CO$_2$ storage; Legislation and risk management in the Netherlands

CCOP Meeting – Phuket 2010
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• Introduction
• The Netherlands in a nutshell
• Legislation
• Risk management
• Barendrecht project
Netherlands Organisation for Applied Scientific Research

- 4500 employees

Geosciences and energy
- Applied geosciences
- Geological Survey of the Netherlands
- Consultant for Ministry of Economic Affairs on mining activities

- 20 years of experience in CCS (National and European projects)
The Netherlands in a nutshell

- Gas producer
  (GIIP 4500 BCM, 70 BCM/y)
- 4 UGS facilities!
- End of gas production many gas fields in coming decades
- Practical storage capacity CO2:
  >2000 Mton in depleted gas fields

Gas fields more suitable than aquifers
- GF: better defined
- GF: proven sealing capacity (CH4)
- GF: dynamic behavior known
- GF: more efficient:
  (less rock volume, energy, pressure)
- GF: existing infrastructure
Current CCS projects in the Netherlands

• Pilot on K12B
  • Started in 2004, ongoing
  • CO2 (13%) produced is reinjected
  • Total 70kT CO2 injected till 1-1-10

• Pilot storage project Barendrecht (+Ziedewij)
  • Start injection 2011/2012
  • 0.4 Mton CO2 per year
  • max 10 Mton

• Two potential “flagship” projects in preparation (>2015)
NL Policy

- Netherlands Government has adopted CCS as one of the solutions for CO₂ emissions.

- Preference for depleted gas fields over other storage options

- Re use of existing infrastructure (see next slide)

- Need for Master plan to ensure efficient use of available capacity and infrastructure

- Research programs ongoing

- Public acceptance still is issue (proposed project Barendrecht)
Existing infrastructure

Abandonment principle: removal of equipment and boreholes
⇒ loss of opportunity for storage

Need for:
• Storage master plan (both for infrastructure and storage capacity)
• Legal authority to prevent abandonment and/or ensure suspended abandonment
• Policy & financial matters: responsibility & financing mothballing
Legislation
Legislation:

- Scope of regulation
- International European context
- Dutch Mining Act
Typicality of CO$_2$ storage: long-term component

- **No monitoring** possible over a very long time period
  - Put emphasis on prevention
    (through proper site selection and characterisation)
  - Assess on sound scientific basis
- **External factors**
  - Be comprehensive in hazard/risk identification
- **Large uncertainty** in properties
  - Apply conservative approach or probabilistic approach
- **Limited performance data**
  - Use natural and industrial analogues
    - (Werkendam gas field, 78% CO$_2$)
What is subjected to regulation of CO$_2$ storage?

- **Effectiveness of emission reduction**
  - Guidelines for monitoring, reporting and verification
  - Kyoto instruments: Emission trading, Clean Development Mechanism, Joint Implementation & accounting of emissions
  - European Emission trade system (ETS) & Linking Directives

- **Health, safety and environment**
  - International guidelines for marine environment: OSPAR Convention and London Convention/Protocol
  - Relevant European Directives, i.e. EU draft storage Directive
  - National regulations in mining and environmental laws

- **Ownership, IPR, responsibility & liability, and insurance**
  - European Environmental Liability Directive
  - National regulation

- **(Spatial planning/resource management)**
General issues in developing regulation (not exhaustive)

- Composition of the CO\textsubscript{2} stream (*overwhelmingly CO\textsubscript{2}* )
- Transfer of responsibility
- Long-term liability
- Cross-boundary effects
- No performance database/lack of actuarial data (UGS analogue)
- Detection limits of monitoring techniques
- Performance standards
Art 4 Site selection

(2) A geological formation shall only be selected as a storage site, if under the proposed conditions of use there is no significant risk of leakage, and if no significant negative environmental or health impacts are likely to occur.
Art 7 Permit applications

Applications to the competent authority for storage permits shall include the following information: …

