Geological Sequestration of CO_2

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Abstract

The IPCC Fourth Assessment Report (AR4) has been released on 17 November 2007 and notes that warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level. The report also suggests that there is *high agreement* and *much evidence* of substantial economic potential for the mitigation of global GHG (Green House Gas) emissions over the coming decades that could offset the projected growth of global emissions or reduce emissions below current levels.

CO_2 capture and storage (CCS) is one of the most feasible mitigation ways of global GHG emissions with several options on the storage of CO_2 in the CCS program. One of the options is to store CO_2 in a geological formation. CO_2 is stored for a long time in oil, gas, and coal layers and the geological formations have large capacity to store global GHG. We have to inject CO_2 into the geological formations without environmental impacts. Monitoring is, therefore, necessary not only during but also after CO_2 injection in order to show how CO_2 is stored in the geological formations. Time-lapse seismic measurements were carried out to demonstrate CO_2 migration within the aquifer and no leakage beyond the cap rocks happened in the CO_2 sequestration fields. The seismic monitoring creates high accurate reflection images, which are very helpful to understand the movements of CO_2. The survey using the active source, however, does not provide the continuous change of CO_2. Measurement tools with passive sources are also necessary to monitor the CO_2 migration continuously. In this presentation several examples for the storage of CO_2 in the geological formations and geophysical studies for the monitoring are shown.

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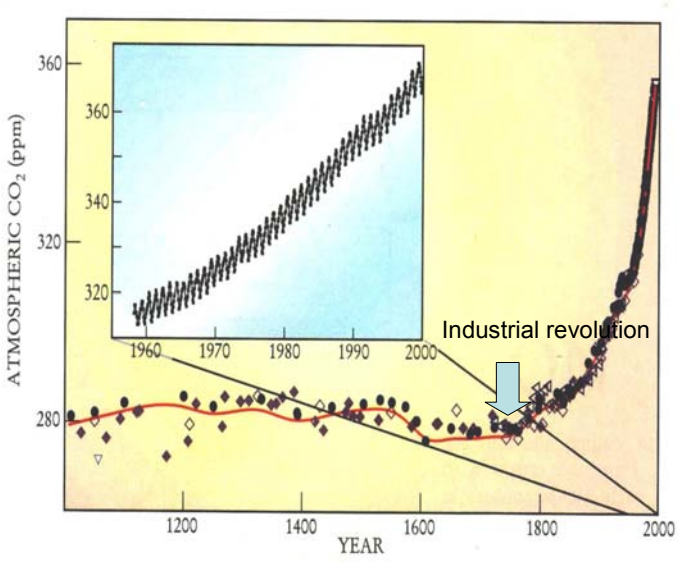
1. Global Warming by Carbon Dioxide
2. Carbon Dioxide Storage
3. CO_2 Sequestration Fields
   (Sleipner Field, North Sea, Norway)
4. Fundamental geophysical parameters
5. Geophysical monitoring at the Nagaoka Field, Japan

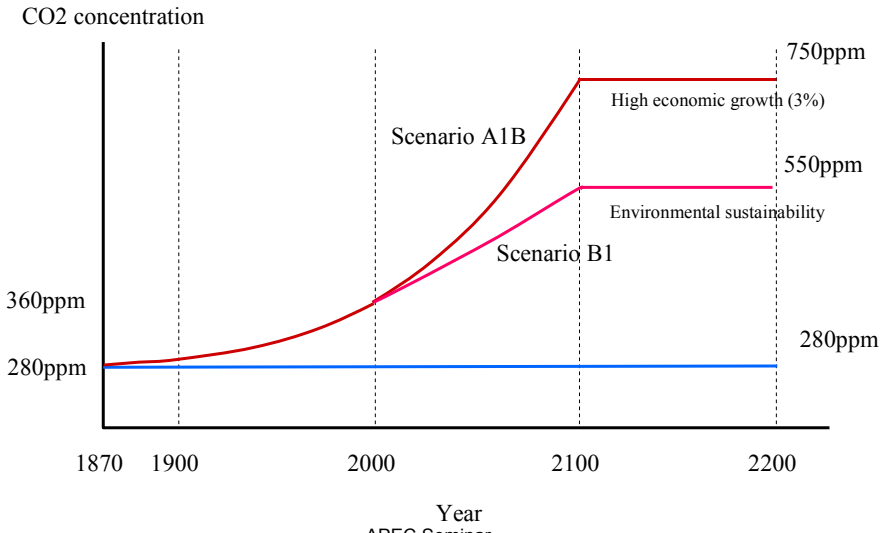
Atmospheric CO_2 levels



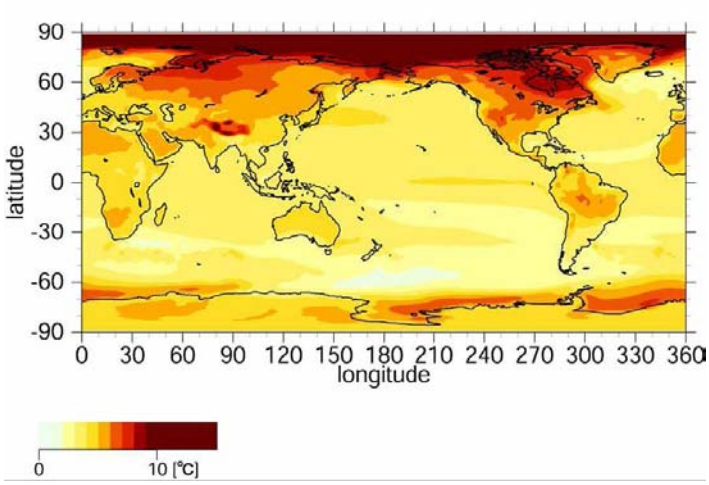
Erosion by the sea level rise

Majuro Atoll at the Marchall Islands

Scenarios for CO_2 concentration at the atmosphere

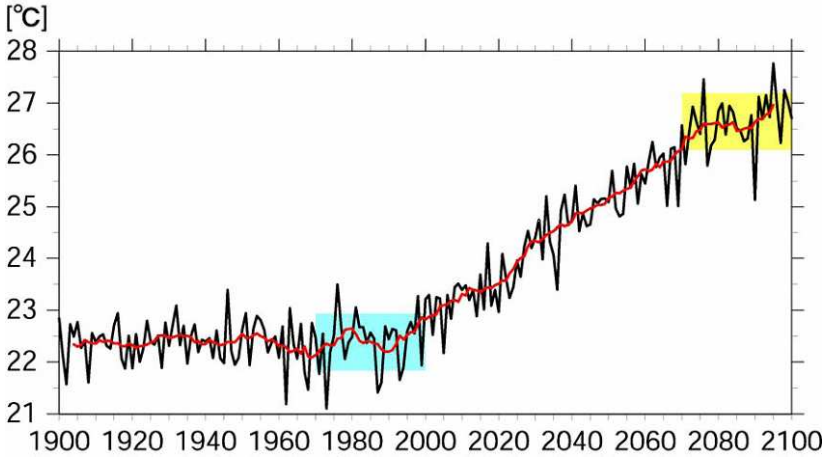


Simulation



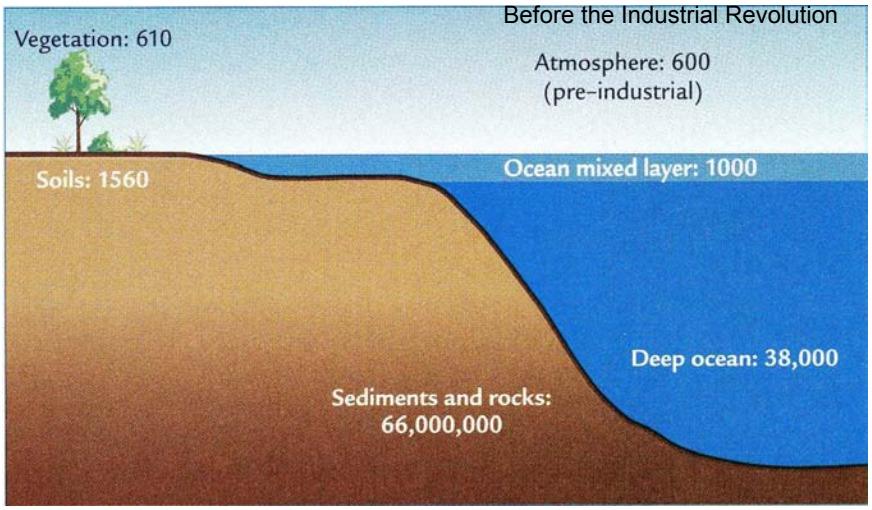
Annual mean temperature difference between 2100 and 2000

