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## Methodologies and technologies for mitigation of undesired CO<sub>2</sub> migration in the subsurface

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## Methodologies and technologies for mitigation of undesired CO<sub>2</sub> migration in the subsurface

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# Request from the IEAGHG

For the risk scenario **undesired CO<sub>2</sub> migration in the subsurface**

→ The state of knowledge of **novel and standard mitigation and remediation practices** and **associated costs**

→ Review of **mitigation plans in place on current/past/future CO<sub>2</sub> geological projects**



# Context

- Less information in the public domain on this topic compared to other ones, but **increasing interest**
- **Europe**, Directive on GCS: the permit application shall include a **corrective measures plan**
- **USA**, U.S. Federal Requirements under the UIC Program for CGS Wells: the owner or operator must provide **an emergency and remedial response plan** as part of the permit application
- **Australia**, Offshore Petroleum and Greenhouse Gas Storage Act 2006: **well operations management plan** with explanations on how the **risks can be dealt with**



# Approach, three main questions

- Which are the **current** mitigation and remediation **techniques contemplated** in the literature?
  
- From an **operational** perspective
  - which measure is **achievable**?
  - how to **distinguish/prioritize** among various feasible measures?
  
- How is this measure **incorporated/integrated** in the intervention plan or **set-up** in case of a detected CO<sub>2</sub> migration?



# Review of techniques

- The contemplated measures are:
  - **Taken / adapted from other domains**
  - **Theoretically-based**
  
- In the study, comprehensive state of knowledge of mitigation and remediation practices, **standard** and **technically feasible** or **innovative** and **under development**
  
- Considered measure types:
  1. **Interventions on wells**
  2. **Fluid management techniques**
  3. **Breakthrough technologies**
  4. **Remediation measures on potential impacts**



# Interventions on wells

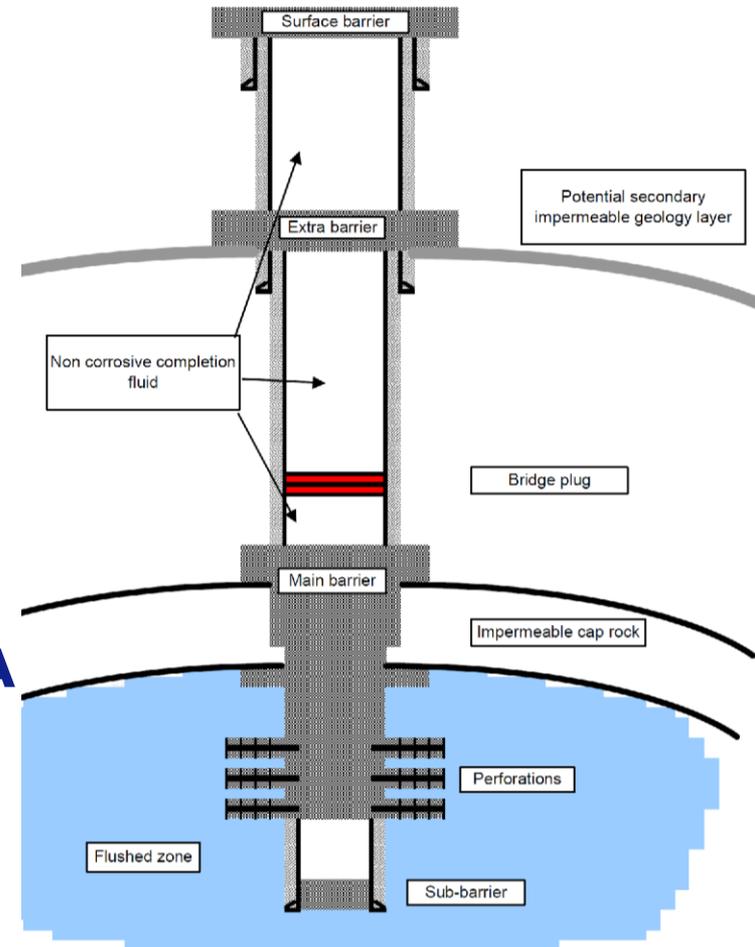
## → Operations on:

- **Wellhead** (repair)
- **Packers** (replacement)
- **Tubing** (repair)
- **Casing** (squeeze cementing, casing patch, swaging)
- **Well** (well killing, relief well)

