Air Capture
Introduction and Overview

Robert Socolow
Princeton University
socolow@princeton.edu

Direct Air Capture Summit

Institute for Sustainable Energy, Environment and Economy (ISEEE)

University of Calgary

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The Case for DAC

DAC might someday enable the world to lower the atmospheric CO_2 concentration gradually, thereby reducing the negative impacts of climate change.

DAC may also have a role to play eventually in countering recalcitrant *decentralized* CO_2 emissions, such as emissions from buildings and vehicles, which prove expensive to reduce by other means.

It can be useful in niche CO_2 markets.

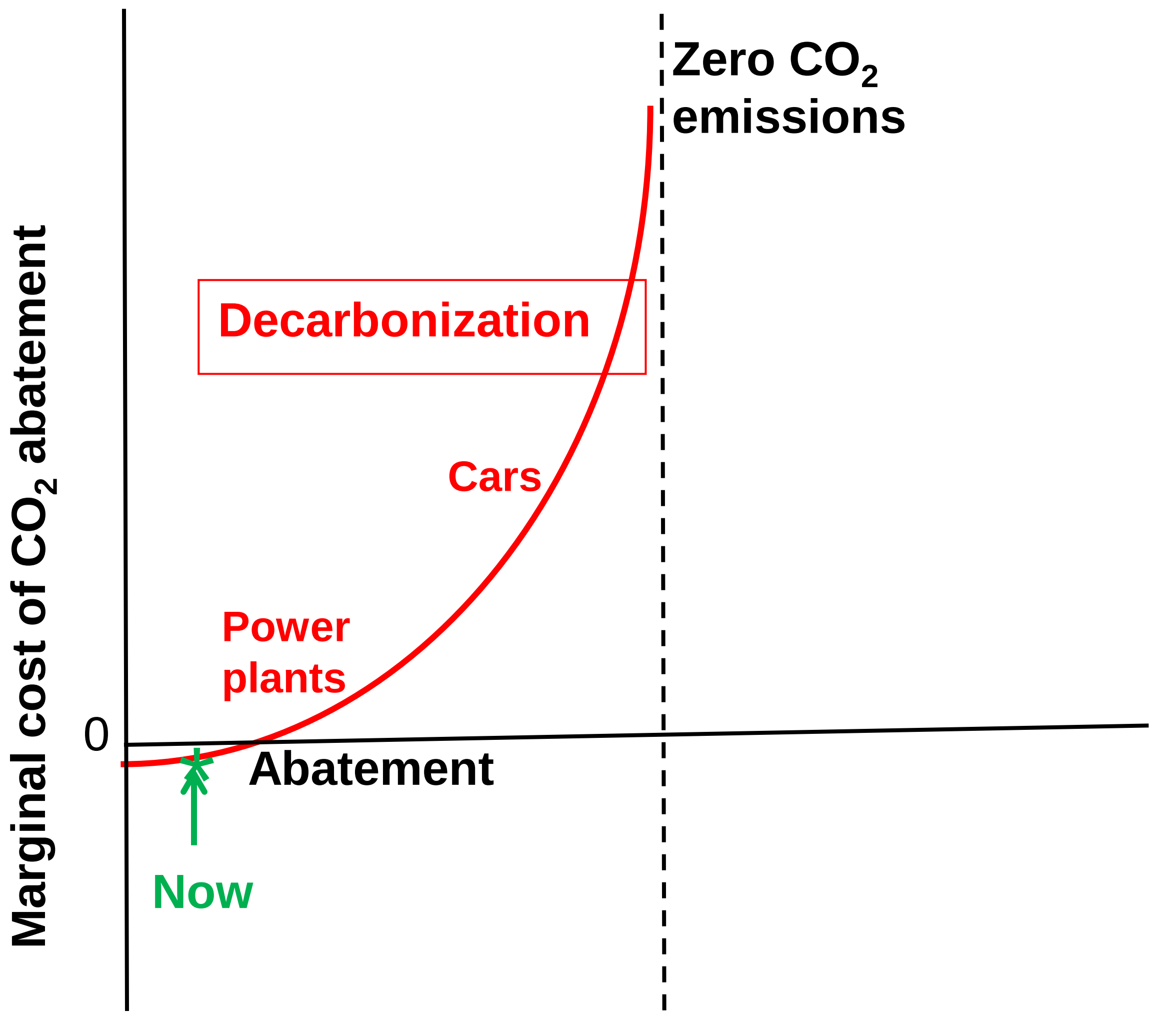
Overall message: First things first

My principal message today, however, is:
"First things first."

