Reservoir Pressure Management

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Benefit to the program

- Project benefits statement
  - This project provides an analysis of extraction of formation fluids as a method for increasing the storage capacity and reducing the risk of failure at carbon storage sites. Our results are aimed at enabling a cost-benefit analysis of fluid extraction at carbon sequestration sites and recommending methods for applying the technology.

- Program goals being addressed
  - Support industry's ability to predict CO_2 storage capacity in geologic formations to within ±30 percent.
  - Develop and validate technologies to ensure 99 percent storage permanence
  - ***Develop technologies to improve reservoir storage efficiency while ensuring containment effectiveness.***
  - *Develop Best Practice Manuals for monitoring, verification, accounting, and assessment; site screening, selection and initial characterization; public outreach; well management activities; and risk analysis and simulation*

Overview and Accomplishments

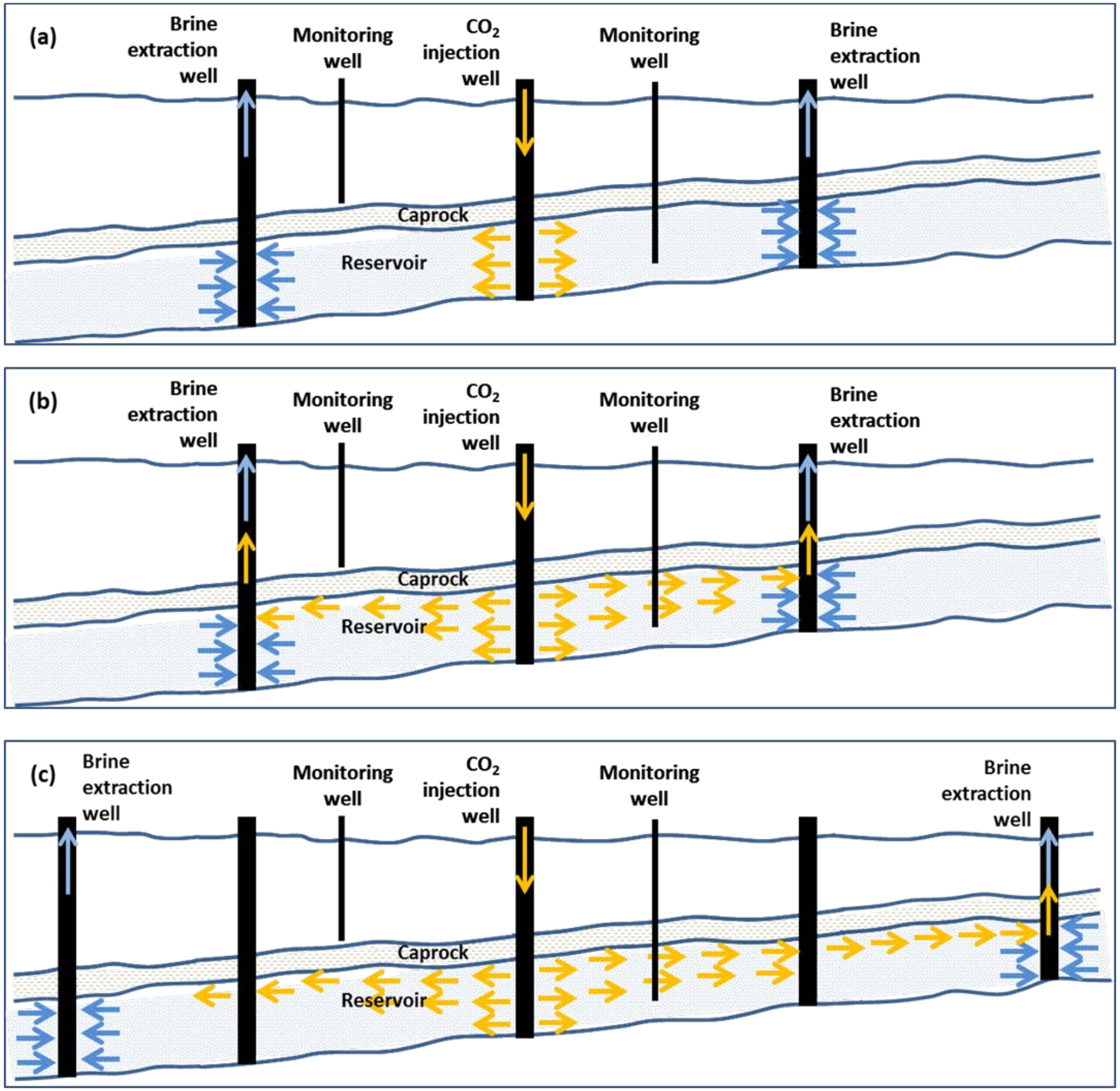
- We are investigating a range of pressure management approaches
  - *single-mode*, brine-extraction and CO_2-injection wells **[… FY13]**
  - *dual-mode*, brine extraction/CO_2-injection wells **[FY14 …]**
- We continue to consider benefits/needs
  - suppressed CO_2 and brine leakage and migration
  - hydraulic isolation from neighboring subsurface activities **[… FY13]**
  - reduced pore-space competition and AOR **[... FY13]**
  - reduced risk of caprock fracturing and induced seismicity **[FY14 …]**
- Past pressure management studies have emphasized
  - large well fields comprised of single-mode wells, including
    - ✓ brine-extraction wells
    - ✓ CO_2-injection wells
  - wide well spacing between extraction and injection wells, which assumes/requires homogeneous reservoirs with
    - ✓ good lateral hydraulic communication between wells
    - ✓ large compartment volumes

Overview (continued)

- We are now addressing the efficiency of brine management operations and strategies for a field demonstration
  - reduce well cost (dual-mode wells = fewer wells)
  - reduce brine extraction cost
    - ✓ brine production by artesian flow (reduce brine lifting cost) **[… FY13]**
    - ✓ pre-injection brine extraction (increases benefit/cost ratio) **[FY14 …]**
  - utilizing dual-mode wells for
    - ✓ pilot studies
    - ✓ reservoir diagnostics **[FY15…]**
    - ✓ site screening **[FY15…]**
    - ✓ pressure-management planning **[FY15…]**