(3) The characterization of the storage site and complex and an assessment of the expected security of the storage pursuant to Article 4(2) and (3) …

(5) A proposed monitoring plan pursuant to Article 13(2) ..
(1) Member States shall ensure that the operator carries out monitoring (...) for (...):

- comparison actual – modelled behaviour CO₂
- detecting migration of CO₂
- detecting leakage of CO₂
- detecting significant adverse effects for surrounding environment, human populations, or users biosphere
- assessing effectiveness corrective measures
- assessing whether stored CO₂ will be completely contained in future
Dutch Mining Legislation

• Mining Act(2003) provides basic framework for storage licensing (CH$_4$, CO$_2$, N$_2$ etc.): storage permit, storage plan, monitoring, inspection, closure plan.

• No special rules on:
  - access to transport and storage of CO$_2$
  - long term stewardship of storage sites
  - financial arrangements long term monitoring
Regulation in the Netherlands – Important milestones in licensing

**Preparation phase**
- EIA Approval by EIA-Commision
- Environmental License
- Storage Plan: site characterisation, assessment, monitoring, well integrity
- Measurement/monitoring Plan
- Drilling Programme

**Closure phase**
- Closure plan
- Well abandonment plan

**After care**
- Transfer of responsibility/liability
- Optional Monitoring

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CCS legislation - CO2 storage
EU CCS directive vs Dutch Mining Act

New elements for Dutch Mining Act

- Transfer of responsibility (20 years after closure)
- Financial security operators during storage and before transfer
- Financial contribution operators for post transfer monitoring (30 years) and containment CO2
- General rules on access to transport and storage
- Role EU Commission:
  ✓ information on permit applications & transfer report by operator
  ✓ non-binding opinion on draft storage permits and draft decision of approval of transfer of responsibility (both within 4 months)

Implementation EU directive + OSPAR guideline in progress
Risk analysis and Risk management
Content

• Types of risk

• What is risk management?

• Stages of a storage project

• Risk assessment (RA)
  • Qualitative RA
  • Quantitative RA

• Risk-based monitoring

• Remediation: Preventive and corrective actions
Types of risk: impact

Global impact

- Leakage of CO$_2$ back to the atmosphere lowering the affectivity of global CO$_2$ emission reduction

Local impacts

- Leakage of CO$_2$ to the biosphere leading to unacceptable effects on men and environment
- Pressure/stress changes leading to gradual (aseismic) or episodic (seismic) ground movement
- Displacement of brine and fresh water

Source: Cudd Well control
Potential migration pathways to be managed

Risk management of CO2 storage
Risk management

• The process of assessing, monitoring and mitigating risks during the lifetime of a CO$_2$ storage facility so that they can be kept below pre-defined performance/risk levels.

• The active process of risk management comes to an end when the facility has reached a fail-safe condition.
Risk management during CO₂ storage lifecycle

- **CO₂ storage**
- **Site selection & preparation**
- **Operation (CO₂ injection)**
- **Closure**
- **Post-closure**

**Risk management of CO₂ storage**
Risk management
I. Assessing risks

Assessing

Remediating

Monitoring
Risk assessment

Objective
- Identify and evaluate risks which may affect the containment of $\text{CO}_2$ and can lead to leakage of $\text{CO}_2$

1. Assessment basis
Defining the scope and purpose of assessment

2. Qualitative assessment
Review of existing programme of technical studies

3. Quantitative assessment
Quantitative evaluation of $\text{CO}_2$ containment
Risk Assessment Work Flow

Definition of assessment basis

- FEP identification classification
- FEP ranking screening
- FEP interaction/grouping
  - Scenario (element) formation
  - Conceptual model development
  - 3D <> 2D numerical model
  - Testing with (natural) analogues

Qualitative
- Scenario analysis

Quantitative
- Model development
- Consequence analysis

Risk management of CO2 storage
Qualitative scenario analysis

- FEP identification
- FEP classification
- FEP selection and interaction
- Scenario definition and selection
- Model concept
- Model building
  - Consequence analysis
- SA of key factors

