Carbon Dioxide Capture and Storage (CCS) and Negative Emissions

MITEI EAB

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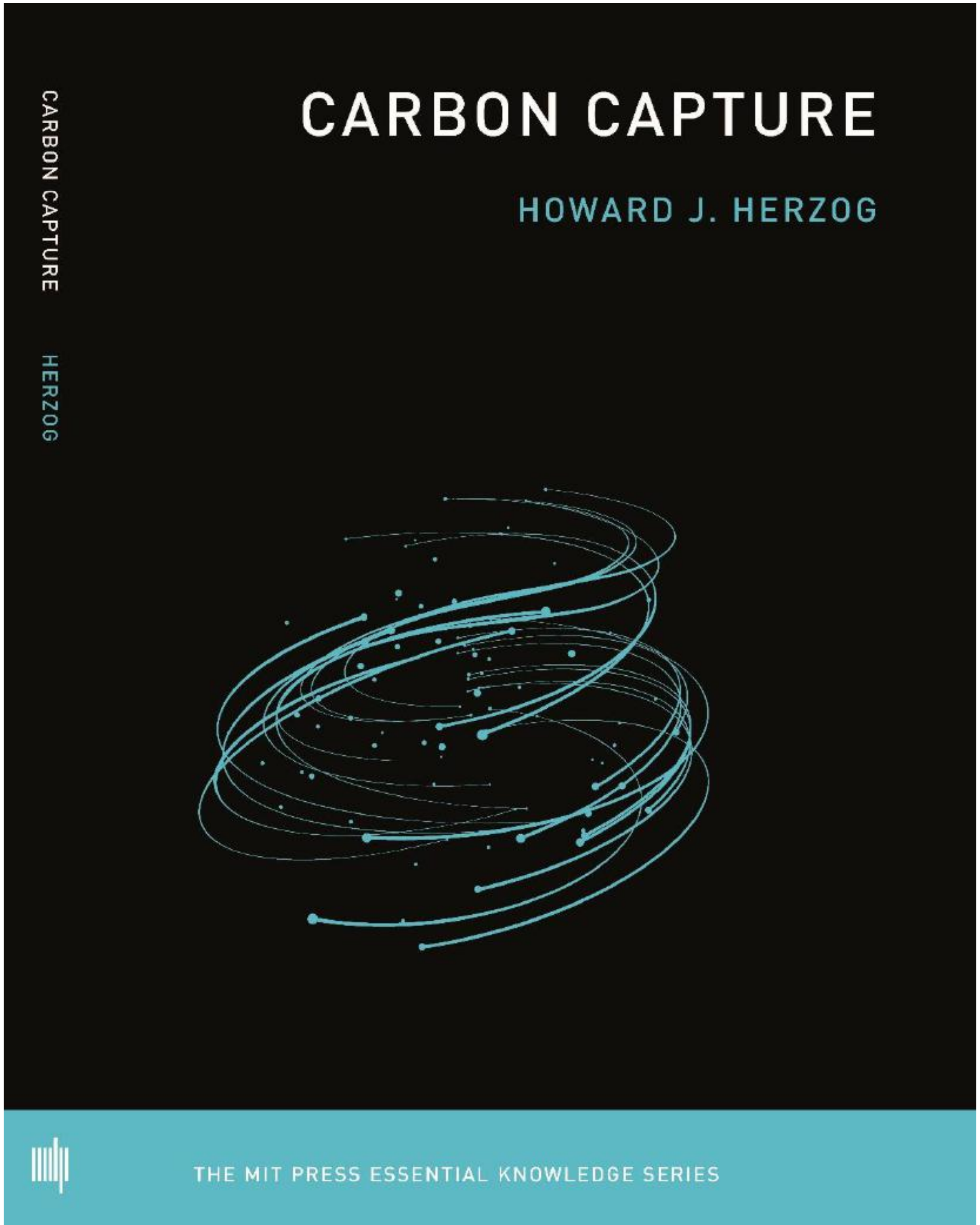


1 Climate Change

2 Fossil Fuels

3 Carbon Capture

4 Carbon Storage and Utilization

5 Carbon Capture in Action

6 Negative Emissions

7 Policies and Politics

8 The Future

Deep Decarbonization

- Climate stabilization requires achieving net-zero emissions of greenhouse gases (GHGs)
- A significant percent (may be as high as 30%) of our greenhouse gas (GHG) emissions can be classified as hard to eliminate and/or very expensive to eliminate
- Negative emissions allows getting to net-zero without eliminating all GHG emissions
- What about net-negative?

