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Flue Gas Injection as an Alternative to CO₂ Capture: Subsurface Risk Considerations and Financial Tradeoffs

Brandon Schwartz, Penn State

coauthored by:

Mohammad Badghaish, Mohammed Alarfaj, Hamad Alsunaid, Mychal Kearns,
and Anne Menefee

Summary

Results:

- Flue gas injection can be cheaper than carbon capture, depending on the %CO₂ in the waste stream
- Decreased %CO₂ in the waste stream leads to larger pressure buildups
- Pressure-driven risks can be mitigated with increased well spacing

Motivation

| Estimates of CO ₂ Stationary Source Emissions and Estimates of CO ₂ Storage Resources for Geologic Storage Sites | | | | | | | | | | | |
|--|---|-------------------|---|--------|--------|------------------------|--------|------|-----------------------|--------|------|
| RCSP or Geographic Region | CO ₂ Stationary Sources | | CO ₂ Storage Resource Estimates (billion metric tons of CO ₂) | | | | | | | | |
| | CO ₂ Emissions (million metric tons per year) | Number of Sources | Saline Formations | | | Oil and Gas Reservoirs | | | Unmineable Coal Areas | | |
| | | | Low | Med*** | High | Low | Med*** | High | Low | Med*** | High |
| BSCSP | 115 | 301 | 211 | 805 | 2,152 | <1 | <1 | 1 | <1 | <1 | <1 |
| MGSC | 267 | 380 | 41 | 163 | 421 | <1 | <1 | <1 | 2 | 3 | 3 |
| MRCSP | 604 | 1,308 | 108 | 122 | 143 | 9 | 14 | 26 | <1 | <1 | <1 |
| PCOR* | 522 | 946 | 305 | 583 | 1,012 | 2 | 4 | 9 | 7 | 7 | 7 |
| SECARB | 1,022 | 1,857 | 1,376 | 5,257 | 14,089 | 27 | 34 | 41 | 33 | 51 | 75 |
| SWP | 326 | 779 | 256 | 1,000 | 2,693 | 144 | 147 | 148 | <1 | 1 | 2 |
| WESTCARB* | 162 | 555 | 82 | 398 | 1,124 | 4 | 5 | 7 | 11 | 17 | 25 |
| Non-RCSP** | 53 | 232 | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Total | 3,071 | 6,358 | 2,379 | 8,328 | 21,633 | 86 | 205 | 232 | 54 | 80 | 113 |

Source: U.S. Carbon Storage Atlas –Fifth Edition (volumes VI); data current as of November 2014

* Totals include Canadian sources identified by the RCSP

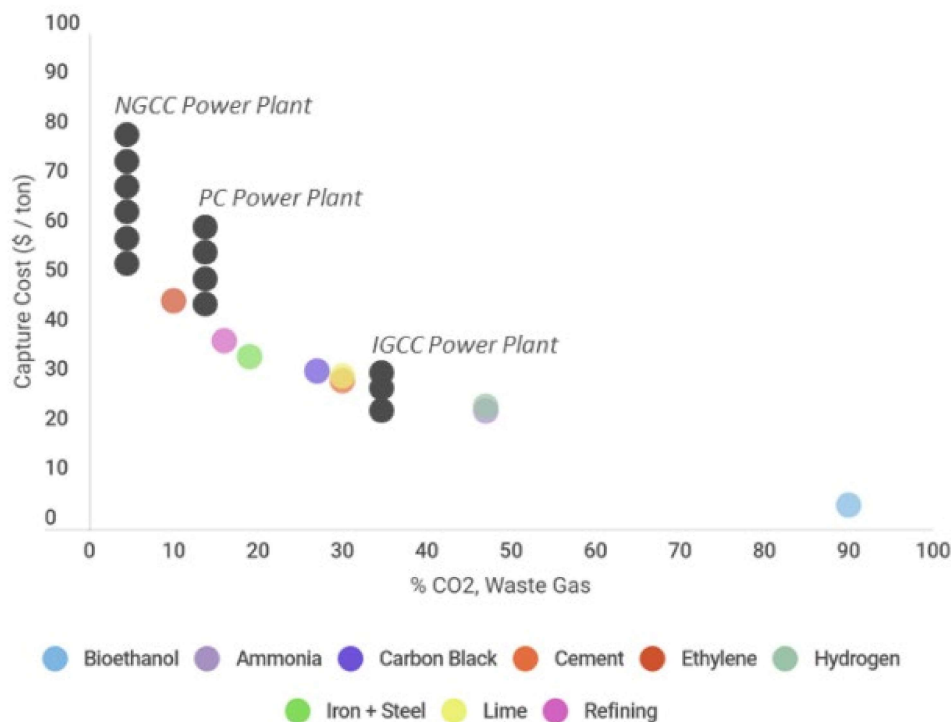
** As of November 2014, "U.S. Non-RCSP" includes Connecticut, Delaware, Maine, Massachusetts, New Hampshire, Rhode Island, Vermont, and Puerto Rico

