Assessment of Geological CO_2 Storage: Technology, Capacity, and Public Safety

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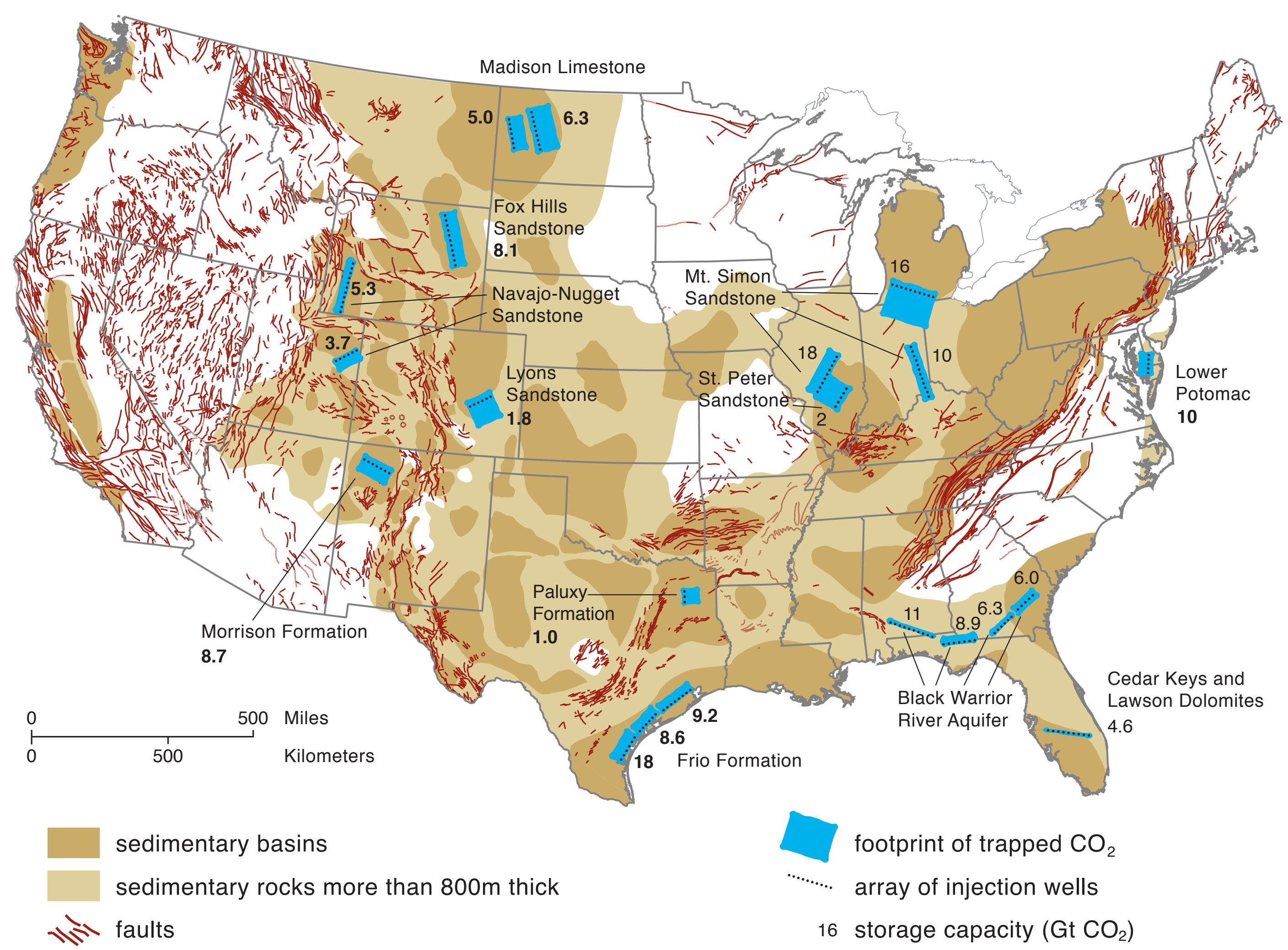

