# Remediation of Possible Leakage from Geologic $CO_2$ Storage Reservoirs into Groundwater Aquifers


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## INTRODUCTION

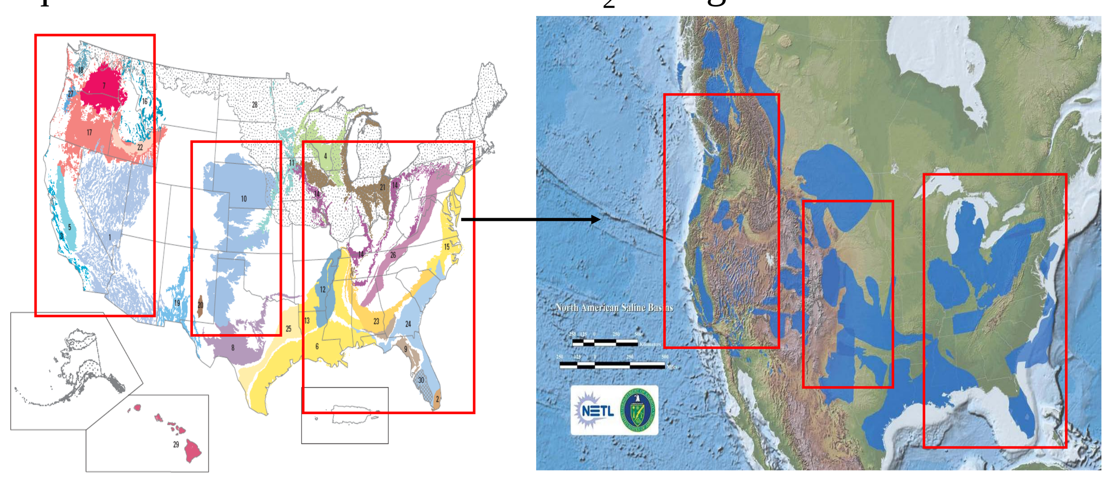
Maintaining the long term storage of the injected $CO_2$ is an important criterion when designing a large scale geologic $CO_2$ storage project. The possibility remains that the $CO_2$ will leak out of the storage formation into overlying groundwater aquifers. A leak could disrupt agricultural activities and groundwater extraction operations. Also, a leak into a drinking water source poses a threat to human health if the drop in pH from the leakage leads to the dissolution of arsenic, lead, or other harmful minerals that are present in the rock.

Different remediation techniques are being compared to determine the most appropriate technique for remediating the leakage. These techniques include the direct extraction of the plume of $CO_2$ and the injection of water to dissolve and dilute the $CO_2$. The comparison criteria include the half life of the $CO_2$ plume and the difficulty in remediation.

## BACKGROUND

### Groundwater Aquifers

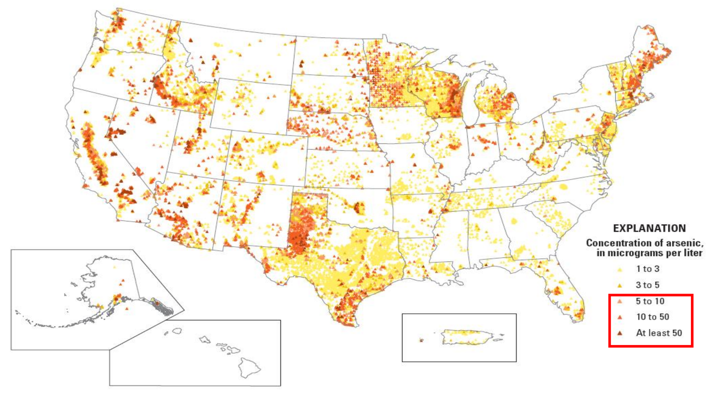
- Thirty principal aquifers account for 94% of the U.S. total groundwater usage
- The distribution of groundwater aquifers coincides with saline aquifers under consideration for $CO_2$ storage