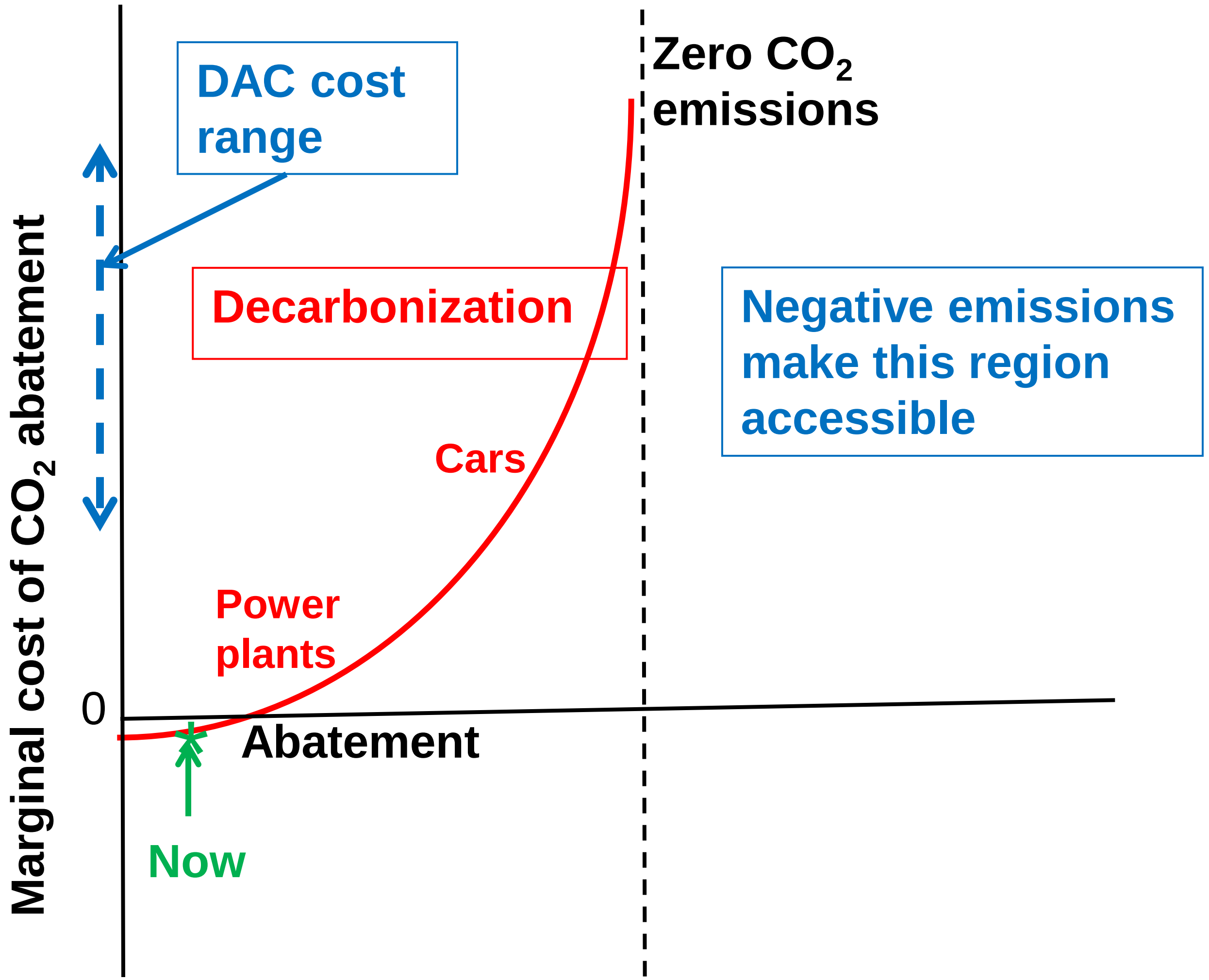
It is much cheaper to capture CO_2 from the flue gas of a coal power plant than from ambient air, where it is 300 times more dilute.