*** Medium = p50

Source: NETL NATCARB Atlas, 2014

- CCS captures 70%-90% of CO₂, conserving pore volume
- Capture costs have slowed down deployment
- There are 2-22 trillion tons (!) of PV available in US saline aquifers *alone*
 - Compared to 3.1 Gtpa CO₂ emissions from PSEs in the US
- Why not just inject the flue gas?

Carbon Capture vs Transport

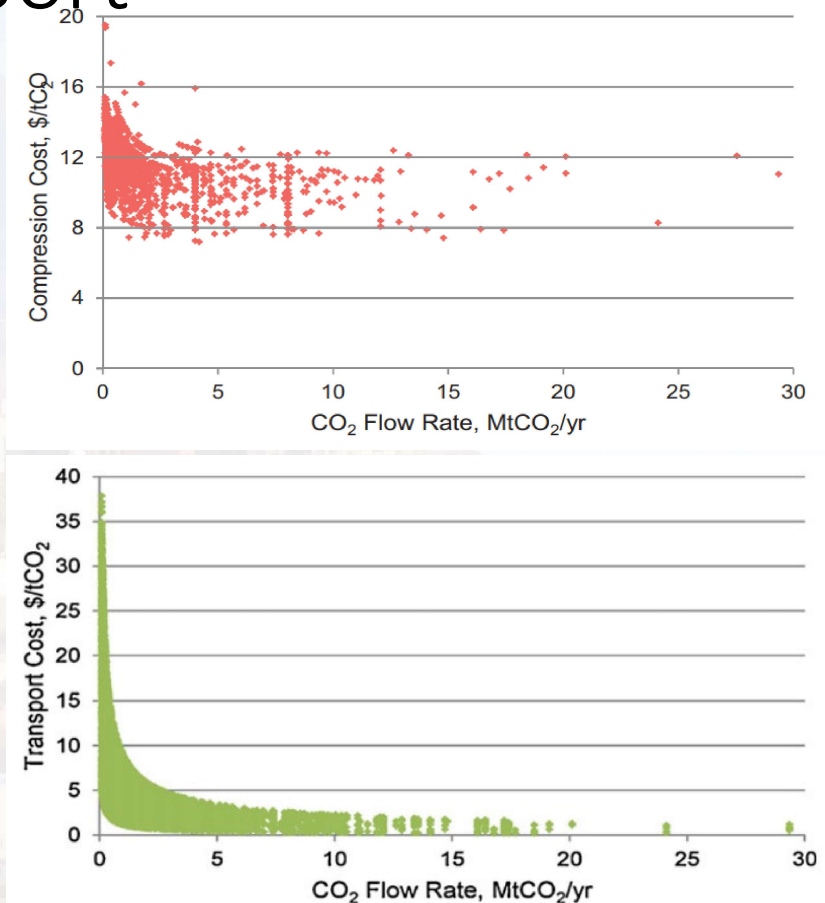


Source: Pilorgé et al., *Env. Sci. & Tech.*, 2020

- Wide range on capture costs for each PSE
- Cost increases as %CO₂ decreases
- Represents a parasitic load on PSEs, up to 30% power production
- Does not include the cost of compression, transport, and storage (CTS)