Calculated Temperature in Summer in Japan



Calculation is based on the global warming scenario A1B

Major Carbon Reservoirs



Unit in gigatons = 10^{15} grams

Problems today

Production of Carbon dioxide by human activities after the industrial revolution

⇨

Rapid increase of the discharge rage of Carbon dioxide into the atmosphere

Earth's system can accept a gradual increase of CO2

High Capacity of the reservoir is expected on land

CO2 sequestration : reduction of CO2 increase rate at the atmosphere

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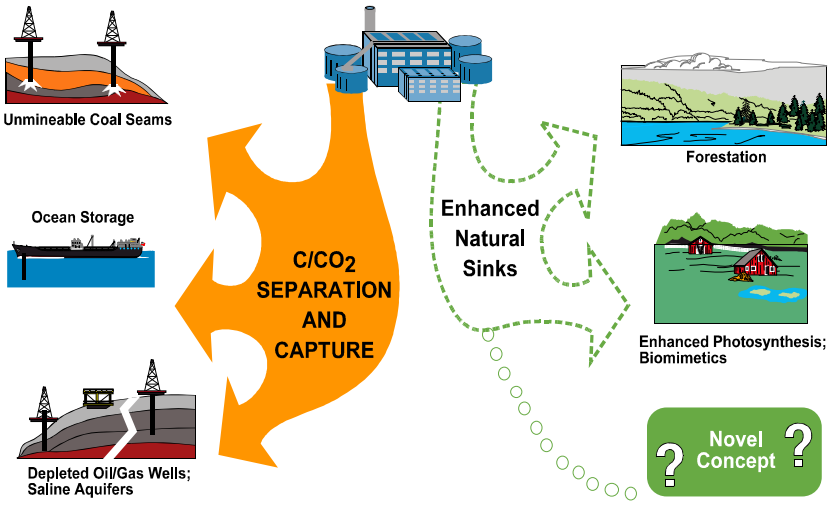
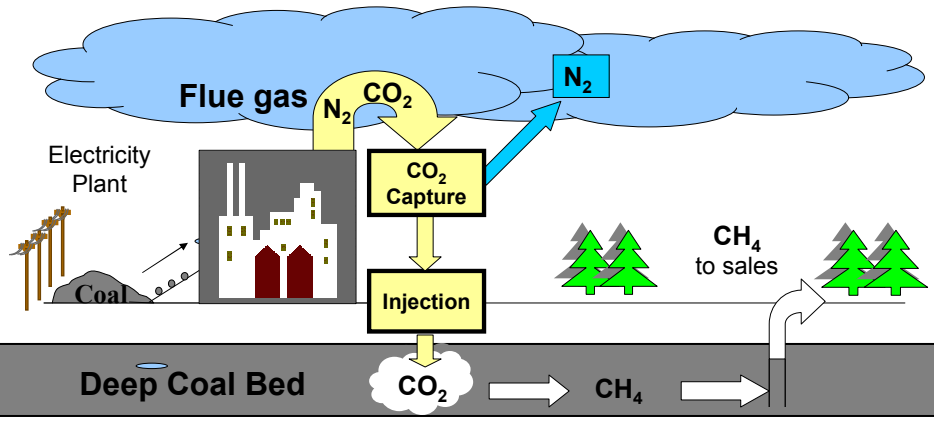
Sequestration Sinks

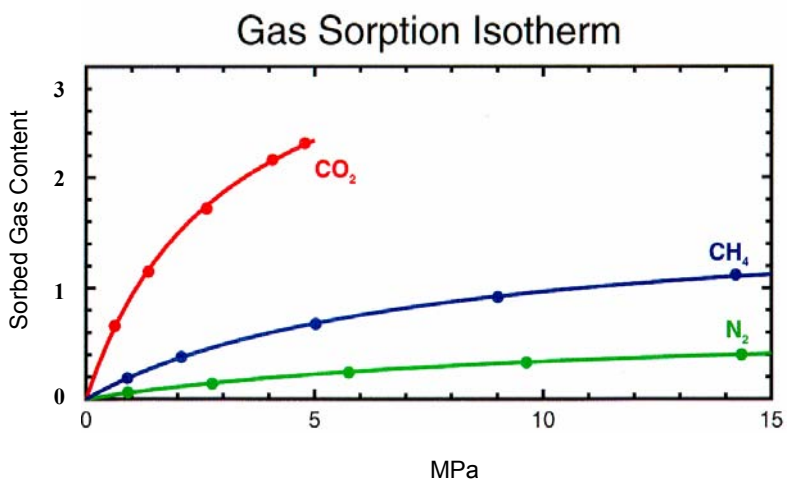


Enhanced Coal Bed Methane Recovery (ECBM)



- One-well field tests indicates that the amount of CO_2 that can be stored varies from two to five times the volume of methane produced

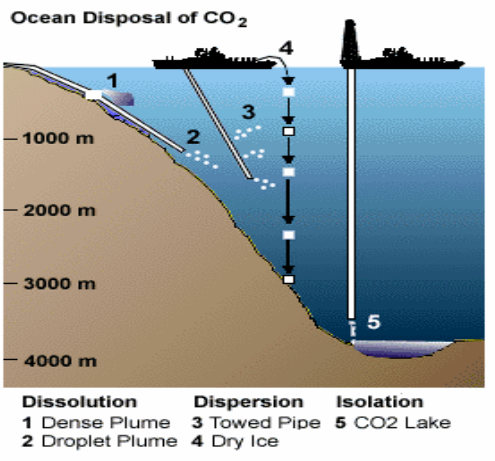
Sorption Data for Different Pure Gases



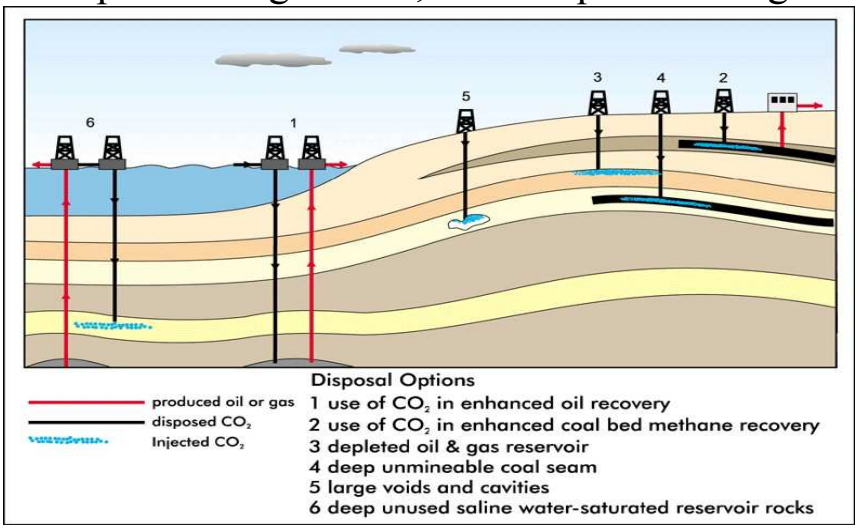
Ocean Sequestration

- Deep Ocean Injection CO_2
  - Theoretically the largest sink (>100,000 GTs)
- Potential for Significant Indirect Carbon Sequestration