**Principal Groundwater Aquifers** **Deep Saline Formations**

### Trace Metal Contamination

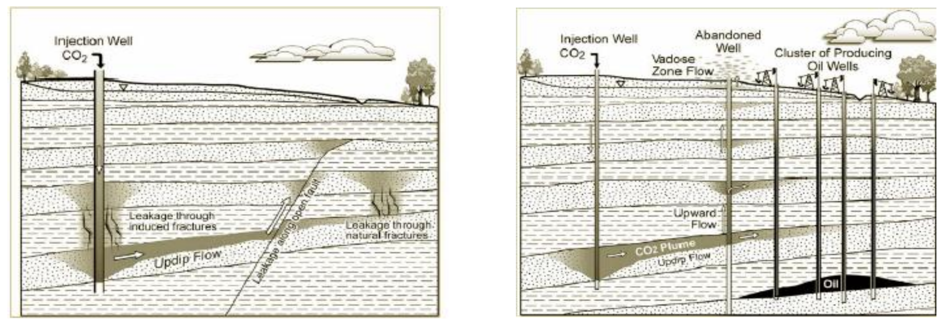
- The decrease in pH due to the formation of carbonic acid from the $CO_2$ intrusion leads to greater dissolution of lead and arsenic
- Arsenic is present in many locations above the MCL of 5µg/L
- Leakage of $CO_2$ into groundwater could exacerbate this problem



**Groundwater arsenic samples collected from 1973-2001**

### Potential Leakage Pathways

- $CO_2$ can leak from the storage reservoir through natural faults and fractures and abandoned or poorly sealed wells



**Geologic Pathways** **Well Leakage**

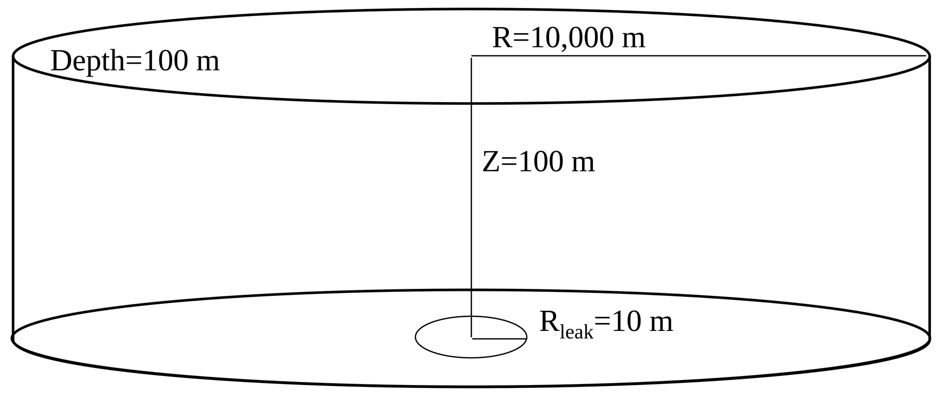
## METHODS

### Simulator:

Multiphase flow simulator TOUGH2 with ECO2N equation of state

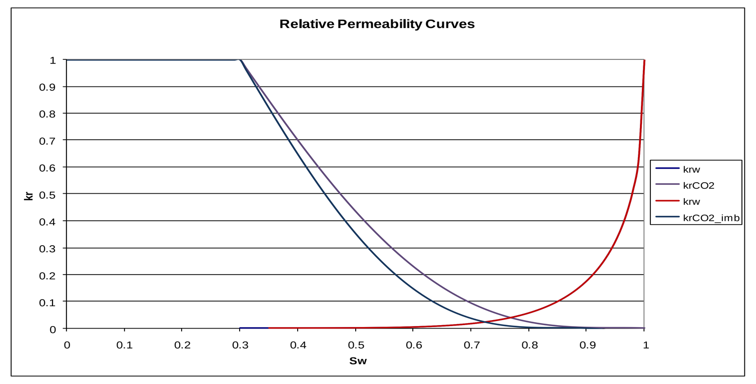
### Model

- Confined groundwater aquifer
- Radial axisymmetric grid
- $k_r$=100 md $k_z$=10 md
- XNaCl=0.1 wt%
- φ=15%