Aggressive deployment of DAC makes little sense until the world has largely eliminated *centralized* sources of CO_2 emissions, especially at coal and natural gas power plants, either by substitution of non-fossil alternatives or by capture of nearly all of their CO_2 emissions. *This is the priority objective for climate change mitigation for the indefinite future.*

Structure of Costs



Structure of Costs



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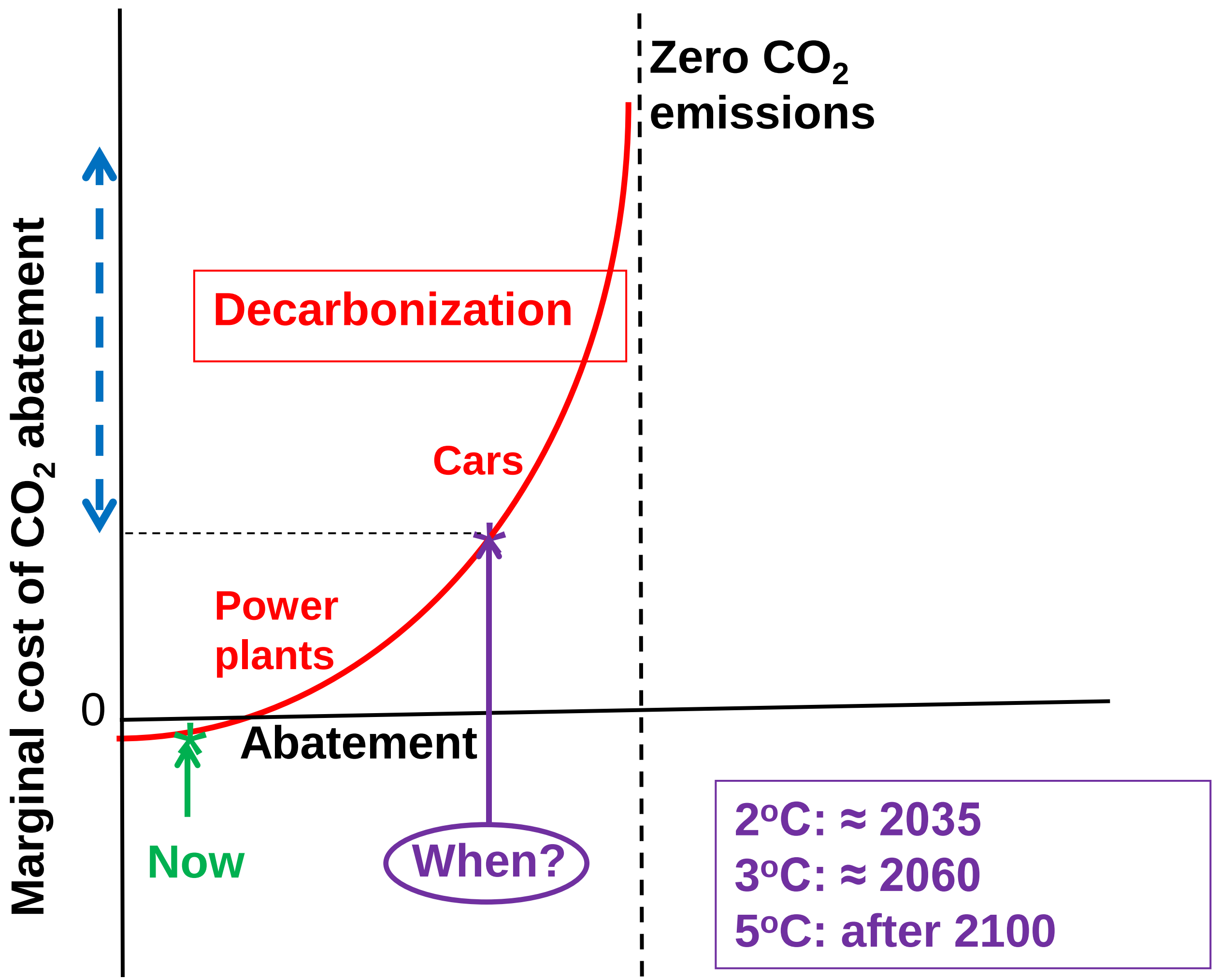

Four World Views

		Are fossil fuels hard to displace?	
		NO	YES
Is climate change an urgent matter?	NO	A nuclear or renewables world unmotivated by climate.	Most people in the fuel industries and most of the public are here. **5ºC.**
	YES	Environmentalists, nuclear advocates are often here. **2ºC.**	OUR WORKING ASSUMPTIONS. **3ºC, tough job.**

American Physical Society, 2008-2011
Direct Air Capture of CO_2 with Chemicals

Goals:

1. Empower various audiences to evaluate DAC critically.
2. Establish an assessment model that could be used to scope any pre-commercial technology.

    Examples of candidate technologies: geothermal power, small nuclear reactors, cellulosic ethanol, advanced batteries.