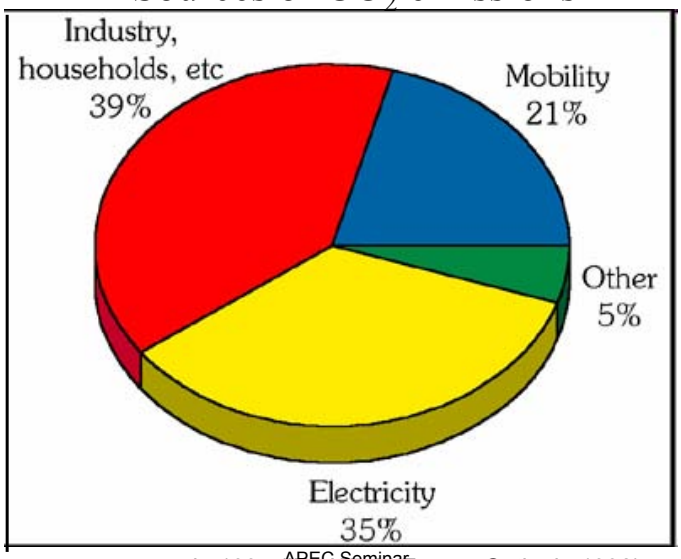
Suspension of the project
Environment at the deep wat



Depleted oil/gas field, saline aquifer Storage

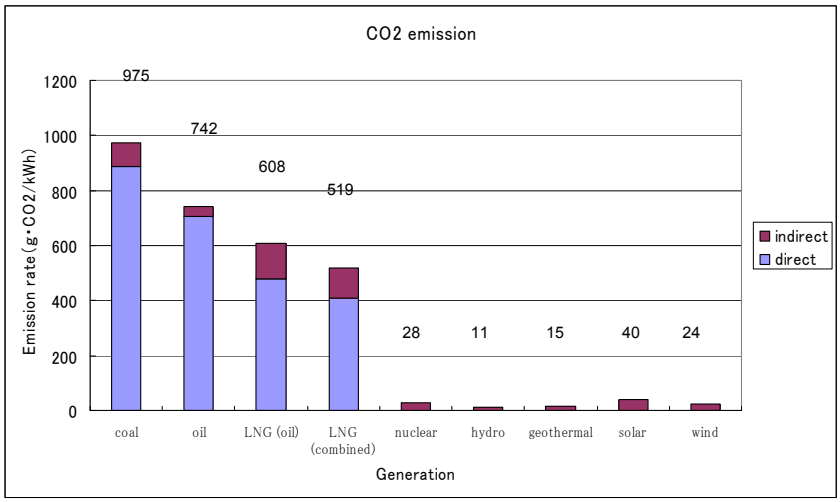


Sources of CO_2 emissions

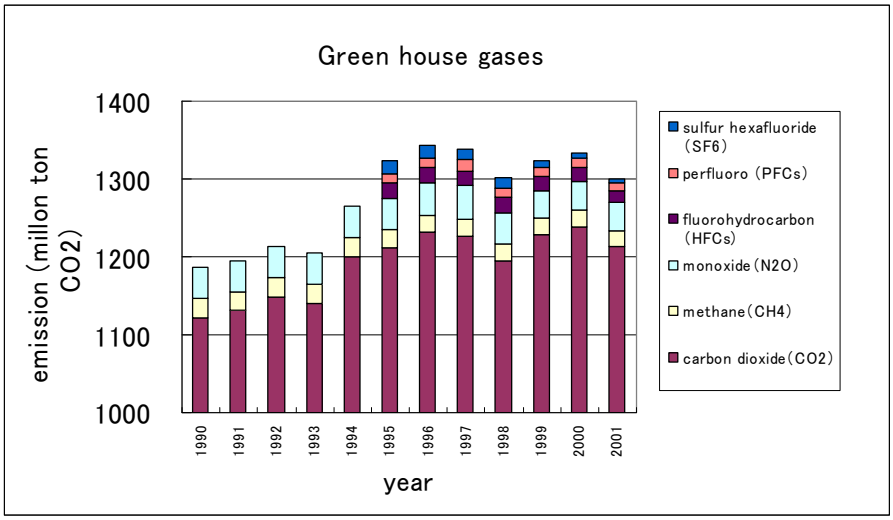


in 1995 (IEA World Energy Outlook, 1998)

Typical CO_2 emission in major power plant



Green house gases in Japan



CO_2 Emission of Japan

Major CO_2 output sources
- coal fired thermal power plants: 13 mol%
- cement plants: 25 mol%
- steel plants: 27 mol%

Output of CO_2 in 1990: 112,600 $\times 10^5$ ton (=1.1 billon ton)
6% = 67 million ton
Output of CO_2 in 2001: 1.3 billion ton
→ reduction more than 250 million ton

Carbon in 1 m^3 (standard condition): 0.539 kg

Emission of CO_2 by coal fired thermal power plants: 778t/h (6.8 Mt/y)

CO_2 Capture & Storage

Main message of IPCC Special Report on Carbon Dioxide Capture and Storage:

"With continued reliance on fossil fuel energy, deep reduction of CO_2 emission is attainable by this technology"

"Subsurface storage of CO_2 requires the skill of underground engineering"

CONTENT

CO_2 Storage Projects Worldwide

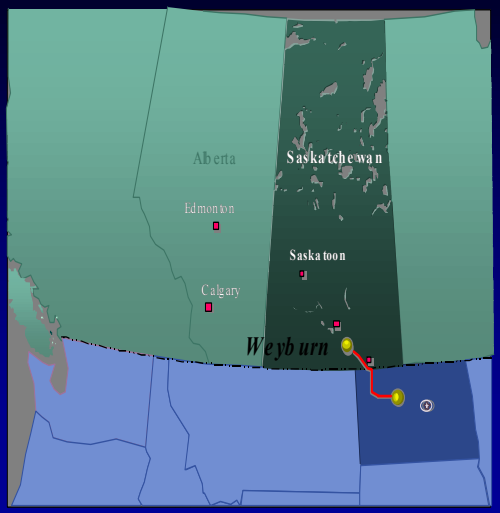
CO_2 Storage Projects Summary

- Only a dozen projects are injecting commercial scale volumes of CO_2 (e.g 1 Mt/CO_2/y)
  Weyburn (Canada), In-Salah (Algeria),
  Sleipner (Norway), Rangely (US)
- Many are research projects that will inject 100's to 1000's tonnes CO_2
  Frio (US), West Pearl Queen (US), CO2SINK(EU)
- Several large projects in the development stage
  Snöhvit (Norway) and Gorgon (Australia)

Major Project Experiences

- ✓Weyburn (Canada)
  - No evidence of surface seepage after 3 years of CO_2 injection
  - Presence of CO_2 within oil field identified using seismic surveying
- ✓Sleipner (North Sea)
  - Injected CO_2 accumulating under cap rock can be monitored with seismic surveying
  - No evidence of migration out of the reservoir after 8 years of injection