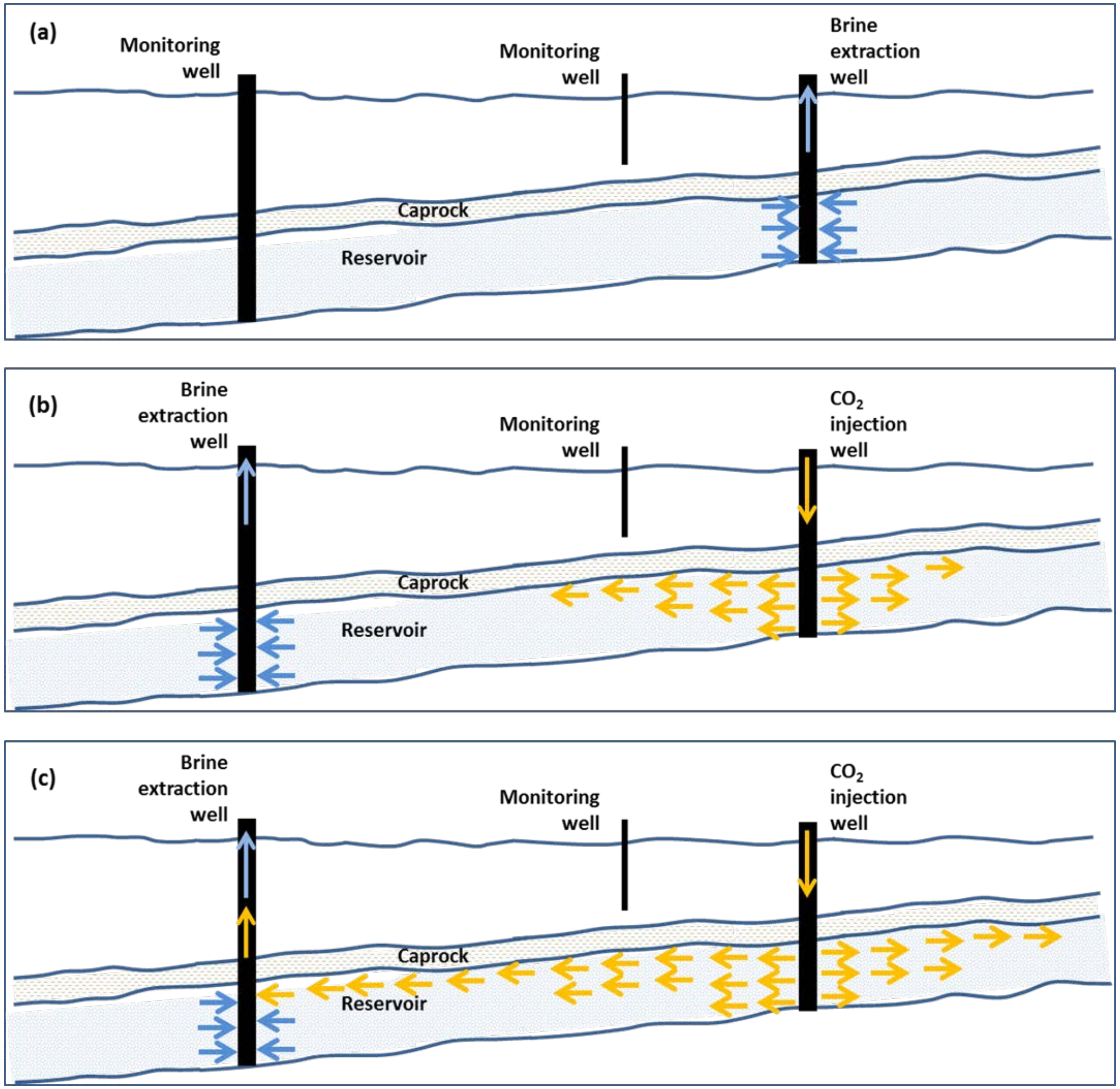
Past work has considered well fields with *single-mode* wells, including brine-extraction and CO_2-injection wells

- (a) Achieving early-time pressure relief may require close well spacing
- (b) Breakthrough of CO_2 at brine-extraction wells will limit how long they can provide pressure relief
- (c) Additional brine-extraction wells may need to be staged for ongoing pressure relief
- A monitoring well may be completed in the storage reservoir to assess plume migration
- A monitoring well may be completed in an overlying formation to assess caprock leakage



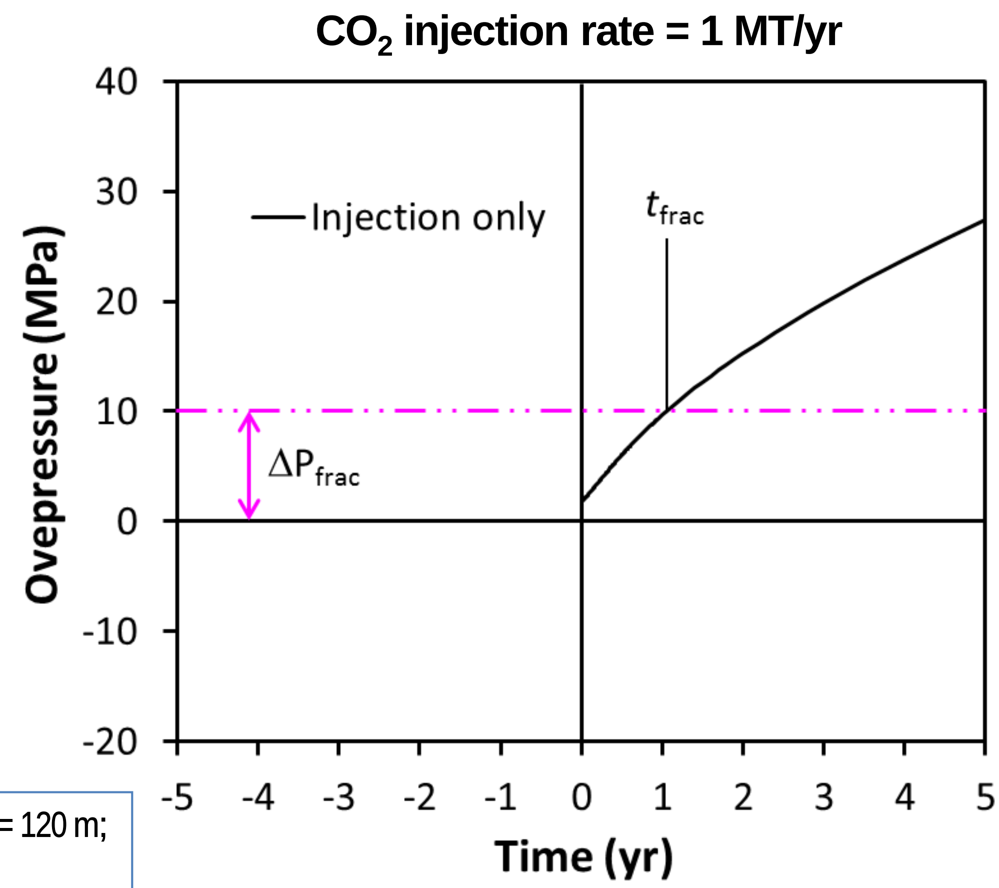
Dual-mode brine-extraction/CO_2-injection wells can reduce the total number of wells required for pressure management