## → Similar operations for **managing abandoned wells**

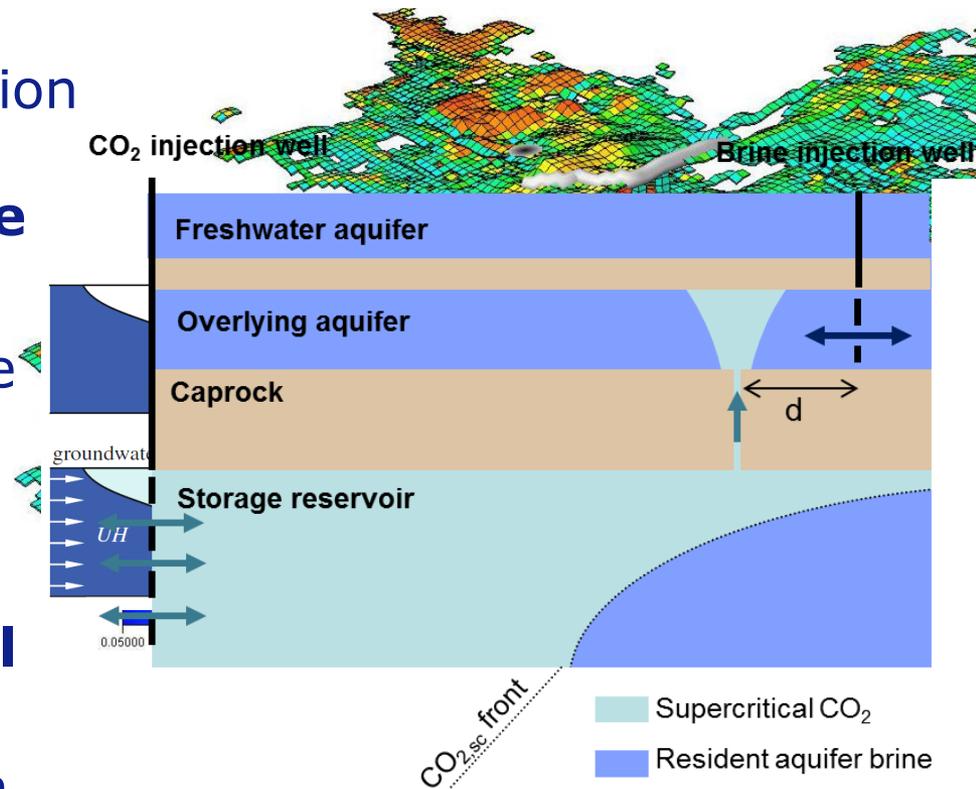
## → **Requirements for wells P&A** to be followed for injection wells and leaking abandoned wells

*After Randhol et al. 2007*



# Fluid management techniques

- For potential CO<sub>2</sub> migration pathways **non accessible/remediable**
- 1-**Pressure relief** in the storage formation
- 2-**Hydraulic barrier**
- 3-Enhancement of **CO<sub>2</sub> dissolution or residual trapping**
- 4-CO<sub>2</sub> **back production**

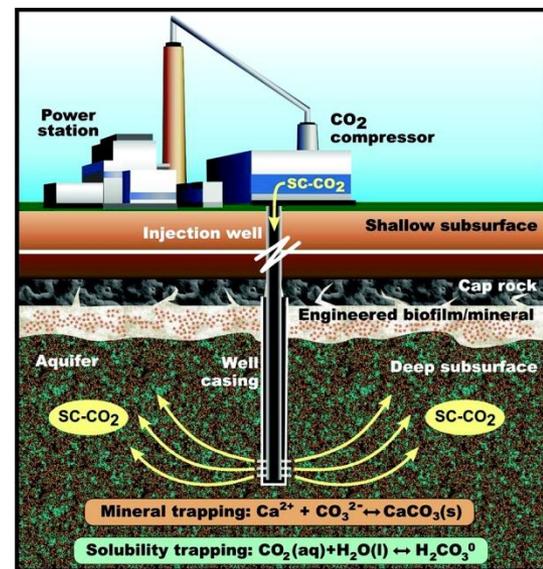


*Réveillère et al., 2012*



# Breakthrough technologies

- New **opportunities** for
  - Further **improvement of already existing** technologies
  - **Development of more advanced** CO<sub>2</sub> leakage mitigation tools
- 1-**Geopolymer** as an alternative option for well cementing
- 2-**Foams and gels** for controlling fluids migration
- 3-**Biofilms** notably to decrease formation and pathways permeability