Sponsors

American Physical Society
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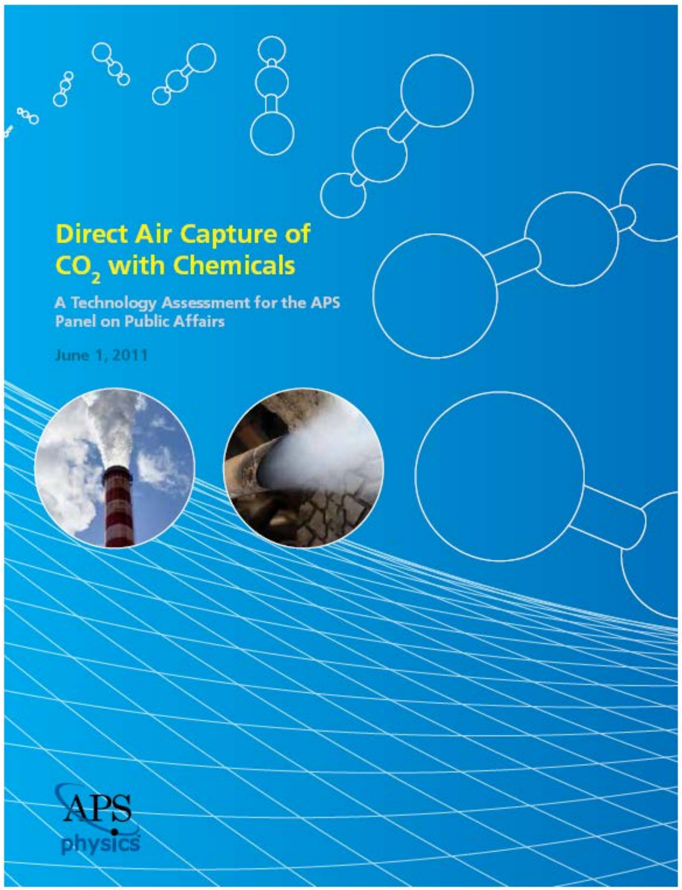
National Commission on Energy Policy
U.S. Department of Energy
Gerry Lenfest

American Physical Society, 2008-2011
Direct Air Capture of CO_2 with Chemicals



Earlier co-chairs:
Bill Brinkman, then Arun Majumdar

Report Committee ***Green: We are here.***

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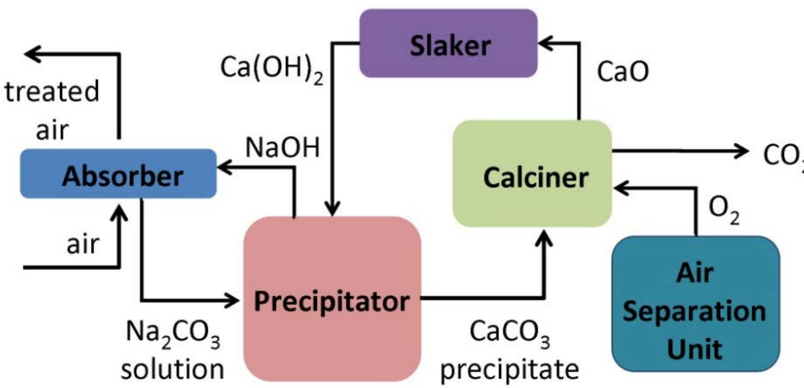
The APS benchmark system

•NaOH counterflow sorption

•$Ca(OH)_2$ – $CaCO_3$ recovery

•mass and energy balances from Baciocchi *et al*., 2006.



Costs: Industry methodology. Oxygen-blown kiln is only non-commercial component.

Klaus Lackner calls the APS benchmark system a penguin. He says we studied a penguin to see if a bird could fly. Perhaps. There may be systems that work that are totally unlike our benchmark system and others we considered. Or, systems we have doubts about could turn out to work.

What question about costs did APS try to answer?

Certain industry professionals evaluate the promise of new technologies day in and day out. For a DAC facility built today that they think would work, what cost would they estimate, and what methodology would they use?

We anchored our cost to the cost of a facility that captures CO_2 from the flue gas of a coal power plant, keeping all possible assumptions the same.

We generally estimated low: We assumed a constant CO_2 removal rate, ignoring environmental variability. We were bullish about pressure drop.

Our system boundary excluded CO_2 sequestration.

Cost domains, in \$/tonCO_2

30 | 300 | 3000 | 30,000

80

600-800

Flue-gas capture today

A DAC system built today that could work

air ≈ 10*flue-gas

R&D?