- (a) Pre-injection brine extraction provides early-time pressure relief where it is most needed
- (a) Early-time pressure relief allows greater spacing between CO_2-injection and brine-extraction wells
- (b,c) Additional dual-mode wells may be staged as needed for ongoing pressure relief
  - preferably completed down-dip of the primary dual-mode well
- A monitoring well may be completed in an overlying formation to assess caprock leakage
- *The total number of wells is significantly reduced*



Time to reach a threshold overpressure ΔP can be significantly increased with pre-injection brine production

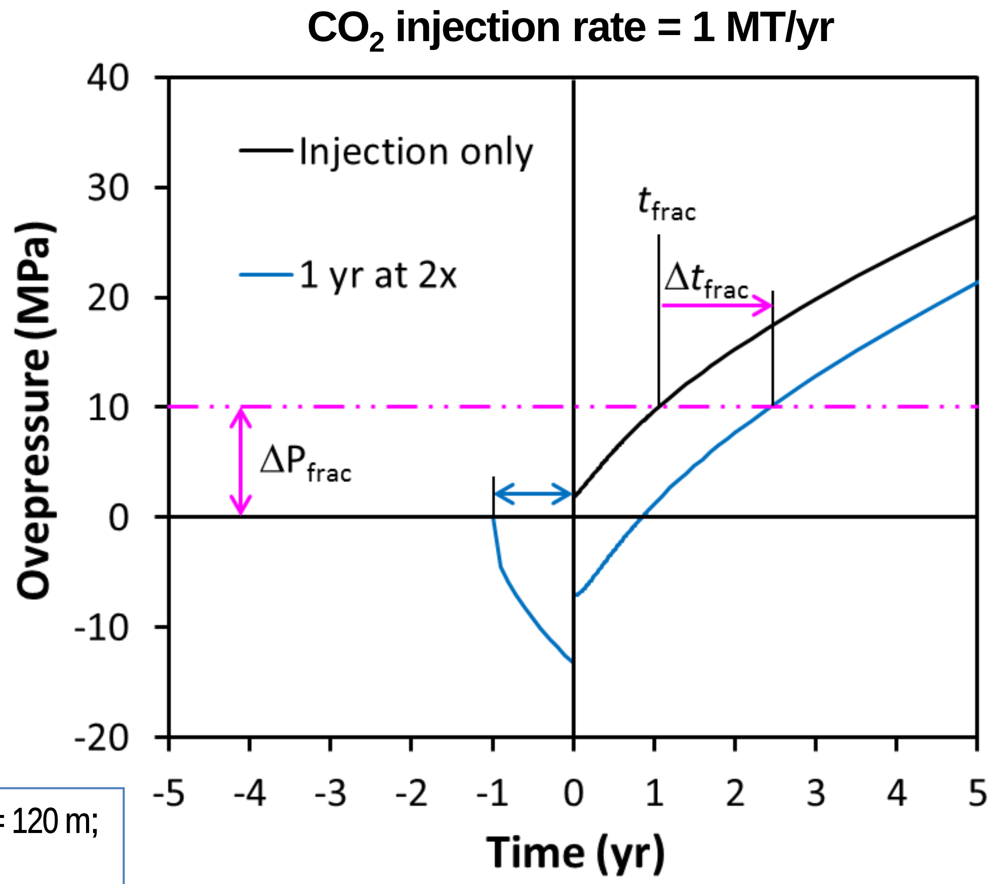
- Small reservoir compartments can result in rapid pressure buildup



Notes: compartment area = 1.6 km^2; compartment thickness = 120 m; for brine extraction: 1x = 1 MT/yr and 2x = 2 MT/yr

Time to reach a threshold overpressure ΔP can be significantly increased with pre-injection brine production

- Small reservoir compartments can result in rapid pressure buildup
- Extract 1622 acre-ft (2 MT) of brine in 1 year



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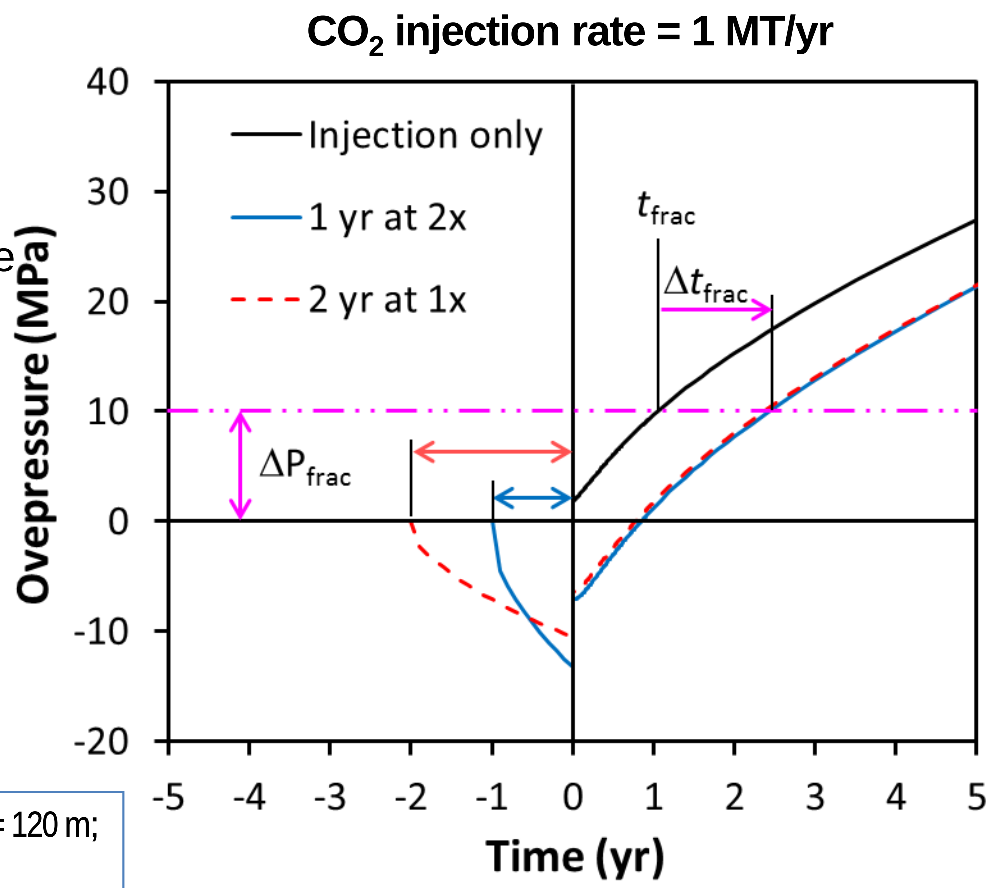
Time to reach a threshold overpressure ΔP can be significantly increased with pre-injection brine production