Risk management of CO2 storage
1. Defining the assessment basis

- Geographical and geological setting
- Containment concept
- Assessment target
2. Qualitative assessment

Objective
• Evaluate completeness of programme of technical studies

Qualitative assessment
1. Preparation and screening of the FEP database
2. Ranking of FEPs by experts
3. Preparation of a workshop document for the experts
4. Input of the experts is processed by TNO
5. Workshop with experts: Identifying leakage paths and related FEPs
6. Brief report of the conclusions of the workshop: Review of existing programme of technical studies
Improvements

- SQL database – web based

- Questionnaire

- Online Database Manager (FEPMan)

Risk management of CO2 storage
Outcome and Expected Results of FEP Workshop

• Initial step for feasibility study

• Risk scenario formation

• Gain confidence on suitability and feasibility of the site

• Traceability and transparency for the decision making
3. Quantitative assessment

Objective
- Quantitative evaluation of risks which may affect the integrity of the storage site and can lead to leakage of CO$_2$
- Predict the performance, i.e. the leakage rates, of CO$_2$

- Research items
  - Analysis of seal integrity (C, M)
  - Reservoir integrity (F, C)
  - Well integrity (C, M)

- Methods:
  - Numerical Models and Reservoir Simulators
  - Deterministic and Probabilistic Models

(F = Fluid flow processes)
(C = Chemical processes)
(M = Mechanical processes)
Performance Assessment (PA)
Fault leakage

Risk management of CO2 storage
Mechanical seal and fault integrity

Fracture propagation: PWRI-Frac simulator

The largest stress change at reservoir edges
Chemical integrity of reservoir and seal

Significant re-arrangement Minerals

Decreased porosity

Risk management of CO2 storage
Risk management of CO2 storage

II. Monitoring risks

- Assessing
- Monitoring
- Remediation
### Risk Management: 2. Risk – based Monitoring

**Monitoring requirement:**
- Provide (short-term) measurements to test long-term assessment

**Other monitoring purposes**
- Operational monitoring
- Control HSE criteria
- Initiate mitigation measures
- Verify for emission trading
- Understand storage process
- Test novel monitoring technique
- Visualise storage for public

<table>
<thead>
<tr>
<th>Time (logarithmic)</th>
<th>Monitoring surface installations</th>
<th>Monitoring underground facility</th>
</tr>
</thead>
<tbody>
<tr>
<td>-x Y Baseline</td>
<td>0 Y Construction</td>
<td>Operation</td>
</tr>
<tr>
<td>10 Y Abandonment</td>
<td>100 Y</td>
<td>1000 Y</td>
</tr>
<tr>
<td>Decision to recover CO₂ or semi-permanently store CO₂</td>
<td></td>
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- **monitoring period**
- **optional prolonged monitoring**

Risk management of CO₂ storage
Risk management

III. Remediating risks

Assessing

Remediating

Monitoring
Risk management: 3. Mitigation

- *Control measures of preventive nature*
  - Site characterization
  - Engineering design

- *Corrective nature*
  - Adapt operation plan
  - Adapt engineering design
  - Stop injection
  - Release injected CO₂
Risk management: 3. Mitigation measures

**Potential Escape Mechanisms**

A. CO\textsubscript{2} gas pressure exceeds capillary pressure & passes through siltstone
B. Free CO\textsubscript{2} leaks from A into upper aquifer up fault
C. CO\textsubscript{2} escapes through ‘gap’ in cap rock into higher aquifer
D. Injected CO\textsubscript{2} migrates up dip, increases reservoir pressure & permeability of fault
E. CO\textsubscript{2} escapes via poorly plugged old abandoned well
F. Natural flow dissolves CO\textsubscript{2} at CO\textsubscript{2} / water interface & transports it out of closure
G. Dissolved CO\textsubscript{2} escapes to atmosphere or ocean