R&D?

Mountaineer
AEP, WV

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Mountaineer
AEP, WV

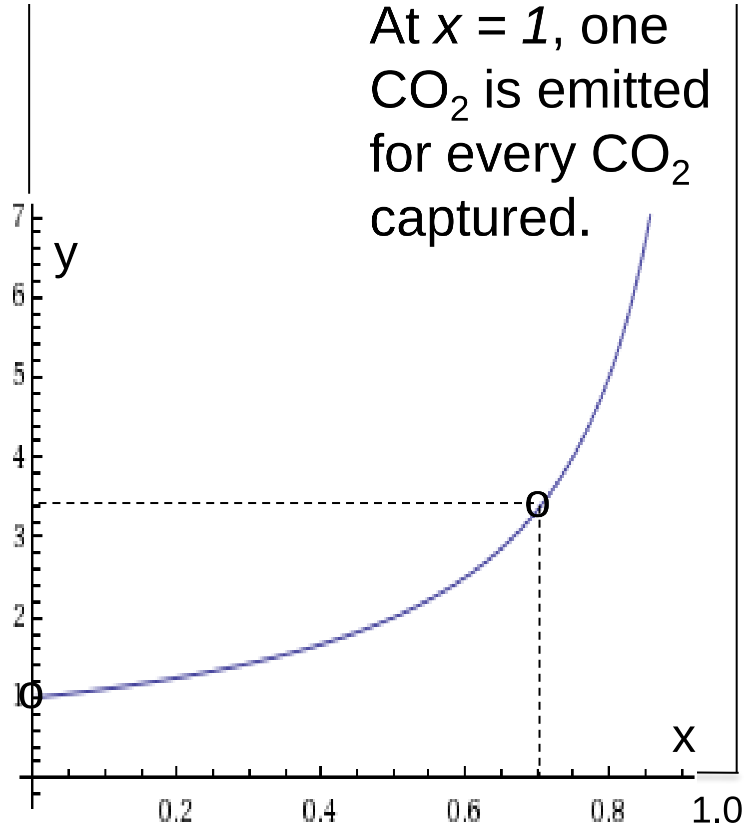
During a full year of contentious review after our report was submitted to APS, *all* of the criticism was that our DAC costs were too low and that our treatment of DAC was too generous.

“Net-carbon” can drive up costs

The cost-multiplier, *y*, is the ratio of avoided cost to capture cost:

$$y = 1/(1 - x),$$

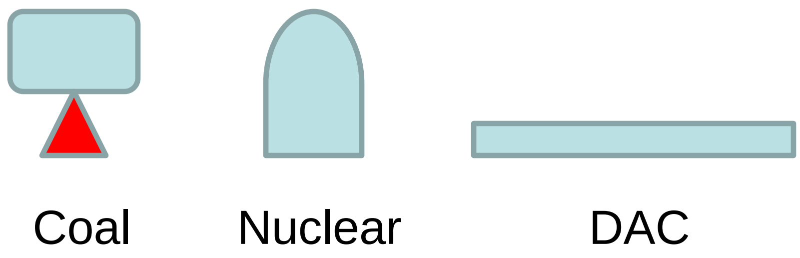
where *x* is the amount of CO_2 emitted per CO_2 captured.



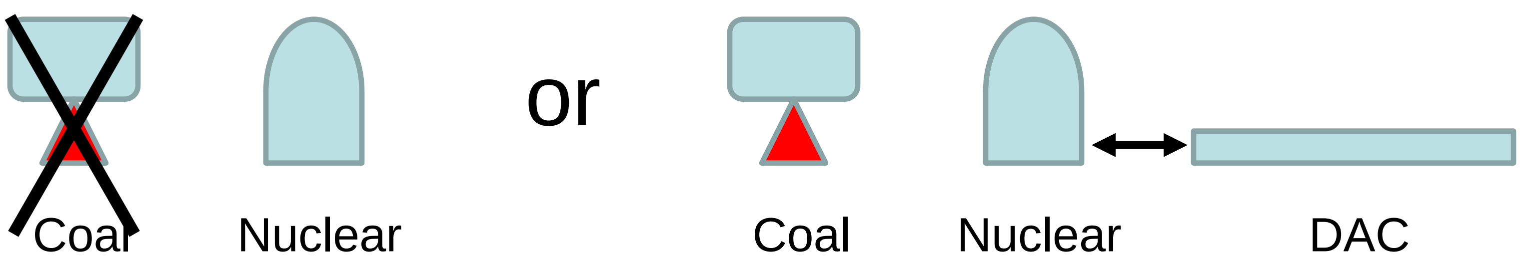
x = CO_2 emitted per CO_2 removed

The APS benchmark system has *x* = 0.3. Grid power runs the fans and compressor, but regeneration heat is provided by natural gas with CCS. Without CCS, *x* = 0.7.

