webinar on reliable CO2 storage

NRC/NAS committee (17 members), info at [http://nas-sites.org/dels/studies/cdr/](http://nas-sites.org/dels/studies/cdr/)

developing a research agenda for carbon dioxide removal and reliable sequestration

1. coastal 2. terrestrial biosphere 3. direct air capture 4. reliable storage
The National Academies

• Advisors to the Nation on science, engineering, and medicine.
• The National Academies is the umbrella term for NAS, NAE, NAM, and NRC.
• NAS created in 1863 under Lincoln Administration.

Strengths of our work:
– Stature of Academies’ memberships
– Ability to get the very best to serve
– “Pro bono” nature of committee service
– Special relationship to the government
– Quality control procedures
– Independence, scientific objectivity, balance
Statement of Task

• Identify the most urgent unanswered scientific and technical questions needed to:
  – assess the benefits, risks, and sustainable scale potential for carbon dioxide removal and sequestration approaches; and
  – increase the commercial viability of carbon dioxide removal and sequestration
• Define the essential components of a research and development program and specific tasks required to answer these questions
• Assess the costs and potential impacts of such a research and development program to the extent possible in the timeframe of the study
• Recommend ways to implement such a research and development program
webinar on reliable CO2 storage

developing a research agenda for carbon dioxide removal and reliable sequestration

1. coastal 2. terrestrial biosphere 3. direct air capture
4. reliable storage (today & two weeks from today)
storage

1. carbon mineralization
   moderator: Kelemen, 10:00 to 11:15
   three 15 minute talks, then 20 minute discussion

2. storage in subsurface pore space
   moderator: Benson, 11:15 to 12:15
   two 15 minutes talks, then 20 minute discussion
storage

1. carbon mineralization
   topic split between “direct” air capture (with storage) in October, and this section today, we will focus on storage via mineralization driven by fluids with $P(\text{CO}_2) > \text{ambient}$

2. storage in subsurface pore space
solid silicate + CO$_2$ $\Rightarrow$ (Ca,Mg,Fe)CO$_3$ + SiO$_2$

elementary

olivine + 2CO$_2$ $\Rightarrow$ 2 magnesite + quartz
Mg$_2$SiO$_4$ + 2CO$_2$ $\Rightarrow$ 2MgCO$_3$ + SiO$_2$

disequilibrium between Earth interior and atmosphere

peridotite: tectonically exposed rocks from the Earth’s mantle
high Mg/Si, low Al, fast reactions, lower permeability, less common

basalt: lavas derived via partial melting of the Earth’s mantle
lower Mg/Si, higher Al, slow reactions, higher permeability, more common

Seifritz Nature 1990; Lackner et al. 1995
**Mg-Ca-C-O-H**

- $\Delta G_i$, kJ/mol(C)

  - graphite
  - Mg, Ca, O$_2$ (g), H$_2$ (g)
  - H$_2$O (l)
  - CO$_2$ (g)
  - MgO, CaO
  - Mg(OH)$_2$, Ca(OH)$_2$
  - MgCO$_3$, CaCO$_3$

**Ground state:**

- Carbonate minerals

**Reactions: 1**

- 2 olivine + 3H$_2$O = serpentine + brucite + H$_2$O
- Brucite + CO$_2$ = magnesite + H$_2$O
- Olivine + 2CO$_2$ = 2 magnesite + quartz
- 2 olivine + 3H$_2$O + 4CO$_2$ = serpentine + brucite + 4CO$_2$ = 4 magnesite + 2 quartz + 3H$_2$O

**Diagram:**

- Olivine (Mg$_2$SiO$_4$)
- Serpentine (Mg$_3$Si$_2$O$_5$(OH)$_4$)
- Brucite (Mg(OH)$_2$)
- Quartz (SiO$_2$)
- H$_2$O - CO$_2$
GIANT storage capacity ~ Gt CO$_2$ / km$^3$ rock

peridotite: ~ 100 trillion tons 0-3 km depth on the continents
~1000 trillion tons near slow spreading mid-ocean ridges

basalt: maybe 10x more on continents, 100x more on seafloor

largely powered by chemical potential for free spontaneous reactions, …

natural examples to show the way
potentially slow kinetics

potentially expensive to mine, transport, grind

potentially negative permeability feedbacks in subsurface
air capture: not today!
mine tailings
  low total capacity readily available
  huge volume if mined for this purpose
produce existing low C, alkaline water
  from peridotite-hosted aquifers
potentially small capacity
need to recirculate or dispose of water
recharge by circulating water in subsurface
huge total capacity
cost, clogging
storage using $P(\text{CO}_2) > \text{ambient}$: today

ex situ using captured CO2
expensive? (compared to what?)
$10/\text{ton}$ to mine and grind rock
(4% reacted = $250/\text{ton}$, 40% = $25/\text{ton}$)
flue gas instead of purified CO2?

in situ injection: bring CO2 to the rocks
use geotherm for P,T, exothermic to maintain T
reaction-driven cracking: chemical potential to work
negative feedbacks?
fills porosity, decreases permeability
armors reactive surfaces (passivation)
storage using $P(\text{CO}_2) > \text{ambient}$: today

*in situ* in basalt
- high permeability, porosity
- common rock type
- relatively slow reactions

*in situ* in peridotite
- low initial permeability, porosity
- less common rock type
- relatively fast reactions
today’s speakers in context:

flue gas rather than purified CO2
Prof. Marco Mazzotti, ETH-Zürich

giant offshore basalt reservoir (pore space and carbon mineralization)
Dr. David Goldberg, Lamont Doherty Earth Observatory

feasibility (or not) of subsurface storage in peridotite
Prof. Chris Spiers, Univ. Utrecht
ex situ carbon mineralization: expensive

IPCC Report on Carbon Capture & Storage, 2005
Chapter 7: Mineral carbonation and industrial uses of carbon dioxide
Marco Mazzotti et al.

The technology is … not yet ready for implementation.

The best case studied so far is [carbonation of] olivine
quarry rock, transport to power plant,
grind to 10-100 microns, capture CO₂ from flue gas,
combine in high pressure + high temperature reactor

⇒ 60-180% more energy
"This is the first good example of a site that is of the scale that can potentially make a dent on the problem of carbon dioxide storage," said Dave Goldberg, a researcher in the highly-respected Lamont-Doherty Earth Observatory.
“when applied to in-situ CO2-storage, the mineralization reaction will be limited by transport through clogged fractures, and proceed at a rate that is likely too slow for the process to accommodate the volumes of CO2 expected for sequestration”