[International Workshop on CO2 Geological Storage]

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CO_2地中貯留実用化に向けたシステム的研究

Socio-economic and Environmental Studies for CCS Technology

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Socio-economic and Environmental Studies of CO_2 Geological Storage Technology at RITE

(1) Evaluation of costs, potential etc.

Economic competitiveness against other technological options

(2) Risk analysis

(3) Study on public acceptance

(4) Investigation on legal aspects

Compatibility with existing international and domestic laws?

Necessity of amendments/ new laws?

Accounting rule of CO2 emission inventory

Kyoto mechanism

RITE Research Institute of Innovative Technology for the Earth

Risk Analysis-- Objectives

Risk analysis

CO_2 leakage

Impacts of CO_2 leakage on human and environments

Analysis results to be used for

Site dependency!

Preparation of Guidelines/Standards

Selection of storage site

Operation of CO2 injection

Post injection monitoring etc.

Risk communication, PA promotion

Risk Analysis—3 Steps

1. How possibly does stored CO_2 escape from the reservoir?

   Identification of risk scenarios

2. How much and how fast does stored CO_2 escape?

   Quantitative evaluation of CO_2 behavior for the identified scenarios

3. How much impacts of escaped CO_2?

   End point assessment (Human health, ecosystem, groundwater etc.)

Identification of Risk Scenarios

- **How possibly does stored CO2 escape from the reservoir?**
- **No established methodology for the scenario identification**
- **Tentative use of FEP methodology**

  F, E and P are defined to describe the storage environment

  Development of scenarios using FEPs to describe possible future states of the storage environment

  ーー＞ 網羅性、透明性

***Feature*; physically distinct entity, such as the rock or groundwater**

***Process*; dynamic phenomenon that influence the evolution of the system, such as groundwater flow**

***Event*; Process that take place over comparatively short timescales, such as earthquake**

Construction of FEP Database

Generic database by IEA GHG Program; 178 FEPs

+

35 FEPs that are characteristic of Japanese geological and strata conditions

⇩

213 FEPs in total, each of which is provided with linking function to other FEPs to generate risk scenarios

Examples in the original database

F; Reservoir geometry（リザーバー形状）、Soils and sediments（土壌・堆積物）

E; Bolide impact（隕石影響）、Accidents and unplanned events（事故・不慮の出来事）

P; Subsidence or uplift（陥没・隆起）、Effects of pressurization on cap rock（キャップロックへの加圧効果）

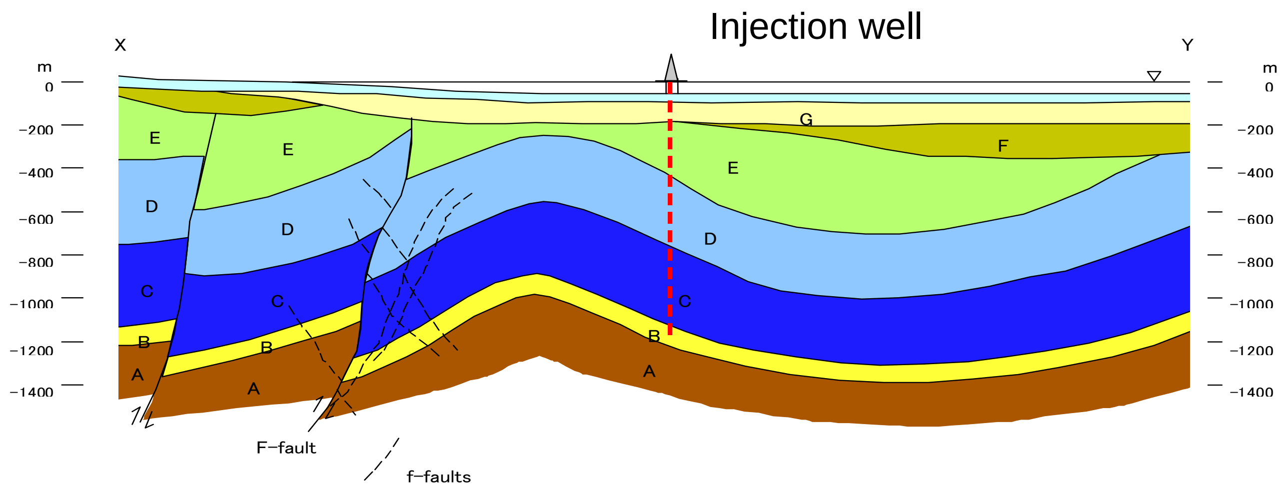
Examples of added FEPs

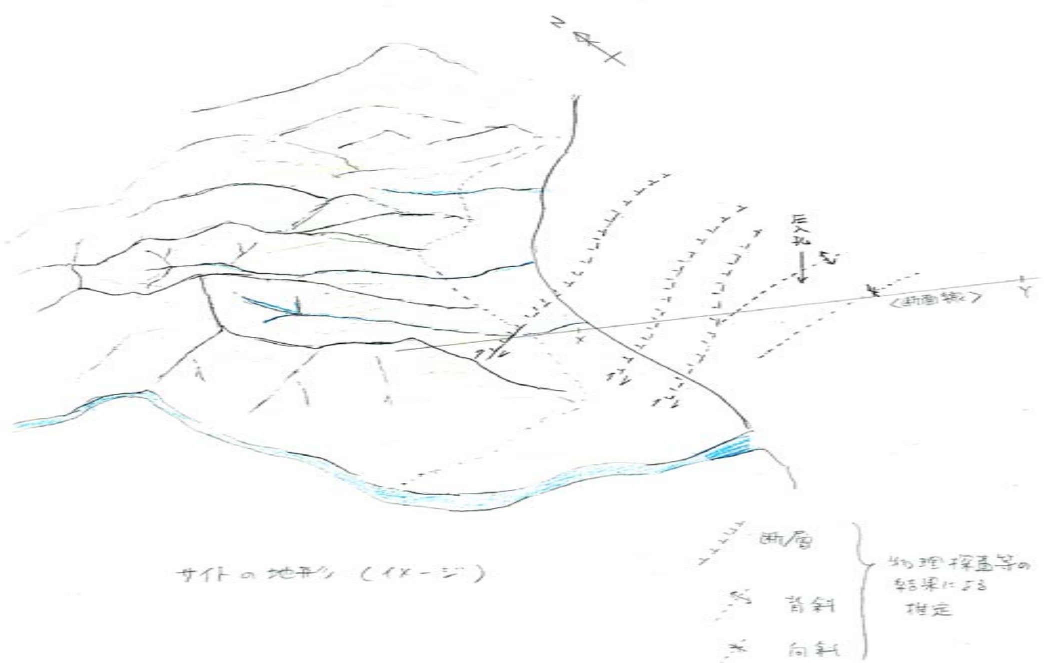
F; Magma chamber（マグマ溜り）、Fault zone（断層帯）、Plate boundary（プレート境界）