As long as there are high-carbon sources of power and heat, any low-carbon sources should back these out, not run DAC



Baseline: A coal plant is running, and a nuclear plant is being built. Which use of the nuclear plant is best for the climate?



Need it be said that "nuclear" is a place-holder for any low-C baseload energy source, e.g., geothermal energy, hydropower, and fossil energy with CCS.

The research frontier for DAC

Priorities:

Alternative strategies for bringing air into contact with chemicals

New chemistries for sorption and regeneration

Materials that can operate effectively and efficiently over thousands of consecutive cycles

Press release, American Physical Society, May 9, 2011

It is likely, I think, that DAC research will lower the cost of post-combustion capture of CO_2 from industrial facilities.

Research Questions

1. Ocean and land “takeback”
2. Maximum deployment rate
3. Upwind-downwind spacing
4. Carburetion of flue gas

Data: Half of CO_2 emissions stay in the atmosphere

1.4 GtC/yr

+

7.7 GtC/yr

Half to air

4.1 GtC/yr

45%

≈2.0 ppm/yr
Increase

2.7 GtC/yr

29%

Land sink

26%

2.3 GtC/yr

Ocean sink,
lowers pH

Data are from 2000-2008.

Source: Le Quéré et al. 2009, Nature Geoscience; Canadell et al. 2007, PNAS, updated by S. Pacala, Feb 2012.

Reverse the flows

Scaled to -1 ppm/yr

- 4 GtC/yr removed

≈ $-15\ GtCO_2/yr$

Half from air

-2 GtC/yr
50%

-1.0 ppm/yr

-1 GtC/yr
25%

Land source

25%
-1 GtC/yr

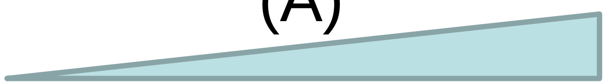
Ocean source, will raise pH

"Takeback": Conservatively, to reduce the mass of CO_2 in the atmosphere by one ton, one must remove ≈2 tons.

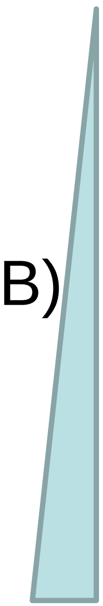
CO_2 removal: not matched to emergencies

Lower the CO_2 concentration by **100 ppm** (capture **1500 $GtCO_2$**):

A. Over 100 years (e.g., 2050-2150)
B. Over 10 years (e/g., 2050-2060)



1 ppm/yr: plausible build-rate?

