Carbon Dioxide Capture and Storage: Overview with an Emphasis on Geological Storage

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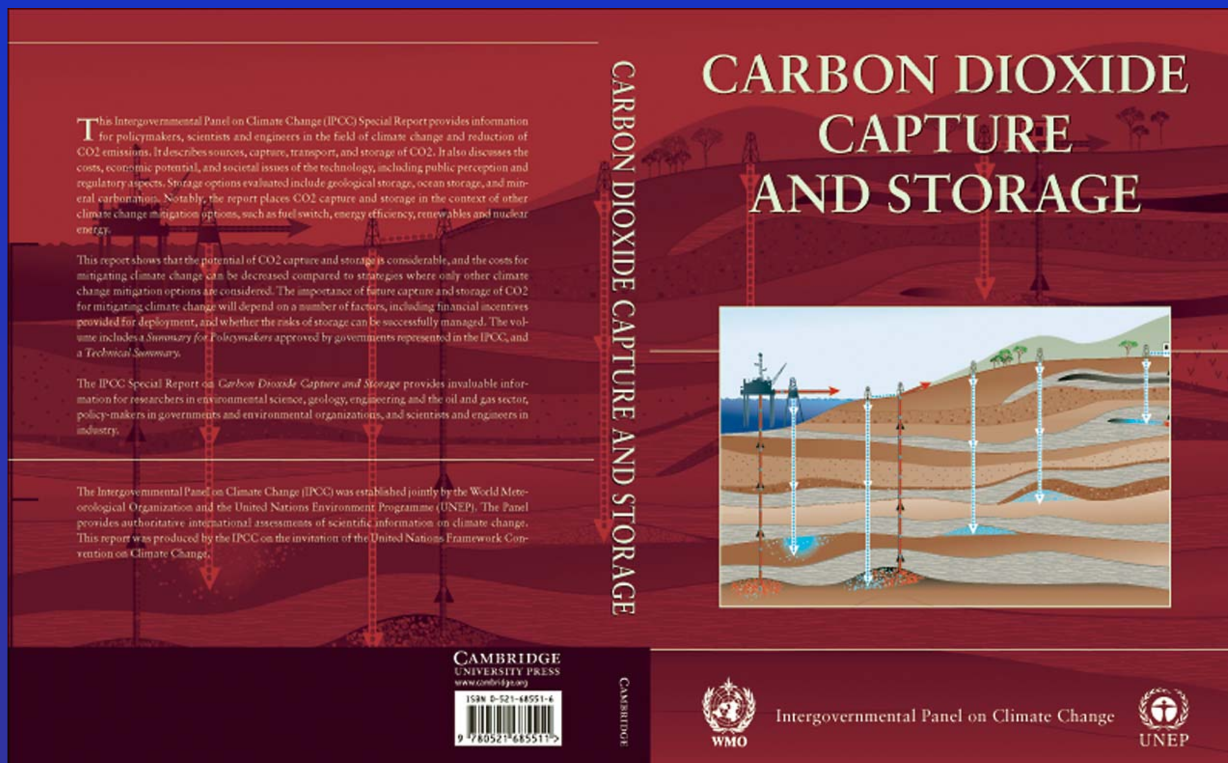
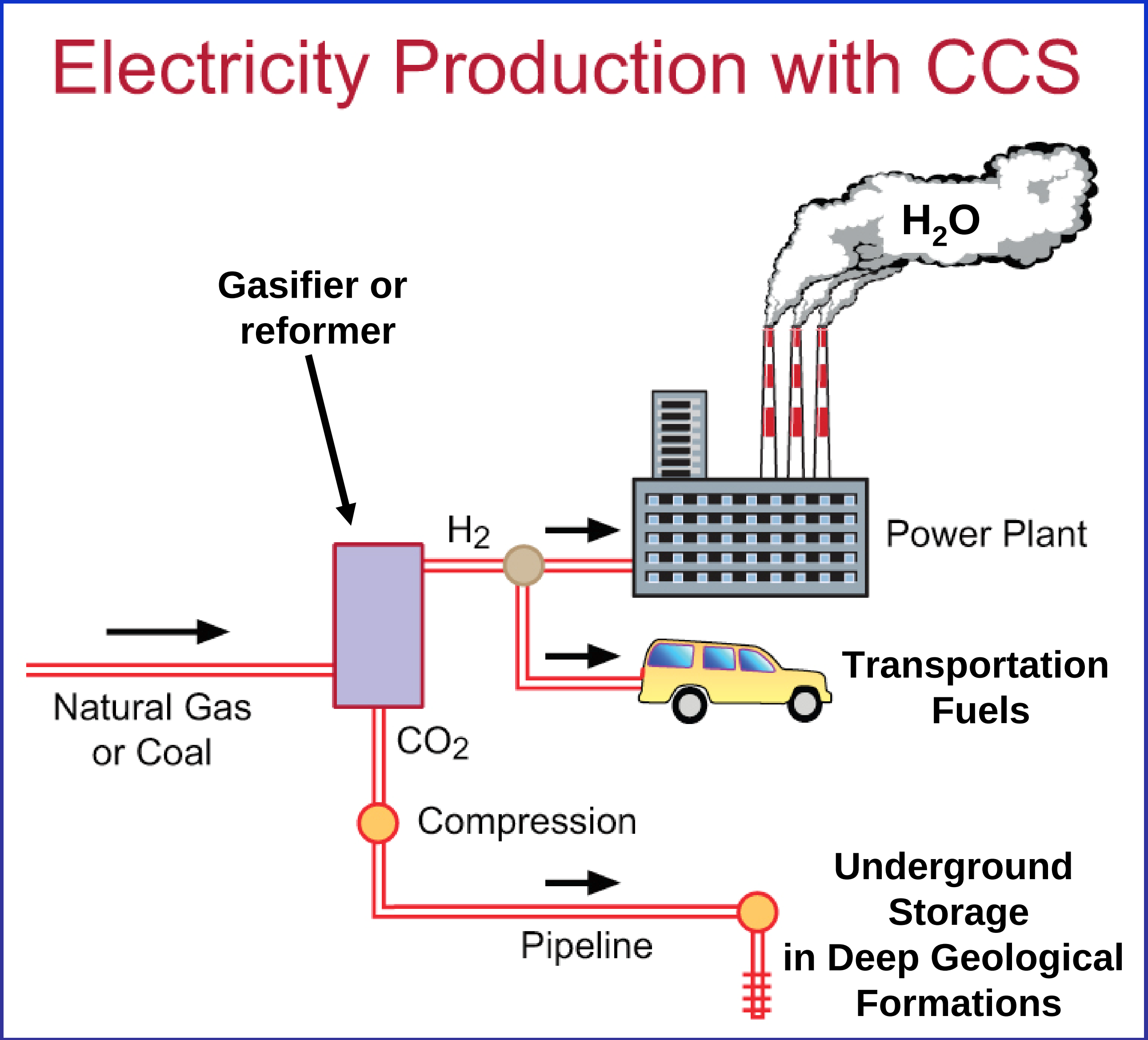
IPCC Special Report on Carbon Dioxide Capture and Storage



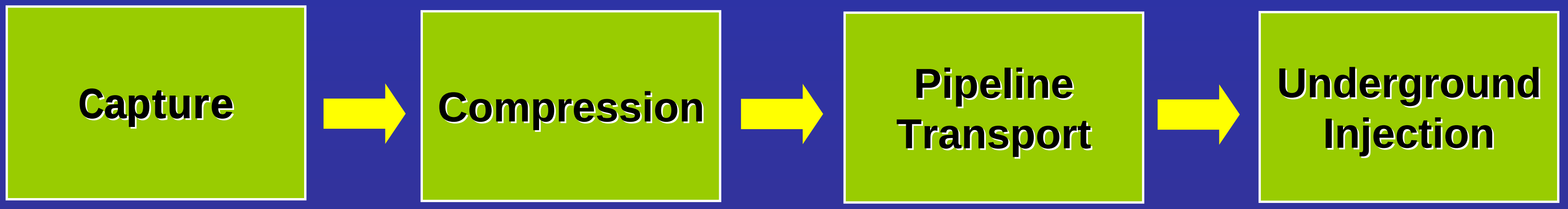
December 2005

CO_2 Capture and Storage Technology

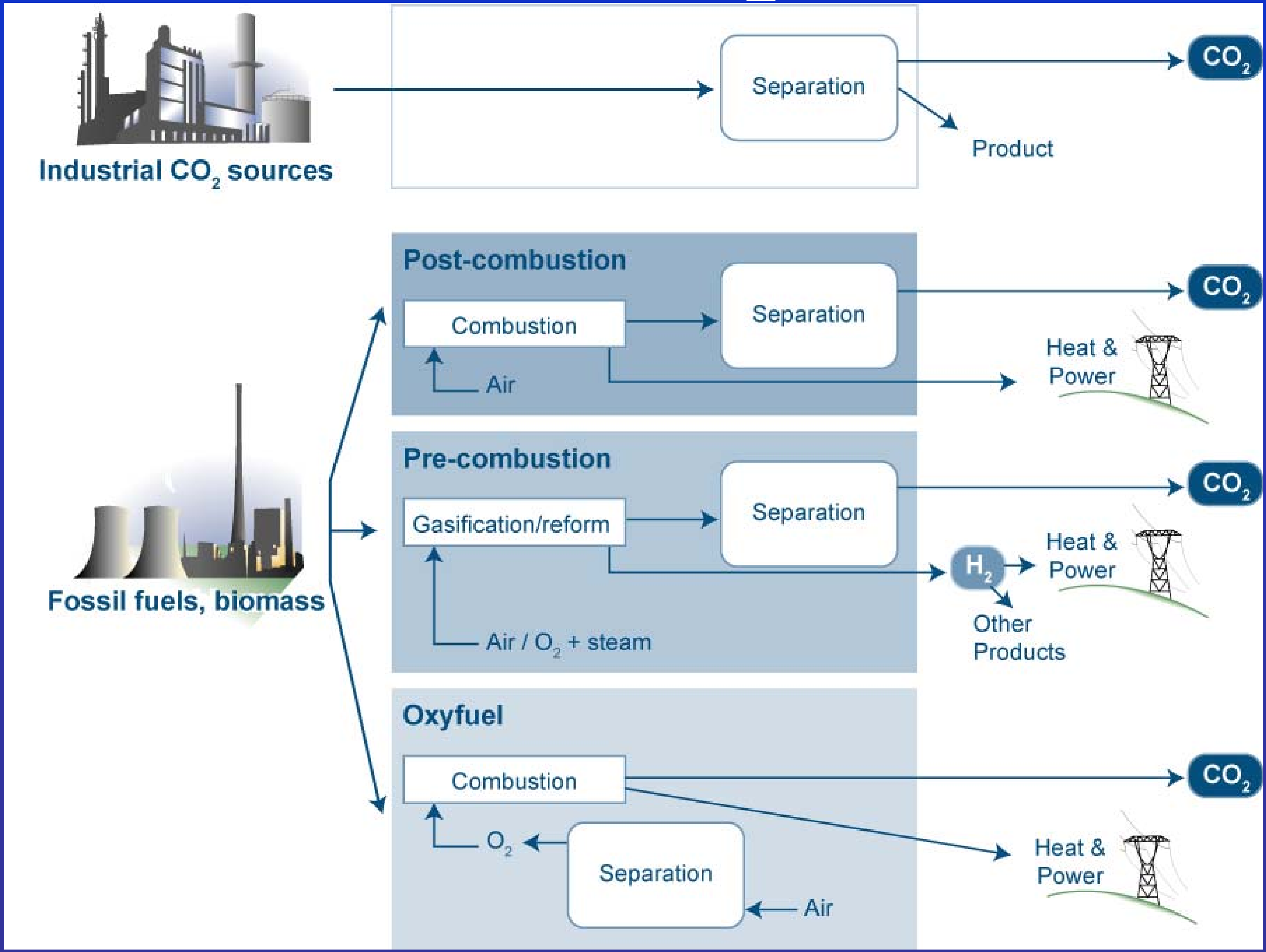


CO_2 Capture and Storage Technology

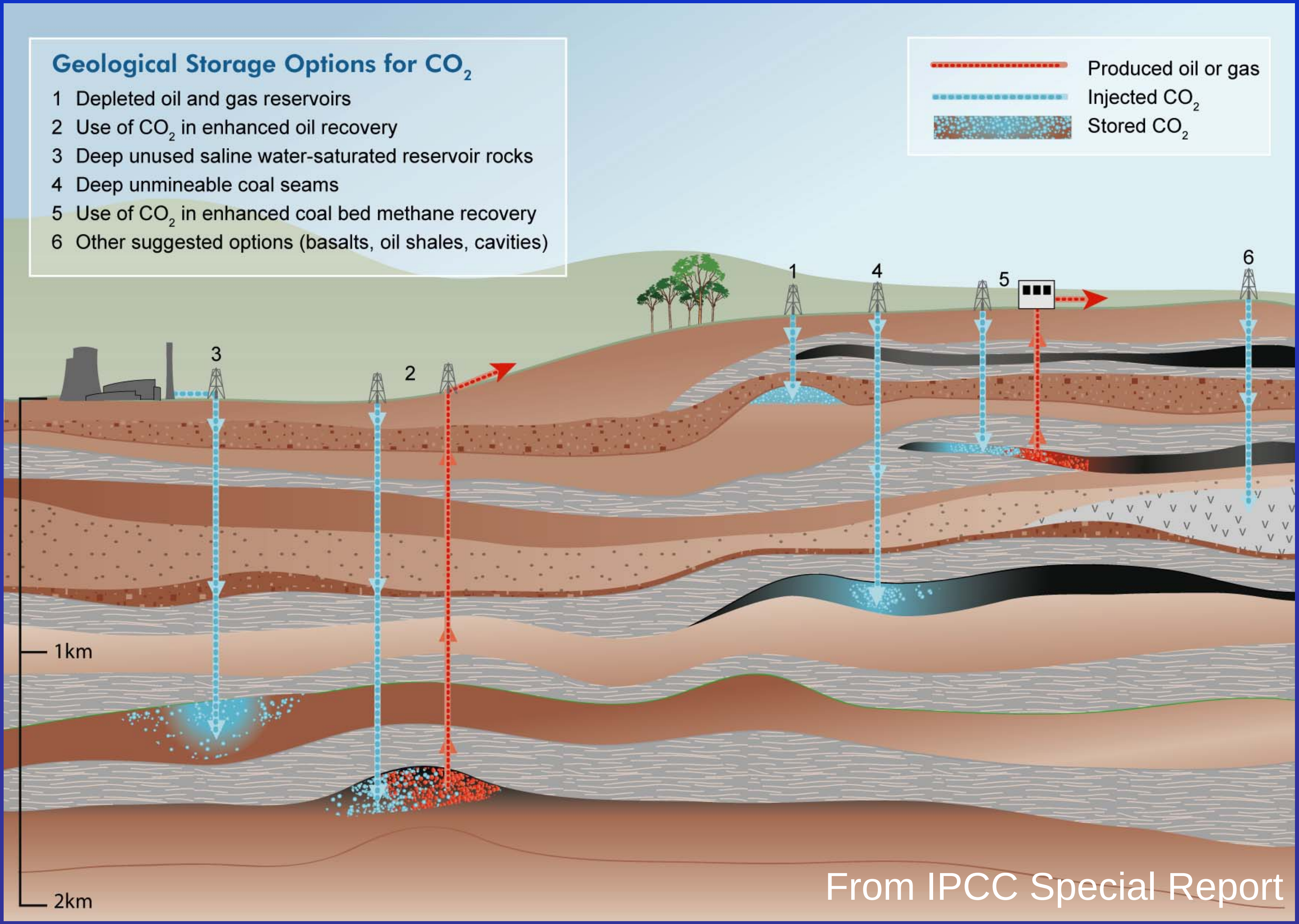
- CCS is a four-step process
  - – Pure stream of CO_2 captured from flue gas or other process stream
  - – Compressed to ~100 bars
  - - Transported to injection site
  - - Injected deep underground geological formations