E; Seismic vibration（地震振動）、Pyroclastic flows（火砕流）

P; Tilting（傾動）、Active folding（活褶曲）

Assumed Storage Site





An off-shore site

Sea water depth: 50 m

Composed of sedimentary facies from Neogene, Miocene to Quaternary period, Pleistocene

Syncline and anticline structure
向斜および背斜

F-fault and f-faults across the fold

Identification of Important Risk Scenarios for the Assumed Site

[Tentative approach]

1. Selection of important FEPs from the database

Expert judgment!

- a. **Undetected faults（未検出断層）**
- b. **Fault zone（断層帯）**
- c. **Borehole/ Borehole abandonment（圧入井・廃坑）**
- d. **Human intrusion（人的侵入）**

2. Construction of all the risk scenarios that are associated with one of the above 4 FEPs

3. Identification of important risk scenarios

[Underway]

Quantitative Evaluation for a Risk Scenario Associated with FEP c

Risk scenario

1. Deterioration of the well bottom cement plug by chemical reaction with groundwater containing CO2
2. Crack through the deteriorated plug
3. CO2 leakage from the reservoir through the deteriorated plug having cracks
4. Accumulation of CO2 inside the well

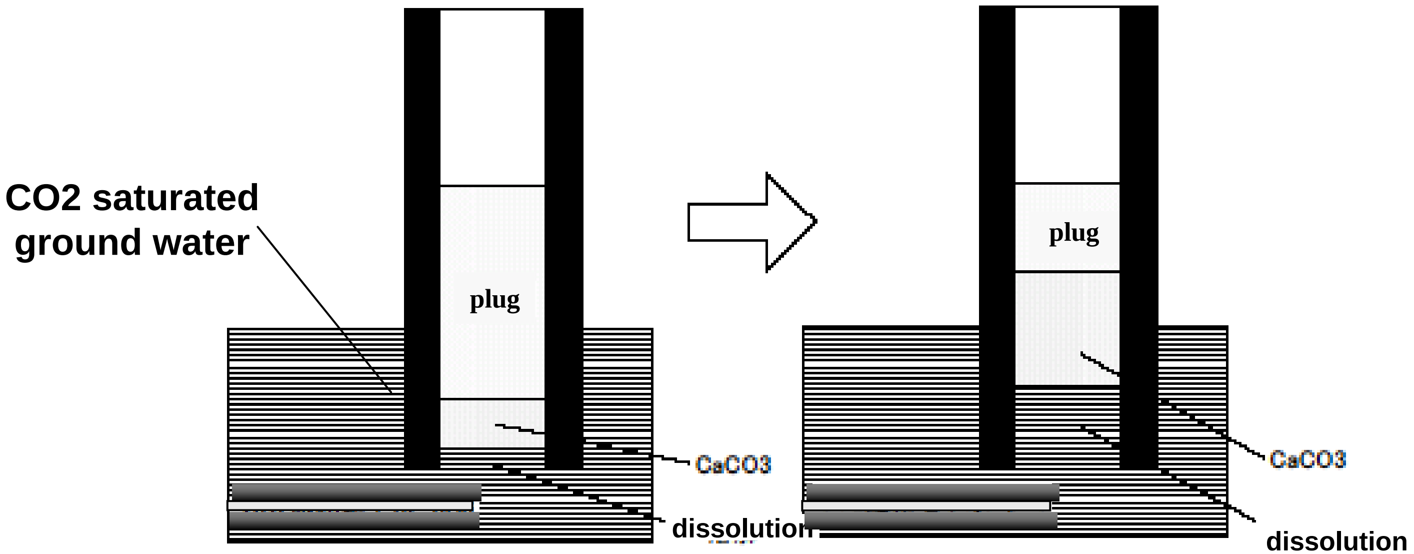
Quantitative calculation

1. Cement plug deterioration; speed and magnitude
2. Leakage of CO2 into the well; pressure inside the well and its rise
3. Others when necessary