**Remedial Measures**

A. Extract & purify groundwater
B. Extract & purify groundwater
C. Remove CO\textsubscript{2} & reinject elsewhere
D. Lower injection rates or pressures
E. Re-plug well with cement
F. Intercept & reinject CO\textsubscript{2}
G. Intercept & reinject CO\textsubscript{2}
Closing remarks

- Typicality of CO$_2$ storage:
  - long-term component
- No monitoring possible over a very long time period
  - Put emphasis on prevention
    (through proper site selection and characterisation)
  - Assess on sound scientific basis
- External factors
  - Be comprehensive in hazard/risk identification
- Large uncertainty in properties
  - Apply conservative approach or probabilistic approach
- Limited evidence to date
  - Natural and industrial analogues
Bow tie Risk model

Hazards  
<table>
<thead>
<tr>
<th>Hardware Barriers</th>
<th>Organisational Barriers</th>
</tr>
</thead>
</table>

undesired Top event

Consequences  
| Hardware Barriers | Organisational Barriers |

Causes  

Events
Main points of attention

Hazards
• Well integrity
• Cap rock
• Faults
• Spill point

Barrier

Monitoring
Well Integrity Failure:
Main Hazards(1)

- **Hazard**
  - Failure of casing
  - Failure of cement plugs or sheath

- **Barriers**
  - $\text{CO}_2$ resistant well completion material (surface and downhole)
  - $\text{CO}_2$ resistant cements
  - $\text{CO}_2$ Blow out control and equipment
  - Well abandonment designs

- (Time lapse) logging methods to identify hydraulic isolation, porosity- & permeability cement, casing corrosion, detection of flow behind casing etc.
Reservoir and caprock:
Main hazards (2)

- **Hazard**
  - Reactivity, dissolution, settlement and mineralization.
  - Post production caprock integrity.
  - Fracture sensitivity and injectivity behavior.
  - Dehydration of shale by CO$_2$.
  - Lower CO$_2$ breakthrough pressures through shale (as compared to hydrocarbons).
  - Self enhanced leakage behavior.
  - Geomechanical modeling.

- **Barriers**
  - Thickness of seal and reservoir
  - Composition of seal and reservoir
Monitoring (barriers)

- Micro seismicity
- Down hole pressure and temperature
- Well logging
- Continuous H$_2$O monitoring
- Geochemical tracers
- Soil gas survey
- Others..
Messages on CO$_2$ storage

• CO$_2$ storage: *individual* site studies.
• CO$_2$ storage is not the usual E&P activity.
• E&P has the technical and scientific basis and best practice to make a significant contribution.
• Empty gas reservoirs have, compared to aquifers, a proven seal for CH$_4$.
• “Indefinite future” is a long time.
Barendrecht Demonstration project
Barendrecht project scope

Pernis Refinery:
Almost 1 million tonnes of pure CO$_2$ annually

Winter:
400,000 tonnes CO$_2$ in Barendrecht reservoirs

Annually:
150,000 tonnes of CO$_2$ to soft drinks industry

Summer:
380,000 tonnes of CO$_2$ to greenhouses
Barendrecht Field

CO2 fill up

KNNSL – De Lier sd

KNNSY - Ysselst. sd

KNGLG – Hld Grn sd
What makes Barendrecht so suitable?

- Relatively unique situation:
  - Available in short term
  - Suitable CO$_2$ source (>99% purity)
  - Suitable field reservoirs (safe, almost fully depleted)
  - Learnings on entire life cycle would be quickly available
  - Short distance to CO$_2$ source
  - Region where people take climate problem seriously and are keen to develop a CO$_2$ infrastructure (Rotterdam Climate Initiative)
Public misinterpreted size of trees vs depth

Hoe wordt CO$_2$ opgeslagen?

2 à 3 km.
Barendrecht field located under populated area. Many worries not based on facts

Barendrecht-velden
Thank you!