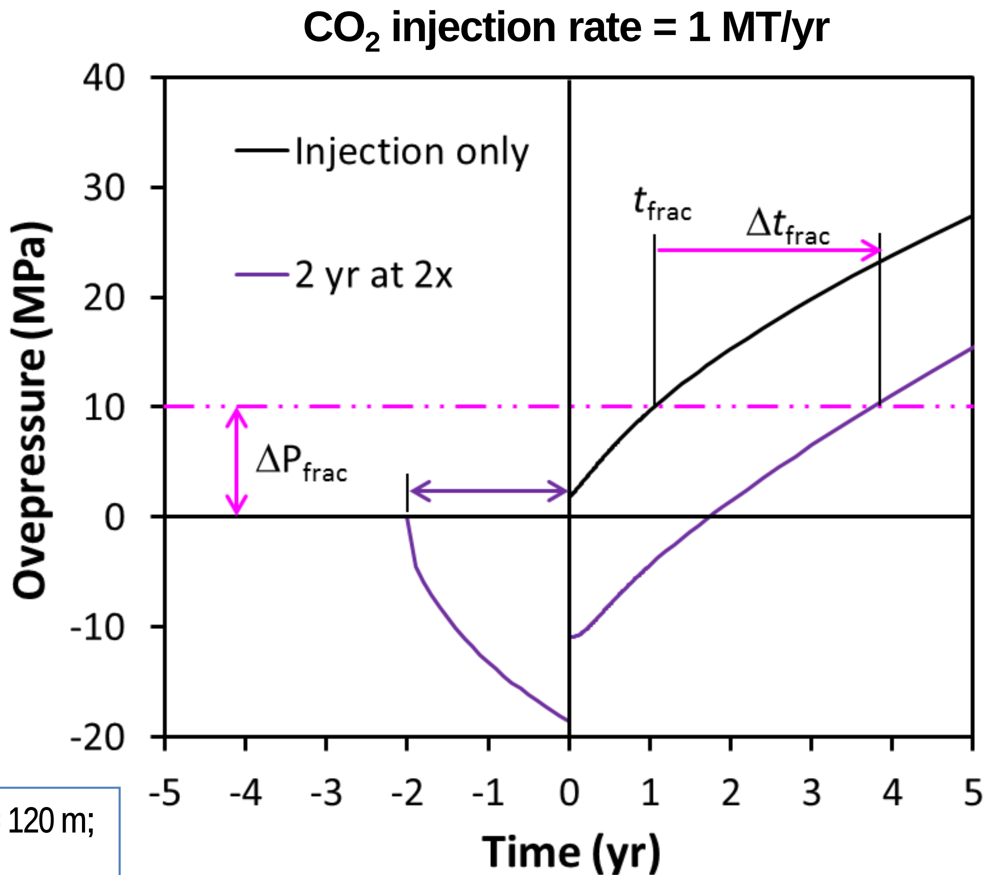
- Small reservoir compartments can result in rapid pressure buildup
- Extract 1622 acre-ft (2 MT) of brine in 1 year
- Extract 1622 acre-ft (2 MT) of brine in <u>2 years</u>
- Pressure drawdown is slightly less for the smaller brine extraction rate
- Time to reach threshold ΔP is similar for these two cases
- Pre-injection pressure response is diagnostic of pressure behavior during injection



Notes: compartment area = 1.6 km^2; compartment thickness = 120 m; for brine extraction: 1x = 1 MT/yr and 2x = 2 MT/yr

Time to reach a threshold overpressure ΔP can be significantly increased with pre-injection brine production

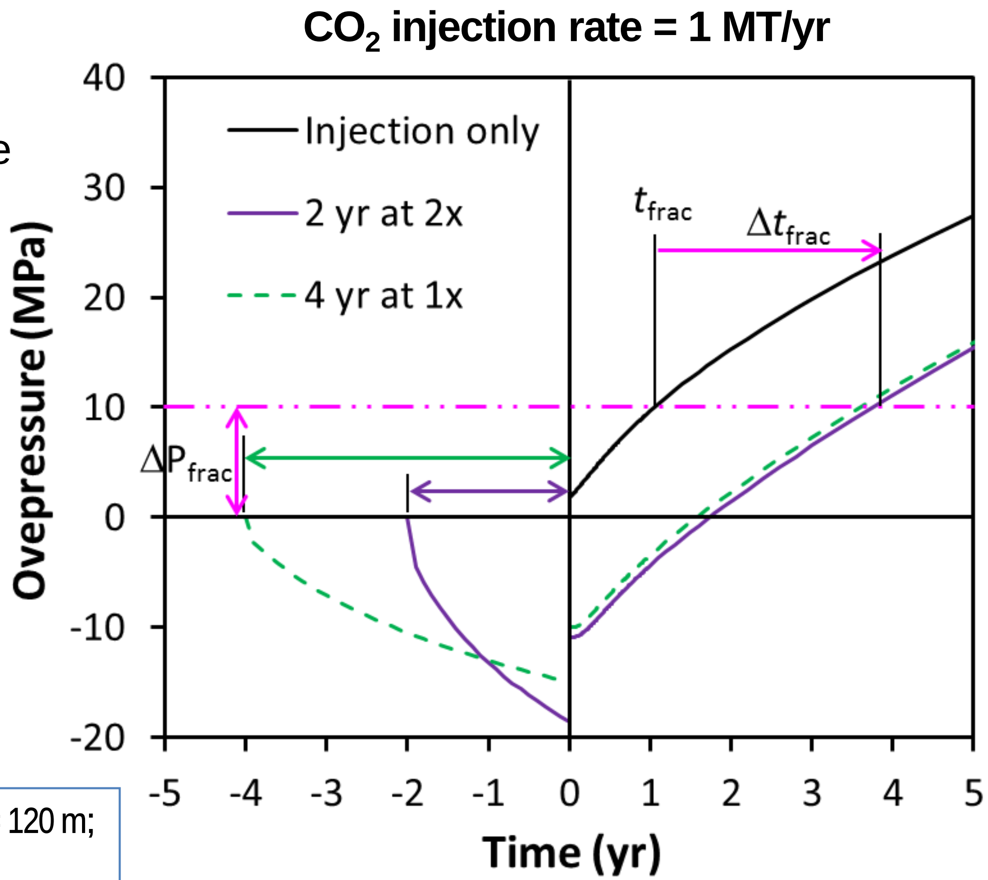
- Small reservoir compartments can result in rapid pressure buildup
- Extract 3244 acre-ft (4 MT) of brine in 2 years