Deterioration of Cement Plug

Cement Material：Ca(OH)2, CSH, CaCO3

I.D of Well: 220.5 mm

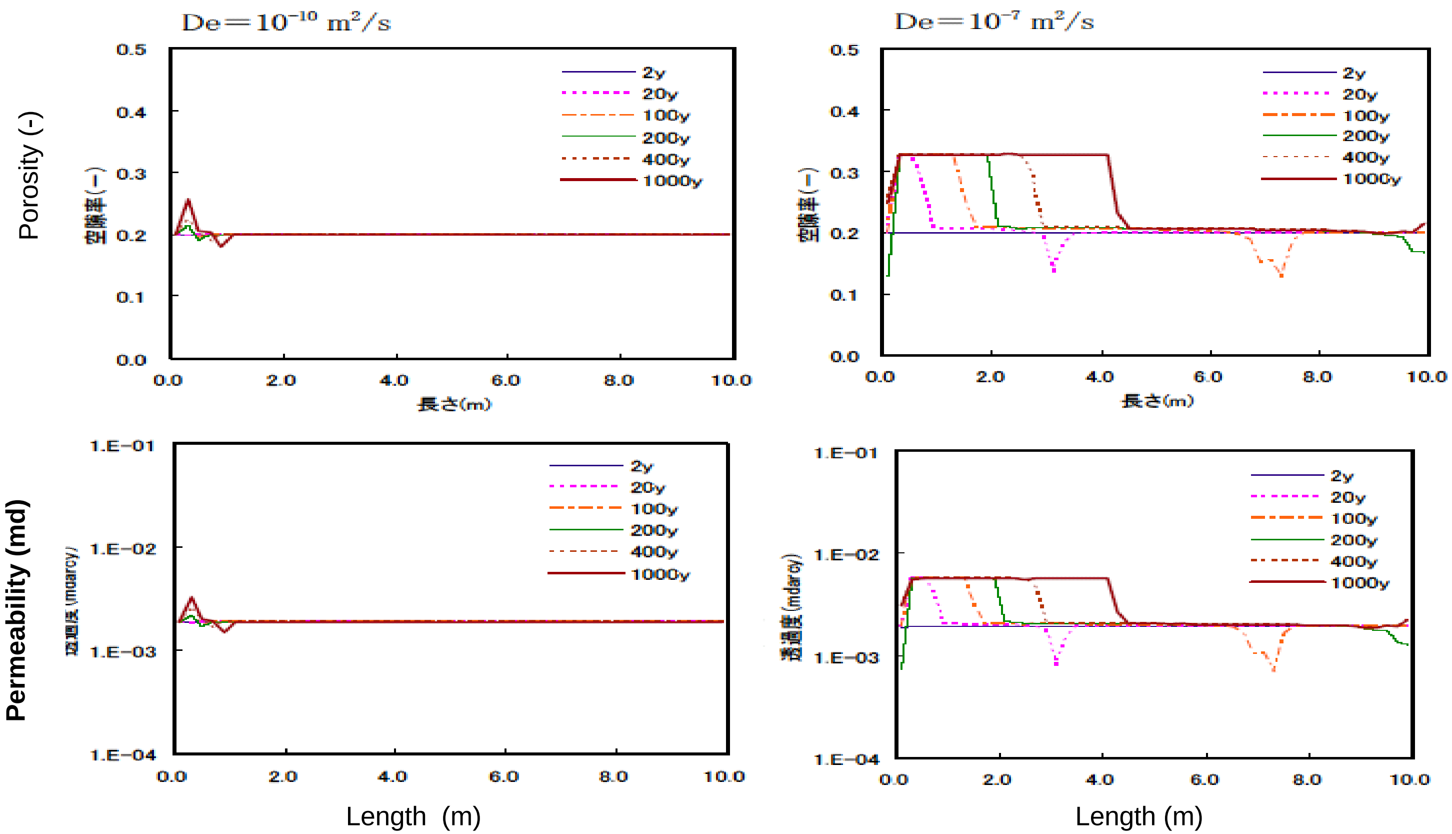


At the contact surface of groundwater
$Ca(OH)_2 + CO_3^{2-} + 2H^+$
$\rightarrow CaCO_3 + 2H_2O$
⇒ dense material (CaCO3) is generated

At the bottom of plug
$CaCO_3 + 2H^+ \rightarrow Ca^{2+} + H_2CO_3$
⇒ dissolution of main component

The plug deterioration is likely to continue.

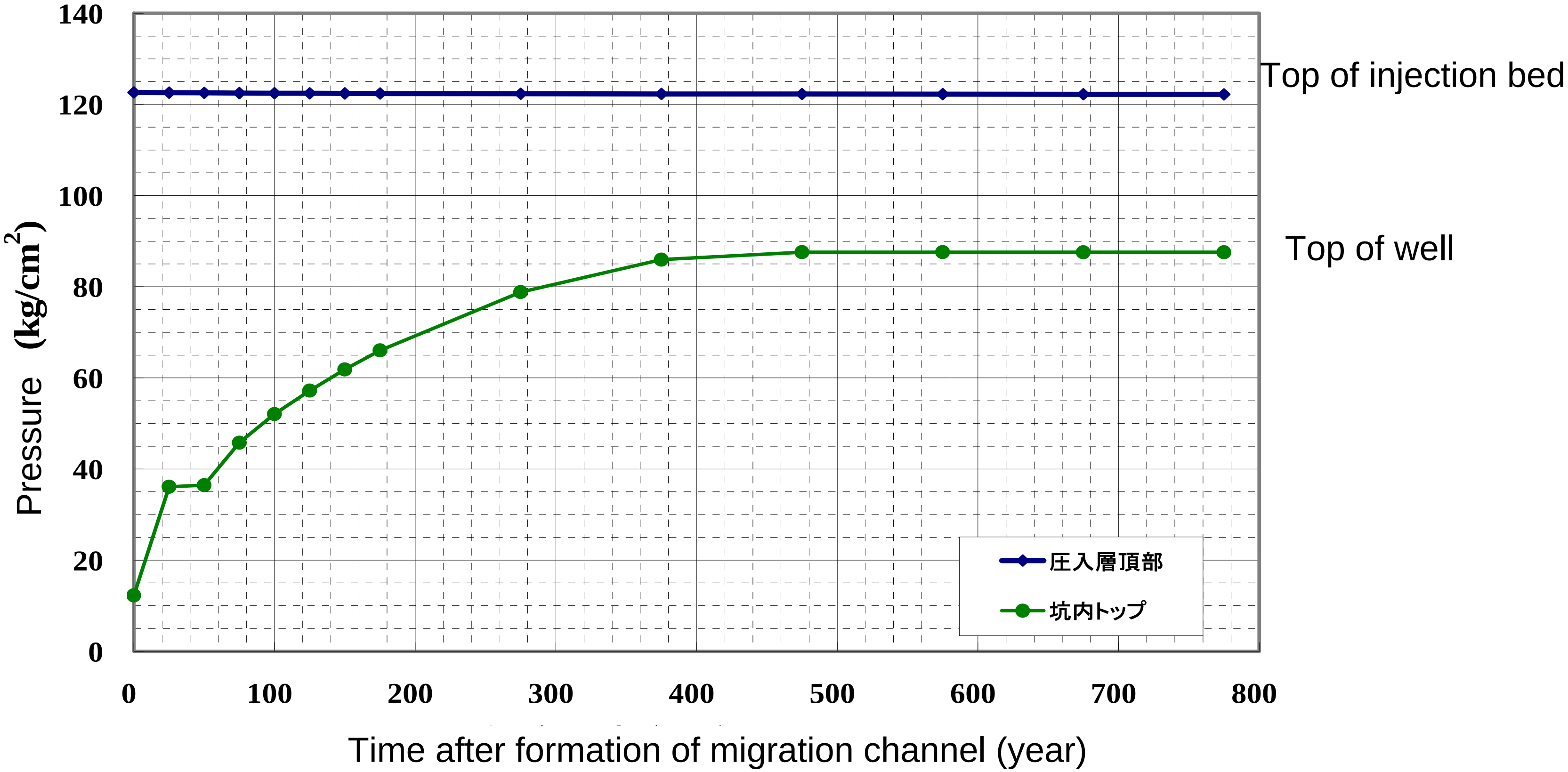
Porosity and Permeability Changes due to the Deterioration