Weyburn CO_2 Miscible Flood Project

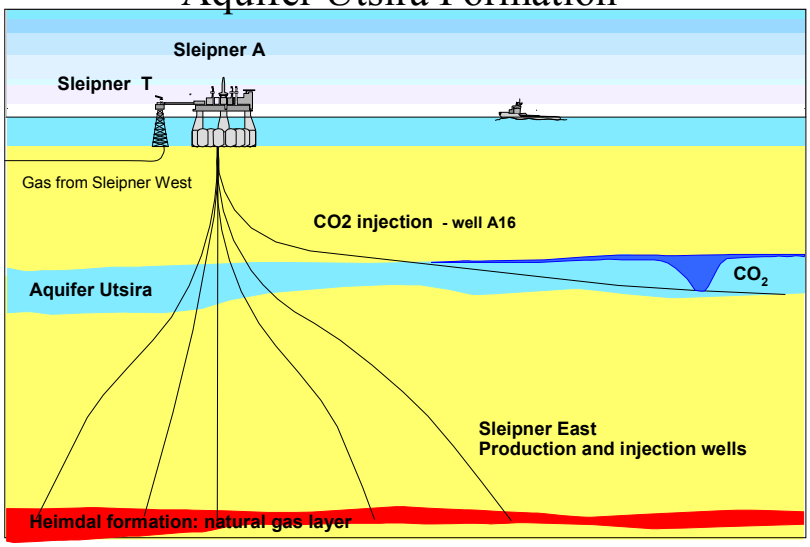


- PanCanadian Petroleum project EOR (C$1.1 billion)
  - Duration 15-20 years
  - CO_2 from Dakota Gasification Co., North Dakota
  - Pipeline, 325 km, delivers 5000 t/d of CO_2
  - 70% of CO_2 will remain in reservoir
- IEA CO_2 Monitoring Project (C$35 million over 4 years)
  - Assessments of long-term storage integrity, migration and fate of CO_2
  - Participants include Canadian and European Governments and companies

Location of the Sleipner Field

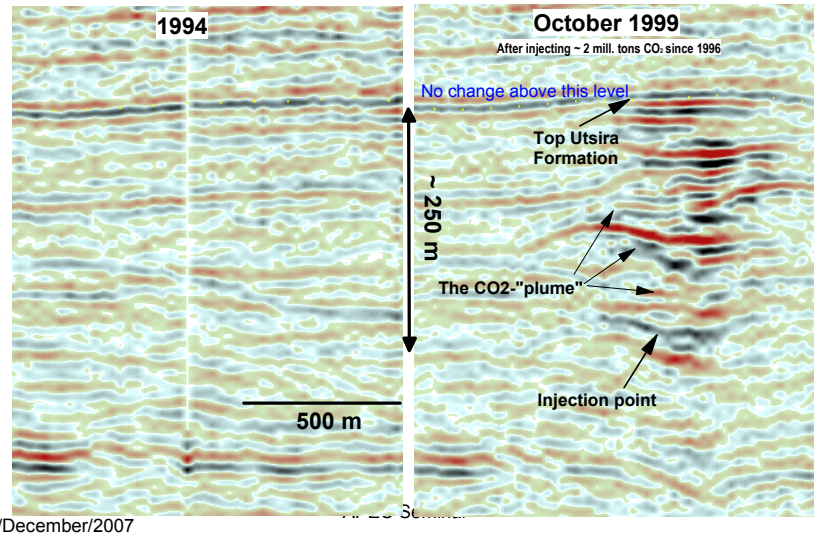
Sleipner field in North Sea

Aquifer Utsira Formation

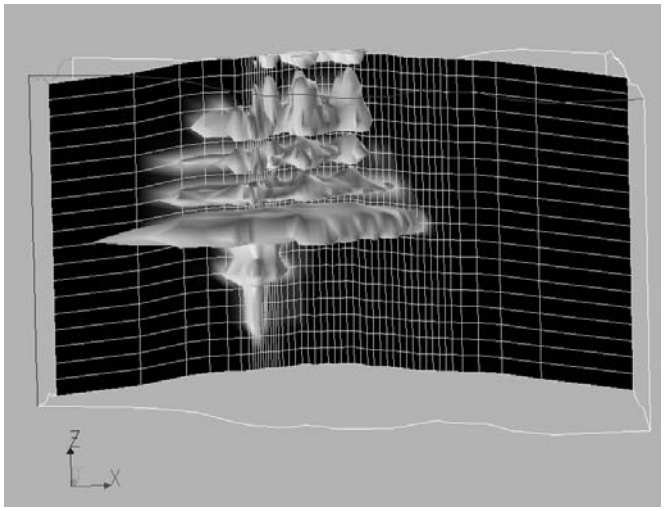


Seismic monitoring

Sleipner CO_2 injection seismic monitoring--Preliminary comparison of 1994 and 1999 data

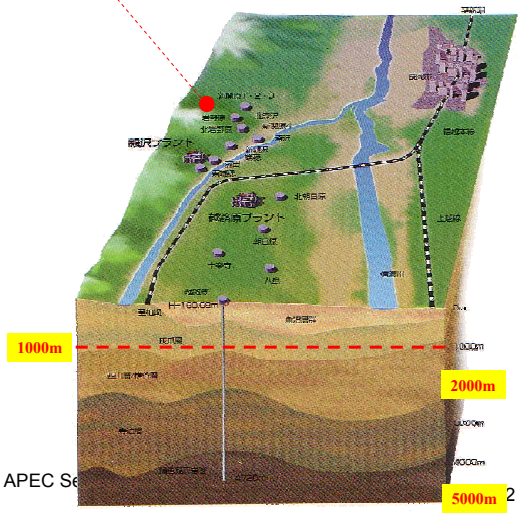


Seismic monitoring at Sleipner field

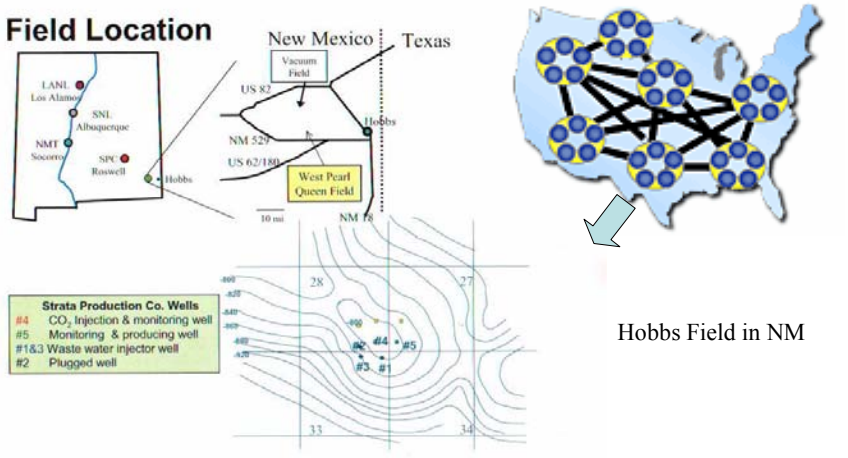


Nagaoka Field (Test field)

Teikoku Oil, Niigata Prefecture



Carbon Sequestration - Regional Partnerships



Hobbs Field in NM

Southwest Regional Partnership for Carbon Sequestration

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Critical point of CO2

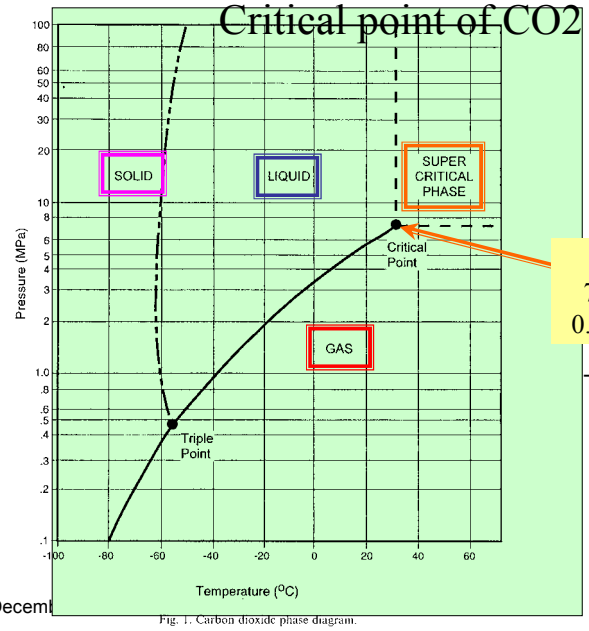

Fig. 1. Carbon dioxide phase diagram.

