Investigation of CO_2 Leakage into Drinking Water Formations During Carbon Sequestration

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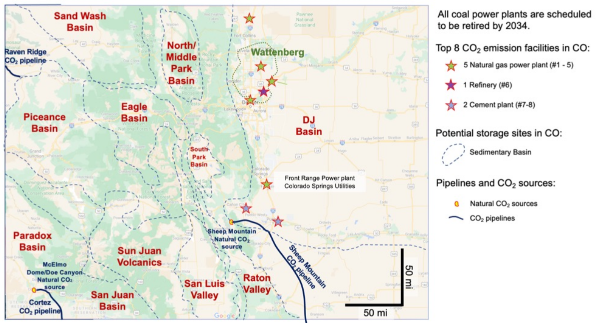
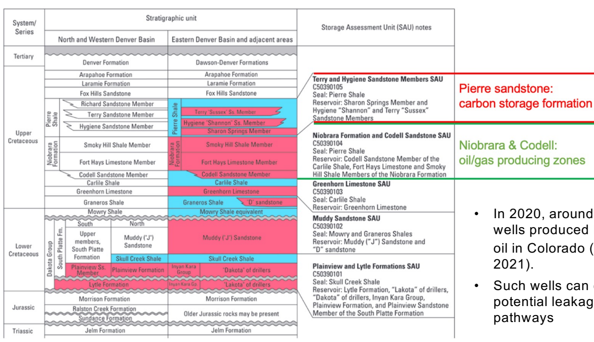
Area of Investigation

Top Carbon Sources and Sinks in Colorado



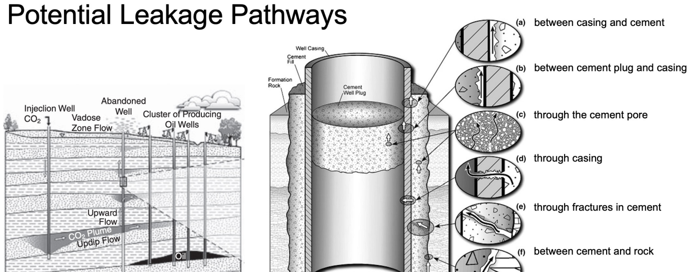
Stratigraphic column of the DJ Basin



Drake et al., 2015

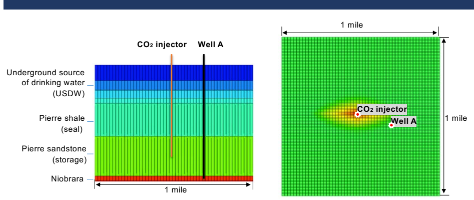
- In 2020, around 25,734 wells produced little to no oil in Colorado (Jaffe, 2021).
- Such wells can create potential leakage risk pathways

Potential Leakage Pathways



Gasda et al. 2004

Simulation Models: CMG & NRAP-IAM



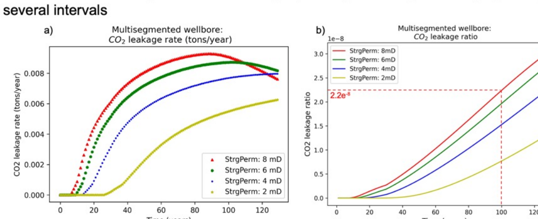
One-square-mile Layer-cake Model

Properties
- Pierre sandstone: 2000 ft thickness, porosity = 14%
- Effective well permeability along the seal
  - Specific to each well and formation

Injection
- 30-year CO_2 injection (1MMton/year) + 100-year post-injection

Scenario 1: Multi-segmented wellbore (MSW) case study

- Leakage occurs in the annulus between the outside of the casing & borehole
  - MSW allows for the segmentation of the legacy wells penetrating the overlying stratigraphy into several intervals

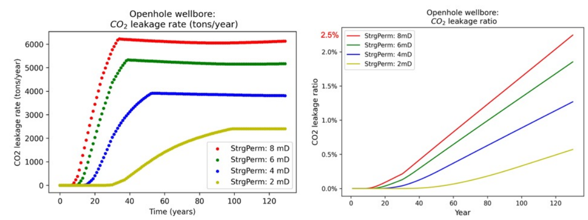


Year 100:
- total CO_2 leakage: 0.67 tons
- total CO_2 injection: 30 MM tons
- ratio: $2.2e^{-8}$

Simulation Modeling Results

Scenario 2: Open wellbore case study

- Assumption
  - Wellbore is completely open
    - indicating that the annular space outside the casing completely lacks cement or other material
    - Unrealistically high CO_2 leakage rates may be generated
  - This assumption is consistent with EPA's guidance for calculating the Area of Review



- Observed well leakage in the Wattenberg field, DJ Basin, Colorado

Table 1: Vertical well barrier summary.