Reaction conditions: 50℃、100kg/cm²、pH: 3、
CO_3^{2-} diffusion coefficient (inside plug): 1×10⁻¹⁰、1×10⁻⁷ m²/s

Based on USGS PhreeqC

CO_2 Accumulation inside the Well



Permeability of cement plug 1,000 md, Permeability of crack 10,000 md, Area ratio of crack 10％
Simulation software GEM-GHG

Risk Analysis--Summary

1. "Generic" FEP database for CO_2 geological storage in Japan was constructed

2. Four important FEPs were identified for important risk scenarios of CO_2 geological storage in a "typical" Japanese aquifer
   a. Undetected faults（未検出断層）
   b. Fault zone（断層帯）
   c. Borehole/ Borehole abandonment（圧入井・廃坑）
   d. Human intrusion（人的侵入）

3. Quantitative evaluation for an important risk scenario that is associated with "Borehole" revealed;
   a. Deterioration speed of cement plug is small and CO_2 leaking-out is very unlikely due to the deterioration
   b. Monitoring of well top pressure may allow the detection of the anomaly of well bottom plugging, and necessary countermeasures to be taken.

Risk Analysis--Summary(2)

4. Future work;

   a. Improvement in identification process of important risk scenarios; Transparency

   b. Identification of important risk scenarios

   c. Quantitative evaluation for the important risk scenarios

Study on Public Acceptance

Objectives/background

- Gap between scientific knowledge and public perceptions
- Public acceptance is formed through perceptions, value judgment etc.
- Investigation of the effects of certain information on the public perceptions, public acceptance

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To know what kinds of information are effective to help increase the public acceptance

Investigation of Public Acceptance

Outline of questionnaire survey

Studies on;

1. Risk and benefit perceptions and acceptance of CO2 geological storage relative to other risk events, technologies, activities etc.

2. Effects of following introductory information on
   a. global warming and
   b. CO2 geological storage, simultaneously

1st survey

3. Effects of following information on
   a. natural analogues and
   b. field demonstrations of the technology, individually

2nd survey

The same questions were asked before and after the information supply.

Conduct of Questionnaire Survey

- **Method : 7 point-scale SD method （意味的尺度法）**
- **Respondents :**
  - **[First survey] 267 university students**
  - **[Second survey] 423 university students**
- **Analysis : factor analysis（因子分析）**

Questionnaire design (1st survey)

Evaluated 20 risk-associated items

Risk items related to **Global Warming** and **Global Warming Mitigation options**	1. ***Global Warming*** 2. ***Nuclear Power*** 3. ***Fossil-fueled Power (Coal, Oil, Gas)*** 4. ***Hydroelectric Power (Dam)*** 5. ***Phtovoltaics*** 6. ***Wind Power*** 7. ***Waste Residue Power (Biomass)*** :Use of heat produced by waste incineration. 8. ***CO2 Ocean Storage*** :CO2 is sequestered in the ocean for CO2 emission reduction. 9. ***CO2 Geological Storage*** :CO2 is stored in deep geological formations for CO2 emission reduction. 10. ***Forestation*** 11. ***Greening of Deserts*** :Greening of deserts by use of genetically-modified plants. 12. ***Iron fertilization in Ocean*** :Photosynthesis of phytoplankton is accelerated by iron spray into the ocean for CO2 reduction.
Risk items related to NIMBY facilities and others	13. ***Industrial Waste Disposal Site (Landfill)*** 14. ***Geologic Disposal of High-level Radioactive Waste (HLW)*** :Liquid waste with a high level of radioactivity from nuclear power plants is vitrified, and stored in deep geologic formations. 15. ***Gasoline-fueled Vehicle*** 16. ***Fuel-cell Vehicle (Hydrogen tank loading)*** :Only water is exhausted. 17. ***Genetically Modified Food*** 18. ***Smoking*** 19. ***Alcohol Beverage*** 20. ***Bicycle***

Questionnaire design (1st survey)