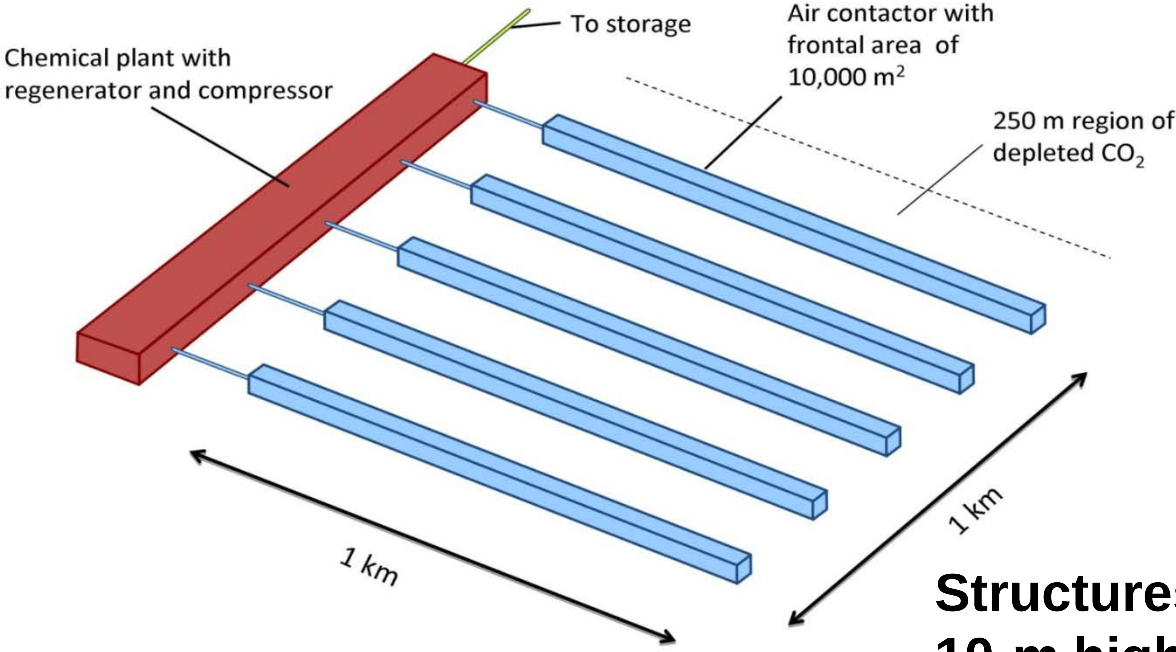


10 ppm/yr:
crisis response

"Pace" (slope, rate of increase in removal capability):
(A) 0.30 $GtCO_2/yr^2$; (B) 30 $GtCO_2/yr^2$ (100 times larger).

The pace in (B) is far too fast for DAC. It is equivalent to canceling the entire global fossil-fuel system in one year.

DAC footprint depends on “spacing”

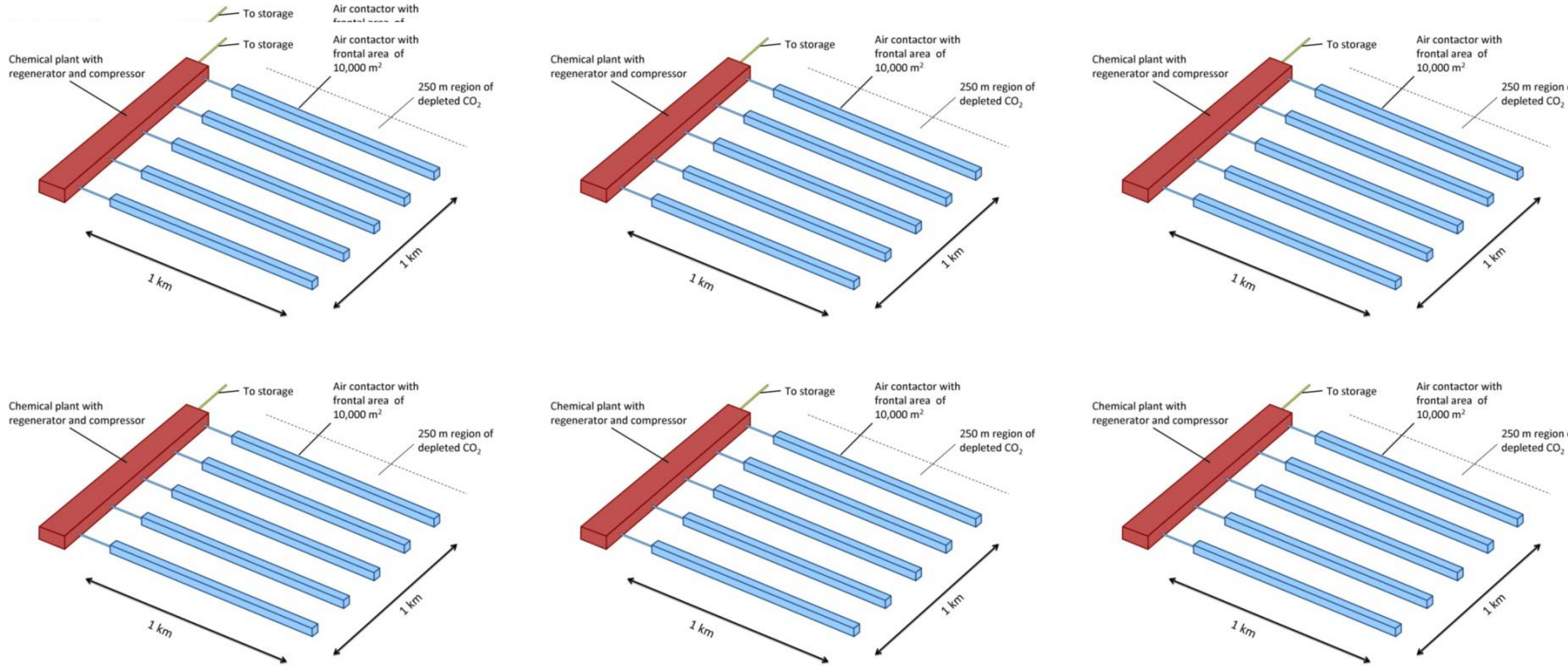


Structures are 10-m high

A 1 MtCO_2/yr system (50% capture, 2 m/s air velocity)

Is 200 meter spacing adequate? The intake at the downwind structure must not entrain depleted air from the upstream structure.