Negative Emissions

CO_2 Removal Options

Negative Emission Technology (NET)	Description	CO_2 Removal Mechanism	CO_2 Storage Medium
Afforestation/reforestation	The planting of trees to fix atmospheric carbon in biomass and soils	Biological	Soils/Vegetation
Modified agricultural practices	Adopting agricultural practices like no-till farming to increase carbon storage in soils	Biological	Soils
Biochar	Converting biomass to biochar and using the biochar as a soil amendment	Biological	Soils
Ocean (iron) fertilization	Fertilizing the ocean to increase biological activity to pull carbon from the atmosphere into the ocean	Biological	Ocean
Ocean alkalinity	Adding alkalinity to the oceans to pull carbon from the atmosphere via chemical reactions	Chemical	Ocean
Enhanced weathering (Mineral carbonation)	Enhancing the weathering of minerals, where CO_2 in the atmosphere reacts with silicate minerals to form carbonate rocks	Geochemical	Rocks
Bioenergy with CO_2 capture and storage (BECCS)	Removal the CO_2 from the air by plants into biomass, combustion of the biomass to produce energy and CO_2, which is captured	Biological	Deep Geologic Formations
Direct air capture (DAC)	Removal of CO_2 from ambient air by engineered systems	Physical/chemical	Deep Geologic Formations

Direct Air Capture (DAC)

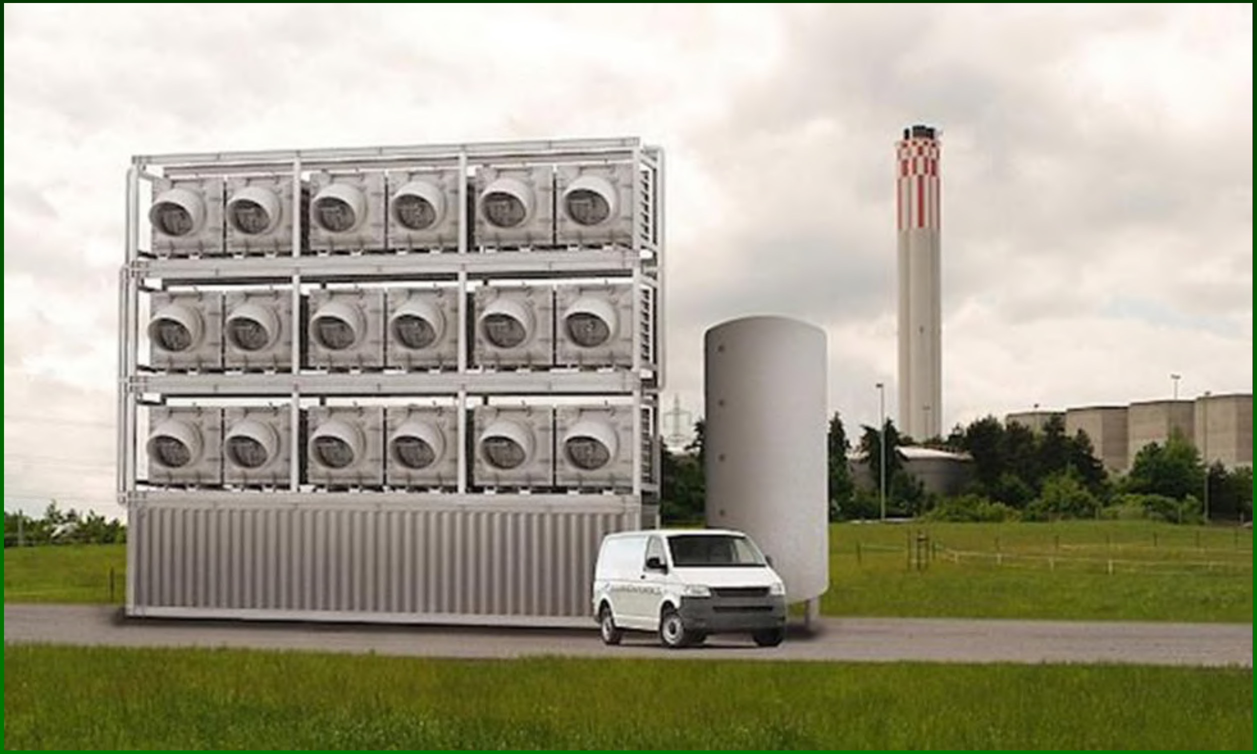
- Direct air capture is a very seductive concept
- The question is not whether we can suck CO_2 out of the air, but whether we can do it economically
- I estimate the cost on the order of $1000 per ***net*** tonne of CO_2 removed
  - Reference: House *et al*., "Economic and Energetic Analysis of Capturing CO_2 from Ambient Air," *Proceedings of the National Academy of Sciences* 108, no.51 (December 2011). http://sequestration.mit.edu/pdf/1012253108full.pdf