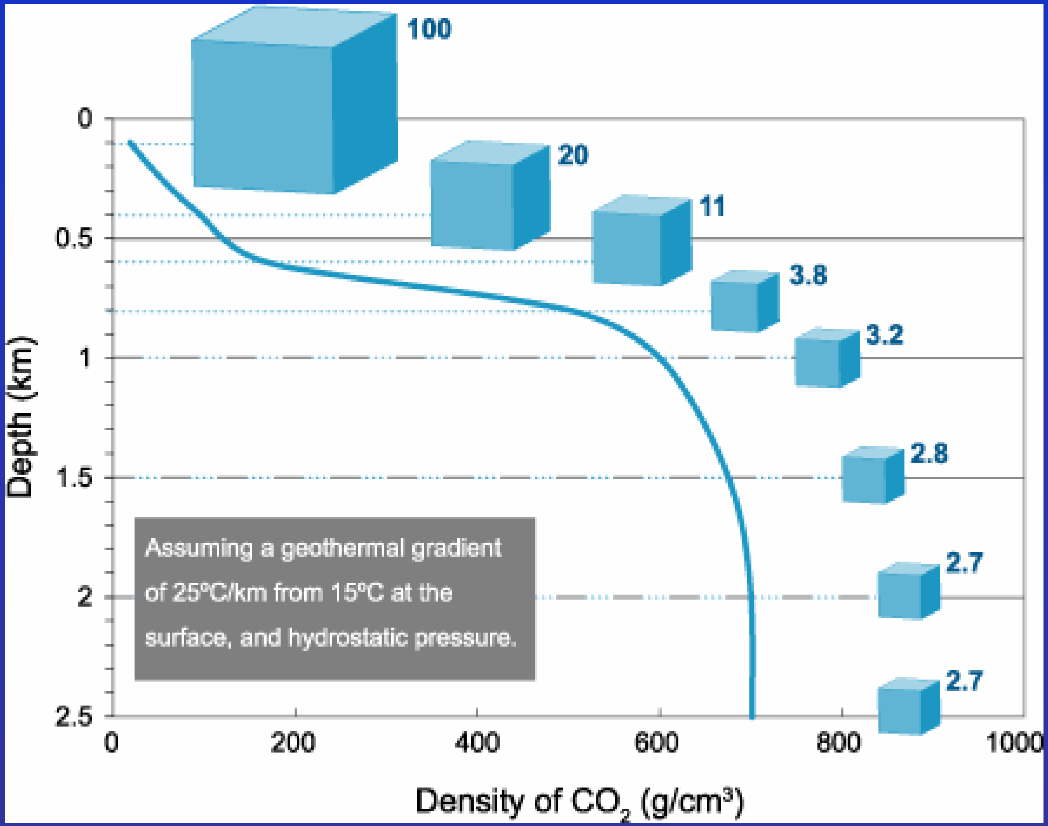
Options for CO_2 Capture



Options for geological storage



Storage in Deep Underground Geological Formations

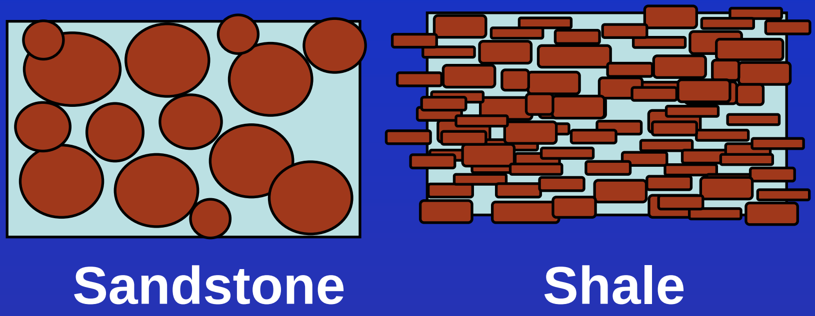


Storage efficiency increases with depth because the density of CO_2 becomes greater

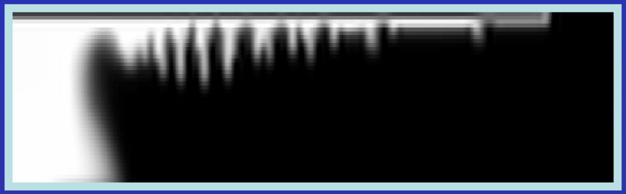
From IPCC Special Report

Storage Security: Trapping Mechanisms

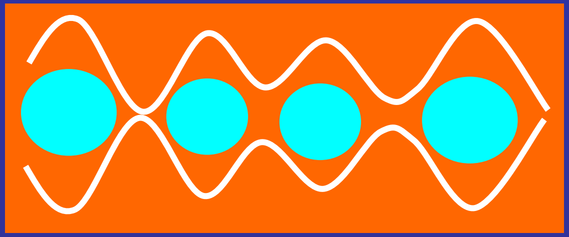
- Structural and stratigraphic trapping
  - Permeability barrier
  - Capillary barrier



- Solubility trapping



- Residual saturation trapping (capillary trapping)



- Mineral trapping

Topics

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- How much capacity is there?
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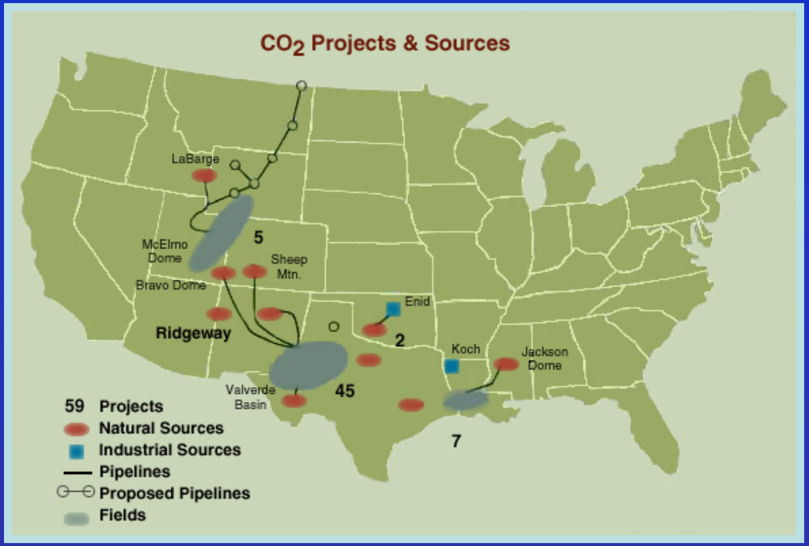
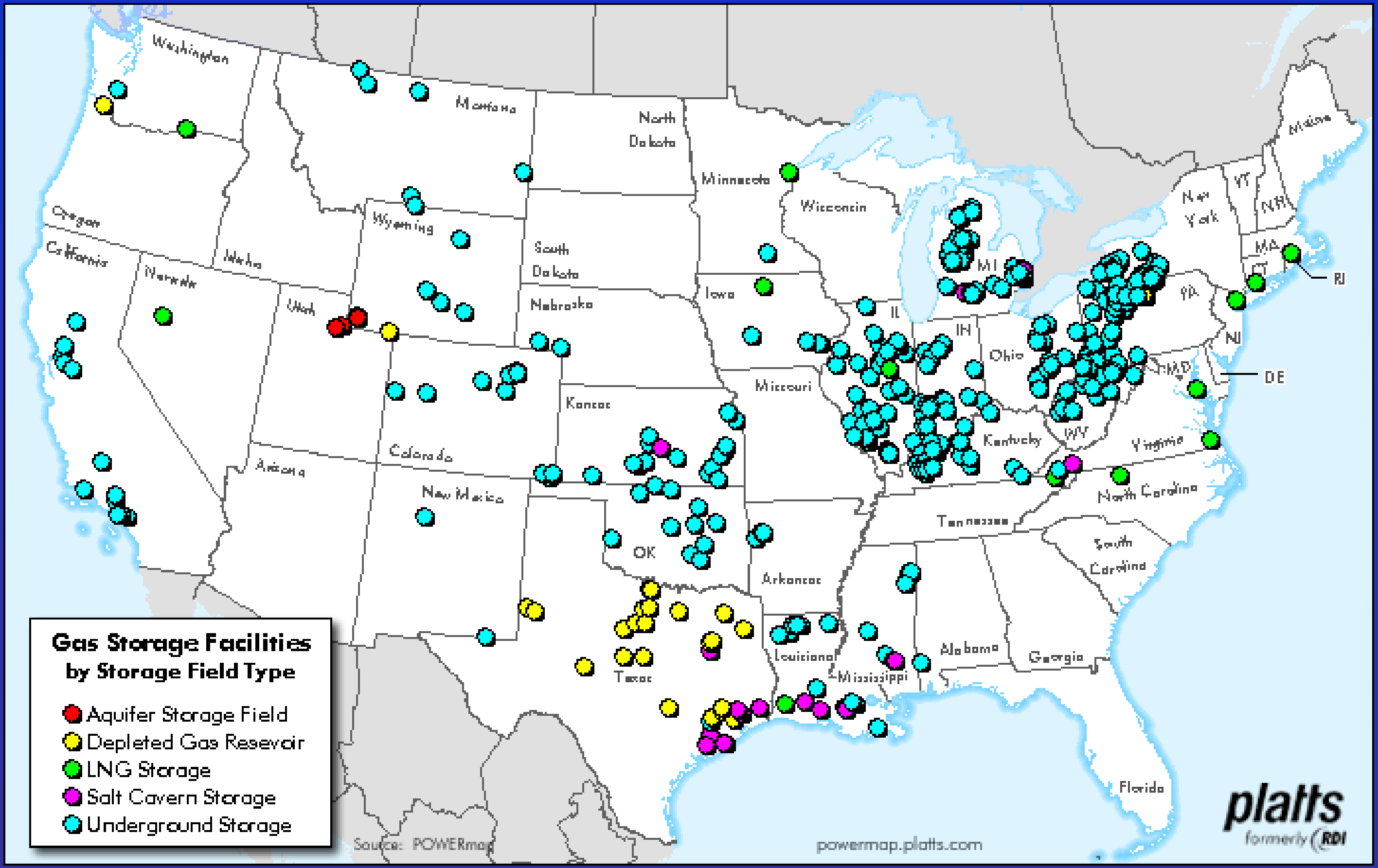
Multiple Lines of Evidence Indicate Storage Can Be Secure and Effective

1. Natural analogues
   - Oil and gas reservoirs
   - CO_2 formations
2. Industrial analogues
   - CO_2 EOR
   - Natural gas storage
   - Liquid waste disposal
3. Fundamental physical and chemical processes
4. Numerical simulation of long term performance
5. Monitoring existing projects



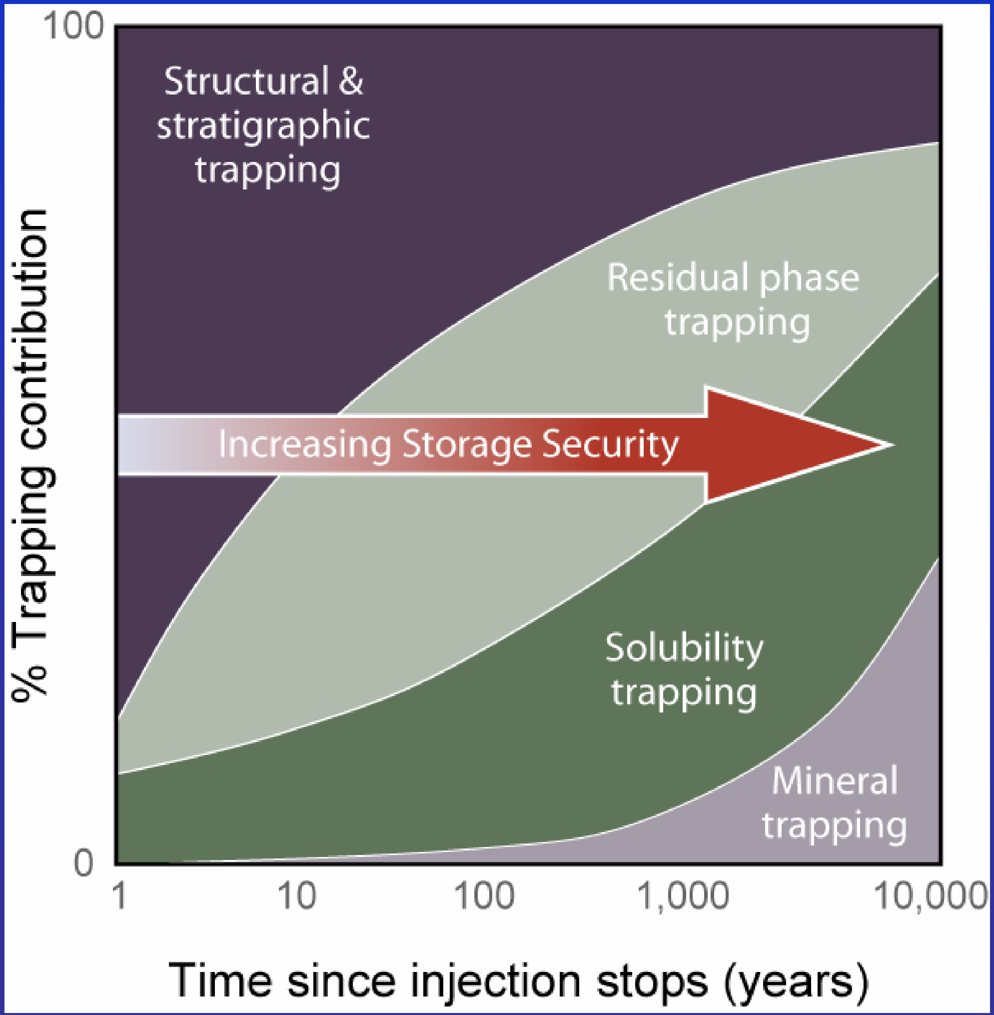
Industrial Analogues



Location of Natural Gas Storage Projects in the U.S.