Carbon Capture vs Transport

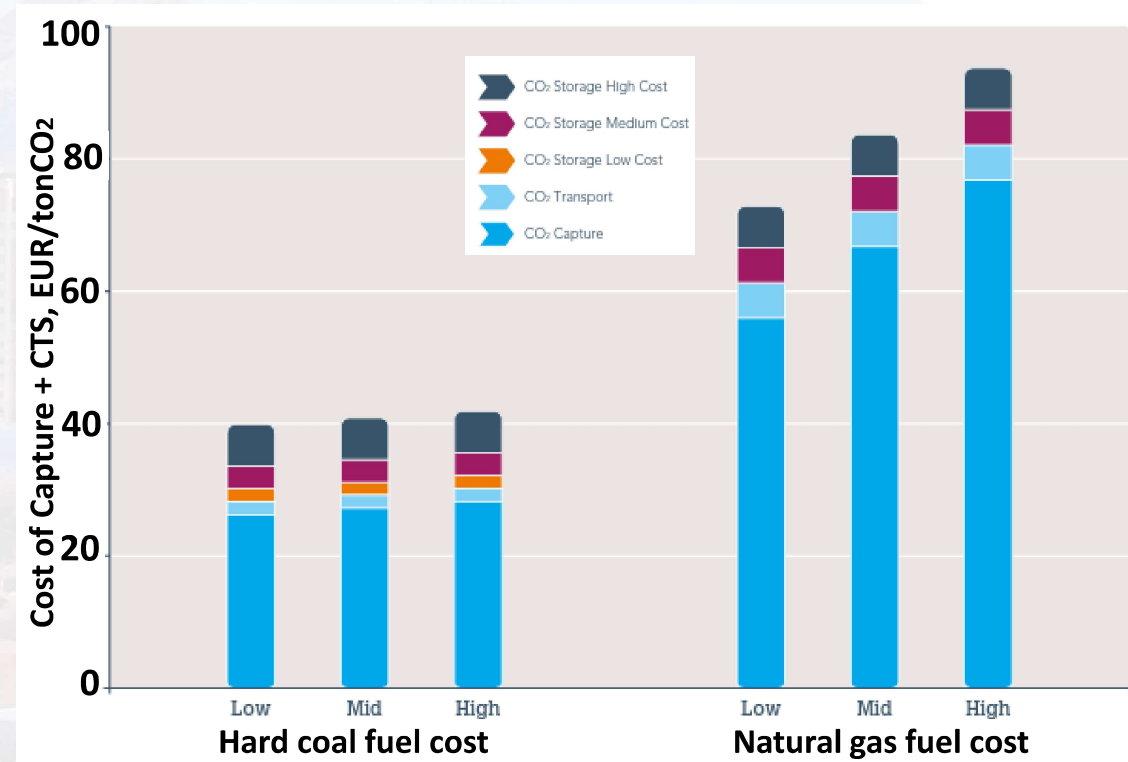
- Cost of CTS also variable
- Compression ranges from \$7 to \$20 per ton CO₂
- Transport adds another \$1 to \$10 per ton
- Wholesale discounts, shorter travel distances can make a big difference
- This is added on after the cost of capture