MIT Climate Symposium – Economy-wide Deep Decarbonization: Beyond Electricity
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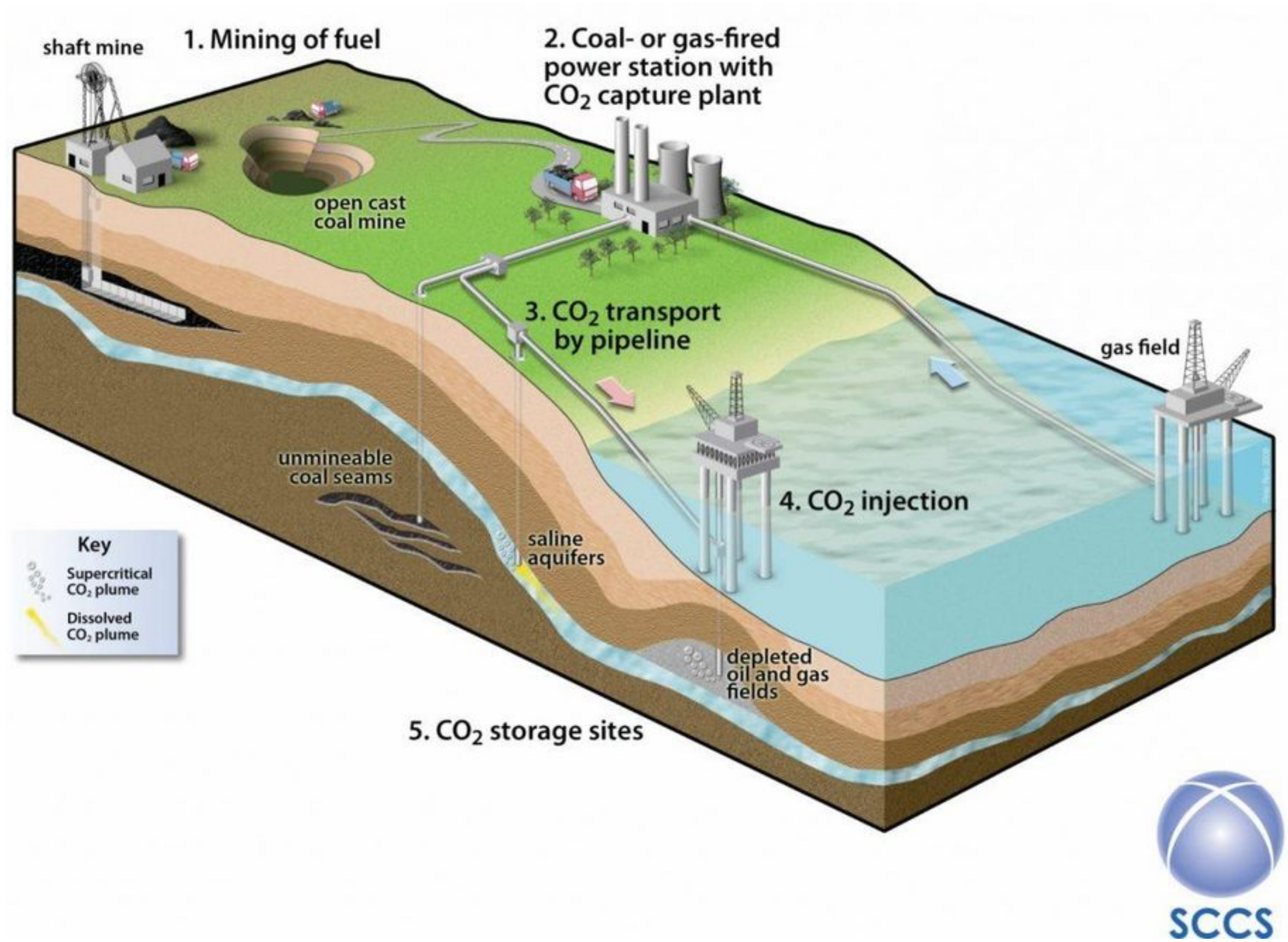
What is CCUS?