Temporal Evolution of Trapping Mechanisms

Storage security should increase with time at an effective storage site.



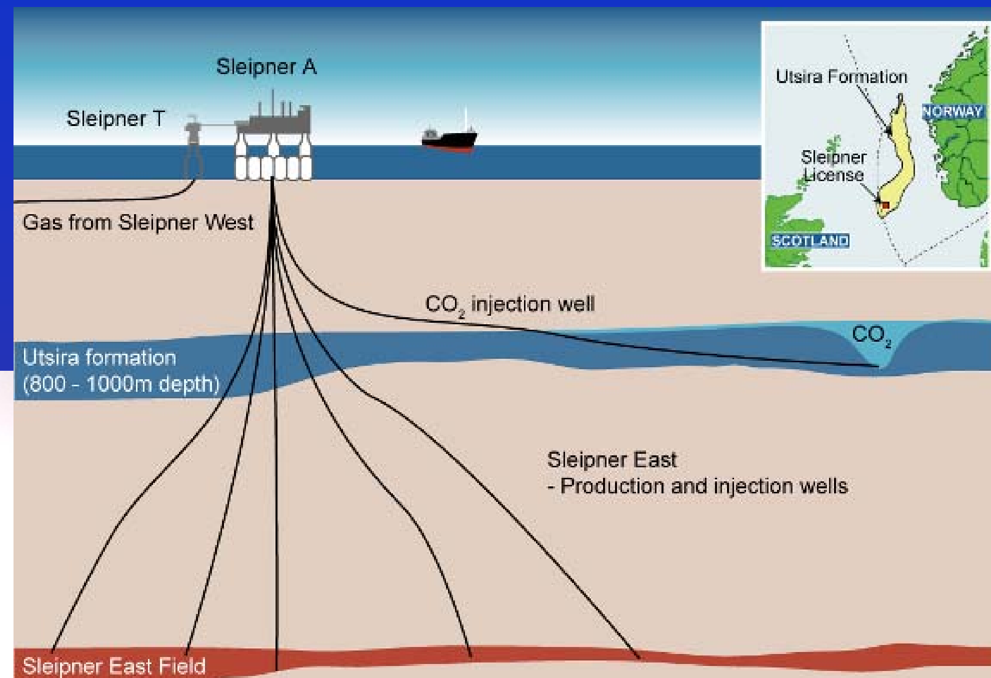
From IPCC Special Report

Existing Storage Sites

From IPCC Special Report

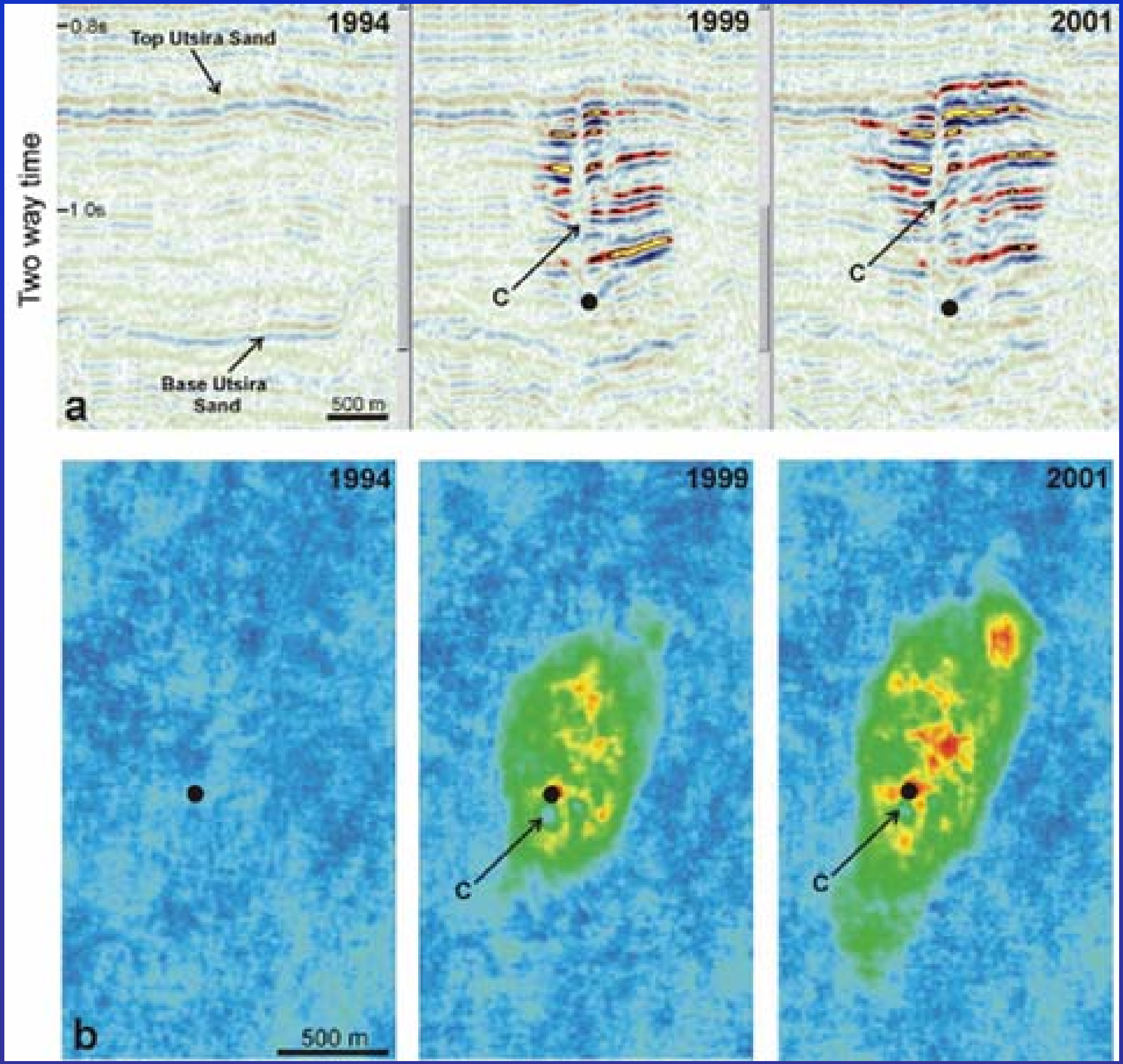
Sleipner Project, North Sea

- 1996 to present
- 1 Mt CO_2 injection/yr
- Seismic monitoring



Picture compliments of *Statoil*

Monitoring CO_2 Migration with 3-D Seismic Imaging



From Chadwick, 2004

Weyburn CO_2-EOR and Storage Project

- 2000 to present
- 2.7 Mt/year CO_2 injection
- CO_2 from the Dakota Gasification Plant in the U.S.

Photo’s and map courtesy of PTRC and Encana

In Salah Gas Project

In Salah Gas Project

- Krechba, Algeria

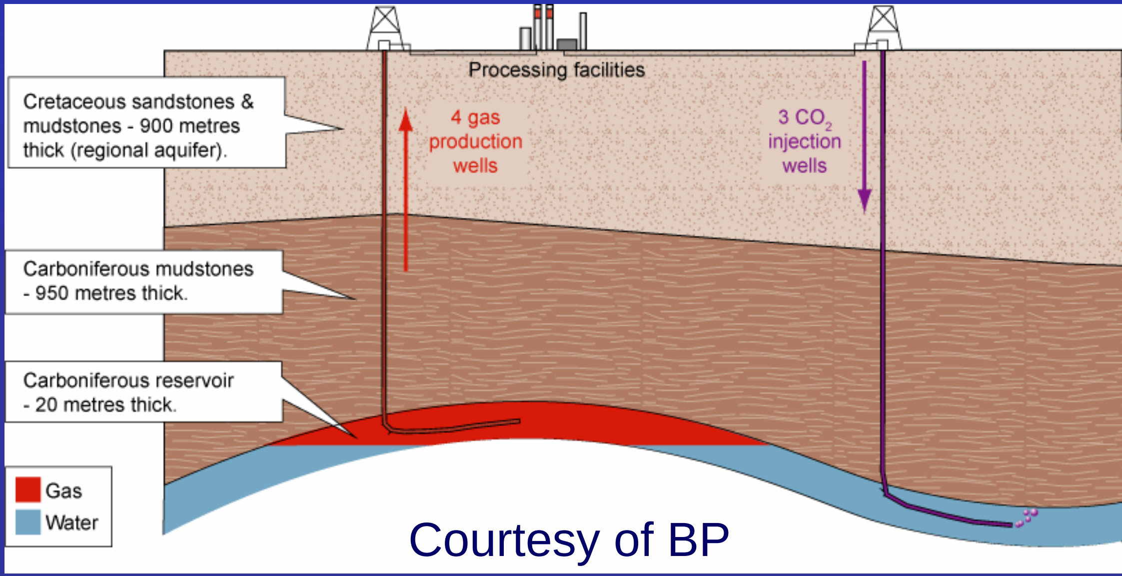
Gas Purification

- Amine Extraction

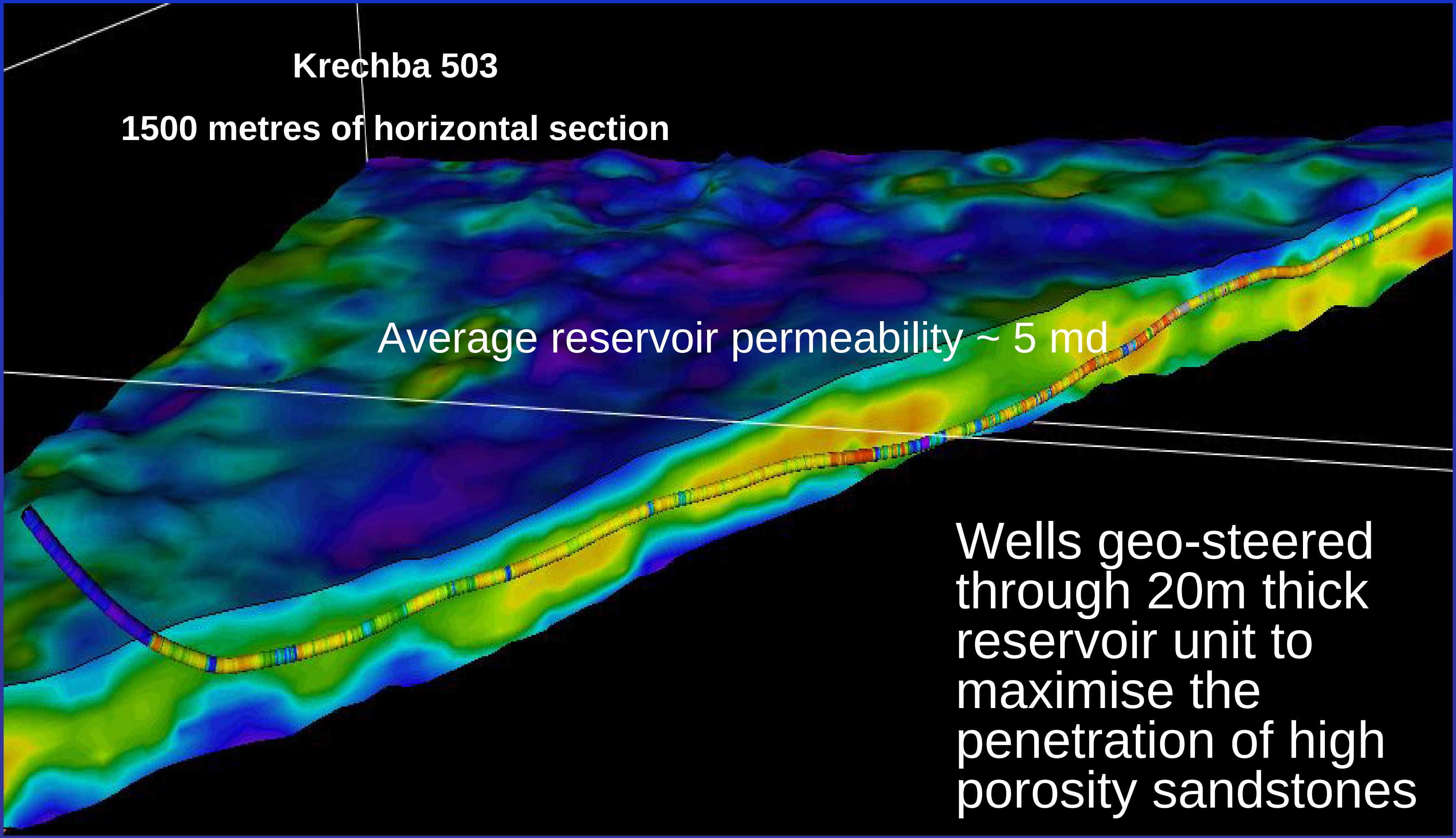
1 Mt/year CO_2 Injection

Operations Commence

- June, 2004



Optimizing Sweep Efficiency and Injectivity with Long Reach Horizontal Wells



Courtesy of BP

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 ($<10^{-4}$/yr), and is likely** to exceed 99% over 1,000 years ($<10^{-5}$/yr).”*