Source: Dahowski et al., IJGGC, 2012

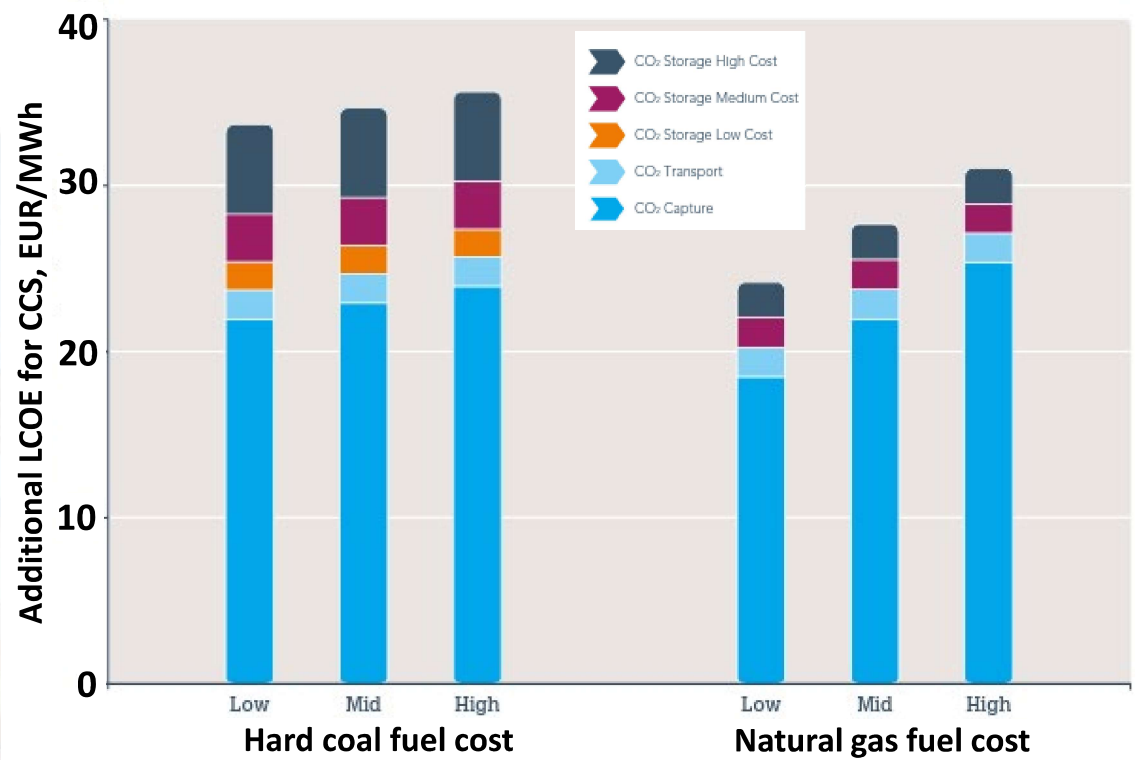
Carbon Capture vs Transport

- Compression, transport, and storage (CTS) make up a small fraction of CCS
- Estimates vary from \$8 - \$20 per ton CO₂
- We use \$10 and \$16 per ton CO₂ in our study



Source: The Costs of CO₂ Capture, Transport and Storage, European Technology Platform for Zero Emission Fossil Fuel Power Plants, 2011

Parasitic Load on PSEs



Source: The Costs of CO₂ Capture, Transport and Storage, European Technology Platform for Zero Emission Fossil Fuel Power Plants, 2011