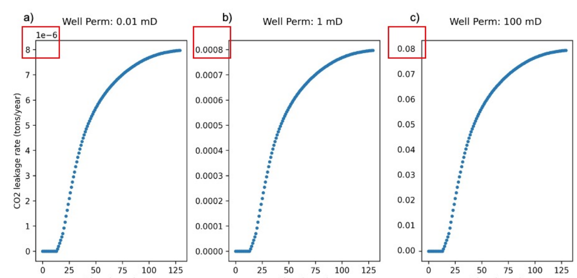
	BARRIERS	BARRIER TYPE	DESCRIPTION
CATEGORY 1	1	HYDROSTATIC PRESSURE	VERTICAL WELL, SHALLOW SURFACE & TOC NOT ABOVE TOP OF NIOBRARA
CATEGORY 2	1	HYDROSTATIC PRESSURE	VERTICAL WELL, SHALLOW SURFACE & TOC NOT ABOVE TOP OF SUSSEX
CATEGORY 3	2	PRODUCTION CASING + HYDROSTATIC PRESSURE	VERTICAL WELL, SHALLOW SURFACE & TOC ABOVE TOP OF SUSSEX
CATEGORY 4	2	PRODUCTION CASING + CEMENT COLUMN	VERTICAL WELL, SHALLOW SURFACE & TOC ABOVE SURFACE CASING SHOE
CATEGORY 5	3	SURFACE CASING + CEMENT + HYDROSTATIC PRESSURE	VERTICAL WELL, DEEP SURFACE & TOC NOT ABOVE TOP OF SUSSEX
CATEGORY 6	3	SURFACE CASING + CEMENT + PRODUCTION CASING	VERTICAL WELL, DEEP SURFACE & TOC ABOVE TOP OF SUSSEX
CATEGORY 7	4	2 CASING STRINGS + 2 CEMENT COLUMNS	VERTICAL WELL, DEEP SURFACE & TOC ABOVE SURFACE CASING SHOE

Table 2: Vertical well barrier failure summary.

	WELL COUNT	POSSIBLE BARRIER FAILURES	% FAILURE	CATASTROPHIC BARRIER FAILURES	CATASTROPHIC FAILURE %	AVG AGE OF WELL	P&A WELL COUNT	CURRENT WELL COUNT	AVG SURFACE DEPTH (FT)	AVG TOP OF CEMENT (FT)
CATEGORY 1	399	92	23.06%	3	0.75%	1986	125	114	417	7,296
CATEGORY 2	7,811	276	3.53%	6	0.08%	1994	738	5,446	476	6,022
CATEGORY 3	3,407	20	0.59%	1	0.03%	2007	95	4,548	590	2,719
CATEGORY 4	1,063	0	0.00%	0	0.00%	2008	8	1,289	572	417
CATEGORY 5	1,374	13	0.95%	0	0.00%	2000	112	916	967	6,473
CATEGORY 6	2,069	0	0.00%	0	0.00%	2007	24	2,654	911	2,950
CATEGORY 7	705	0	0.00%	0	0.00%	2010	1	758	941	710
TOTAL	16,828	401	2.4%	10	0.06%		1103	15,725		

Fleckenstein et al., 2015

Scenario 3: Impact of effective well permeability



Conclusions

The Wattenberg Field in the Denver-Julesburg (DJ) Basin is a good candidate for carbon storage
- It is near major CO_2 producers
- It has stacked formations for carbon storage and seal
- However, pre-existing oil/gas wells in this area can be potential leakage pathways for CO_2 leakage

Carbon leakage rate varies significantly by the type of wellbore

The permeability of the storage formation affects the carbon leakage rate
- The storage formations with higher permeability values correspond to earlier leakage time and higher leakage rate
- The maximum leakage rate may not be reached until 100 years after CO_2 injection

The open wellbore behaves as a leakage conduit
- When selecting the geological sites for carbon storage
  - Open wellbore should be avoided
  - Treatment should be considered
- A good storage site should NOT contain wells
  - Drilled before 1994
  - Have a surface casing depth of 476 ft or shallower

The leakage rate varies significantly by effective well permeability
- Specific field tests are necessary to investigate this parameter and to reduce the uncertainty in the leakage estimates on a case by case basis

Acknowledgements

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