31.1℃
7.39MPa
0.464g/cm^3

Typical thermal gradient
2 ℃/100m

Temperature at the Depth of 1,000m

T=20℃(surface)+20℃ = 40℃

Basic Studies : Laboratory-Scale Research

Injection of CO_2

Decrease of wave velocity

Increase of pore pressure

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Field Monitoring

***Lab Experiments** are required to **Convert Field Results** of Wave Velocity and Attenuation to CO_2 Saturation*

Laboratory work: Objectives

- ***What's really going to happen after injecting CO_2 into rock mass?***

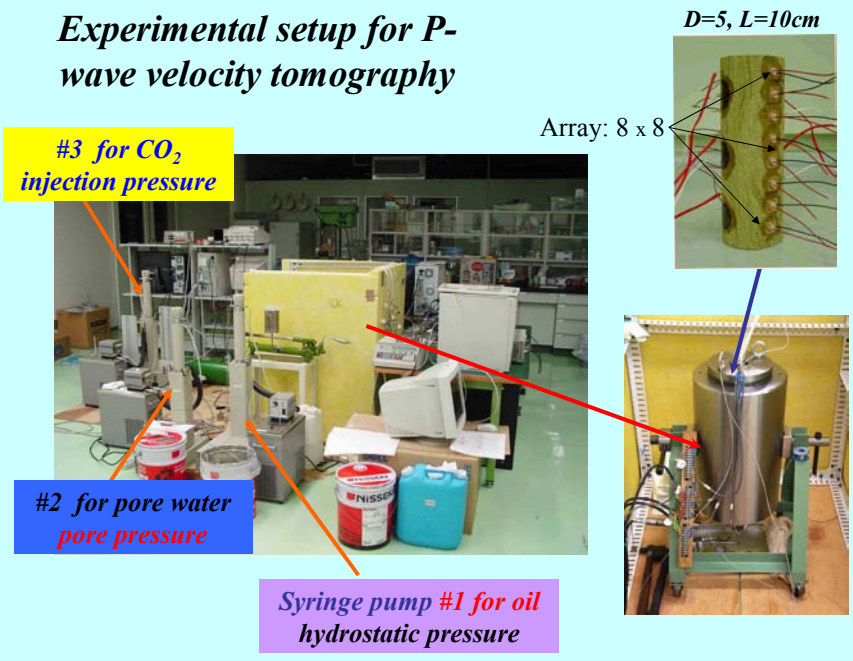
  Pore pressure buildup, CO2-water- rock reactions (induced seismicity, mineral dissolution, CO2-water displacement)

- ***How quickly the injected CO_2 migrates in rock mass?***

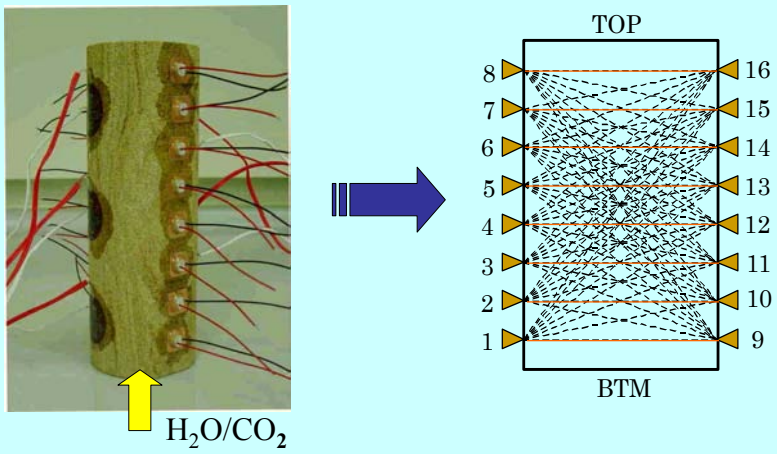
  Permeability, viscosity, electric conductivity etc.

Gas, liquid, and supercritical conditions of CO_2

Experimental setup for P-wave velocity tomography

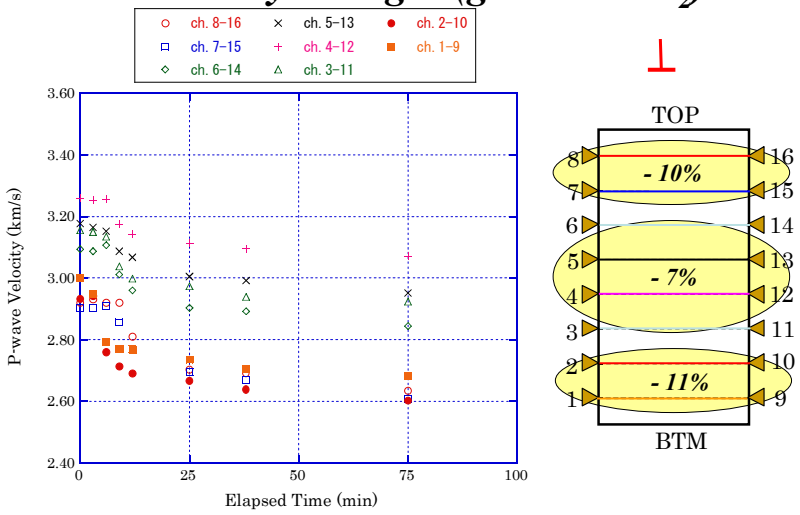


Experimental Study of Seismic Wave Tomography



Xue and Lei, 2006

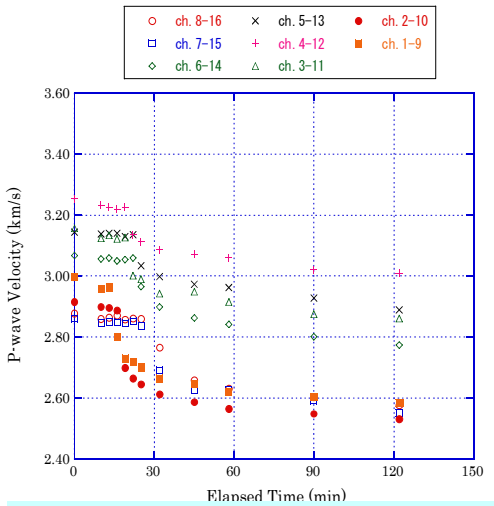
P-wave velocity changes (gaseous CO_2)

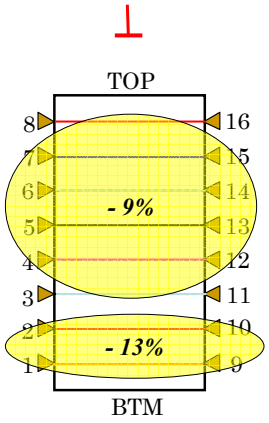


P-wave velocity changes vs the elapsed time when injecting gaseous CO_2 into water saturated Tako sandstone. Pc=10MPa, Pp=3MPa and Pi=5MPa (at 25°C)

Xue and Lei, 2006

P-wave velocity changes (liquid CO_2)