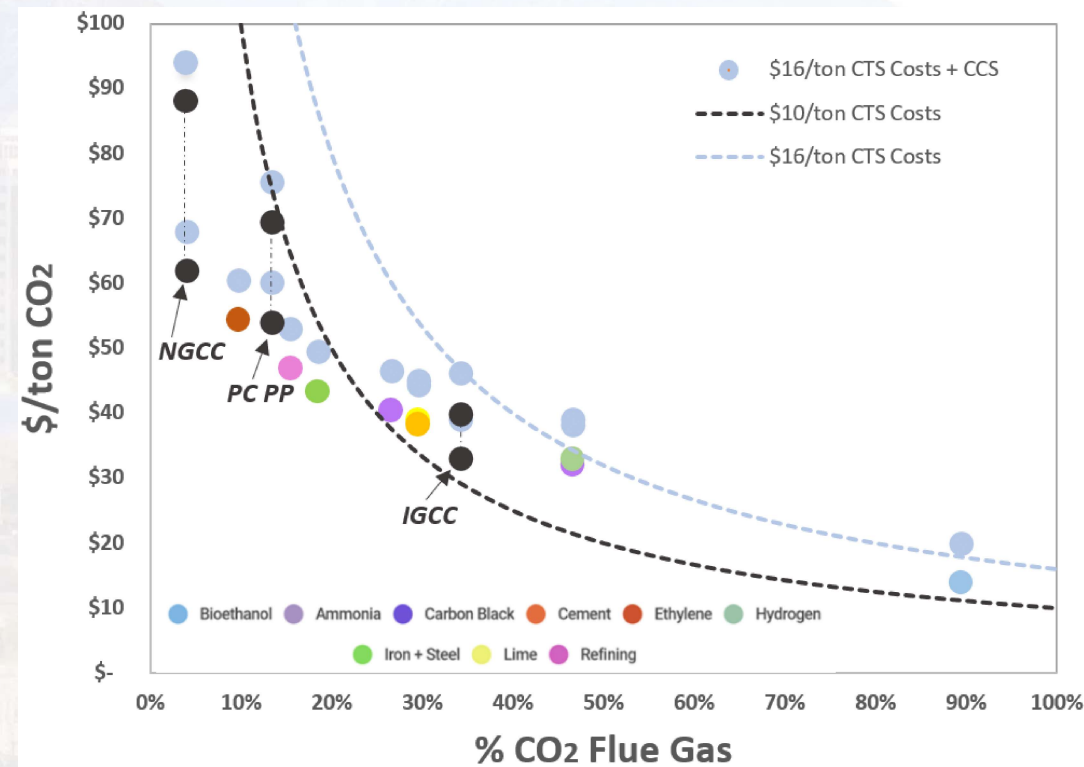
- Capture technology can require 15% to 30% electricity demand from PSE
- CTS requires energy, but not directly from the PSE
- Flue gas injection removes the parasitic load from PSEs

Cost Comparison Model

- Flue gas injection avoids the cost of capture, but requires CTS for more gas volume
 - To inject an equal volume of CO₂ from a waste stream that is 20% CO₂ requires 5 times the volume be compressed, transported, and stored
- We compare the costs of flue gas injection to the cost of capture based on %CO₂ in the waste stream for each PSE
- We add the cost of CTS (\$/ton CO₂) back into the cost of capture using \$10 and \$16 CTS scenarios

Results

- At low CTS costs, flue gas injection is cheaper than CCS when %CO₂ is >20%
- Requires 1.1 to 5x pore volume
- Includes some PC power plants, all IGCC power plants, and many industrial sources of CO₂ emissions
- Results are sensitive to the cost of CTS: at \$16/ton, only hydrogen, ammonia, and bioethanol production still attractive for flue gas injection