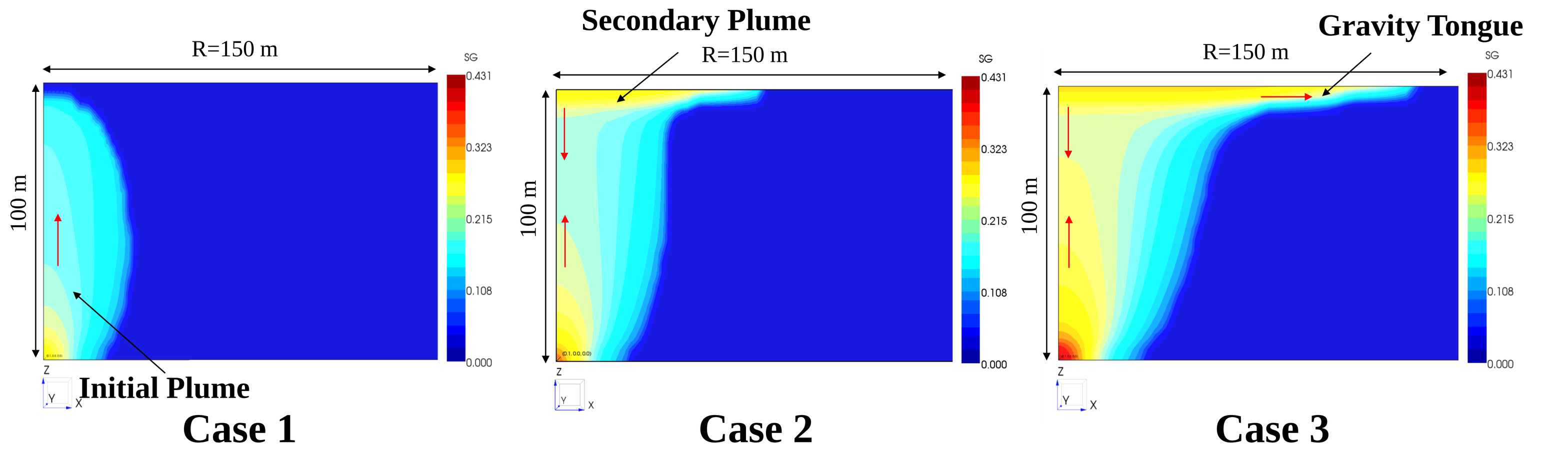

### Leakage

- Radius of leakage zone =10 m
- Leakage Period: 5 years
- $CO_2$ Leakage Rates:
  - Case 1: 175 tons/yr → Total: 875 tons
  - Case 2: 350 tons/yr → Total: 1750 tons
  - Case 3: 700 tons/yr → Total: 3500 tons