Inquired 20 questions

Risk Perception (“Dread” and “Unknown”)	1. Control over risk (ex anti) 2. Control over risk (ex post) 3. Severity of consequences 4. Dread 5. Ease of risk reduction 6. Avoidance of death risk 7. Observability 8. Immediacy of impacts 9. Scientific knowledge about risk 10. Newness
Benefit Perception	11. Social benefit 12. Personal benefit 13. Benefit to future generation 14. Contribution to society 15. Personal necessity
Public Acceptance	16. Personal acceptance 17. Not in my back yard （NIMBY） 18. Public acceptance 19. Acceptance to the future generation 20. Deployment

Items of Provided Information(1st survey)

Information on global warming	Information on CO2 geological storage
1. Cause of global warming 2. Carbon cycle 3. Greenhouse effect 4. Mechanism of global warming 5. Projection of climate change 6. Global warming impact 7. Global warming mitigation	1. Overview of CO2 geological storage technology 2. Geological formation for the geological storage 3. Drilling technology 4. Global warming mitigation options 5. CO2 geological storage in carbon cycle 6. Risk of CO2 geological storage 7. CO2 geological storage in global warming mitigation scenario

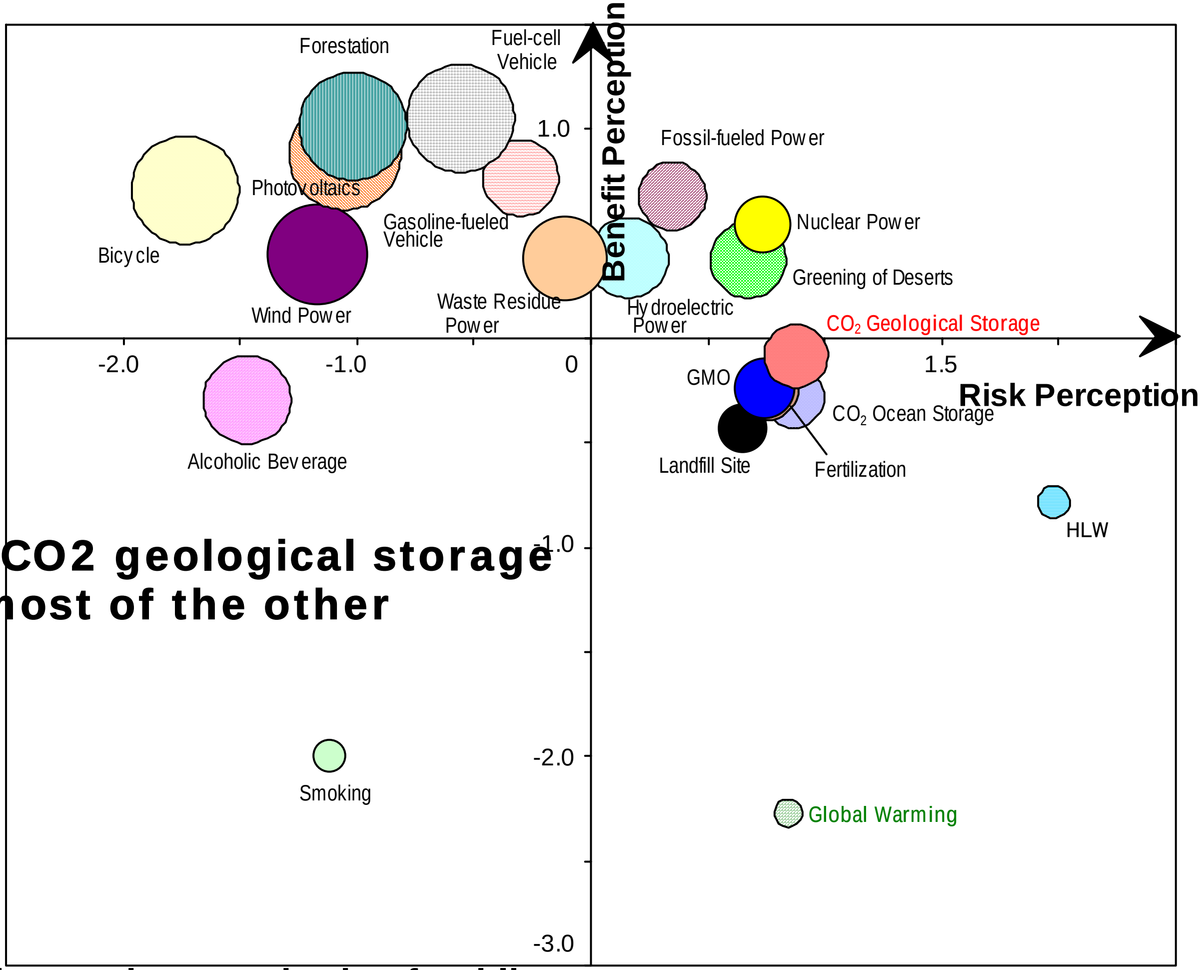
Information supply; a sheet with illustrated explanation for each of the items

Risk, Benefit Perceptions and Acceptance

- **Public acceptance was well explained by the risk and benefit perceptions.**

[Public acceptance] = 0.90 × [Benefit perception]
R^2 = 0.92 - 0.34 × [Risk perception]

Benefit perception is more influential than risk perception on PA.



