Assessment of Geological CO$_2$ Storage: Technology, Capacity, and Public Safety

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What is CCUS?

- CO$_2$ capture (separation and compression), transport (via dedicated pipeline), and injection for long-term geologic storage
  - Mature or depleted oil and gas reservoirs
  - Unmineable coal seams
  - Deep saline aquifers
The Role of CCUS in Climate-Change Mitigation

• CCUS is a **bridge technology**: a bridge from our current energy system to a yet-TBD low-carbon energy system
  
  ‣ “CCS is important because it may enable the continued use of fossil fuels, which supply >80% of the primary power for the planet” (Szulczewski et al., *PNAS* 2012)
  
  ‣ “Geological storage of CO$_2$ is an important piece of the puzzle for negative emissions since it has the potential to store at the gigatonne-per-year scale” (Majumdar & Deutch, *Joule* 2018)

• In particular, CCUS is an **enabling technology** for other climate-change mitigation strategies (e.g., bioenergy with CCS, direct air capture with CCS)
  
  ‣ “BECCS scenarios assume CCS is deployable ‘off-the-shelf’, and the availability of disposal sites for the captured CO$_2$” (EASAC, 2017)
How Big is the Problem, Really?

• World CO₂ emissions …
  ‣ Current emissions ~ 11 billion metric tons of carbon-equivalent per year (11 GtC/yr)
  ‣ Coal-fired and gas-fired power plants ~ 35% ~ 4 GtC/yr

• Take 1 GtC/yr ≈ 3.7 GtCO₂/yr (“1 unit”) …
  ‣ That’s 3.7 billion tons per year, 3.7×10^{12} kg/yr
  ‣ At a reservoir density ~ 500 kg/m³, that’s 7.4×10^9 m³/yr
  ‣ 1 m³ = 6.25 bbl, 1 year = 365 days, gives 125 million barrels per day

• 3500 times the injection rate at Sleipner
  ‣ ~ 1.5 Sleipners every week for the next 50 years

And that is to address just 10% of current emissions
How Much CO\(_2\) Can Be Sequestered Underground?

- Developed storage capacity estimates that, unlike previous estimates, are based on the fluid mechanics of CO\(_2\) injection, migration and trapping.

Can CCS Be a Bridge Technology?

- Storage capacity is limited by CO₂ migration and injection overpressure. Therefore, it must be understood as a dynamic quantity.

- New way to frame the problem: supply and demand.
Can CCS Be a Bridge Technology?

• CCS is a geologically-viable climate-change mitigation option in the United States over the next century (Szulczewski et al., PNAS 2012)

• CCS is a risky, and likely unsuccessful, strategy for significantly reducing greenhouse gas emissions (Zoback and Gorelick, PNAS 2012)
Is Fault Leakage a Show-Stopping Risk?

• Zoback and Gorelick articulate an important, albeit well-known, concern: CCS may induce seismicity, as can other subsurface technologies.

• However, their characterization misrepresents its relevance to CCS:
  ‣ The vast majority of earthquakes are much deeper than CO\textsubscript{2} storage reservoirs.
  ‣ Fault slip does not imply leakage in sedimentary rocks: hydrocarbon reservoirs have existed for millions of years in regions of intense seismic activity (e.g., Southern California).
  ‣ Many geologic formations exhibit excellent promise for storing CO\textsubscript{2} (“soft” sedimentary formations).
Summary and Outlook

• **Storage capacity is dynamic**, and depends on duration of injection: both CO$_2$ migration and pressure dissipation may limit storage capacity

• Importance of **site selection**: high-perm, multiple caprocks, “soft” rocks, away from crystalline basement

• Importance of **multi-faceted monitoring**: high-quality microseismic, pressure monitoring, time-lapse 3D seismic

• Increase our knowledge of **frictional and hydraulic properties of faults**:
  ‣ Laboratory experiments
  ‣ Field experiments: 1-10Mt/year-injection with a range of “risk profiles”

**CCUS remains an attractive and realistic bridge technology in a carbon-constrained world**