Relative Permeability Curves

### Initial Remediation Conditions




**Case 1** Buoyant $CO_2$ rises

**Case 2** $CO_2$ accumulates at the top

**Case 3** Gravity tongue lengthens

## REMEDIATION: EXTRACTION WELL

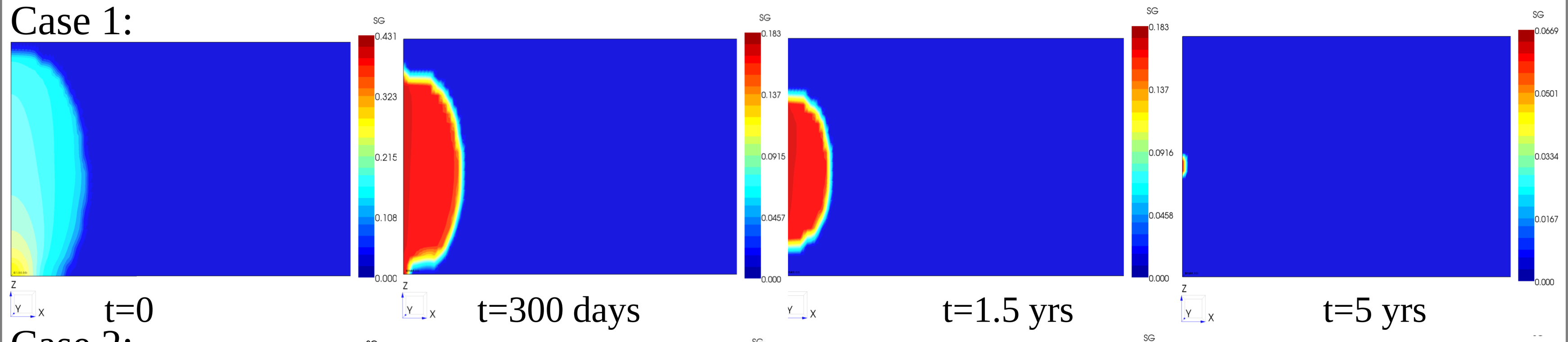
### Extraction Well

- Located at R=0 m and screened the entire depth of the aquifer
- Constant pressure of 1.98 MPa at the top of the well

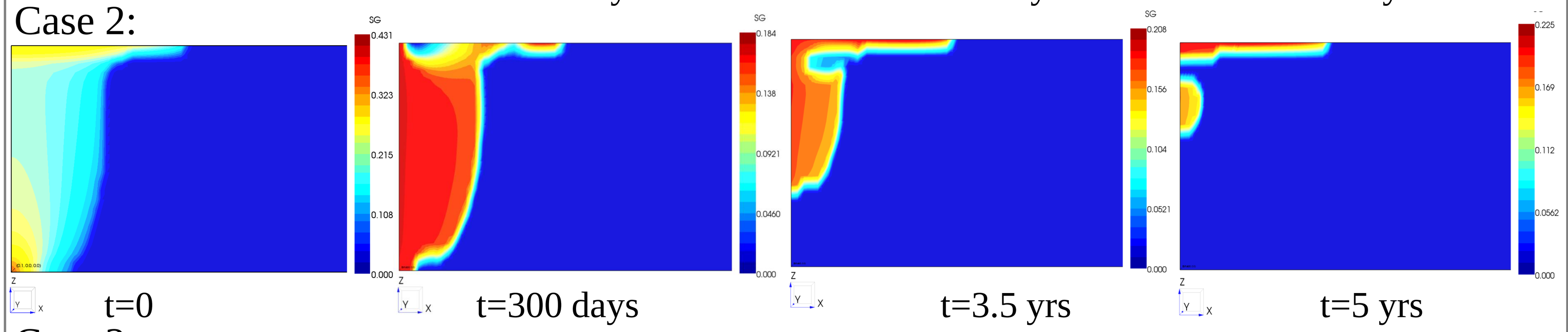
•Extraction allows for many diverse physical processes

- Bypass either above or below of the high gas saturation areas
- Rapid gas extraction above injection area
- Separation of primary and secondary plumes