*Mitchel et al., 2010*



# Remediation measures on potential impacts

- In the study, techniques for the remediation of :
  - **Groundwater**
  - **Unsaturated zone**
  - **Surface water**
  - **Indoor environment**
  - **Atmosphere**
  - **Ecosystems**
  
- Large experience in treatments related to **soil clean-up, aquifer repair** and **intrusion of gas** in buildings
  
- **Discussion on the applicability** of each remediation measure to CGS



| Impacted compartment      | Suggested measure  | Possible application in CCS domain   |
|---------------------------|--|--|
| <b>Groundwater</b>        | Monitored natural attenuation  | - Reduction of contaminants concentration : e.g. aqueous CO <sub>2</sub> concentration (Benson and Hepple, 2005), impurities, mobilized metals and organic compounds<br>- Transformation of contaminants into less toxic products: e.g. impurities, metals, organic compounds<br>- Reduction of constituent mobility and bioavailability: e.g. impurities, metals, organic compounds |
|                           | <b>Pump-and-treat</b>  | - <b>Extraction and treatment of fluids containing dissolved CO<sub>2</sub> or associated substances - (Benson and Hepple, 2005)</b>   |
|                           | Air sparging   | - Volatilization and extraction of dissolved CO <sub>2</sub> and additional contaminants (with properties similar to VOCs) (de Lary and Rohmer, 2010; Rohmer et al., 2010)   |
|                           | Permeable reactive barrier (treatment wall)  | - Trapping through a permeable barrier favouring reactions of mobilized trace elements (metals, organic compounds, impurities) (Benson and Hepple, 2005)   |
|                           | Injection - extraction   | - Extraction of the mobile gaseous plume;<br>- Decrease of the quantity of mobile CO <sub>2</sub> in the groundwater aquifer;<br><br>- Extracting the dissolved CO <sub>2</sub> and potential additional contaminants (Esposito and Benson, 2012)  |
|                           | Remediation using microbes   | - adjustment of ground water pH (Dupraz et al., 2009)<br><br>- mineralization of dissolved CO <sub>2</sub> (Menez et al., 2007)<br><br>- co-precipitation of contaminant (heavy metals) (Mitchell and Ferris; 2005)  |
| <b>Unsaturated zone</b>   | Monitored natural attenuation  | - reduction of CO <sub>2</sub> concentration in soil (Benson and Hepple 2005; Sweatman et al., 2010; Zhang et al. 2004)<br>- Transformation or reduction of mobility of contaminants (e.g. organic compound, heavy metals)   |
|                           | Soil vapour extraction   | - extraction of CO <sub>2</sub> (or organic compounds) from soil (Benson and Hepple, 2005; Rohmer et al., 2010; Zhang et al., 2004; and Sweatman et al., 2010)   |
|                           | pH adjustment (spreading of alkaline supplements, irrigation and drainage)                                       | - adjustment of soil pH (Benson and Hepple 2005; Sweatman et al., 2010)  |
| <b>Surface water</b>      | Passive systems: Natural attenuation   | - reduction of CO <sub>2</sub> concentration in shallow water (Benson and Hepple 2005)   |
|                           | Active venting system  | - remove dissolved CO <sub>2</sub> in deep stratified lakes (Benson and Hepple 2005)   |
| <b>Indoor environment</b> | Usual remediation techniques (radon, VOC...): sealing the opening, (de)pressurization, adjustment of ventilation | - lower CO <sub>2</sub> concentrations in indoor air (Benson and Hepple 2005; Rhomer et al., 2010)   |
| <b>Atmosphere</b>         | Passive system : Natural mixing  | - reduce CO <sub>2</sub> exposure in the atmosphere (Benson and Hepple 2005; Sweatman et al., 2010)  |
|                           | Air jets or large fans   | - reduce CO <sub>2</sub> exposure in the atmosphere (Benson and Hepple 2005; Sweatman et al., 2010)  |
| <b>Ecosystems</b>         | Ecological restoration   | - restore the impacted ecosystem (if needed)   |