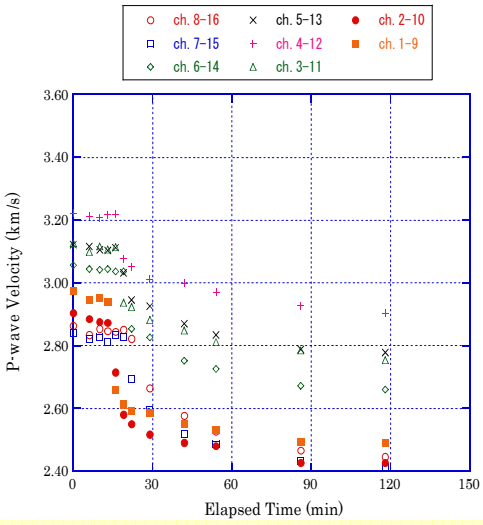


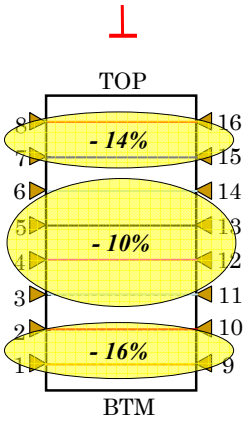


P-wave velocity changes vs elapsed time when injecting liquid CO_2 into water saturated Tako sandstone. Pc=15MPa, Pp=10MPa and Pi=12MPa (at 25°C)

Xue and Lei, 2006

P-wave velocity changes (super critical CO_2)





P-wave velocity changes vs elapsed time when injecting super critical CO_2 into water saturated Tako sandstone. Pc=15MPa, Pp=10MPa and Pi=12MPa (at 33°C)

Xue and Lei, 2006

Experimental Results

Velocity changes caused by the CO_2 injection are typically on the order of -10%.

Injecting super critical CO_2 has greater effect on velocity changes than cases of injecting gaseous and liquid CO_2

Effect on velocity changes caused by the pore pressure buildup is less than -3%, comparing with the pore water displaced by the injected CO_2, ranged from -8% to -16%.

Monitoring P-wave velocity could be a useful tool for mapping the movement of the injected CO_2 in geological sequestration projects.

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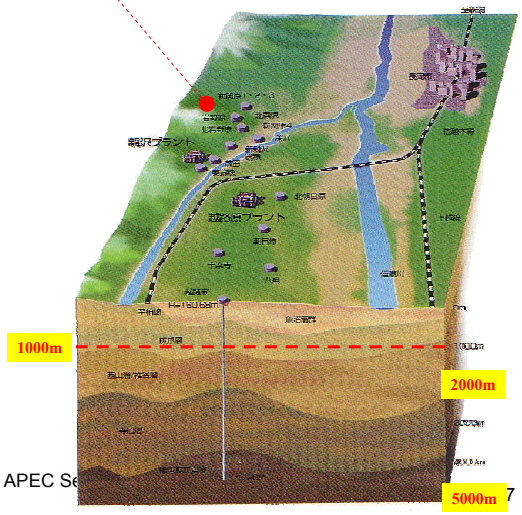
Teikoku Oil, Niigata Prefecture



APEC Se 7

Field Injection Studies for Aquifer Sequestration

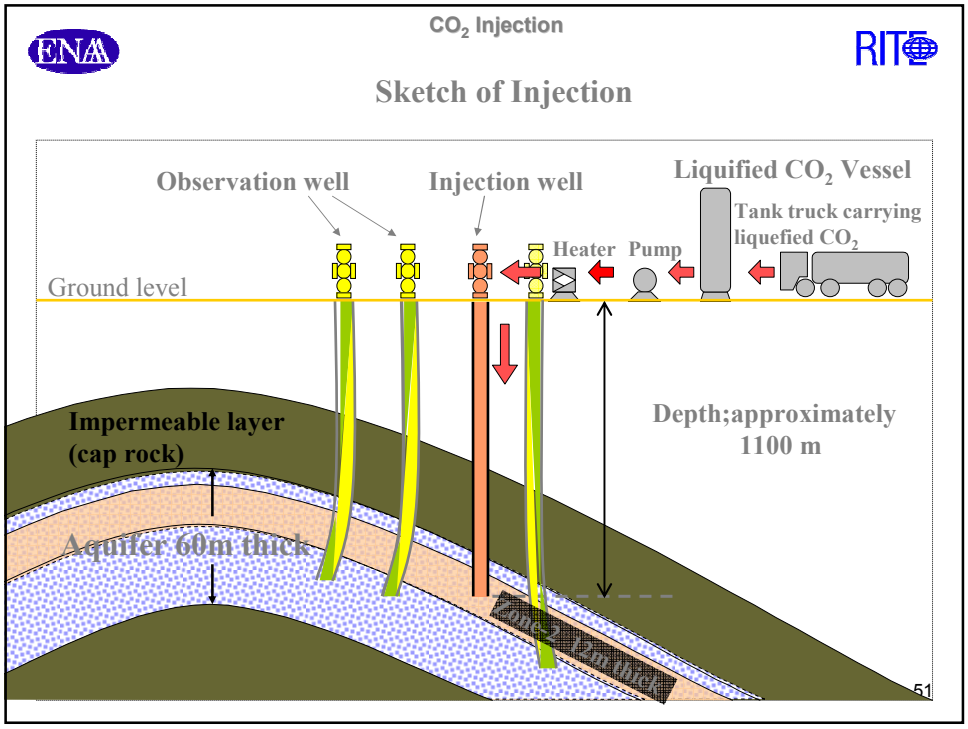
	Target formation	CO_2 injection rate & source	status
SACS at Sleipner Field	offshore saline aquifer with a depth of 1.0 km	1 mil. ton/year, captured from natural gas	Ended (1998 – 2002) Continued to CO2STORE
Weyburn Monitoring Project	on-land oil reservoir with a depth of 1.0 km	1 mil. ton/year, generated in a gasification plant	Phase II started
RITE field demonstration at NAGAOKA	on-land saline aquifer with a depth of 1.1 km in a gas field	20 – 40 tonne/day, purchased in the market	500-day injection