Why is DAC so expensive? Concentration Matters

- Concentration is a critical variable for CO_2 capture
- CO_2 concentration in air is approximately 300 times more dilute than in a coal-fired flue gas:
  - 0.04% (400 ppm) vs. 12%
- This poses significant challenges for DAC
  - Mass transfer driving force is reduced by a factor of 300
  - Have to handle at least 300 times more air

Petra Nova - W.A. Parish Plant CCS Absorber for 1.6 $MtCO_2$/yr

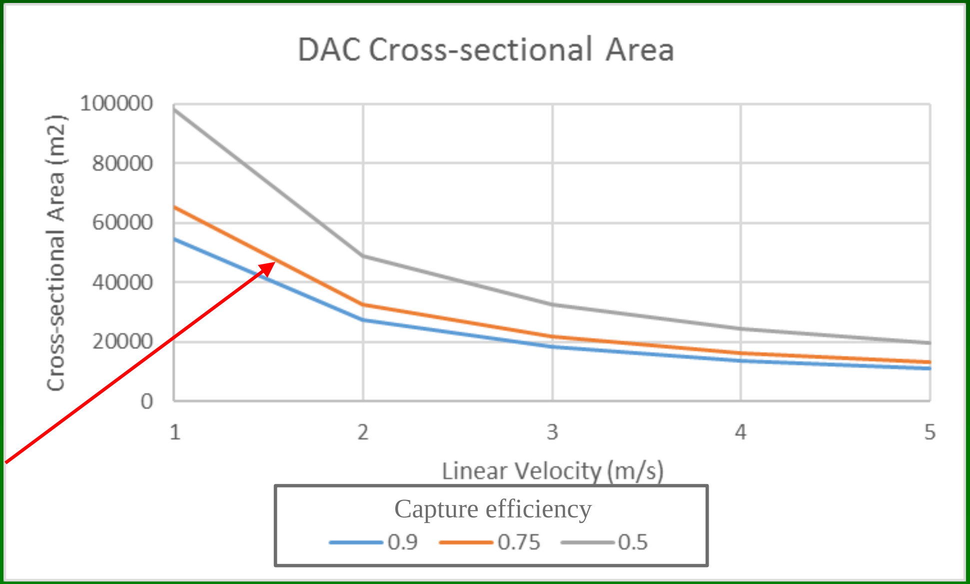
DAC



Climeworks DAC unit. Flow is horizontal, showing large cross-sectional area compared to the depth. Unit size is about 900 tCO_2/year.

Air Handling

- Air at 400 ppm CO_2 and 25°C
  - 0.72 g CO_2 per m^3 of air
  - 1.4 million m^3 of air contains 1 metric ton of CO_2
- Cross-sectional area required to capture 1 $MtCO_2$/year versus linear velocity and capture efficiency (assuming a 90% utilization efficiency):



Carbon Engineering
~47,000 m^2

Howard Herzog / MIT Energy Initiative

BECCS vs. DAC

- The biomass performs two important functions for BECCS
  - Removes CO_2 from the air (no absorbers needed)
  - It provides the energy required for CCS with energy to spare to produce electricity
- The biomass does come with costs regarding land use
  - Implications include impact on food prices, land-use change emissions, and environmental concerns

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