- 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



SCCS

The Role of CCUS in Climate-Change Mitigation

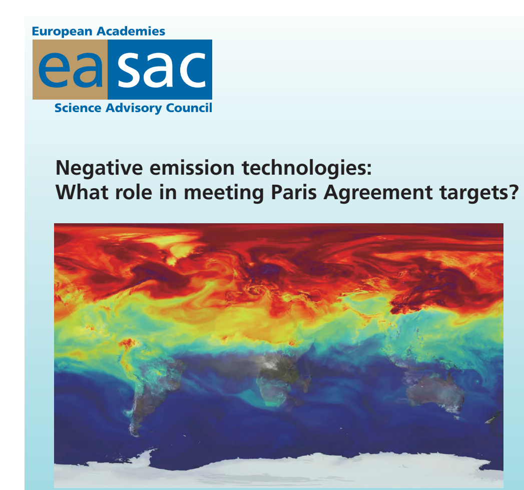
- CCUS is a <u>bridge technology</u>: a bridge from our current energy system to a yet-TBD low-carbon energy system
  - "CCS is important because it may enable the continued use of fossil fuels, which supply >80% of the primary power for the planet" (Szulczewski et al., *PNAS* 2012)
  - "Geological storage 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)

COMMENTARY

Research Opportunities for CO_2 Utilization and Negative Emissions at the Gigatonne Scale

Arun Majumdar[1,*] and John Deutch[2]

- In particular, CCUS is an <u>enabling technology</u> 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)



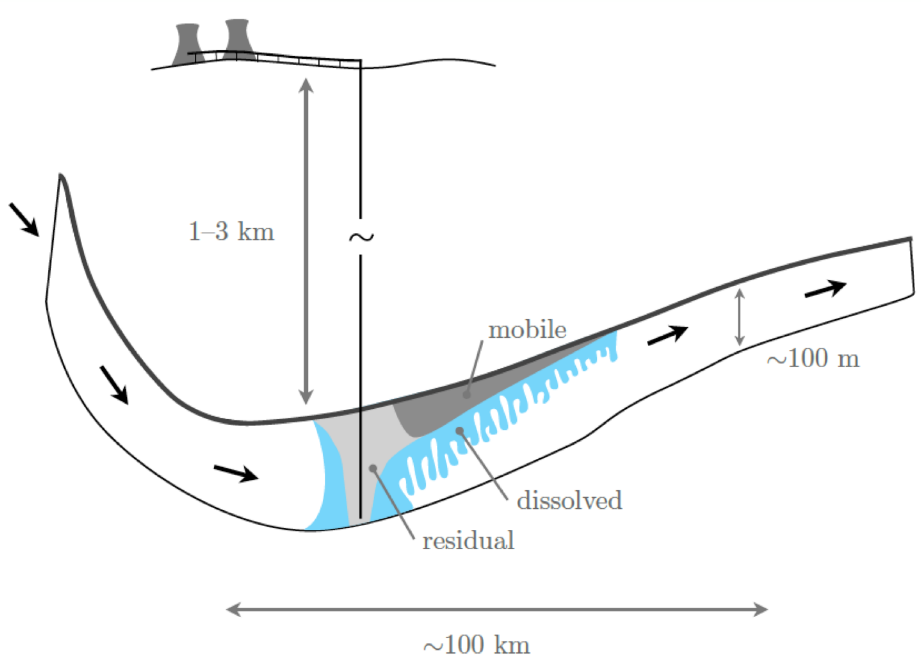
How Big is the Problem, Really?