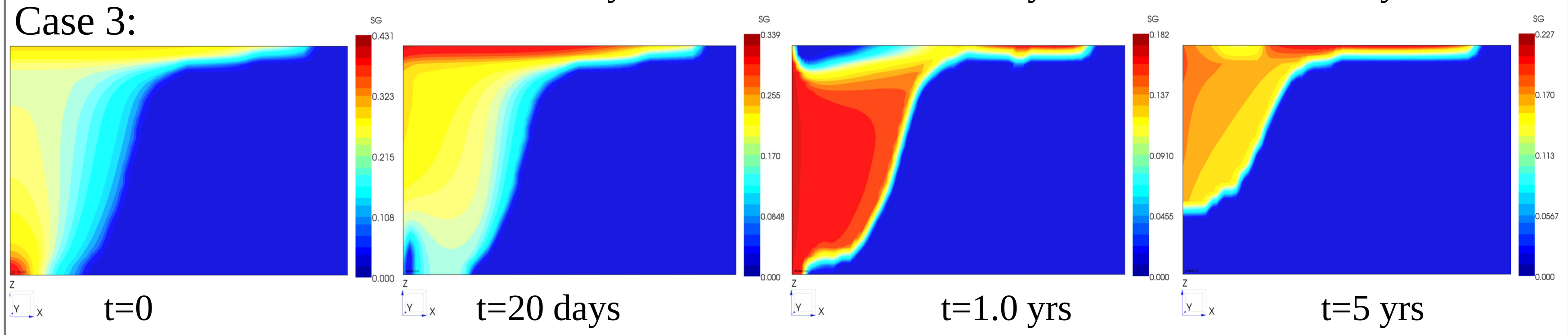
Case 1:




Case 2:



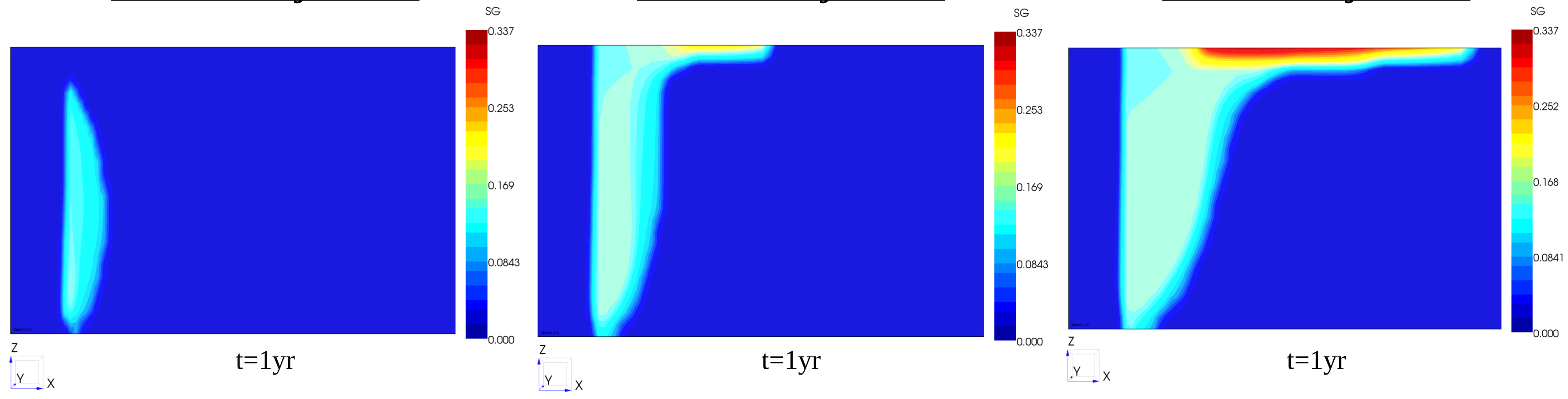

Case 3:




## REMEDIATION: INJECTION WELL

### Injection Well:

- Located at R=0 m and screened the entire depth of the aquifer
- Constant flow rate of 0.5 kg/s water with XNaCl=0.1% into each cell
- Total flow rate of 12.5 kg/s