# Operational perspective: selection of the most suitable action?

- Multiple **criteria**:
  - **Maturity**
  - **Efficacy** (impacts avoided, intervention delay)
  - **Costs** (economic, environmental)
  
- Highly **site-specific** and **situation-dependent**
  
- In the study, generic elements:
  - **On each measure**, on the maturity and intervention specifications
  - The **possible methods and approaches** for decision-making (CBA, CEA, MCA)



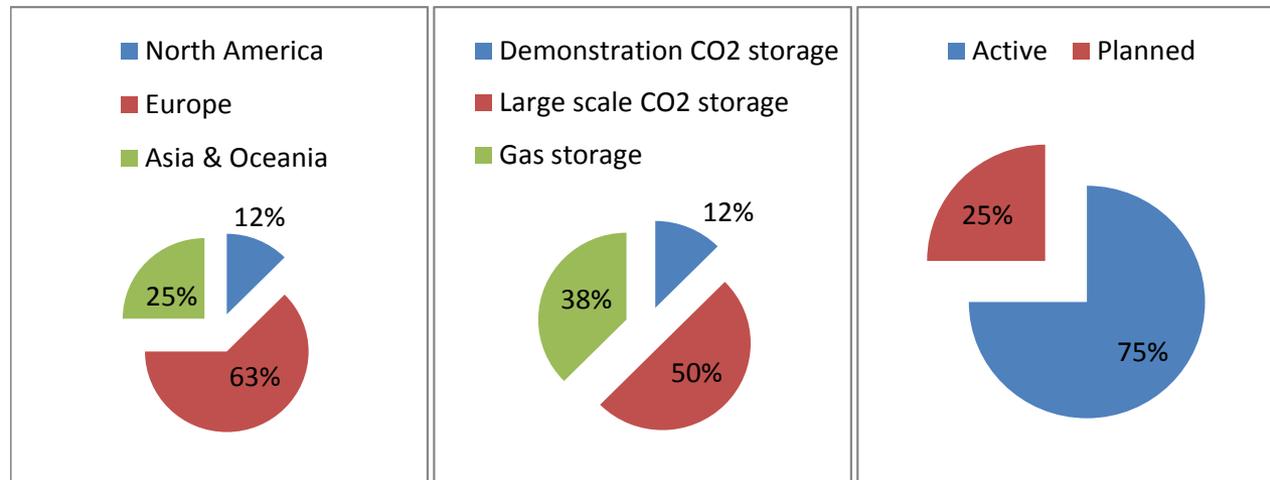
# Operational perspective: Costs

- Site-specificity, degree of maturity: **difficulties in estimating the costs of mitigation and remediation**
  
- In this study:
  - **Literature review** on elements given to estimate the intervention costs
  - **Qualitative elements** given for the described measures
  - **Quantitative elements** only possible for mature techniques
    - with different scenarios (onshore/offshore, geographical locations)



# Implementation: Intervention plans

- State of the art:
  - **CGS regulations**
  - **Guidelines/standard** for implementing mitigation and remediation plans
  - **Two public plans:** Goldeneye project (UK), Gorgon project (Australia)
- In this study, **survey** sent to CO<sub>2</sub> storage projects (14 sent, 8 answers)



# Key messages from the review of existing plans and literature

## → How?

- Plan **integrated** to the **risk assessment plan** and to the **monitoring plan** (site specific)
- Designed by **experts**, reviewed by **stakeholders**
- Very **diverse format** depending on the regulations

## → Which measure?

- Distinction **man-made/natural** pathways
- **Mostly imply actions on wells**
- Pressure management - considered as **preventive** rather than **corrective** measure
- **Immature technologies** are **not contemplated**
- **Remediation measures based** essentially on environmental **clean-up experience**

- **Flexible** plan, seen as a **support for decision-making** at the time of an irregularity detection



# Conclusions

- The report provides
  - 1-a **comprehensive portfolio** of the remediation and mitigation technologies mentioned in literature
  - 2-**qualitative or quantitative criteria** to enable a knowledgeable choice
  - 3-methodologies for **decision-making**
  - 4-**best practices** in terms of intervention plan set-up and implementation
  
- To go forward, some avenues for research:
  - **Migration processes understanding and consequences characterization**
  - Technologies **development** and **adaptation** to the CGS conditions
  - Development of tools for the **intervention optimization**



Thank you.