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

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

From IPCC Special Report

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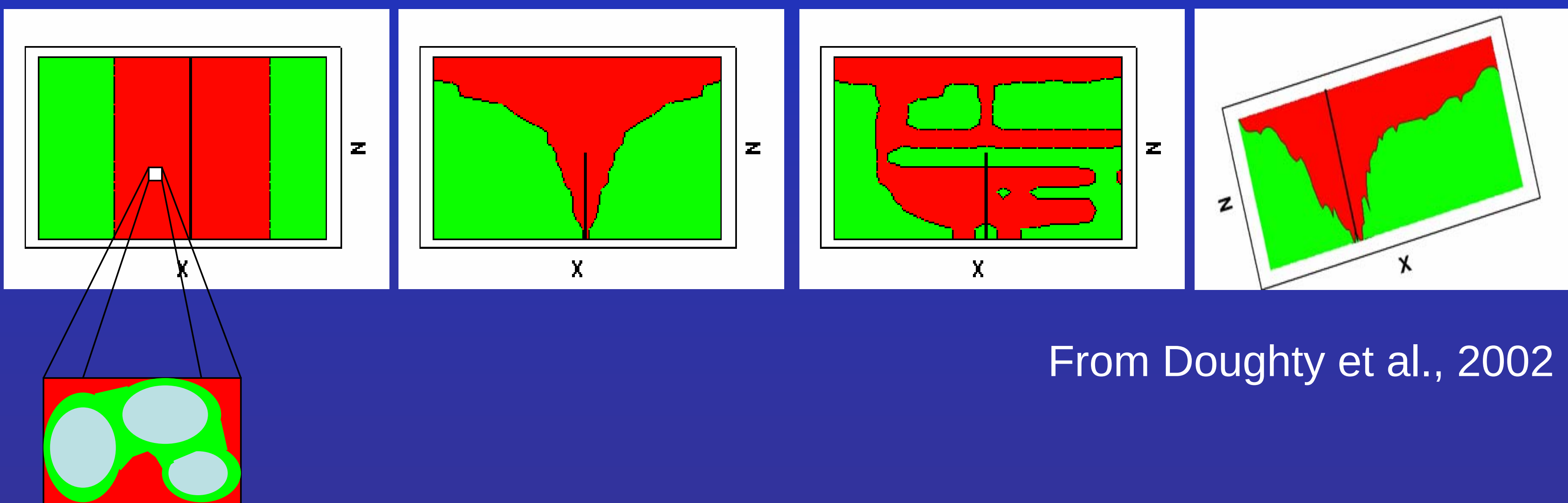
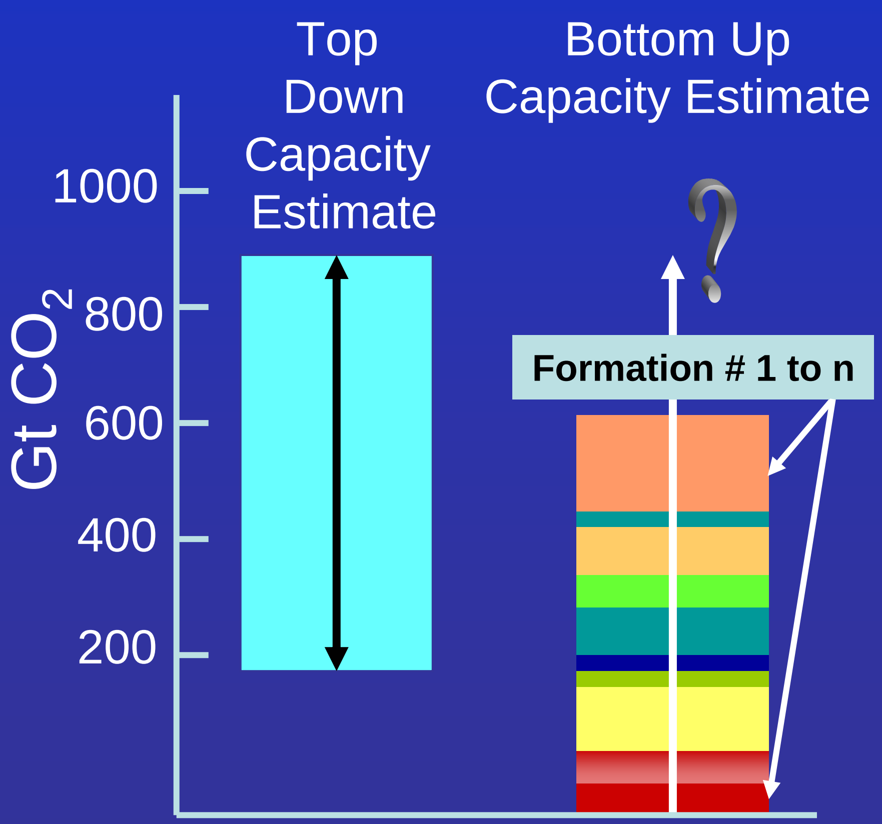
Volumetric Storage Capacity

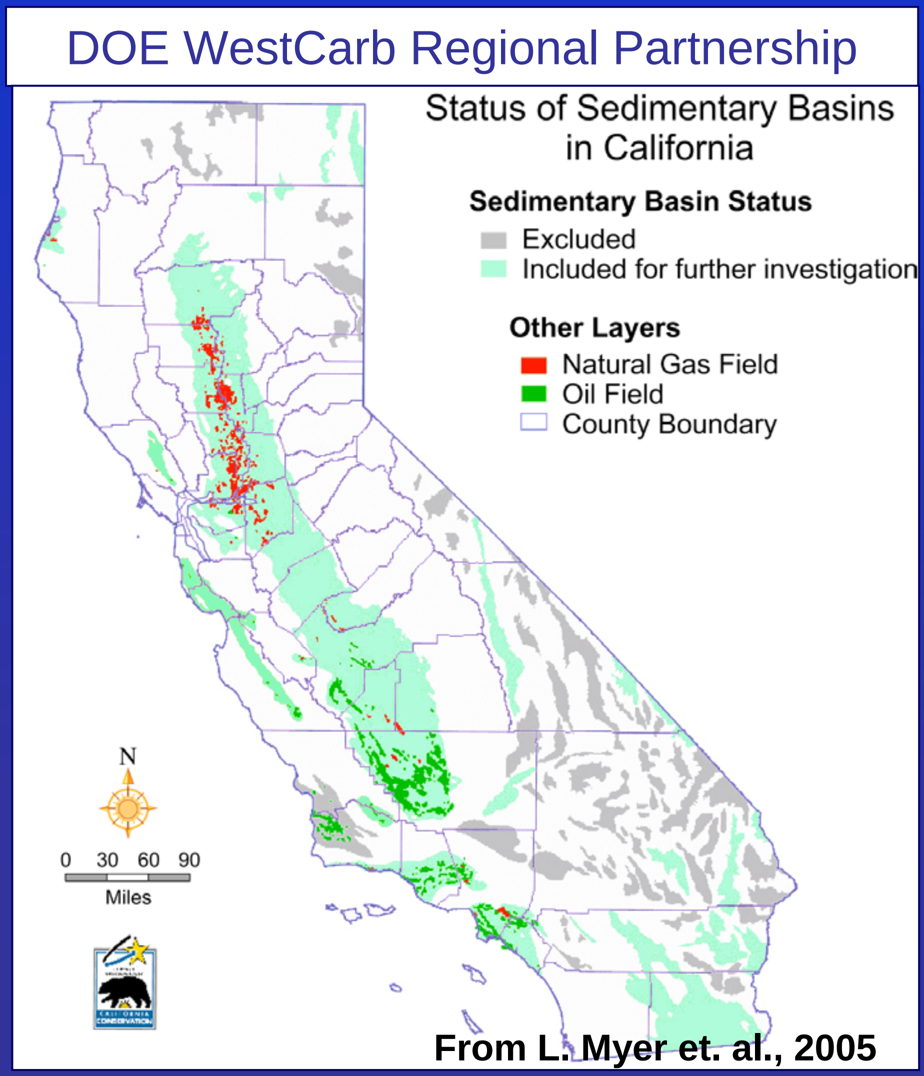
Multiphase Flow Effects	Gravity Effects	Heterogeneity Effects	Structural Effects



From Doughty et al., 2002

Reconciling Top-Down and Bottom-Up Storage Capacity Estimates





Capacity of Storage Formations

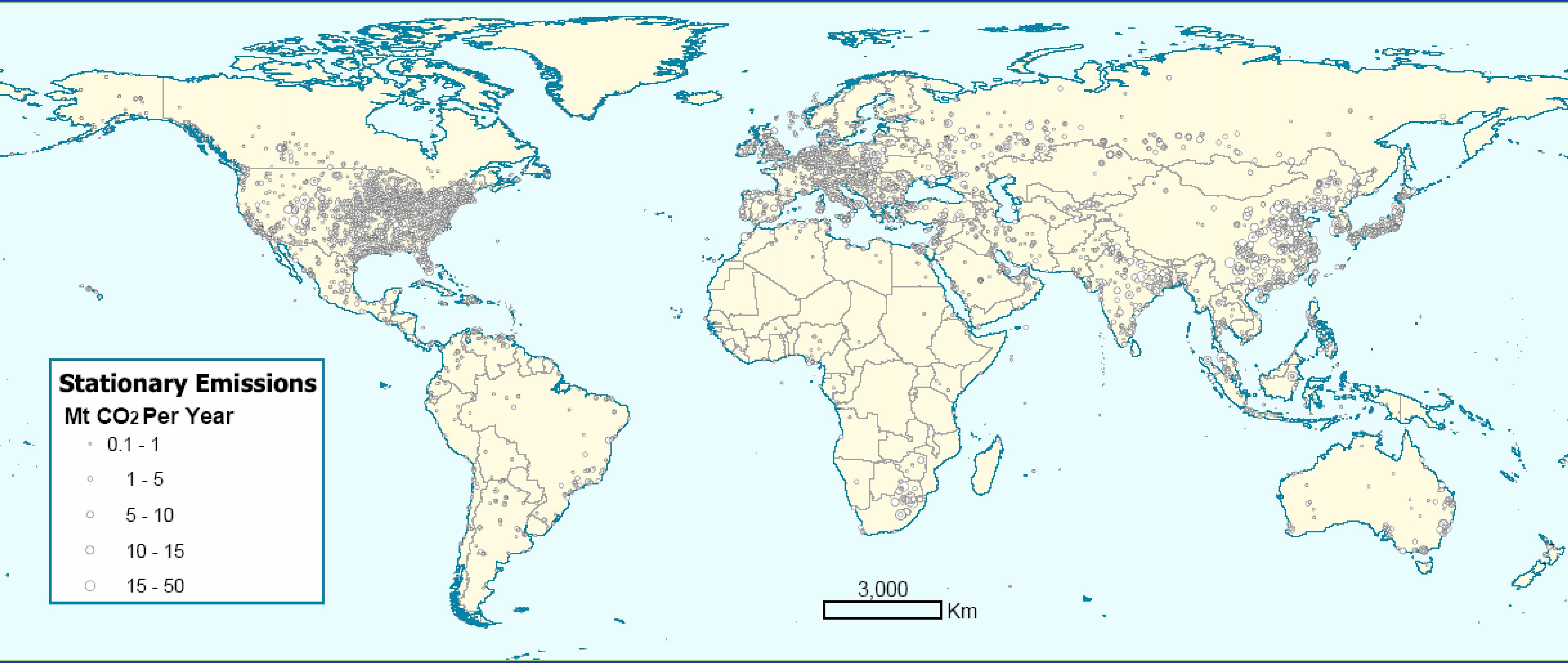
Reservoir Type	Lower Estimate of Storage Capacity ($GtCO_2$)	Upper Estimate of Storage Capacity ($GtCO_2$)
Oil and gas fields	675[a]	900[a]
Unminable coal seams (ECBM)	3–15	200
Deep saline formations	1000	Uncertain, but possibly 10^4