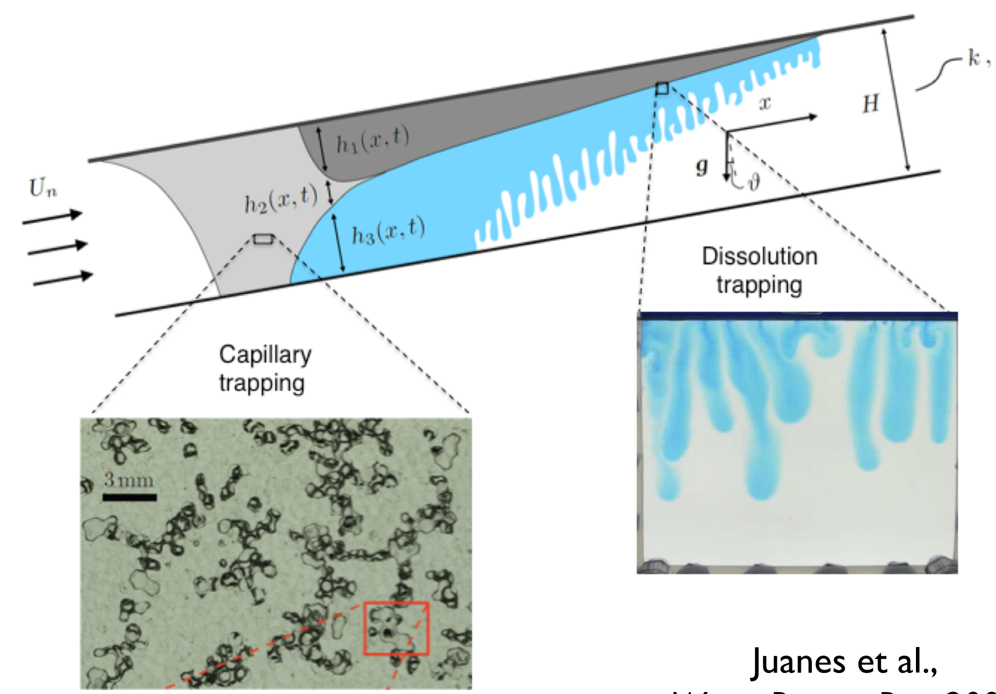
- World CO_2 emissions …
  - Current emissions ~ 11 billion metric tons of carbon-equivalent per year (11 GtC/yr)
  - Coal-fired and gas-fired power plants ~ 35% ~ 4 GtC/yr
- Take 1 GtC/yr ≈ 3.7 $GtCO_2$/yr ("1 unit") …
  - That's 3.7 billion tons per year, 3.7×10^{12} kg/yr
  - At a reservoir density ~ 500 kg/m^3, that's 7.4×10^{9} m^3/yr
  - 1 m^3 = 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

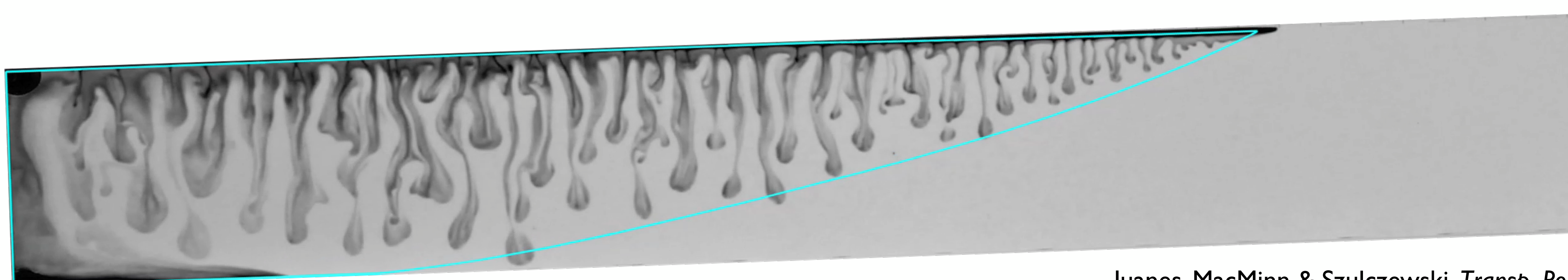
How Much CO_2 Can Be Sequestered Underground?