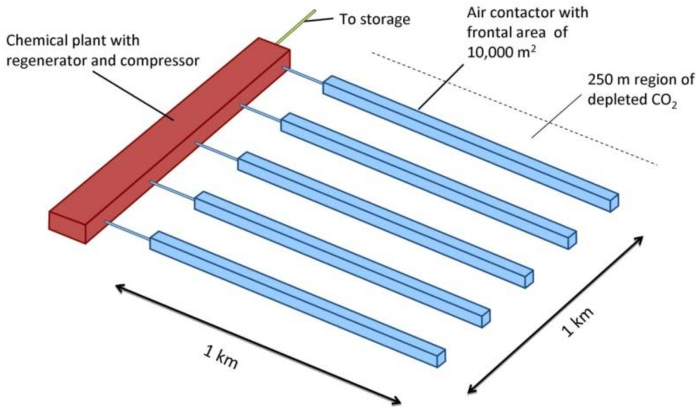
Six 1 $MtCO_2$/yr facility compensate for a 1 GW coal plants

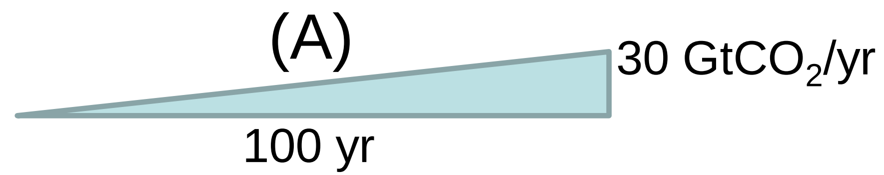


Alternative: A 30 km line of structures, 10 meters high.

Must also allow for power and heat sources, pipelines, and below-ground storage reservoir.

Remove 100 ppm over 100 years





Add 300 facilities per year for 100 years. Final footprint (30,000 facilities @1.5 km^2 each): 45,000 km^2 (less than area of Nova Scotia).

Biological competitors:

1) *Afforestation*: Not enough land.
2) *Biological energy with capture and storage (BECS)*: land area is hundreds of times larger than for DAC.

Advantages of air over flue gas

Peter Eisenberger, briefing the APS committee in March 2009, provided three reasons why capture from air could be less costly than capture from flue gas:

Air is cleaner. DAC saves the cost of flue gas desulfurization. (Still, air pollutants can be a DAC menace.)

Air is cooler. DAC saves the cost of flue gas cooling. Advantageous for thermal swings.

A*ir won't heat up much.* DAC saves the cost of thermal capacity to soak up the heat of the flue-gas CO_2-sorption reaction. Systems with low heat capacity may be adequate for CO_2 sorption from air.

The carburetor

Eisenberger later noted that *the ratio of flue gas to air* in a CO_2 capture system is an optimization parameter. Any such mixed system he calls a “carburetor.” He speculates that today’s DAC research could lead to flue-gas capture by carburetion.

Make no mistake: If the flow through a capture system is *five-sixth* air and *one-sixth* coal flue gas, it is not an air-capture device: more than 98% of the CO_2 removed comes from the flue gas. It is a flue-gas capture system.

High level messages

First things first: Virtually all large-scale industrial CO_2 sources should be decarbonized before DAC is deployed. Not only is DAC much more expensive, but DAC requires low-C power to be carbon-negative.

DAC could compensate cost-effectively for the last fractions of fossil fuels use.

DAC may be used someday to reduce the atmospheric CO_2 concentration. At very large scale, it may well compete favorably with biological strategies for CO_2 removal.

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DAC may be used someday to reduce the atmospheric CO_2 concentration. At very large scale, it may well compete favorably with biological strategies for CO_2 removal.

I cannot persuade myself that DAC is a relevant climate mitigation strategy for this half century.

Our moral responsibility

The various publics concerned about climate change wish that DAC were cheap.

Selectively, people hear what they want to hear, and they assemble their worldviews from the information they let in.

It is obligatory, therefore, for experts (including those here today) not to create false hopes – in this case, not to allow our audiences to infer that humanity can “solve” climate change while being relaxed about fossil fuels.