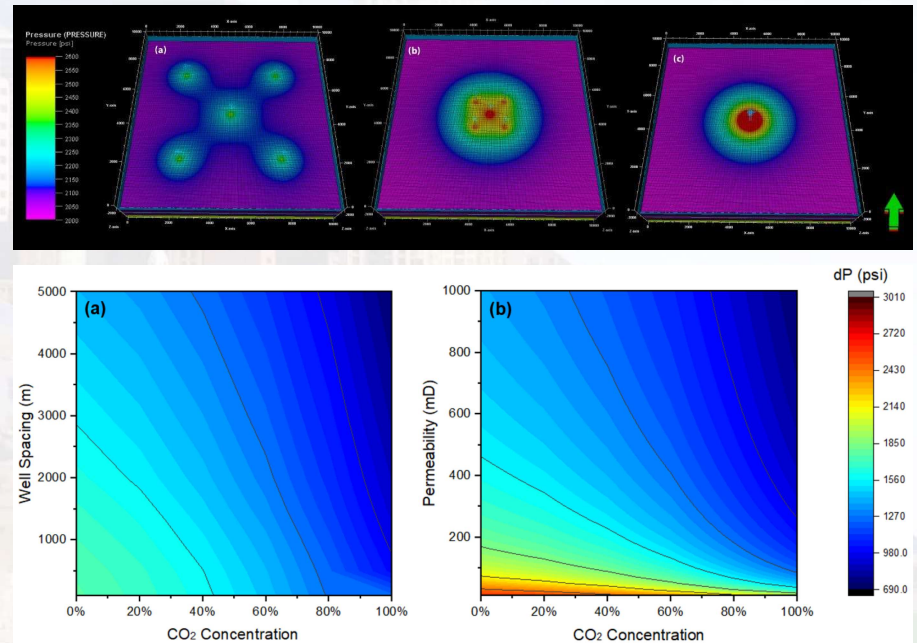


Subsurface Characterization

- Flue gas injection is often cheaper! But what about the subsurface response?
- We model 5 Mtpa flue gas injection to account for 1 Mtpa CO₂ sequestration in a 140 F saline aquifer
- Five injection wells are included in a 2-1-2 pattern with no production wells for pressure relief. We vary spacing.
- Permeability is varied from 10 mD (bad reservoir) and 1,000 mD (great reservoir)
- Flue gas composition is reduced to an N₂-CO₂ binary mixture, which is varied from 0% CO₂ to 100% CO₂

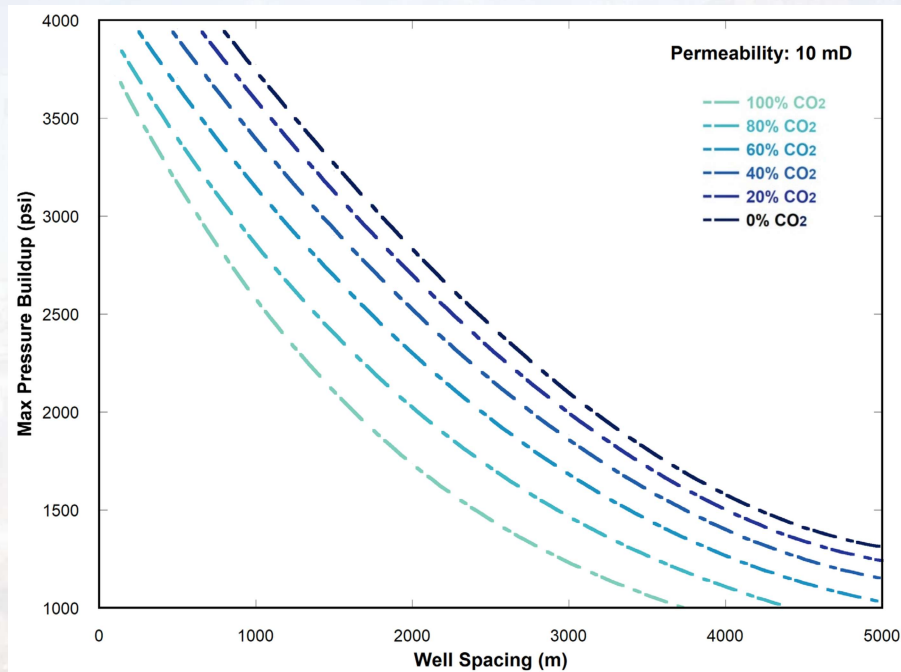
Results

- As CO₂ concentration increases, pressure buildup decreases
- 10 mD permeability experiences high pressure buildup relative to 1,000 mD
- Increased well spacing causes an exponential decrease in pressure buildup