- **The benefit perception of CO2 geological storage was lower than those of most of the other mitigation options.**

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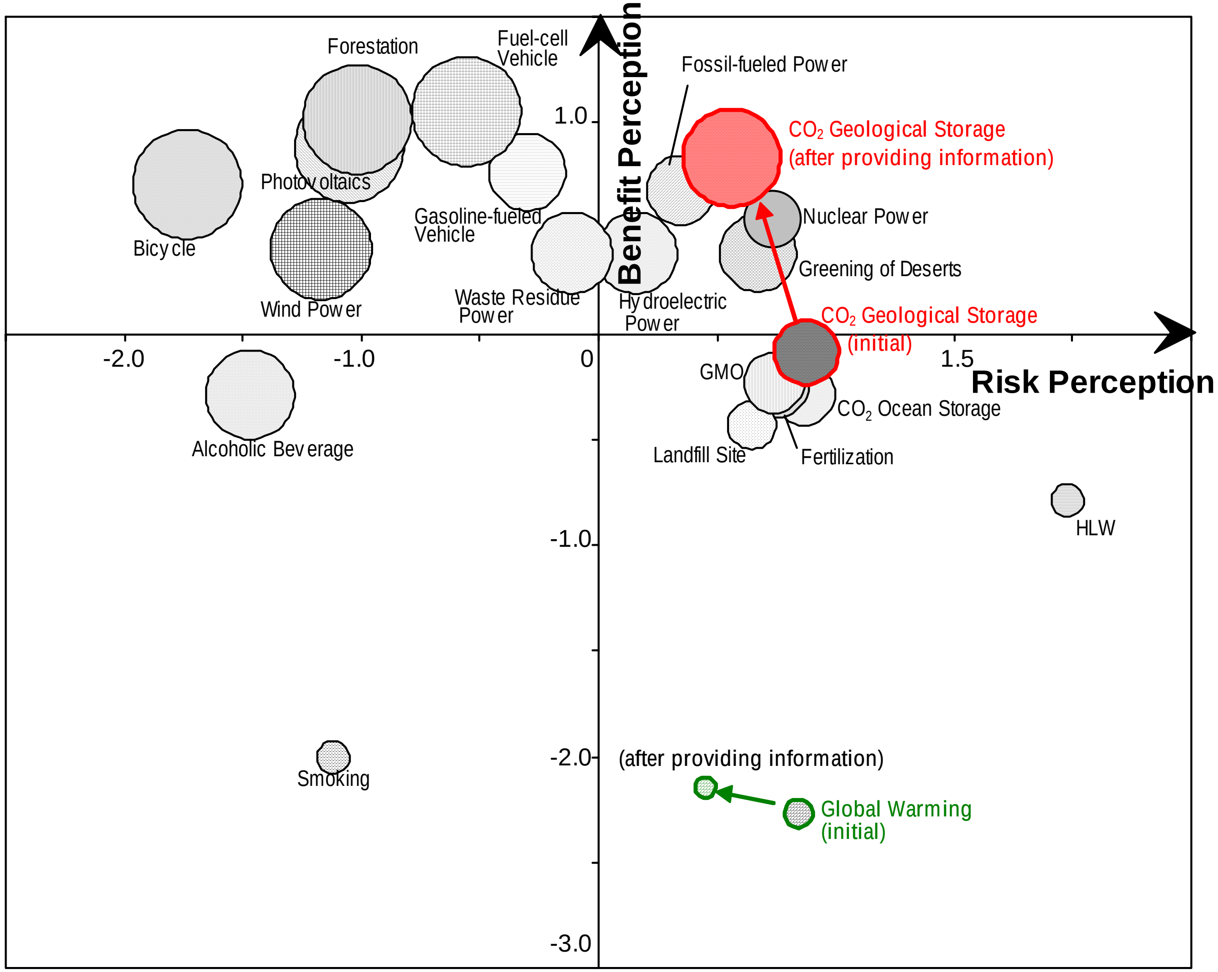
Note) The diameter of the circle indicates the magnitude of public acceptance.

Effects of Information Supply on Risk, Benefit Perceptions and Acceptance

- The benefit perception and public acceptance of CO2 geological storage increased significantly after providing the introductory information, while the risk perception did not decrease very much.



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Risk Perception Breakdown “Dread” and “Unknown”

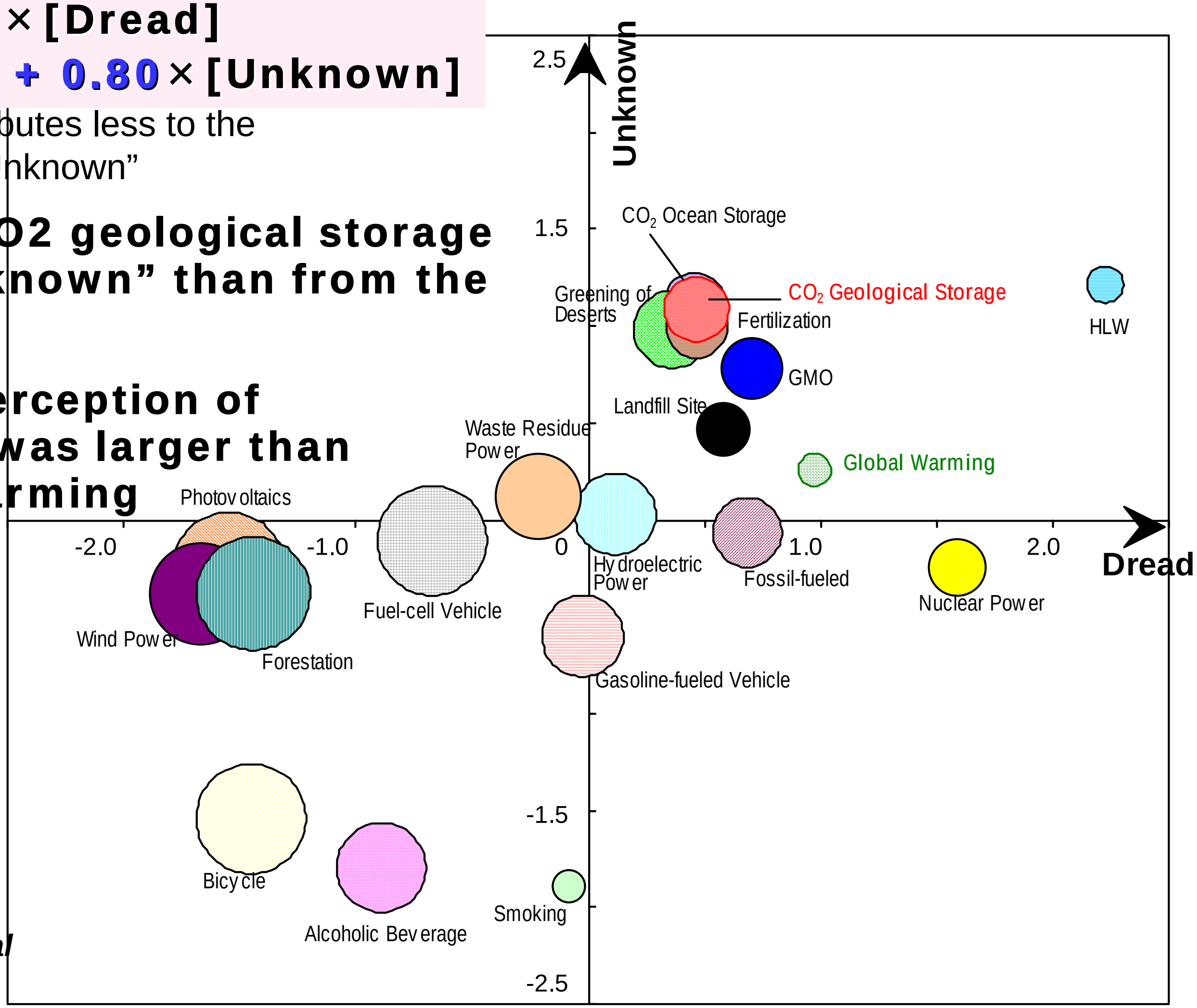
- Risk perception was well broken down into “Unknown” risk perception and “Dread” risk perception.