- Developed storage capacity estimates that, unlike previous estimates, are based on the fluid mechanics of CO_2 injection, migration and trapping





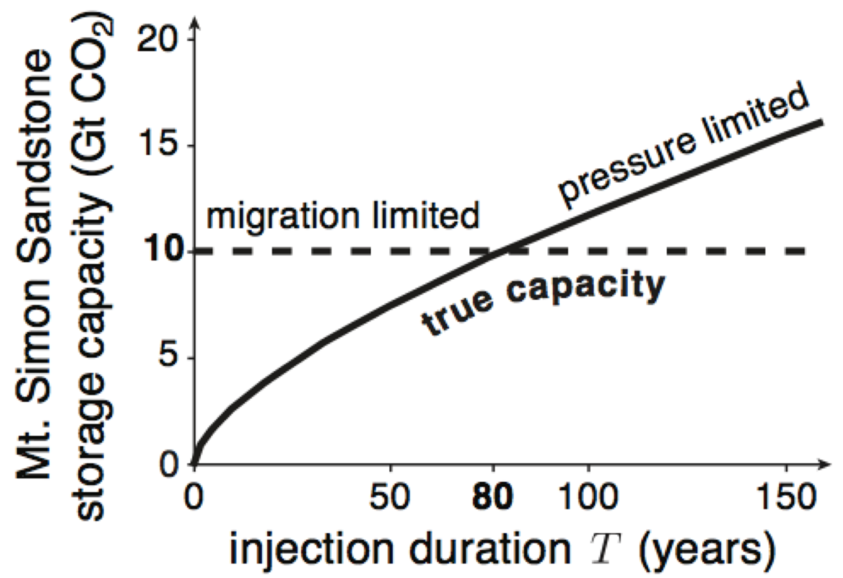
Juanes et al., *Water Resour. Res.* 2006

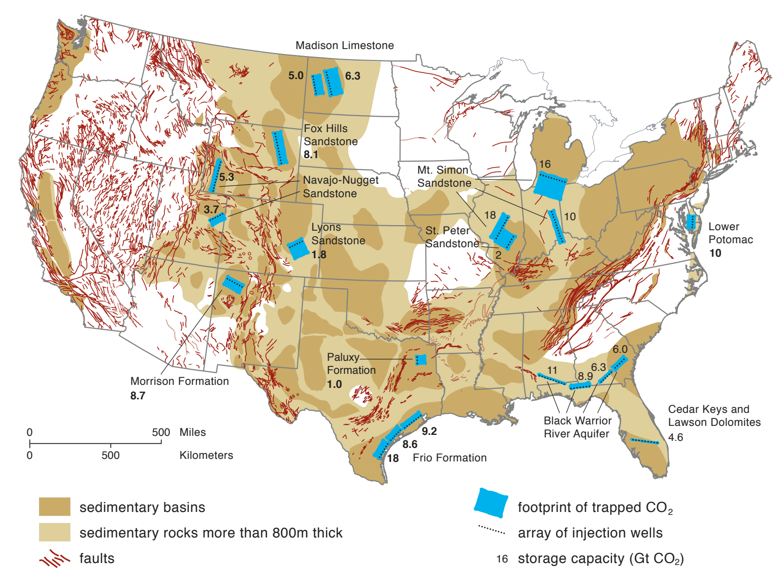


Juanes, MacMinn & Szulczewski, *Transp. Porous Med.* 2010
MacMinn, Szulczewski & Juanes, *J. Fluid. Mech.* 2010, 2011
MacMinn & Juanes, *Geophys. Res. Lett.* 2013