Notes: compartment area = 1.6 km^2; compartment thickness = 120 m; for brine extraction: 1x = 1 MT/yr and 2x = 2 MT/yr

Time to reach a threshold overpressure ΔP can be significantly increased with pre-injection brine production

- Small reservoir compartments can result in rapid pressure buildup
- Extract 3244 acre-ft of brine in 2 years
- Extract 3244 acre-ft of brine in 4 years
- Pressure drawdown is slightly less for the smaller brine extraction rate
- Time to reach threshold ΔP is similar for these two cases
- Pre-injection pressure response is diagnostic of pressure behavior during injection

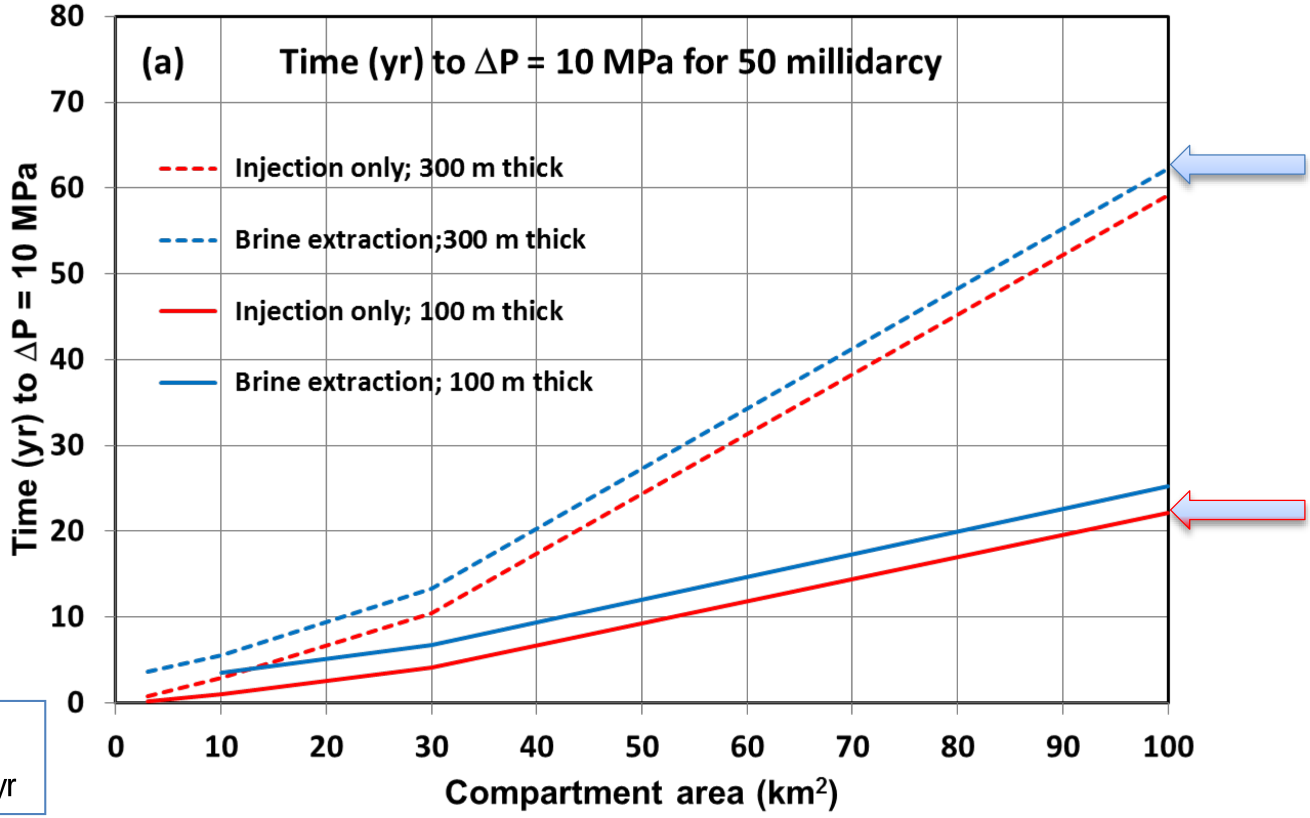


Notes: compartment area = 1.6 km^2; compartment thickness = 120 m; for brine extraction: 1x = 1 MT/yr and 2x = 2 MT/yr

Time to attain an overpressure ΔP of 10 MPa increases with reservoir compartment area and thickness

- Initially, time to ΔP = 10 MPa increases linearly with compartment area and thickness, indicating that it is entire controlled by compressibility
- At later time, this dependence steepens as caprock leakage increasingly influences pressure relief