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

From IPCC Special Report

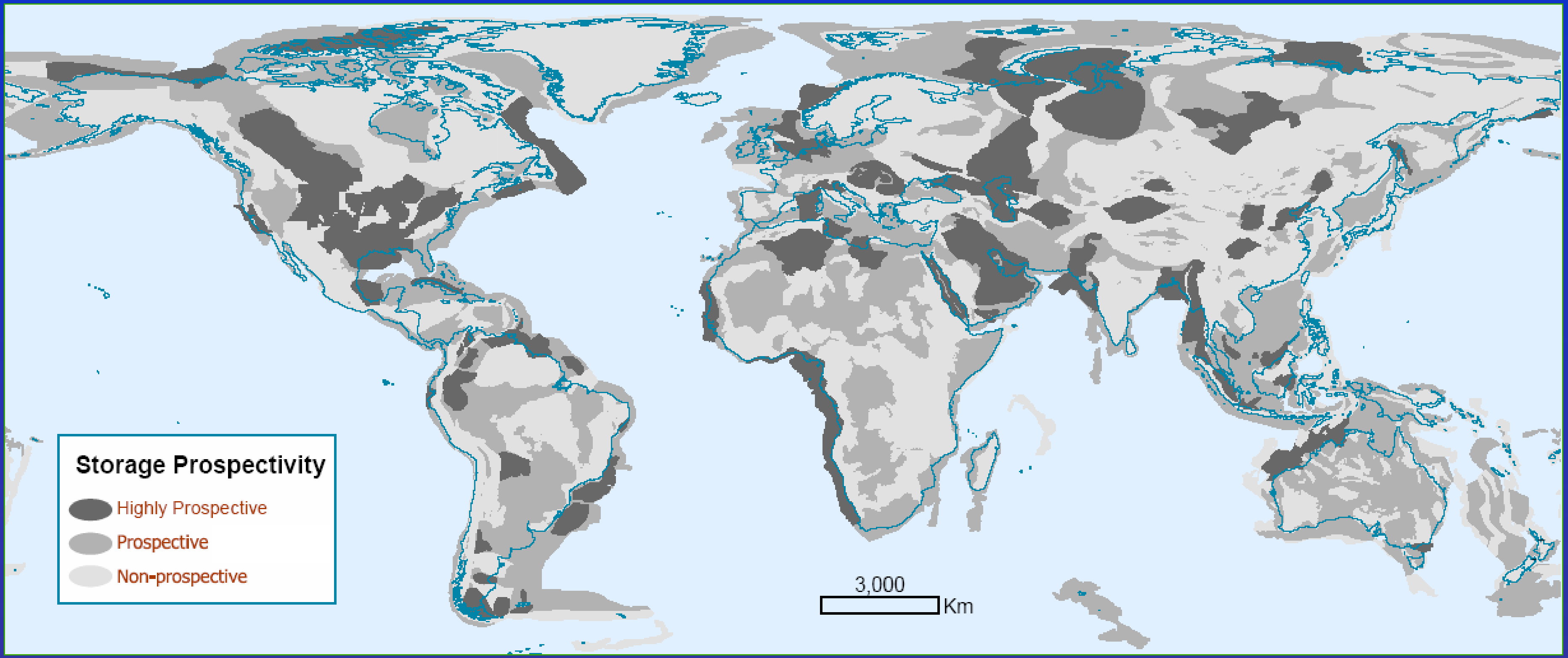
"Available evidence suggests that worldwide, it is likely that there is a technical potential of at least about 2,000 $GtCO_2$ (545 GtC) of storage capacity in geological formations."

Geographical Distribution of CO_2 Sources



From IPCC Special Report

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."

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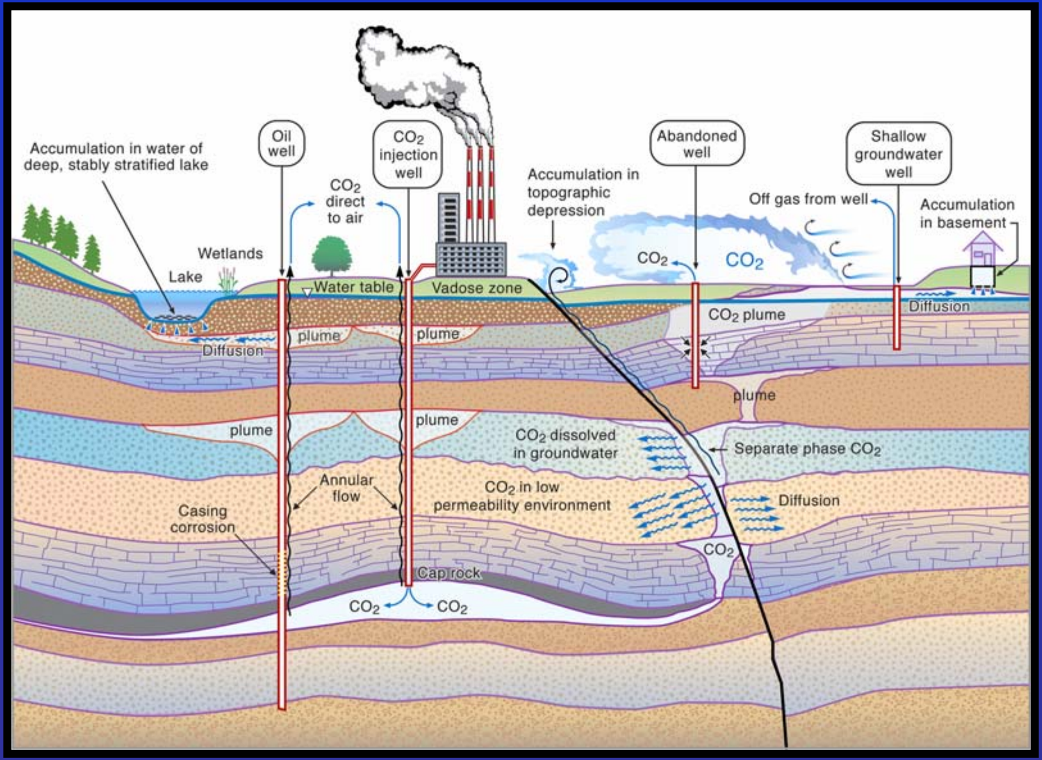
Biggest Risks
Have Been Identified

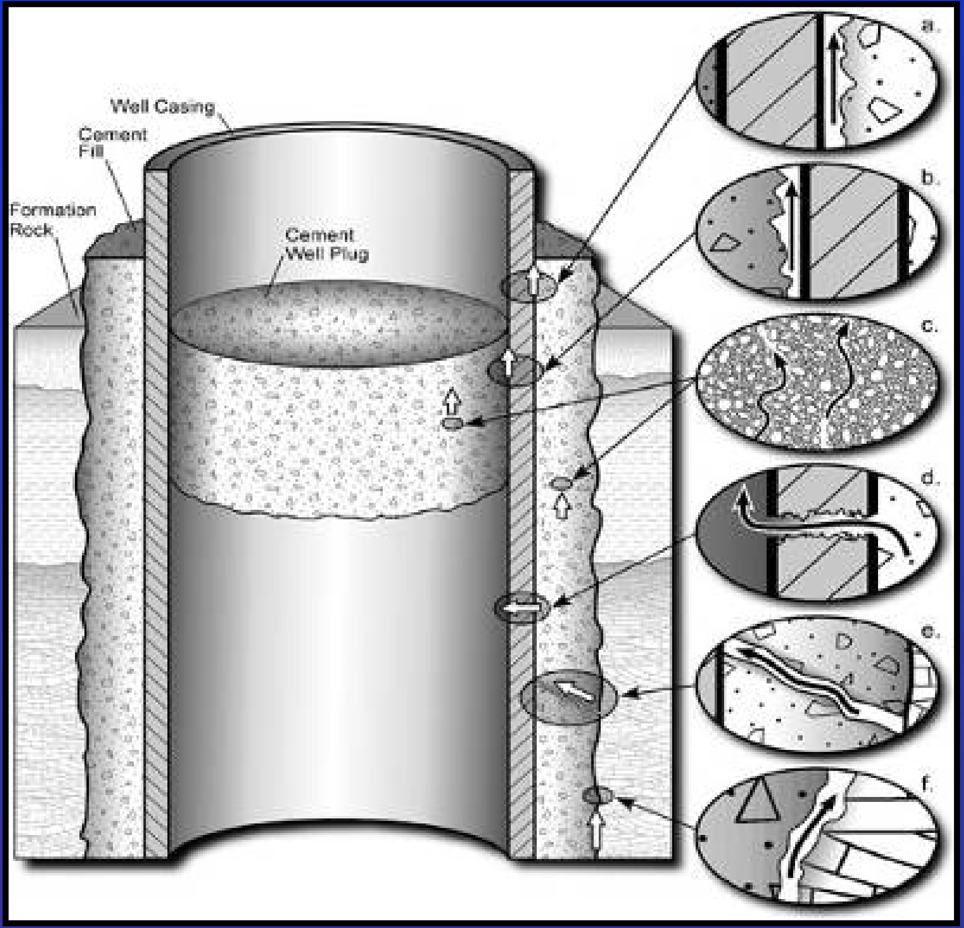
- Industrial analogues identify major risks
- Leakage through poor quality or aging injection well completions
- Leakage up abandoned wells
- Leakage due to inadequate caprock characterization
- Inconsistent or inadequate monitoring



Maturation of the technology and improved regulations have mitigated most of these problems for the industrial analogues.

Leakage Pathways in Abandoned Well

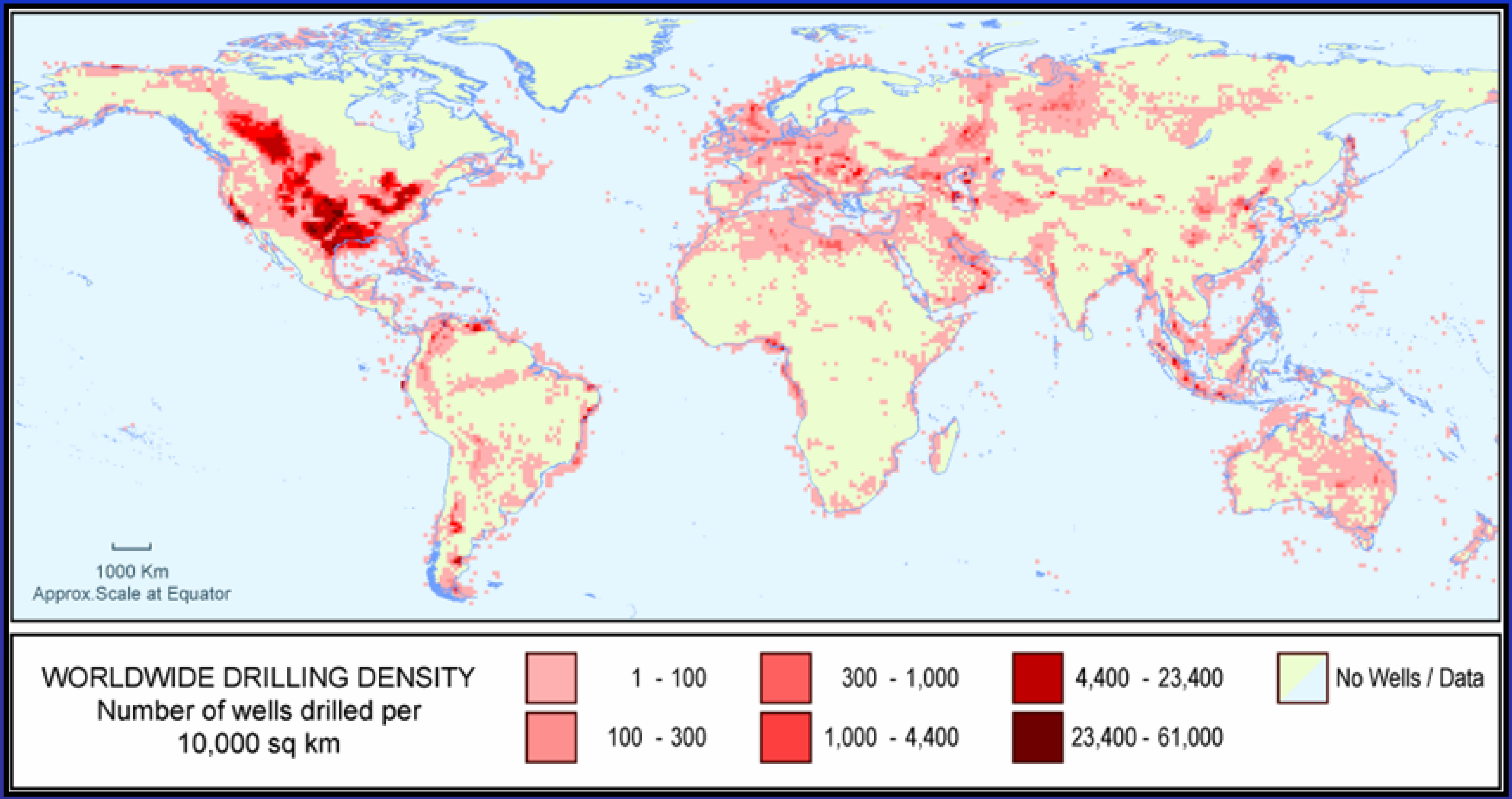
- Between casing and cement wall and plug, respectively
- Through cement plugs
- Through casing
- Through cement wall
- Between the cement wall and rock



Gasda et al., 2004

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

World Oil and Gas Well Distribution and Density



From IHS Energy

Well density and risks from abandoned wells depends on location

Well Selected and Managed Sites are the Key to Safe and Secure Storage

"*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.*"

From IPCC Special Report

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Monitoring is Needed to Ensure that Geologic Storage is Safe and Effective

Requirements for Geologic Storage

Worker and Public Safety

Local Environmental Impacts to Groundwater and Ecosystems

GHG Mitigation Effectiveness

Monitoring Needs

Key Monitoring Needs

- Monitor injection well performance
  - Wellhead and formation pressure
  - Casing annulus pressure
  - Injection rates
- Detect leakage and seepage of CO_2
  - Injection well leakage
  - Leakage from the primary storage reservoir
  - Surface seepage from the ground and abandoned wells

Monitoring Well Integrity

- Injection and production rate
- Wellhead and formation pressure
- Casing and annulus pressure testing
- Well logs
  - Temperature
  - Noise
  - Cement bond
  - Sonic

Geophysical Monitoring Techniques

- Seismic geophysics
  - Surface 2 and 3D
  - VSP
  - Cross-well
- Electrical and electromagnetic geophysics
- Gravity
- Tilt measurements
- Airborne or satellite-based land surface deformation
- Microseismicity