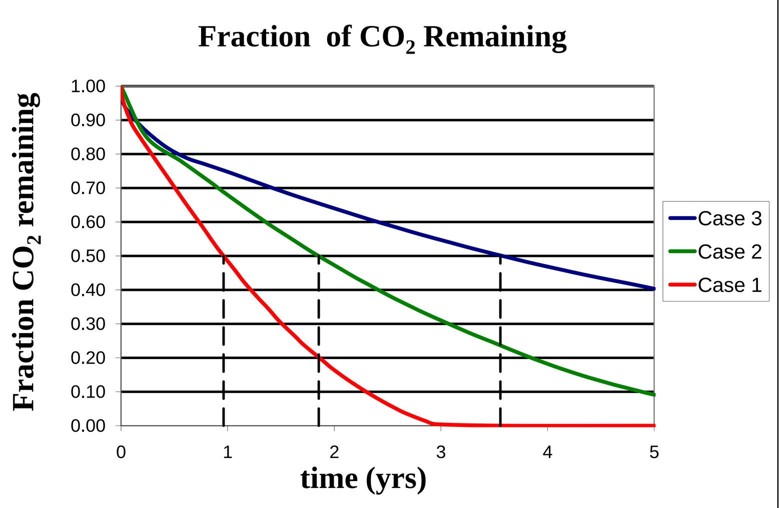

Dissolves majority of initial plume — Some gas still in secondary plume — Gas remains in gravity tongue

## CONCLUSIONS

### Extraction Technique:

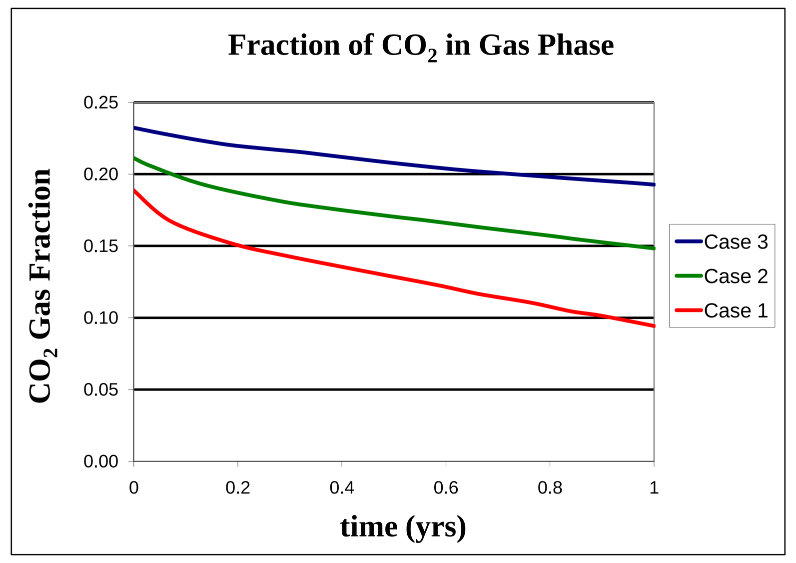
| | Total Leaked | Half Life | Remaining at 5 yrs | % Remaining |
|---|---|---|---|---|
| **Case 1** | 875 tons | 0.96 yrs | 0.01 tons | ~0 % |
| **Case 2** | 1750 tons | 1.85 yrs | 158 tons | 9 % |
| **Case 3** | 3500 tons | 3.58 yrs | 1400 tons | 40 % |

- The amount leaked and the time required to extract half the mass are linearly related.
- After the half life of the plume the extraction rate decreases significantly for all cases.
- Case 2 and Case 3 with secondary plumes are much more difficult to extract.
- Extraction alone is not enough to remediate the leakage in Case 3. This is due to the bypass of the plume through the lower part of the well.




### Injection Technique:

- The relative permeability curves are the main physical process controlling the gas saturation.
- The trapped gas at a residual saturation of 0.15 is only slowly dissolved by the injected water.
- The secondary plume does not create a significant difference between Case 1 and Case 2.
- The gravity tongue in Case 3 is still a remnant feature after remediation similar to the extraction case.




## FUTURE WORK

- Vary extraction rates over time for Case 2 and Case 3
- Determine the impact of partially screened wells on the extraction process
- Include trace metals in simulation to analyze impact on contaminant levels


## ACKNOWLEDGMENTS

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