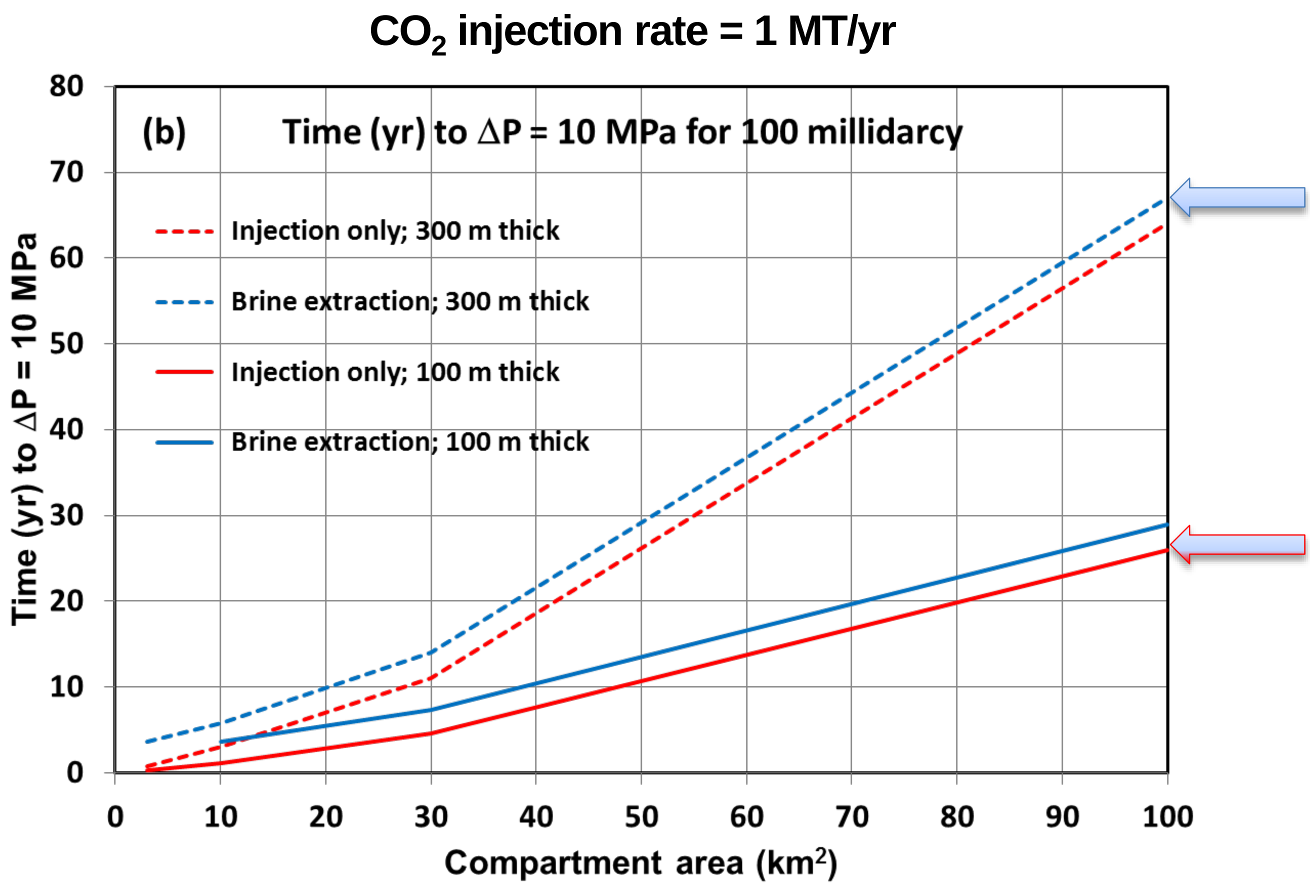
CO_2 injection rate = 1 MT/yr



Note: brine extraction cases extract 1 MT/yr of brine for 4 yr

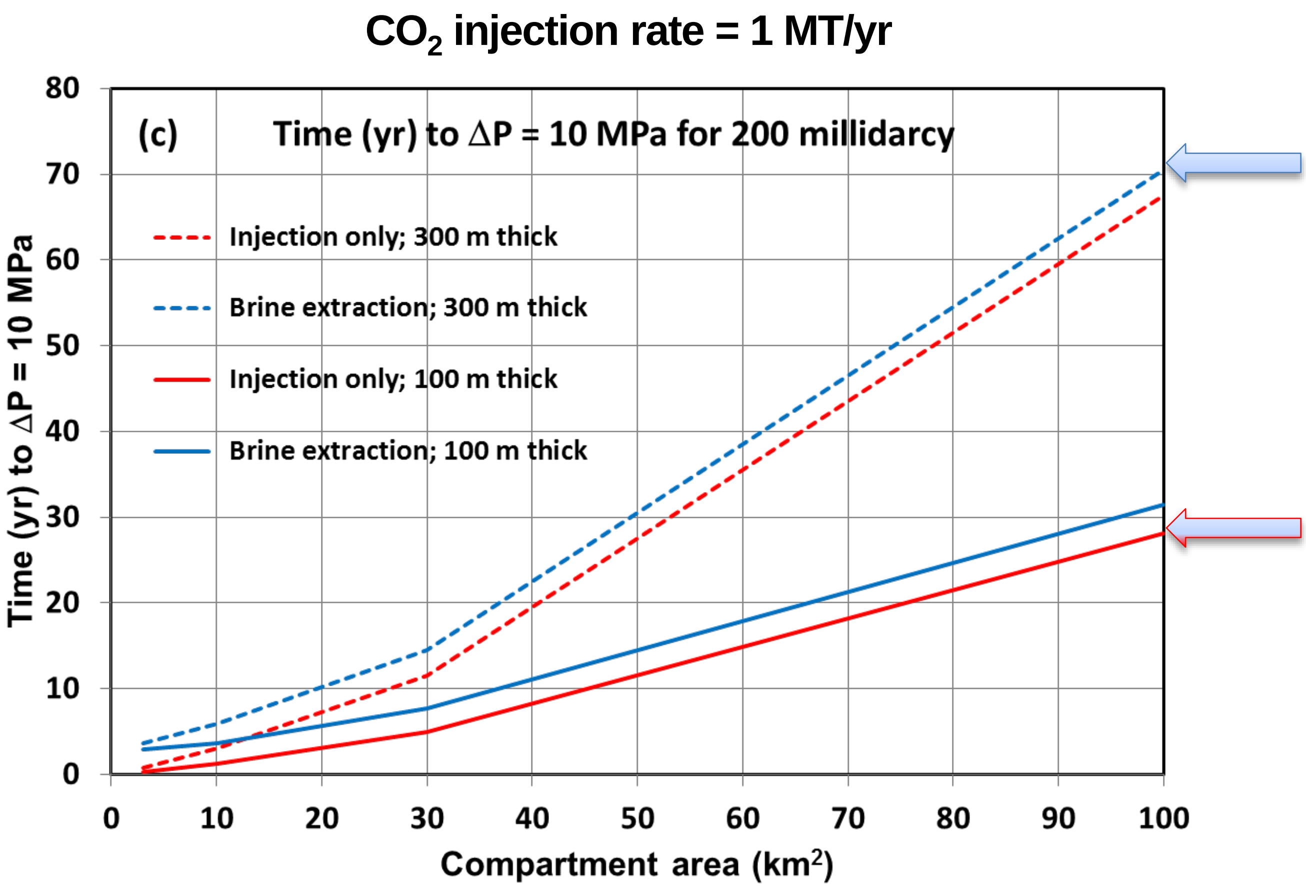
Time to attain an overpressure ΔP of 10 MPa increases with reservoir compartment area and thickness