[Risk perception] = **0.39** × [Dread]
R^2 = 0.79 + **0.80** × [Unknown]

“Dread” risk perception contributes less to the risk perception than that of “Unknown”

- The risk perception of CO2 geological storage was more from the “Unknown” than from the “Dread”

- The “Unknown” risk perception of CO2 geological storage was larger than those of other global warming mitigation options.



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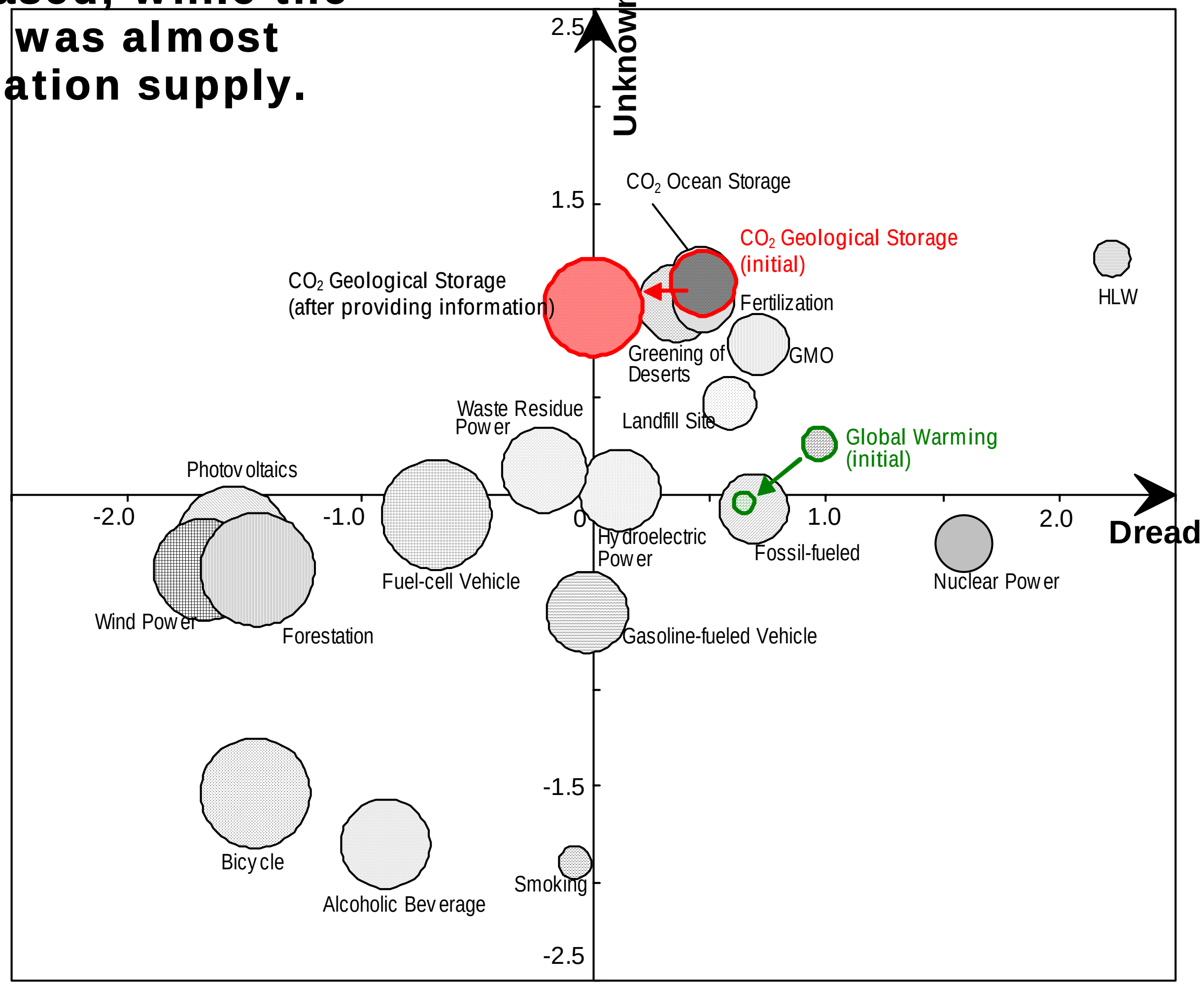
Effect of Information Supply on Risk Perception

- The "Dread" risk perception of CO2 geological storage decreased, while the unknown risk perception was almost unchanged by the information supply.