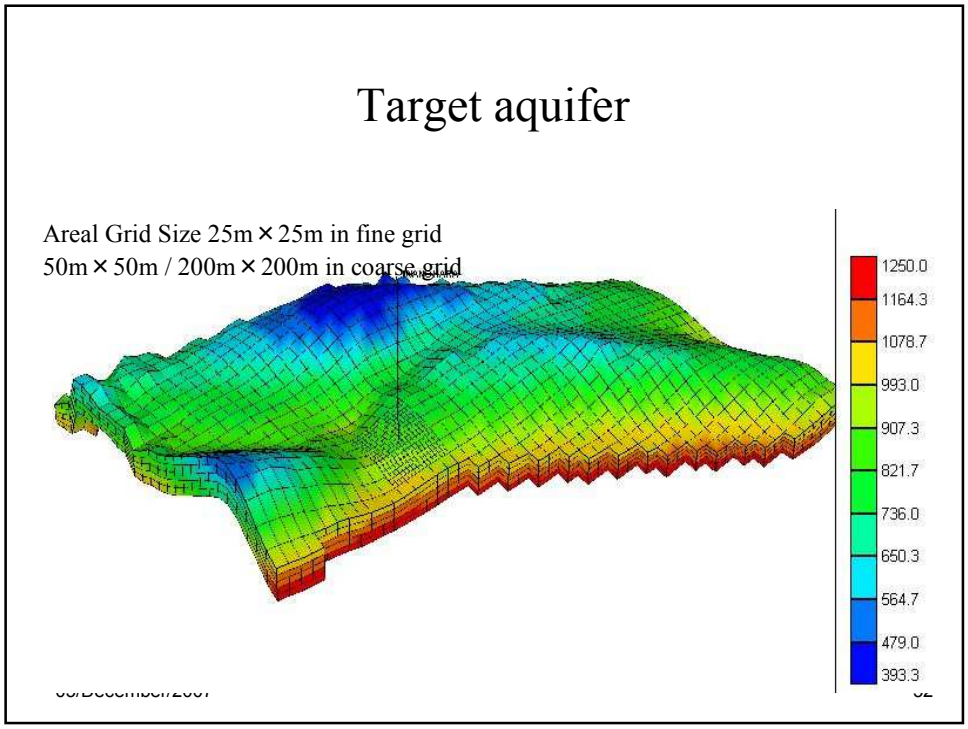
Nagaoka site

－ site facilities －

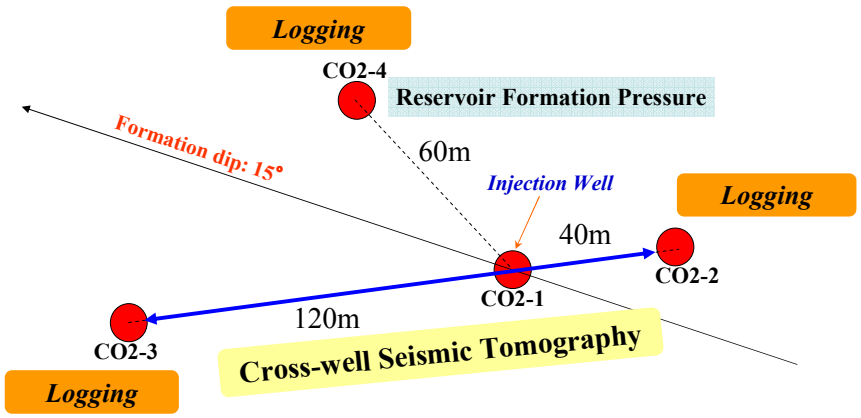
Nagaoka site

－ storage tank －

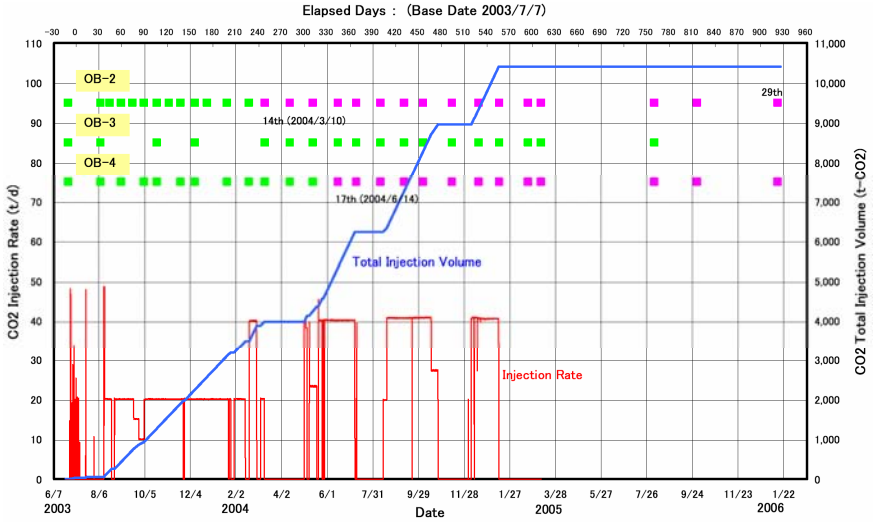

CO2 Injection
Sketch of Injection
Observation well
Injection well
Liquified CO2 Vessel
Tank truck carrying liquefied CO2
Heater
Pump
Ground level
Impermeable layer (cap rock)
Aquifer 60m thick
Depth;approximately 1100 m
51


Target aquifer
Areal Grid Size 25m × 25m in fine grid
50m × 50m / 200m × 200m in coarse grid
1250.0
1164.3
1078.7
993.0
907.3
821.7
736.0
650.3
564.7
479.0
393.3

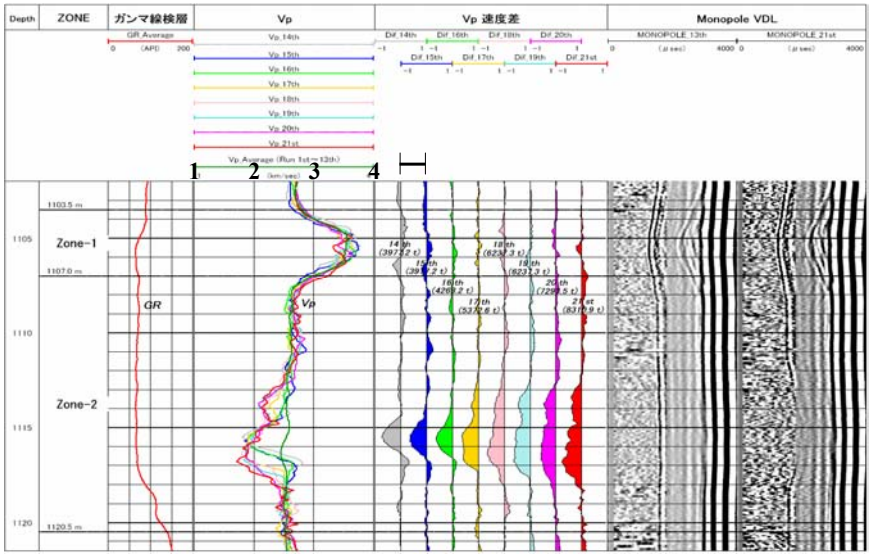
Geophysical Monitoring of CO_2 Sequestration



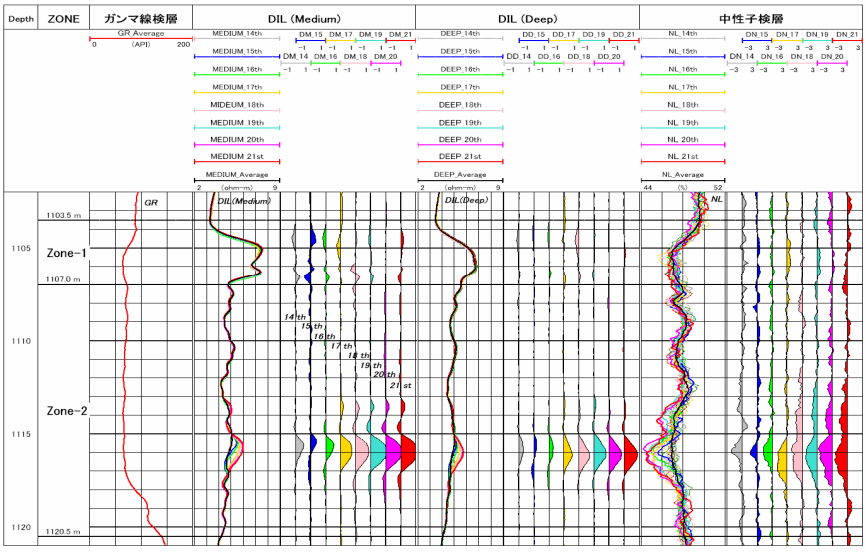
Time lapse logging schedule



CO2-2　Vp (Sonic)

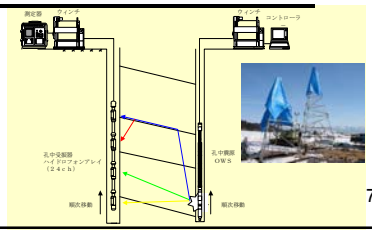


CO2-2 (Induction & Neutron)