- Time to ΔP = 10 MPa is weekly dependent on reservoir permeability



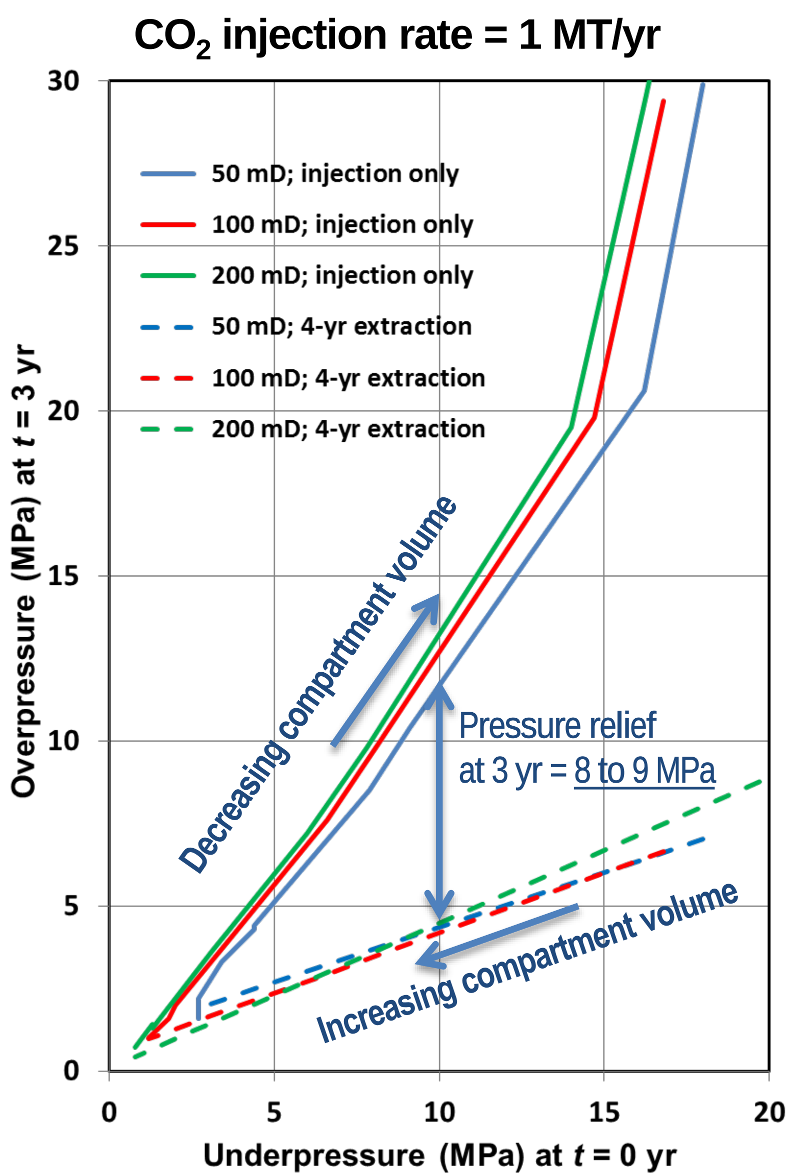
Time to attain an overpressure ΔP of 10 MPa increases with reservoir compartment area and thickness

- Thus, pressure buildup history depends primarily on reservoir compartment volume and leakage through the caprock and, possibly, sealing faults



Underpressure caused by pre-injection extraction is the mirror image of overpressure driven by CO_2 injection

- Overpressure history for a single-mode CO_2-injection well is the mirror image of underpressure history for a corresponding dual-mode well
  - e.g., 10 MPa of underpressure from 4 yr of pre-injection brine extraction corresponds to 12 to13 MPa of overpressure at 3 yr for a single-mode CO_2-injection well and 4 MPa of overpressure for a dual-model well **(8 to 9 MPa of pressure relief)**
- For an initial reservoir pressure of 22 MPa and temperature of 100°C, CO_2 density is 70% that of brine density
- 4 years of 1X pre-injection brine extraction is equivalent to delaying CO_2 injection for 2.8 yr
- Early time pressure relief can be substantial
- Ongoing pressure relief can be achieved using additional dual-mode wells



Note: brine extraction cases extract 1 MT/yr of brine for 4 yr

Summary and Conclusions

- Pressure management can be achieved using a small number of dual-mode brine-extraction/CO_2-injection wells, providing
  - pressure relief where it is needed most
  - reservoir diagnostics to help guide future well-field operations
  - an early source of brine for beneficial use
  - a cost-effective approach for a pilot-scale project
- A monitoring well in an overlying formation can provide
  - diagnostics about the contribution of caprock leakage to pressure relief
  - be used for assessment of the risk of caprock leakage
  - help guide future well-field operations
    - ✓ compartmentalized reservoirs
    - ✓ poor lateral hydraulic communication
  - diagnose reservoir characteristics prior to CO_2 injection
- Future work
  - consider a wide range of scenarios for leakage through the caprock and sealing faults
  - conduct site-specific analyses of well-field operations, using staged dual-mode wells

LLNL publications related to pressure management

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Buscheck, T.A., Sun, Y., Chen, M., Hao, Y., Wolery, T.J., Bourcier, W.L., Court, B., Celia, M.A., Friedmann, S.J., and Aines, R.D., 2012. Active CO_2 reservoir management for carbon storage: Analysis of operational strategies to relieve pressure buildup and improve injectivity. *International Journal of Greenhouse Gas Control* **6**: 230–245.

Buscheck, T.A., Elliot, T.R., Celia, M.A., Chen, M., Sun, Y., Hao, Y., Lu, C., Wolery, T.J., and Aines, R.D., 2013. Integrated geothermal-CO_2 reservoir systems: Reducing carbon intensity through sustainable energy production and secure CO_2 storage, *Energy Procedia*, **37**: 6587–6594.

Buscheck, T.A., White, J.A., Chen, M., Sun, Y., Hao, Y., and Bielicki, J.M., 2014. Pre-injection brine production for managing pressure in compartmentalized CO_2 storage reservoirs, International Conference on Greenhouse Gas Technologies (GHGT-12), 5–9 October, 2014, Austin, TX, USA.