Courtesy of Tom Daley, LBNL

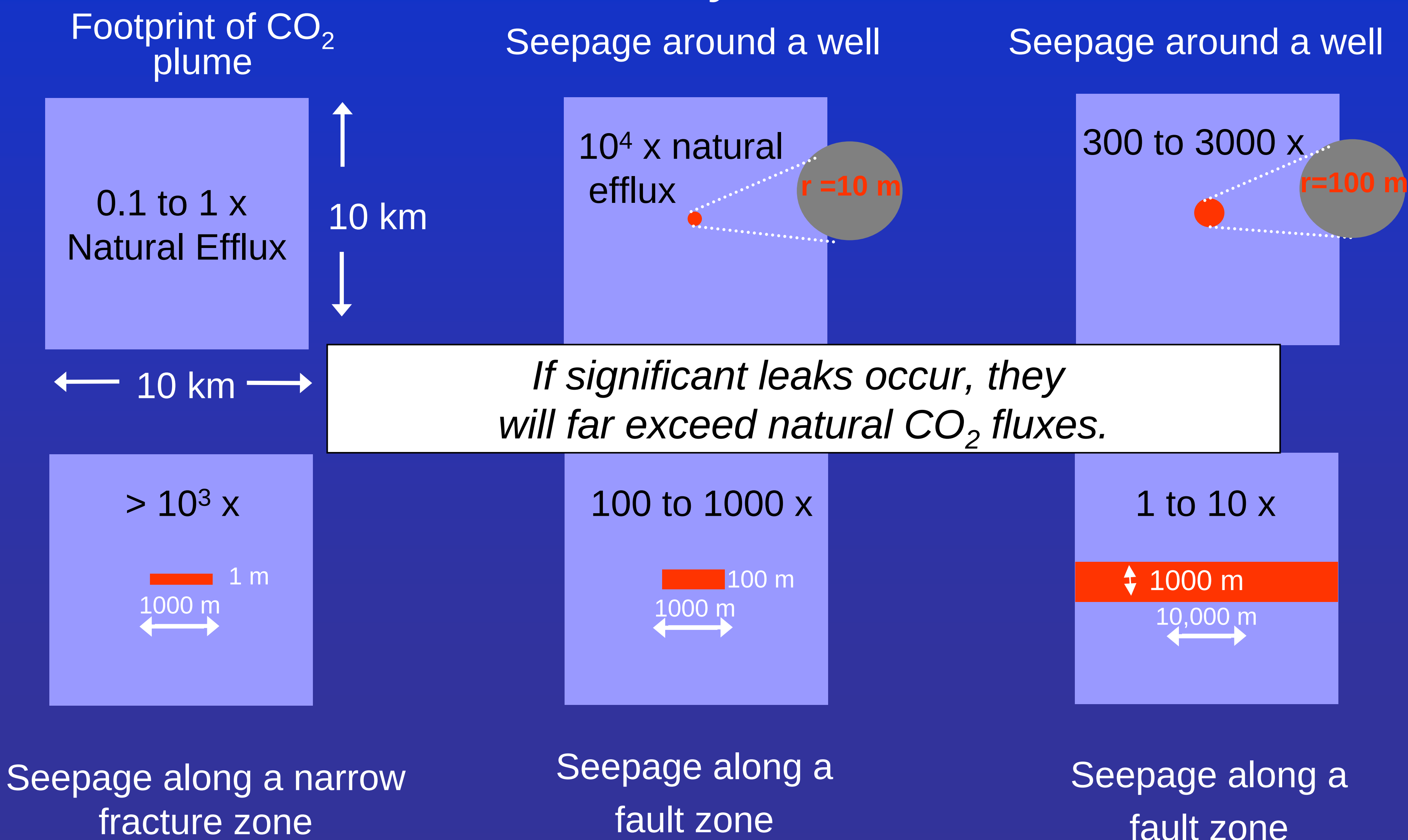
Surface Monitoring for Seepage Detection and Inventory Verification

- Eddy covariance flux monitoring
- Flux chamber monitoring
- Soil gas and vadose zone monitoring
- Fluid and gas phase tracers
- Atmospheric CO_2 concentration

Courtesy of Jennifer Lewicki, LBNL

Example Seepage Detection Scenarios

(150 Mt Storage Project): Seepage rate 0.01 to 0.1%/year



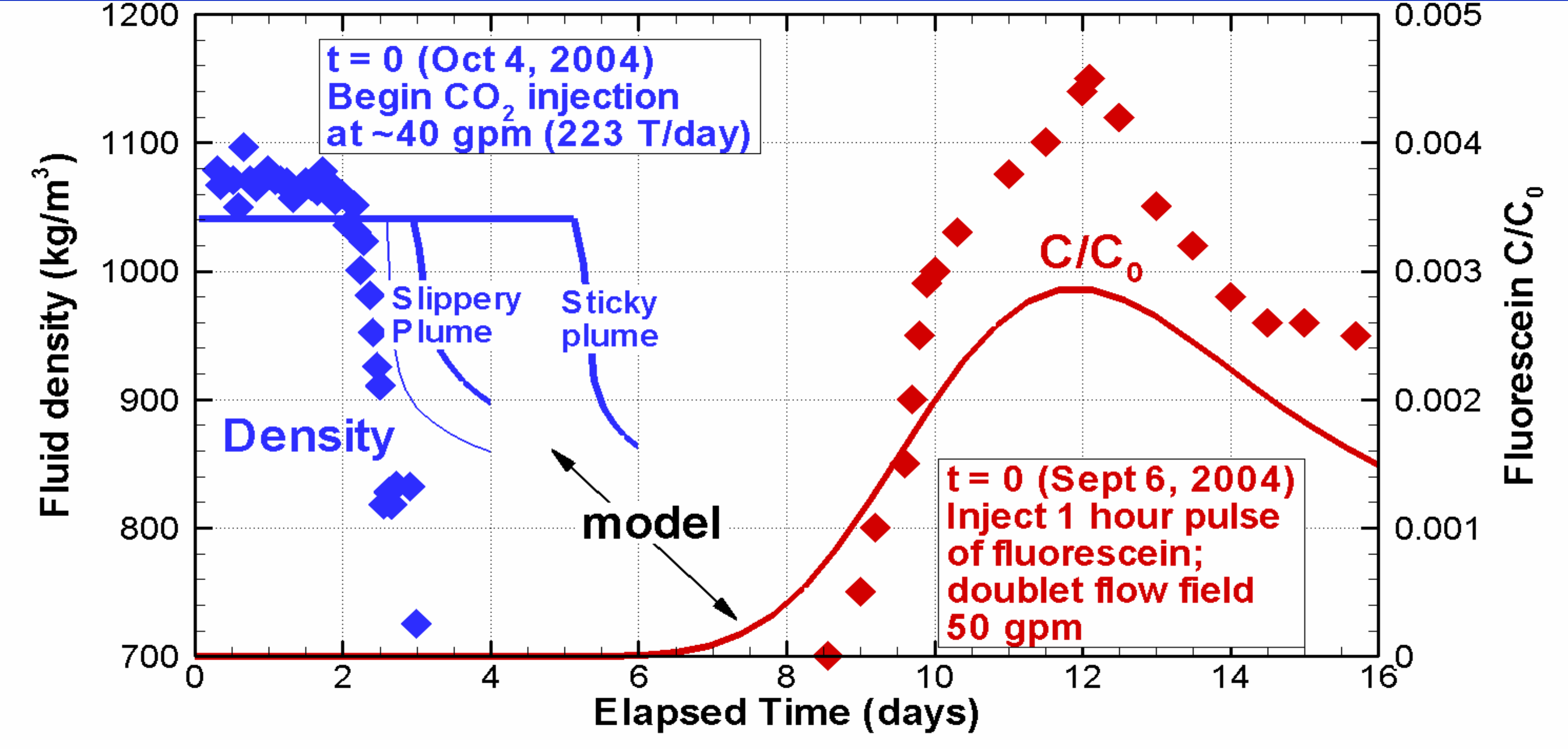
The Frio Brine Pilot, Texas

- Led by Susan Hovorka, UT Austin
- Injection: 1600 tonnes CO_2 over 10 days
- Well Depth: 1540 m
- Observation well 30 m from injection well
- Monitoring
  - Formation pressure
  - Tracers
  - Geochemical sampling
  - VSP
  - Cross-well seismic and EM
  - RST logging