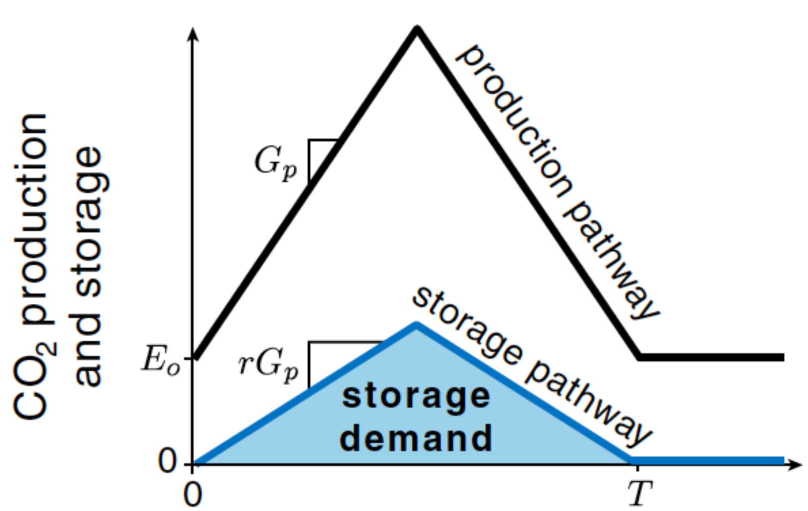
Can CCS Be a Bridge Technology?

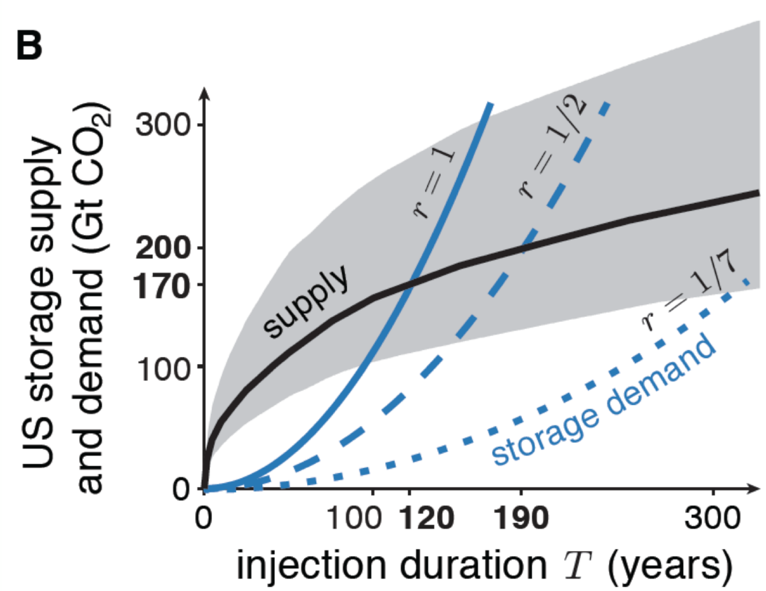
- Storage capacity is limited by CO_2 migration and injection overpressure. Therefore, it must be understood as a dynamic quantity

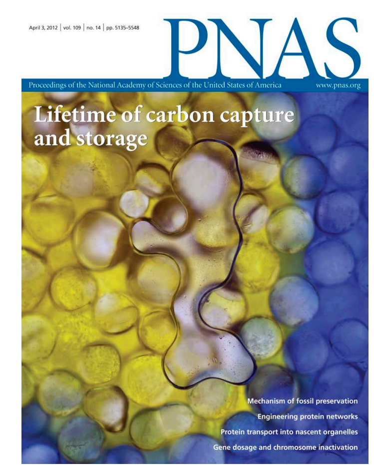




- New way to frame the problem: supply and demand







Szulczewski, MacMinn, Herzog & Juanes, *PNAS* 2012

Can CCS Be a Bridge Technology?

Lifetime of carbon capture and storage as a climate-change mitigation technology

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Edited by M. Granger Morgan, Carnegie Mellon University, Pittsburgh, PA, and approved February 15, 2012 (received for review September 19, 2011)

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

Earthquake triggering and large-scale geologic storage of carbon dioxide

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Edited by Pamela A. Matson, Stanford University, Stanford, CA, and approved May 4, 2012 (received for review March 27, 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

Induced Seismicity Potential in
ENERGY TECHNOLOGIES

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- However, their characterization misrepresents its relevance to CCS
  - The vast majority of earthquakes are much deeper than CO_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 CO2
    (“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