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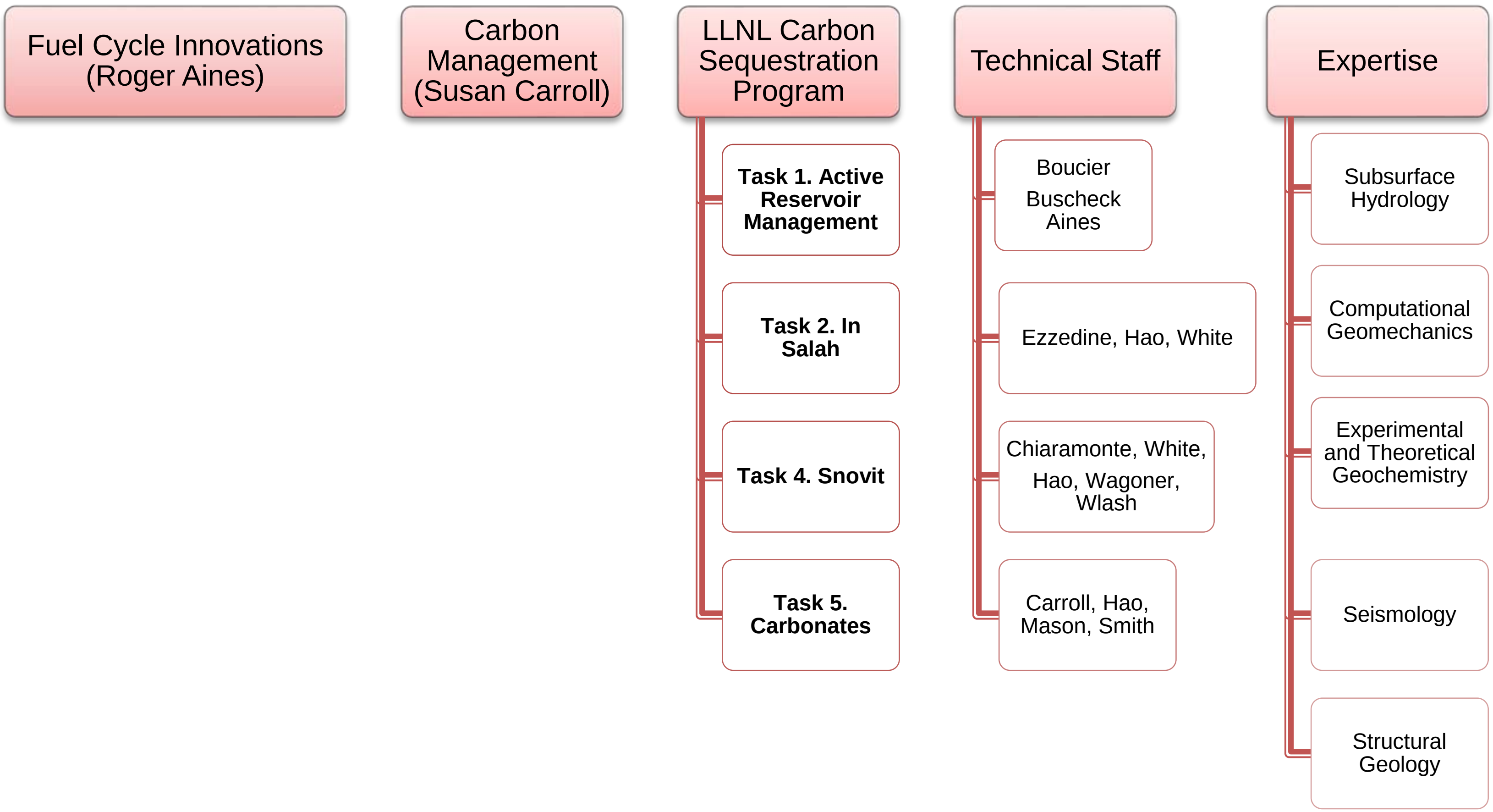
Court, B., Bandilla, K., Celia, M.A., Buscheck, T.A., Nordbotten, J., Dobossy, M., and Jansen, A., 2012. Initial evaluation of advantageous synergies associated with simultaneous brine production and CO_2 geological sequestration, *International Journal of Greenhouse Gas Control* **8**: 90–100.

Elliot, T.R., Buscheck, T.A., and Celia, M.A., 2013. Active CO_2 reservoir management for sustainable geothermal energy extraction and reduced leakage, *Greenhouse Gases: Science and Technology*, **3** (1): 50–65; DOI: 1002/ghg.

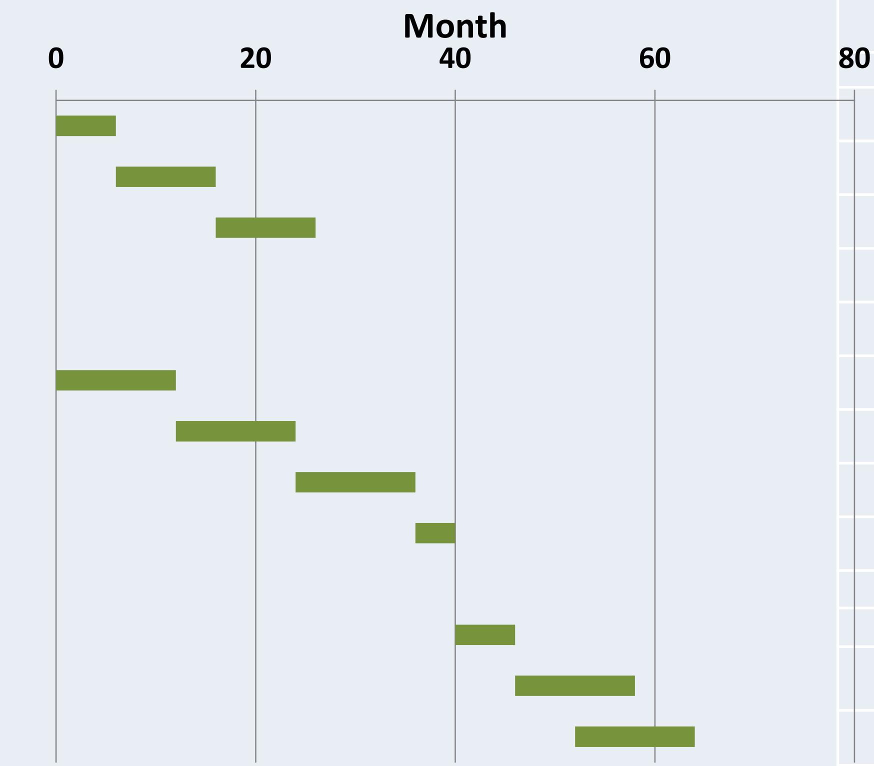
Lu, C., Sun, Y., Buscheck, T.A., Hao, Y., White, J.A. and Chiaramonte, L. 2012. Uncertainty quantification of CO_2 leakage through a fault with multiphase and nonisothermal effects, *Greenhouse Gases: Science and Technology*, **2** (6): 445–459.

Organization Chart



Project Timeline

Tasks		Start	Duration	Finish
Brine Disposition	1			
Brine characterization	1.1	0	6	6
Desalination technology evaluation	1.2	6	10	16
Treatment cost analysis	1.3	16	10	26
Reservoir Management	2.0			
well field analysis	2.1	0	12	12
integration with CO2 injection	2.2	12	12	24
optimization	2.3	24	12	36
Analysis for limited number of wells	2.4	36	4	40
Site Demonstration	3.0			
Site selection and partnering	3.1	40	6	46
Modeling to support site demonstration	3.2	46	12	58
Setup and site work	3.3	52	12	64



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