Geochemical Sampling

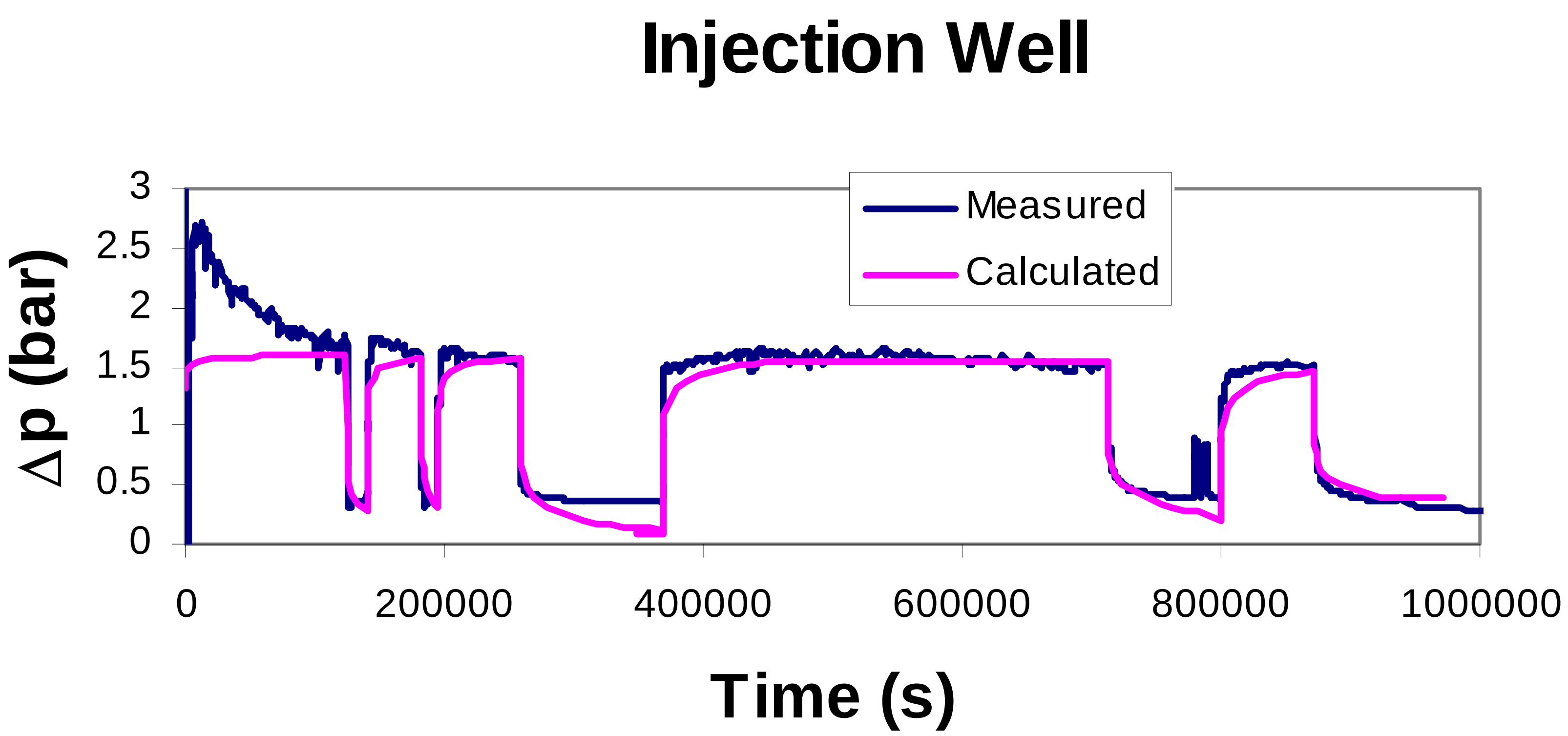
CO_2 Transportation Trucks

Observed Data and Model Predictions

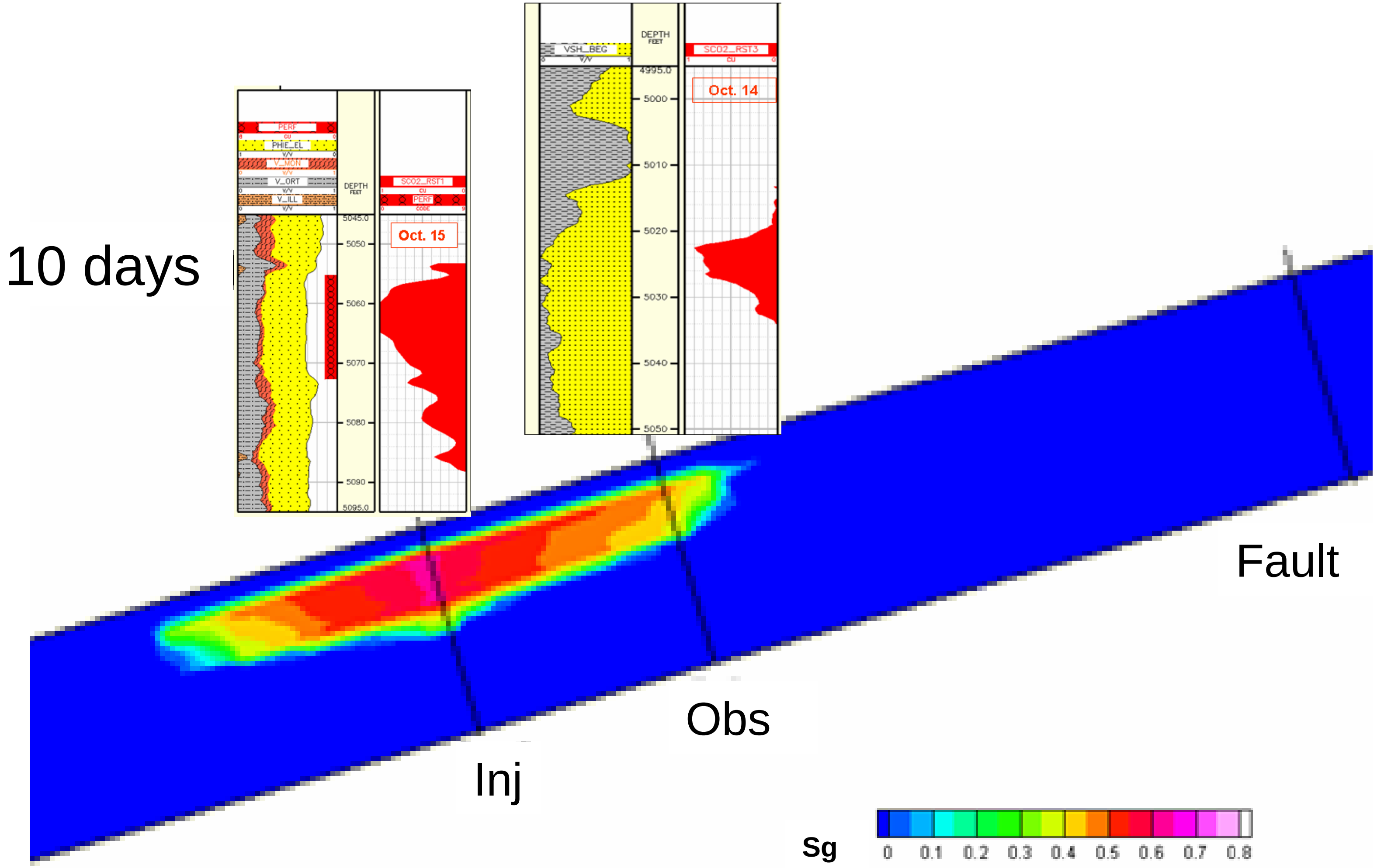


Field data provided by Barry Freifeld and Rob Trautz, LBNL

Pressure Transient Analysis



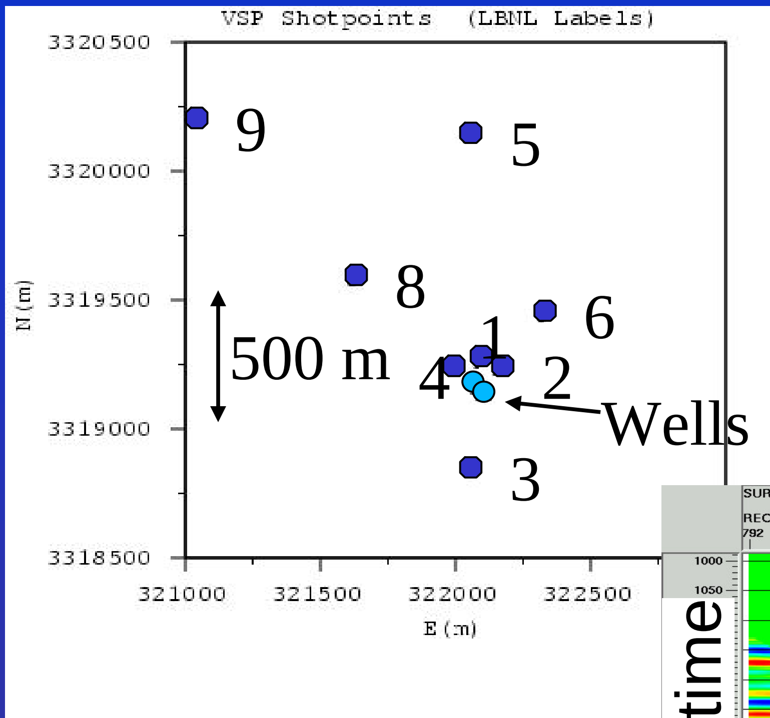
Examples: RST Logs from Frio Formation Compared to Simulated CO_2 Migration



Simulation from Doughty et al., 2005

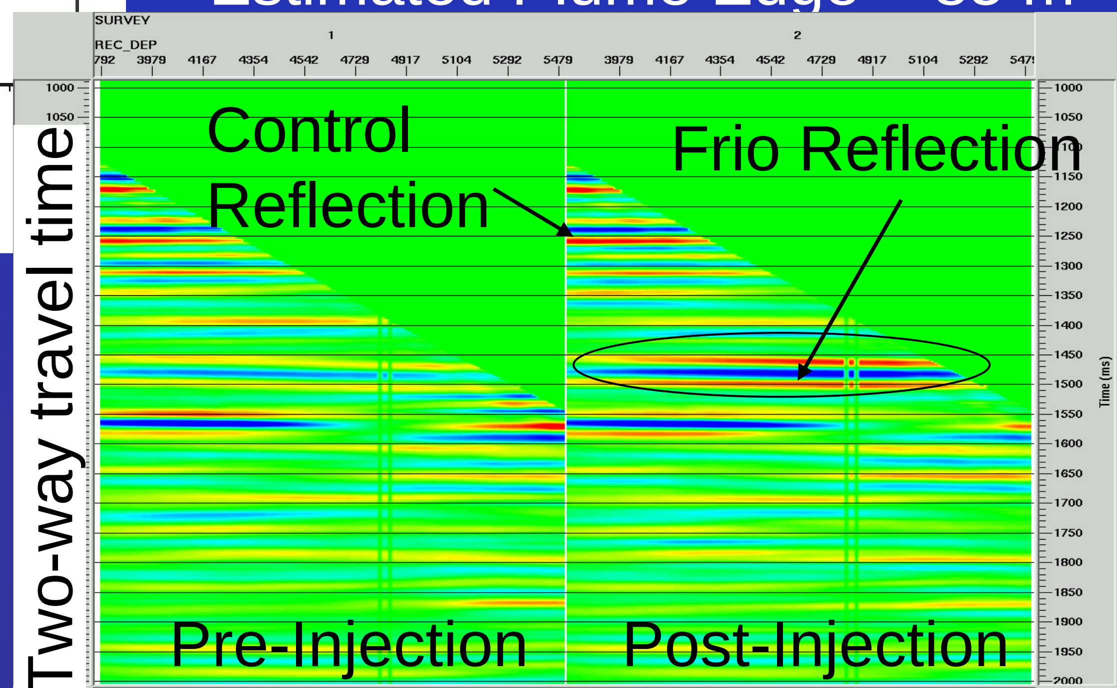
RST data from Sakurai et al., 2005

Frio Brine Pilot: Vertical Seismic Profiling

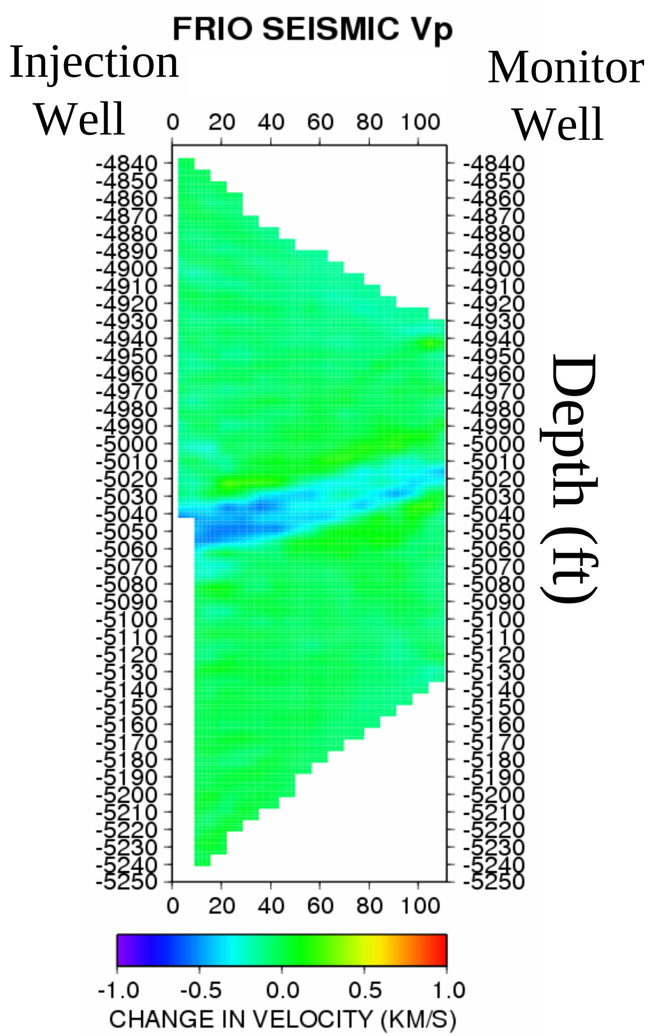


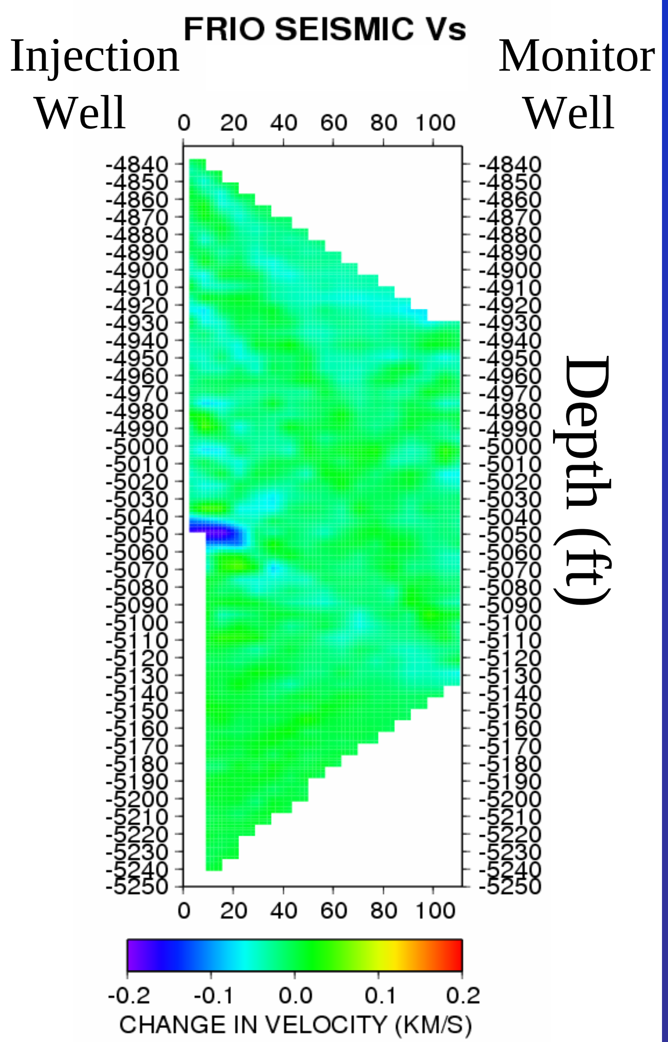
Data and interpretation from Tom Daley, LBNL

