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Methodologies and technologies for mitigation of undesired CO₂ migration in the subsurface

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Request from the IEAGHG

For the risk scenario **undesired CO₂ 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 CO₂ 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 CO₂ 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

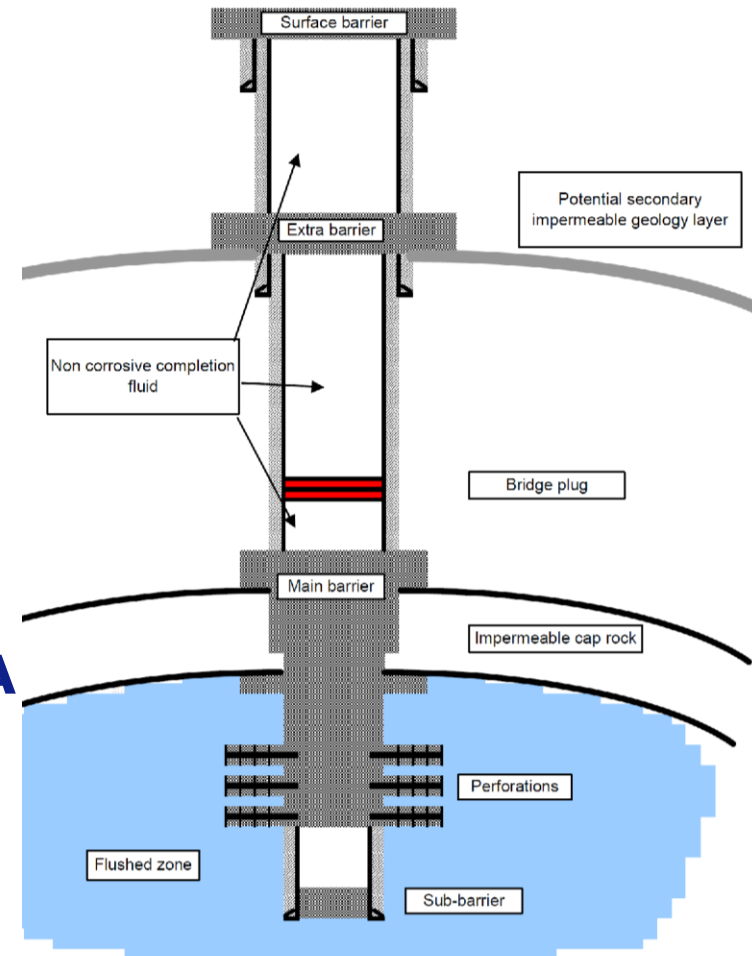
→ Operations on:

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

→ Similar operations for **managing abandoned wells**

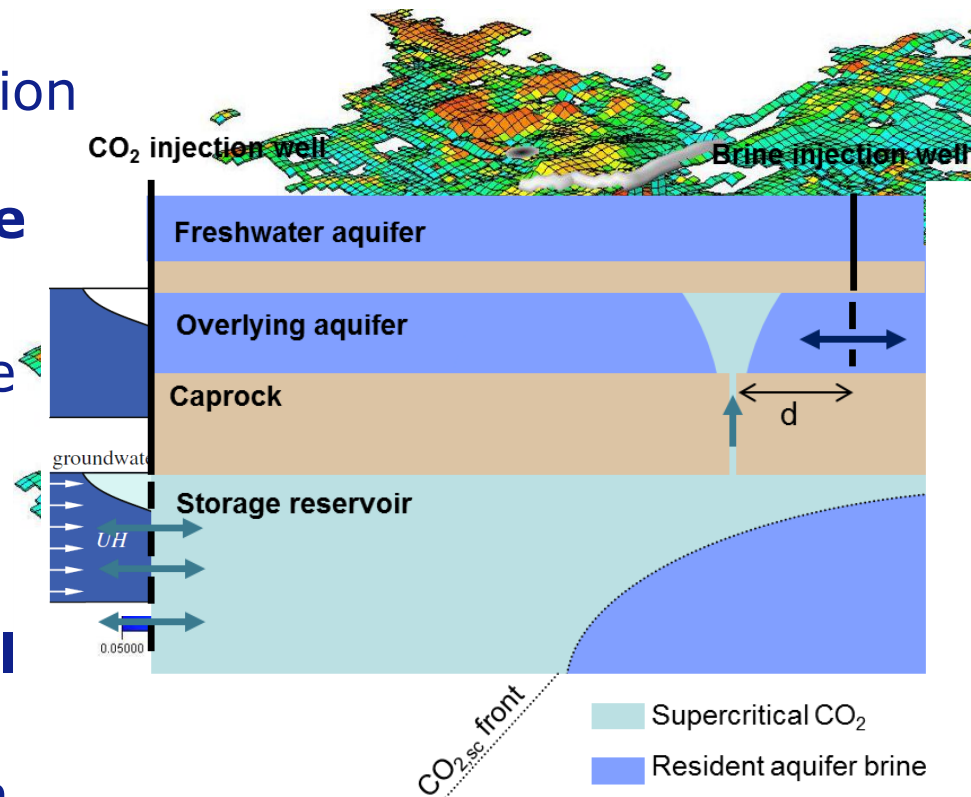
→ **Requirements for wells P&A** to be followed for injection wells and leaking abandoned wells

After Randhol et al. 2007



Fluid management techniques

- For potential CO₂ migration pathways **non accessible/remediable**
- 1-**Pressure relief** in the storage formation
- 2-**Hydraulic barrier**
- 3-Enhancement of **CO₂ dissolution or residual trapping**
- 4-CO₂ **back production**