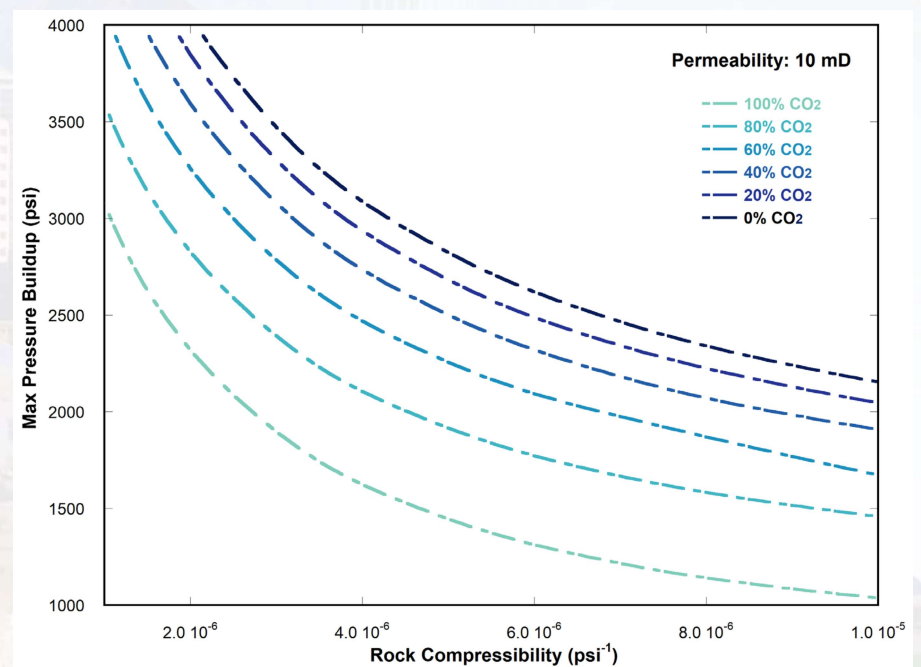


Changing Fluid Compressibility

As the %CO₂ in the flue gas decreases, pressure buildup increases. Increased well spacing decreases pressure buildup

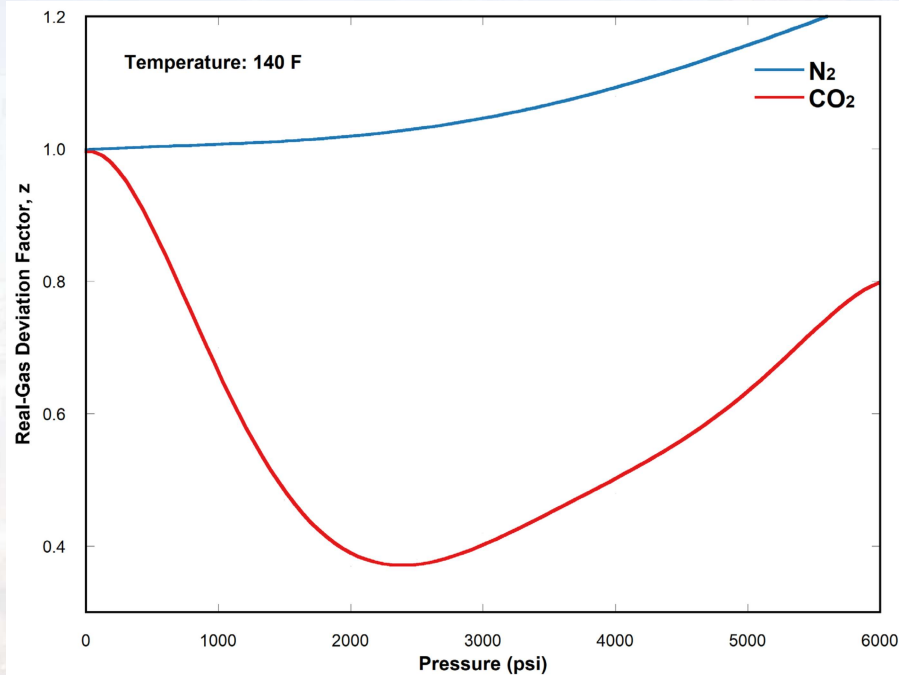


As system compressibility (C_t) increases, pressure buildup decreases. CO₂ is approximately twice as compressible as N₂ at reservoir conditions.

