Direct Air Capture

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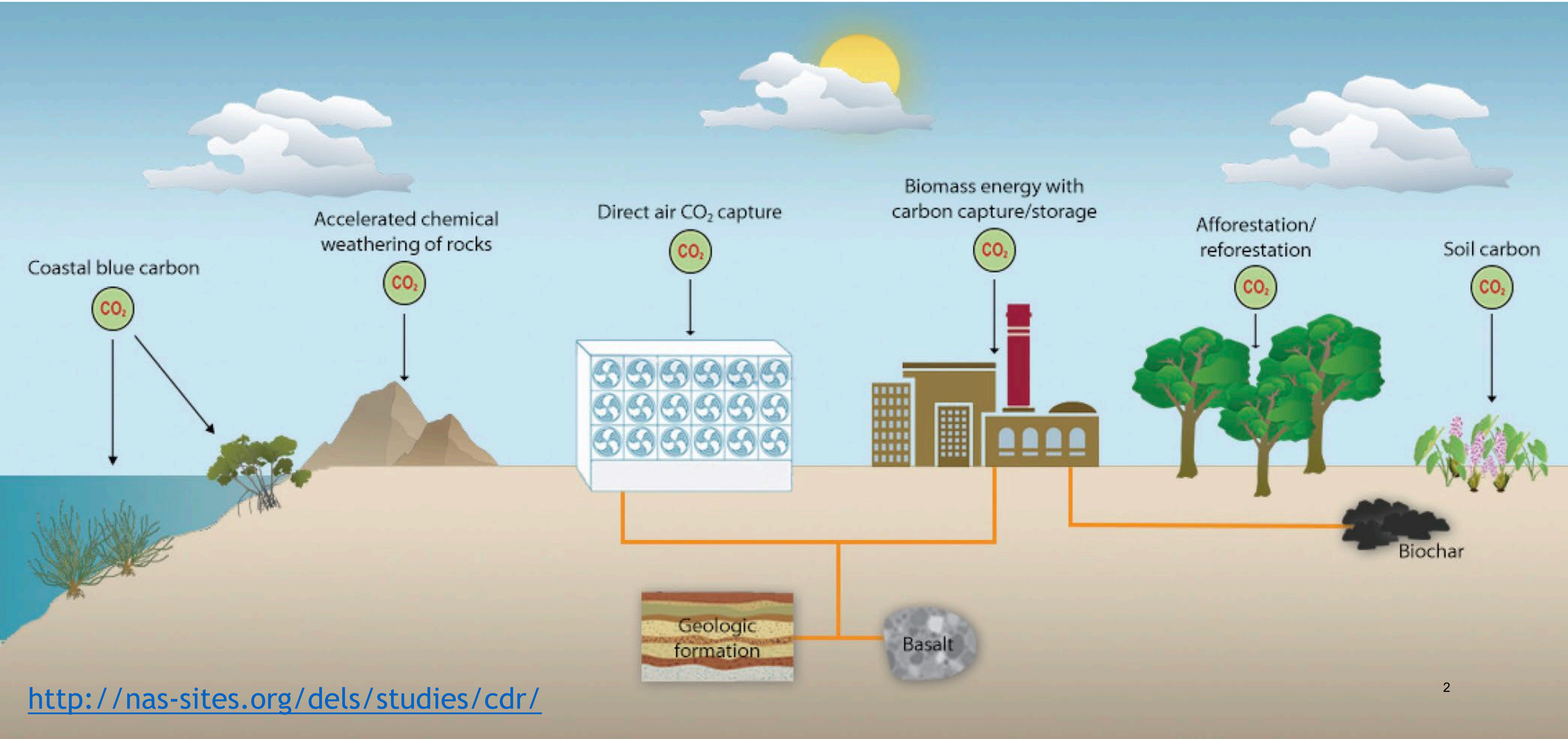
CARB Workshop
December 11th, 2019

