Direct Air Capture

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Negative Emissions Technologies

http://nas-sites.org/dels/studies/cdr/
What is Direct Air Capture?

Using Chemicals to Remove CO$_2$ from the air

Pros:
• Has the potential to be an NET
• Method for dealing with difficult to avoid emissions
• Does not require arable land

Cons:
• Energy inputs are significant
• Land footprint is large

DAC Should Not Replace Mitigation
Closer Look at the Energy

• Minimum work for separation may be derived from combined 1\textsuperscript{st} and 2\textsuperscript{nd} laws of thermodynamics
• Energy scales with dilution – 3× more energy to do DAC vs combustion exhaust
• 300× greater contactor area for CO\textsubscript{2} separation to do DAC vs combustion exhaust
• High purity is desired for transport

Reference: Wilcox, Carbon Capture, 2012
What Does Scrubbing CO₂ from a Point Source Look Like?
First patent filed by Bottoms in 1930!

Petra Nova – 1.4 Mt CO₂/year
115 Meters Tall Absorber

“CO₂-free” gas out

CO₂-loaded solvent out
Direct Air Capture Contactor Looks Very Different

need 10 of these to capture 1 MtCO₂ per year
Today’s technologies are based on liquids or solid materials containing CO$_2$-grabbing chemicals.

Solvents rely on structured packing with solvent flow over the packing.

Solid sorbents rely on a honey-comb structure with chemicals (amines) bound to structure.
To Design a DAC Plant, you First Need to Design a Power Plant

• No matter which approach you choose, the heat required to recycle the material is **dominant** over the electricity required to drive the fans,

• To capture 1 MtCO₂/yr from air requires 300-500 MW of power!

• Choosing which energy resource to fuel the DAC plant will dictate the net CO₂ removed
Cost Differences - CAPEX

Liquid Solvent DAC

- CAPEX: 55%
- OPEX: 45%

Solid Sorbent DAC

- CAPEX: 58%
- OPEX: 42%

Capital Cost Breakdown

- Heat Exchanger
- Vacuum Pump
- Fan
- ASU and Condenser
- Slaker, Causticizer, Clarifier
- Contactor Array
- Oxy-Fired Calciner

Reference: Pacala et al., NASEM, 2019
To drive costs down will require some technological advancement, but more will be needed

Investing as a global society is essential – whether through regulation or subsidies or taxes on carbon.

In 1966 the US invested about 1/2% of gross domestic product in the Apollo Program – today this is ~ $100 billion

... so let’s say we invest 20% in DAC, knowing its one front in our fight against climate change
Where does a $20 billion investment and a cost reduction down to $100/tCO₂ get us?

This would mean building 200 synthetic forests each capturing 1 MtCO₂ per year. This is equivalent to nearly 5% of our annual emissions.

Determining the land area required depends on what energy system you decide on for fueling your DAC plant.
Consider 2 Different Energy System Scenarios

1. Natural Gas w/ CCS

- **Contactor**
  - H₂O + K₂CO₃

- **Causticizer**
  - KOH
  - H₂O
  - Ca(OH)₂

- **Clarifier and Filter Press**
  - CaCO₃

- **Oxy-Fired Calciner**
  - CaO
  - CO₂ + H₂O
  - O₂

- **Cond.**
  - H₂O

- **To Compression**

**Natural Gas-Derived Electricity with CCS**

**Small process heaters/dryers**

**Natural Gas-Derived Thermal Energy with CCS**
Consider 2 Different Energy System Scenarios

2. Solar Electricity + H₂-Fired Kiln
Capturing 200 million tonnes from the air?

- Powered by natural gas with CCS?
  - 200 DAC plants = 1/6 land area of San Francisco roughly 40 mi²

- Powered by solar and H₂?
  - The size of 1/10 of CA roughly 12,000 mi²
Takeaways of Low and High-Temperature DAC Technologies

- Low-temperature technologies couple better to low-carbon and low cost heat, such as geothermal and industrial waste heat, but this coupling keeps them $< \text{MtCO}_2/\text{yr per facility}$
- Coupling low-temp technologies to these energy resources dictates their location and transport costs may be prohibitive
- Cumulative impact in CA based on available geothermal and waste heat opportunities is on the MtCO$_2$ removal scale
- Low-temperature technologies also provide a pathway for industrial facilities to offset their difficult-to-avoid emissions, such as heat

Solid sorbents rely on a honey-comb structure with chemicals (amines) bound to structure – thermal regeneration at 100C
Takeaways of Low and High-Temperature DAC Technologies

• High-temperature technologies are more cost-effective at scales of roughly 1 MtCO₂/yr removal, but due to the heat flow and quality, are well suited for stand alone power – fueled by natural gas w/ CCS for example
  • Changing kiln technology to hydrogen-fired or electric may add flexibility and lead to more significant climate impacts

Solvents rely on structured packing with solvent flow over the packing and calcining at 900C

• In general, decoupling DAC technologies from the energy resource allows for building the DAC plant where the CO₂ will be ultimately stored – but then transport may become cost-prohibitive.
• Siting DAC involves trade-offs with the choice of low-carbon energy being the most significant to achieving positive climate impacts
Reduce Carbon Sources

- Energy efficiency
- Low or zero-carbon fuel sources
- Conventional CCS

Enhance Carbon Sinks

Negative emissions technologies:

- Coastal blue carbon
- Terrestrial carbon removal and sequestration
- Bioenergy with carbon capture and sequestration (BECCS)
- Direct air capture
- Carbon mineralization
- Geologic sequestration

Reference: Pacala et al., NASEM, 2019
Questions?

More Information:

https://users.wpi.edu/~jlwilcox/

https://www.ted.com/talks/jennifer_wilcox_a_new_way_to_remove_co2_from_the_atmosphere

https://www.npr.org/2019/06/07/730392105/jennifer-wilcox-how-can-we-remove-co2-from-the-atmosphere-will-we-do-it-in-time

http://nas-sites.org/dels/studies/cdr/