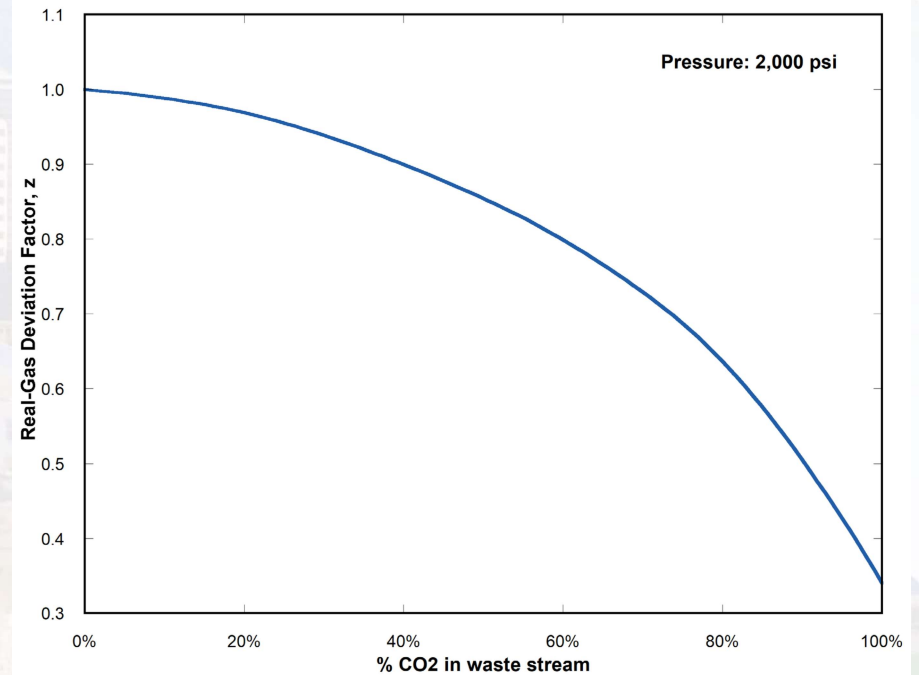


Fluid Compressibility Factor

The Z-factor of CO₂ is very different from N₂ at 140 F and at pressures experienced during flue gas injection.



Binary mixture's Z-factor decreases at initial reservoir pressure as flue gas composition shifts from 100% N₂ to 100% CO₂, also shifting fluid compressibility



Risk Assessment

- Financial risk:
 - Capture facilities are an up-front cost that is typically levelized
 - CTS is largely a cost per unit, flue gas injection reduces financial risk
- Project risk:
 - Capture facilities cannot capture 100% of the CO₂, whereas flue gas injection can
 - CCS represents a large parasitic power load
 - Flue gas injection transfers energy demands away from the PSE, removing the parasitic load
- Subsurface risk:
 - Flue gas injection has a larger pressure buildup, but this can be mitigated with increased well spacing and proper site selection

Conclusions

- There are thousands of years of pore space available at current US emissions from stationary sources
- Flue gas injection “captures” 100% of the CO₂ instead of 70%-90% as in traditional capture technologies at a penalty of 1.1 to 5 times pore volume
- Flue gas injection costs less than carbon capture technologies when the %CO₂ in the waste stream is 20% or greater
 - This includes carbon black, lime, ethylene, hydrogen, ammonia, and bioethanol production. It includes IGCC power plants and can include PC power plants.
 - This is sensitive to the price of compression, transport and storage
- The additional pressure buildup associated with higher N₂ compositions can be mitigated with well spacing

Thank you!

schwartz@psu.edu



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