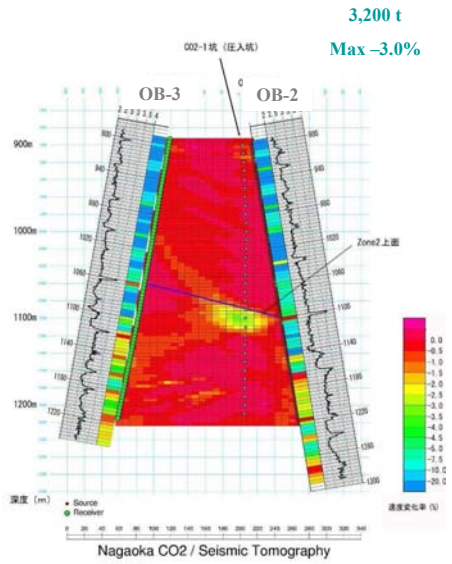


Crosswell Seismic Tomography

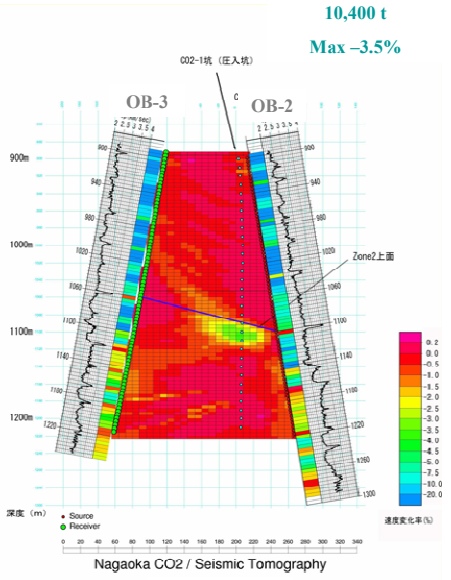
Baseline Survey	BLS	Before injection	Feb. 2003
Monitoring Survey		Injection started	Feb. 2003
	MS1	3,200t-CO_2	Jan. 2004
	MS2	6,200t-CO_2	Jul. 2004
	MS3	8,900t-CO2	Nov. 2004
		Injection ended	Jan. 2005
	MS4	10,400t-CO2	Jan. 2005
	MS5	10,400t-CO2	Oct. 2005



Rate of Velocity Reduction



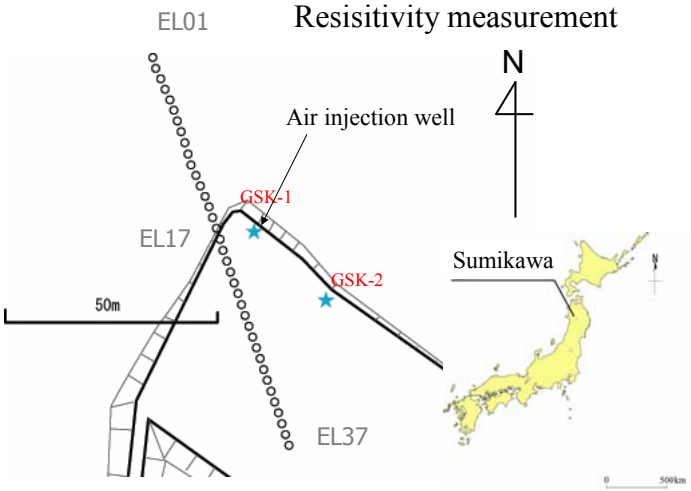
MS1/BLS



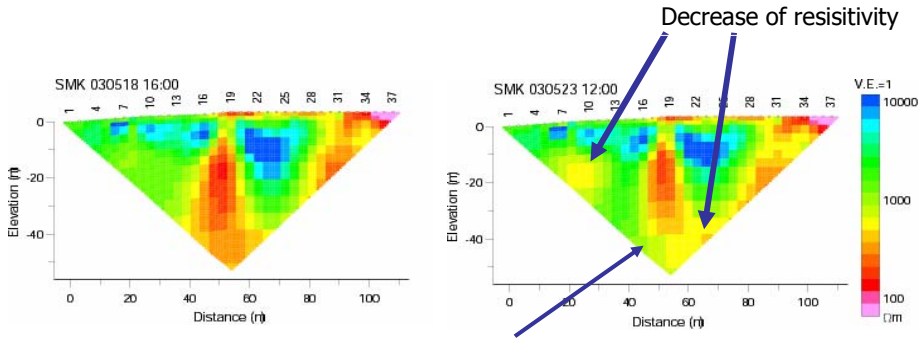
MS4/BLS

Watanabe et al., 2006

Another example of the detect of CO_2 injection



Resistivity change



Before injection

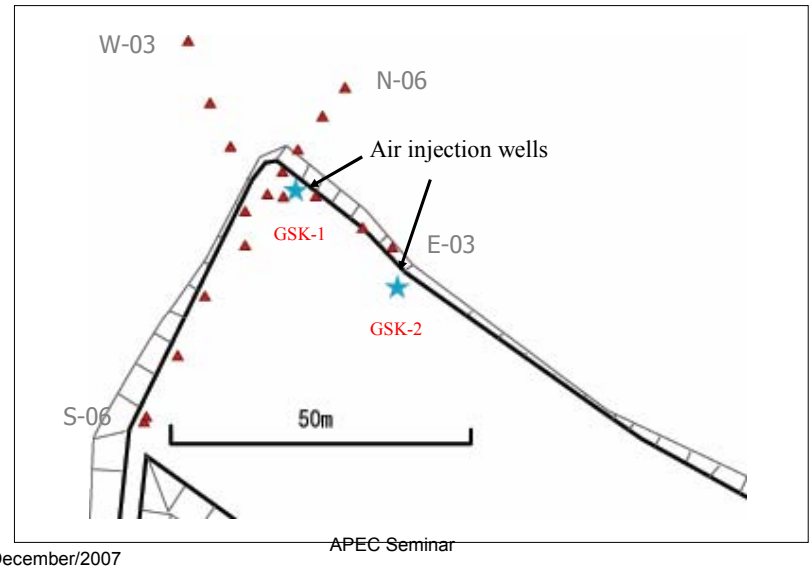
After injection

Archie's law $R_t = \dfrac{aR_w}{\eta^m S_w^n}$

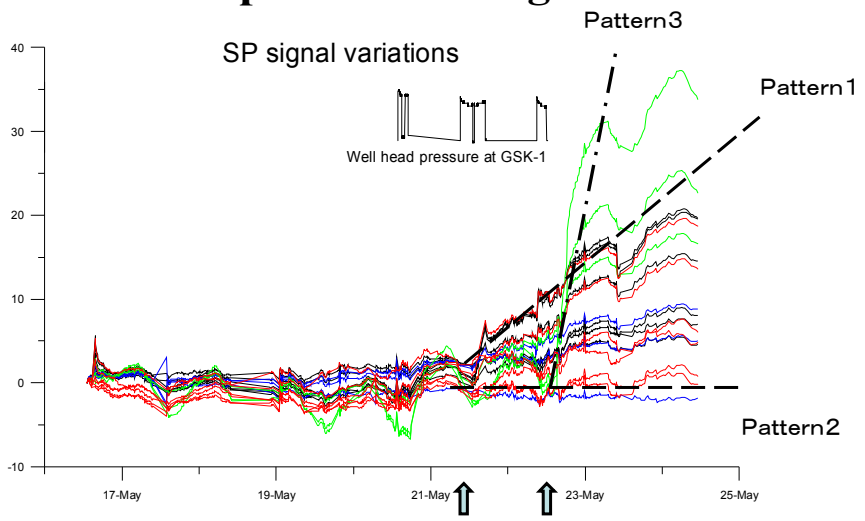
resisitivity change in 60%

⇨ saturation change in 37%

Self-potential observation



Temporal SP changes



Summary

- Rapid increase of CO_2 at atmosphere after the industrial revolution
- CO_2 sequestration (storage) is one of the way to reduce the CO_2 content
- Development of renewable energies is another option
- Geological sequestration into aquifer is tested in several fields
- Electric measurements as well as seismic measurements are possible to detect the change due to the sequestration
- Combining geophysical monitoring with the computer simulation makes a good model for the sequestration

Thank you for your attention

For the better Global Environments

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