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Questionnaire design (2nd survey)

Inquired 34 questions

Risk Perception	*1. Safety* *2. Severity of consequences* *3. Observability* *4. Scientific knowledge about risk* *5. Newness* *6. Leakage of CO2 (marine environment)* *7. Leakage of CO2 (land surface)* *8. Blowout of CO2* *9. Effects of earthquake* *10.Leakage of CO2 (after a thousand years)* *11.Destruction of facilities (by earthquakes)* *12.Destruction of facilities (by corrosion)* *13.Effects on ground environment*
Benefit Perception	*Same as in 1st survey*
Public Acceptance	*Same as in 1st survey*

Risk related questions were specific to risks of CO2 geological storage.

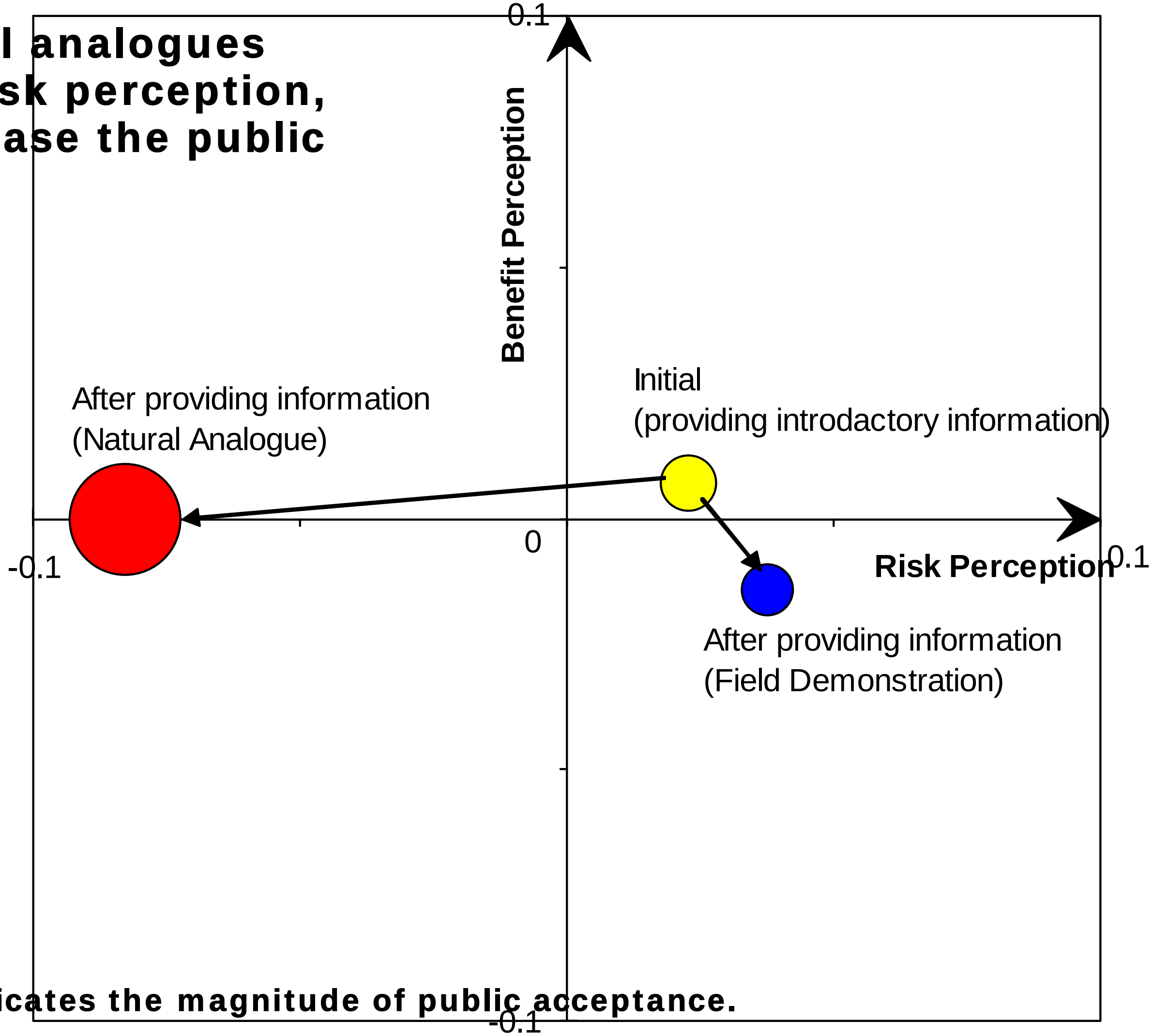
Items of Provided Information (2nd survey)

Information on natural analogues	Information on field demonstrations
• Overview of natural analogues • Example: Greece • Example: Hungary • Example: France • Example: Germany	• Overview of field demonstration / application • Example: Nagaoka project in Japan • Example: Norway • Example: Canada • Example: Australia

The Information was just introduction to the demonstrations and did not contain any data regarding CO2 behavior.

Effects of Information Supply (2nd survey)

- The information on natural analogues and field demonstrations did not increase the benefit perception as was not intended to.
- The information of natural analogues worked to decrease the risk perception, and consequently to increase the public acceptance.



Note) The diameter of the circle indicates the magnitude of public acceptance.

Study on Public Acceptance- -Summary

- **Introductory information of CO_2 geological storage containing its role of global warming mitigation may increase the public acceptance significantly.**

- **The risk perception was more from the "Unknown" risk perception, and therefore the supply of information on the behavior of injected CO_2, risk analysis results etc. is considered to be effective to decrease the risk perception.**

- **The information on natural analogues worked to decrease the risk perception, and consequently to increase the public acceptance, while the simple introduction to field demonstration did not.**