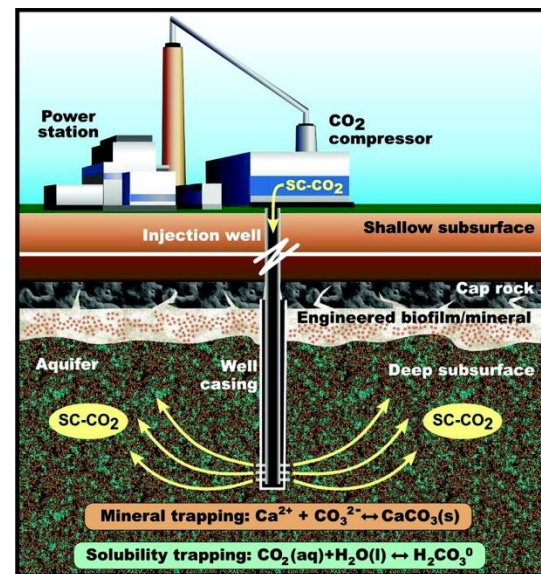


Réveillère et al., 2012



Breakthrough technologies

- New **opportunities** for
 - Further **improvement of already existing** technologies
 - **Development of more advanced** CO₂ 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
Groundwater	Monitored natural attenuation	- Reduction of contaminants concentration : e.g. aqueous CO ₂ concentration (Benson and Hepple, 2005), impurities, mobilized metals and organic compounds - Transformation of contaminants into less toxic products: e.g. impurities, metals, organic compounds - Reduction of constituent mobility and bioavailability: e.g. impurities, metals, organic compounds
	Pump-and-treat	- Extraction and treatment of fluids containing dissolved CO₂ or associated substances - (Benson and Hepple, 2005)
	Air sparging	- Volatilization and extraction of dissolved CO ₂ 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; - Decrease of the quantity of mobile CO ₂ in the groundwater aquifer; - Extracting the dissolved CO ₂ and potential additional contaminants (Esposito and Benson, 2012)
	Remediation using microbes	- adjustment of ground water pH (Dupraz et al., 2009) - mineralization of dissolved CO ₂ (Menez et al., 2007) - co-precipitation of contaminant (heavy metals) (Mitchell and Ferris; 2005)
Unsaturated zone	Monitored natural attenuation	- reduction of CO ₂ concentration in soil (Benson and Hepple 2005; Sweatman et al., 2010; Zhang et al. 2004) - Transformation or reduction of mobility of contaminants (e.g. organic compound, heavy metals)
	Soil vapour extraction	- extraction of CO ₂ (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)
Surface water	Passive systems: Natural attenuation	- reduction of CO ₂ concentration in shallow water (Benson and Hepple 2005)
	Active venting system	- remove dissolved CO ₂ in deep stratified lakes (Benson and Hepple 2005)
Indoor environment	Usual remediation techniques (radon, VOC...): sealing the opening, (de)pressurization, adjustment of ventilation	- lower CO ₂ concentrations in indoor air (Benson and Hepple 2005; Rhomer et al., 2010)
Atmosphere	Passive system : Natural mixing	- reduce CO ₂ exposure in the atmosphere (Benson and Hepple 2005; Sweatman et al., 2010)
	Air jets or large fans	- reduce CO ₂ exposure in the atmosphere (Benson and Hepple 2005; Sweatman et al., 2010)
Ecosystems	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

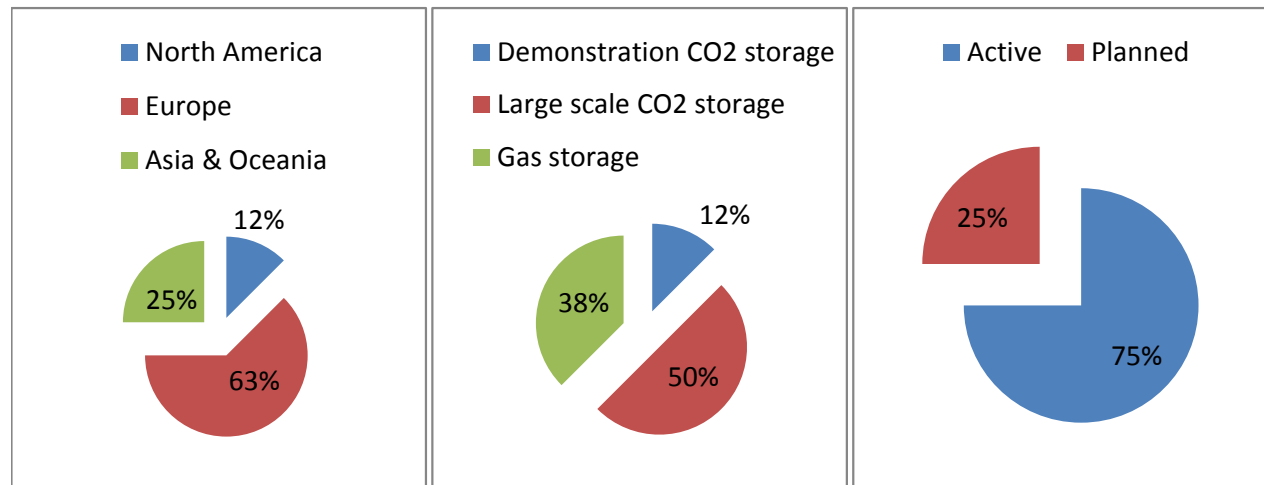
- Site-specificity, degree of maturity: **difficulties in estimating the costs of mitigation and remediation**

- 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 CO₂ 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.

