Saline formation	Offshore	N. Sea	4.7	**7.7**	12.0
Depleted oil field	Onshore	USA	0.5	**1.3**	4.0
Depleted gas field	Onshore	USA	0.5	**2.4**	12.2
Disused oil/gas field	Onshore	Europe	1.2	**1.7**	3.8
Disused oil/gas field	Offshore	N. Sea	3.8	**6.0**	8.1

Monitoring costs - $0.16 to $0.30/tonne

Well Selected and Managed Sites Are the Key to Success



" With appropriate site selection informed by available subsurface information, a monitoring program to detect problems, a regulatory system, and the appropriate use of remediation methods to stop or control CO_2 releases if they arise, the local health, safety and environment risks of geological storage would be comparable to risks of current activities such as natural gas storage, EOR, and deep underground disposal of acid gas."