Estimated Plume Edge = 85 m



Examples: Seismic Tomography from the Frio Formation





Slide compliments of Tom Daley, LBNL

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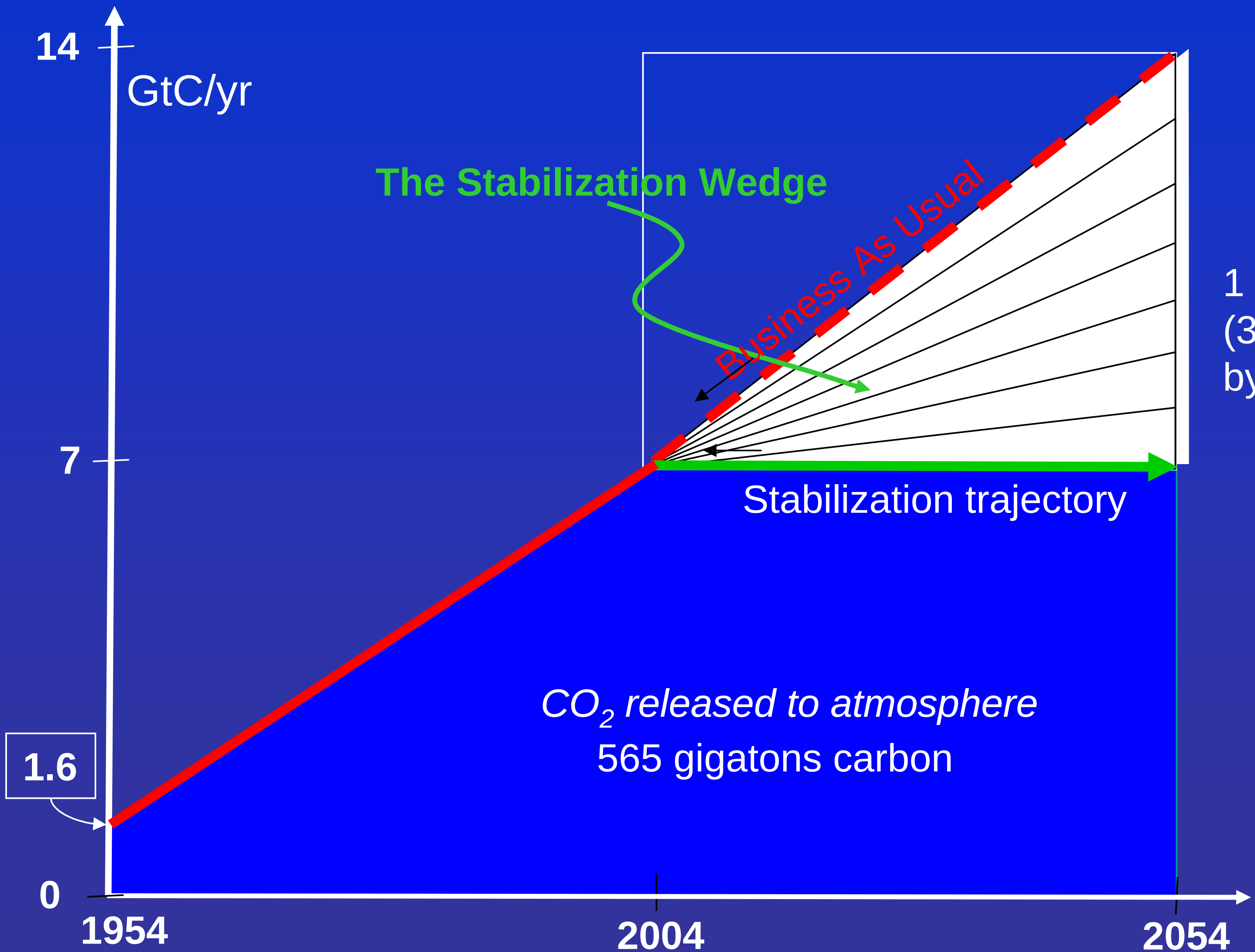
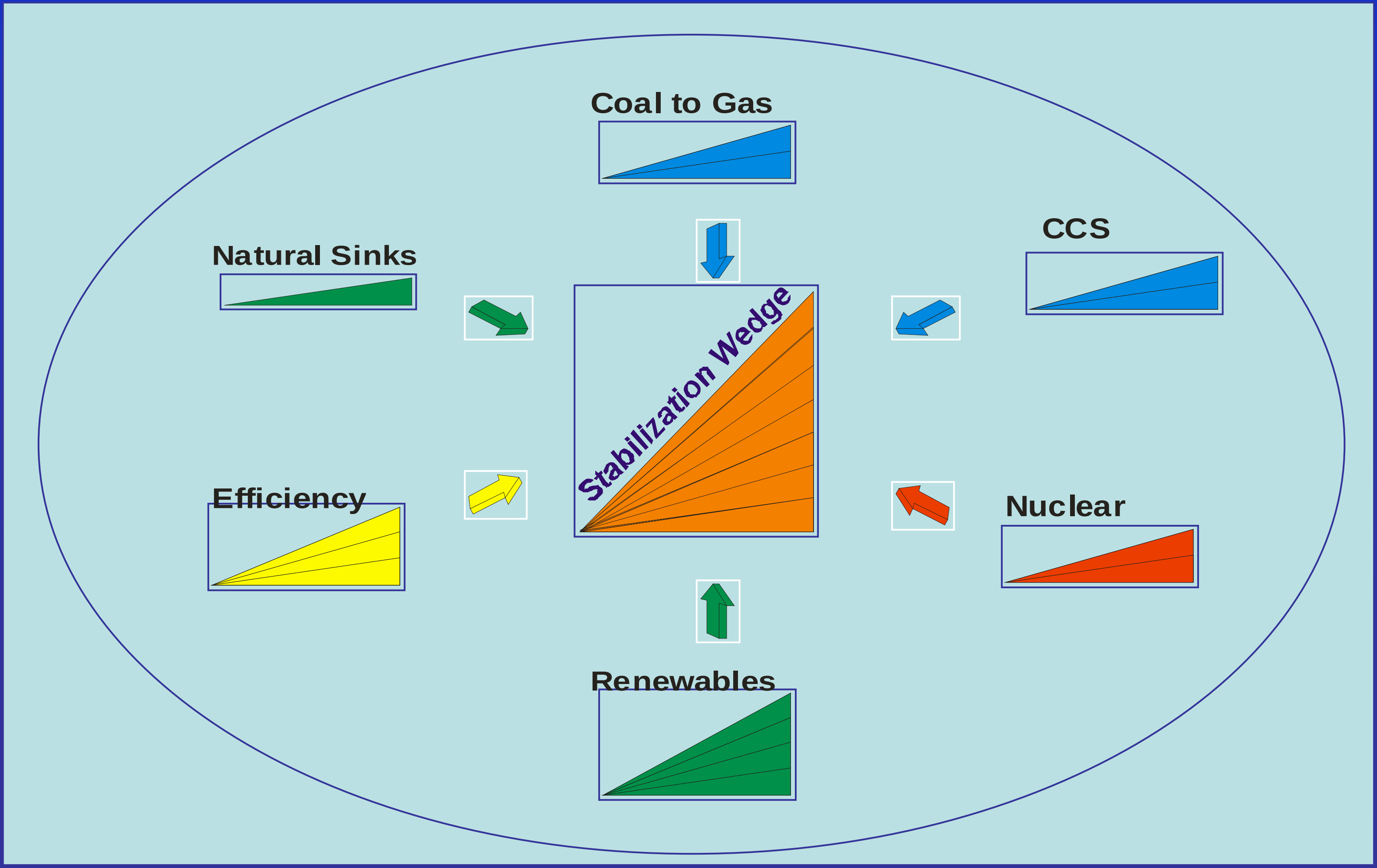
Concept of the Wedge and Slices



From Pacala and Socolow, *Science*, 2004

Filling the Wedge

The strategies available to provide the slices to fill the wedge are grouped below. All strategies are based on technologies already in use.

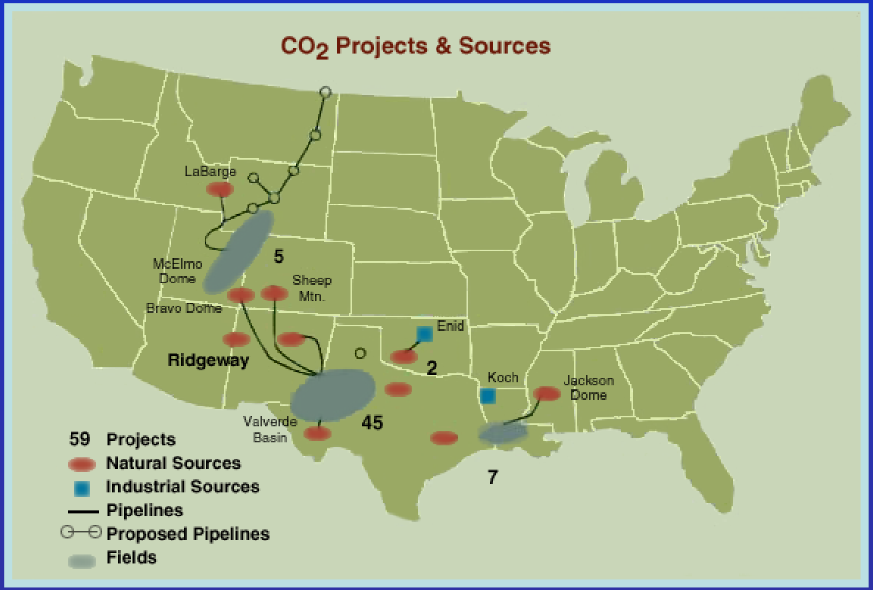


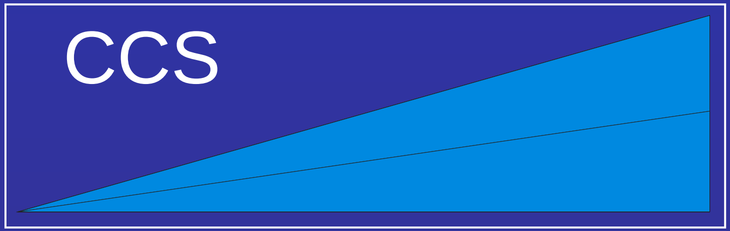
From Pacala and Socolow, *Science*, 2004

CO_2 Capture and Storage

Effort needed for 1 slice: 3.4 Gt CO_2/year by 2050

World-wide, build or replace 7 1000 MW coal fired power plants with CCS every year and maintain them until 2054





World-wide 100-fold increase in the amount of CO_2 injected for EOR each year in the U.S.

Modified from Pacala and Socolow, *Science*, 2004

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Costs for Electricity with CCS

Power plant system	Natural Gas Combined Cycle (US$/kWh)	Pulverized Coal (US$/kWh)	Integrated Gasification Combined Cycle (US$/kWh)
Without capture (reference plant)	0.03 - 0.05	0.04 - 0.05	0.04 - 0.06
With capture and geological storage	0.04 - 0.08	0.06 - 0.10	0.05 - 0.09
With capture and EOR*	0.04 - 0.07	0.05 - 0.08	0.04 - 0.07

Costs with CO_2 capture and storage increase by from 1 to 5 cents/kWhr.

* Based on oil price of $15 to $20/barrel

Based on IPCC Special Report

Cost Per Tonne of CO_2 Avoided

Type of power plant with CCS	Natural Gas Combined Cycle reference plant	Pulverized Coal reference plant
	US$/t$CO_2$ avoided	US$/t$CO_2$ avoided
Power plant with capture and geological storage		
Natural Gas Combined Cycle	40 – 90	20 – 60
Pulverized Coal	70 – 270	30 – 70
Integrated Gasification Combined Cycle	40 – 220	20 – 70

Based on IPCC Special Report

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Key Issues for Technology Development and Deployment of Geological Storage

- Evaluating Abandoned Well Impacts On Storage Integrity (especially in N. America)
- Optimizing Sweep Efficiency and Injectivity
- Demonstrating Long-Term Storage Integrity
- Developing Criteria for Site Selection
- Reconciling Top-Down and Bottom-Up Capacity Estimates
- Establishing Effective Monitoring and Verification Protocols

Life Cycle of a Storage Project and Monitoring Requirements

Pre-operation Phase	Operation Phase	Closure Phase	Post-closure Phase
• Site character-ization • Risk assessment • Establish monitoring baseline	• Verify injection rates • Track location of plume • Ensure safe operations • Detect and prevent environmental impacts	• CO_2 injection stops • Surface facilities removed; wells abandoned • Confirm long-term security of storage project	• Completed records given to regulatory authorities • Monitoring needed only if long term storage security not established

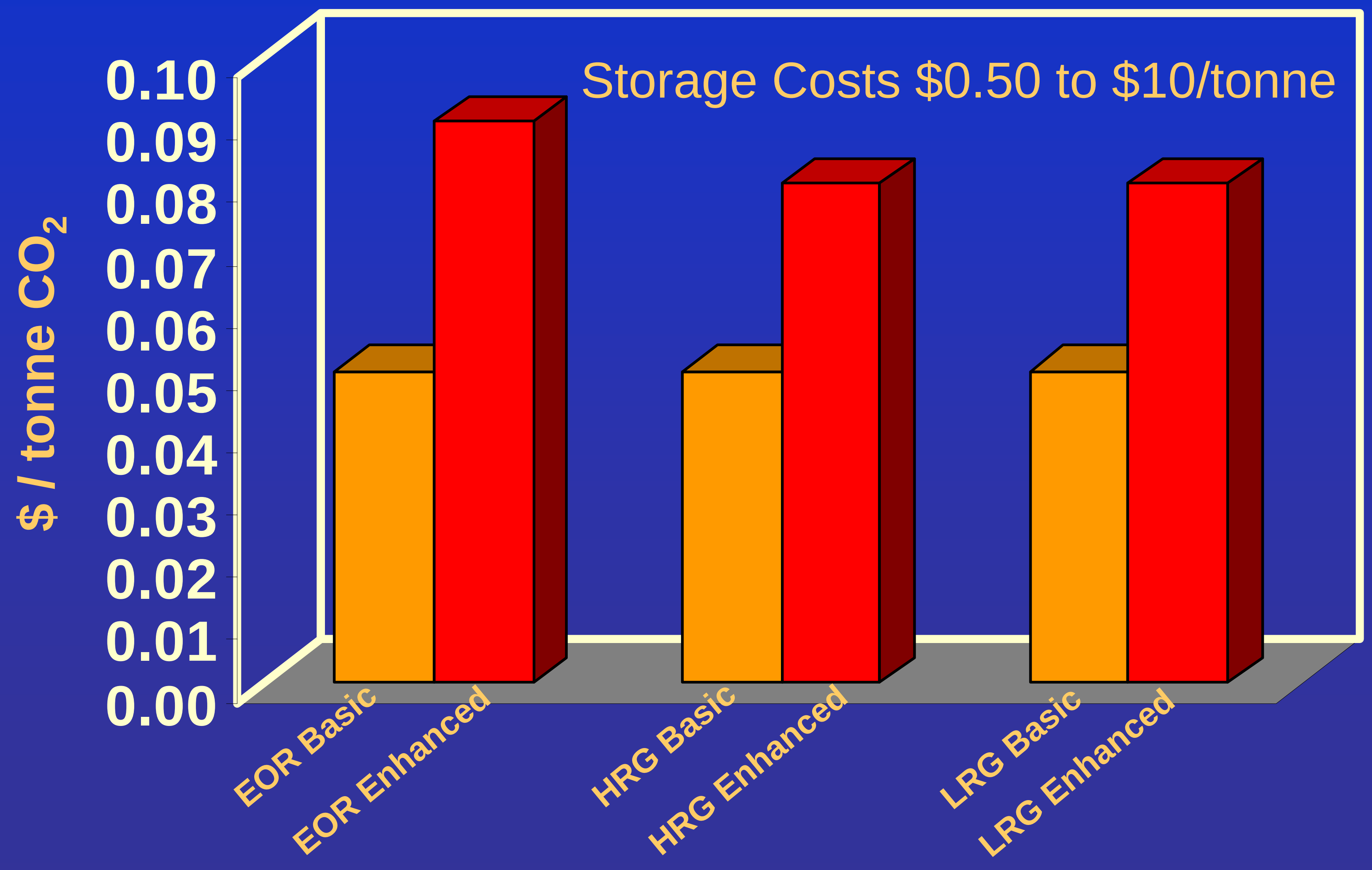
0 | 5 | 35 | 55 - 85

Approximate Time-Line (Years)

Components of the Basic and Enhanced Monitoring Packages

	Basic Monitoring Package	Additional Measurements for Enhanced Monitoring Package
Pre-operational Monitoring	• Well logs • Wellhead pressure • Formation pressure • Injection and production rate testing • Seismic survey • Atmospheric CO_2 monitoring	• Gravity survey • Electromagnetic survey • CO_2 flux monitoring • Pressure and water quality above the storage formation
Operational Monitoring	• Wellhead pressure • Injection and production rates • Wellhead atmospheric CO_2 monitoring • Microseismicity • Seismic surveys	• Well logs • Gravity survey • Electromagnetic survey • Continuous CO_2 flux monitoring at 10 stations • Pressure and water quality above the storage formation
Closure Monitoring	• Seismic surveys	• Gravity surveys • Electromagnetic surveys • Continuous CO_2 flux monitoring at 10 stations • Pressure and water quality above the storage formation • Wellhead pressure monitoring for 5 yeas, after which time the wells will be abandoned

Discounted Monitoring Costs (@10%)



Implications of Longer-term Monitoring

- 1000 year period
- Repeat seismic surveys every 10 years
- Basic monitoring package
  – Intergenerational discount rate of 1% after 30 years
  – $0.053/tonne increases to $0.059/tonne
- 10% increase in cost
- Non-financial issues
  – Responsibility for monitoring
  – Oversight and record keeping
  – Responsibility for remediation