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

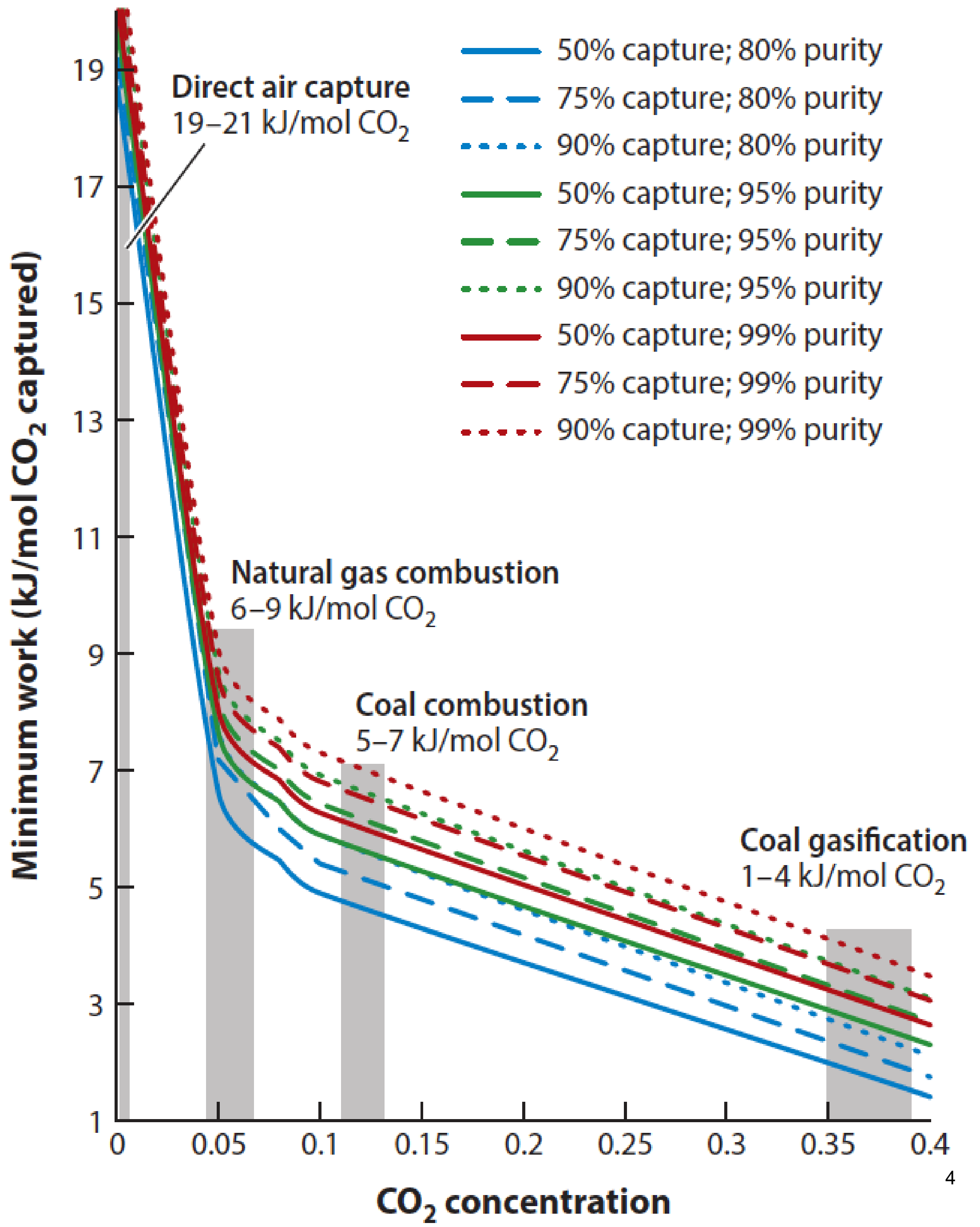
Cons:

- 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 1st and 2nd laws of thermodynamics
- Energy scales with dilution – 3× more energy to do DAC vs combustion exhaust
- 300× greater contactor area for CO_2 separation to do DAC vs combustion exhaust
- High purity is desired for transport

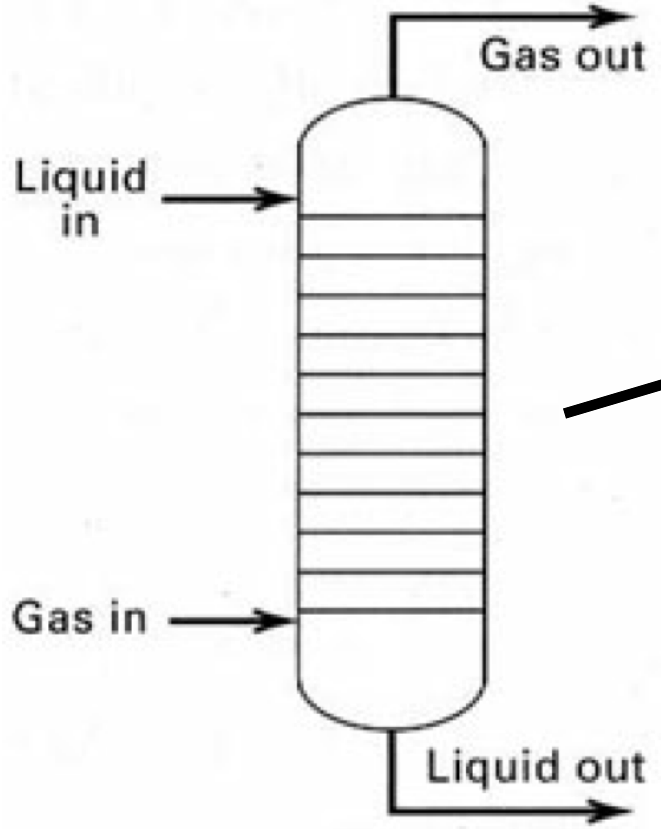


Reference: Wilcox, Carbon Capture, 2012

What Does Scrubbing CO_2 from a Point Source Look Like?

First patent filed by Bottoms in 1930!

“CO_2-free” gas out

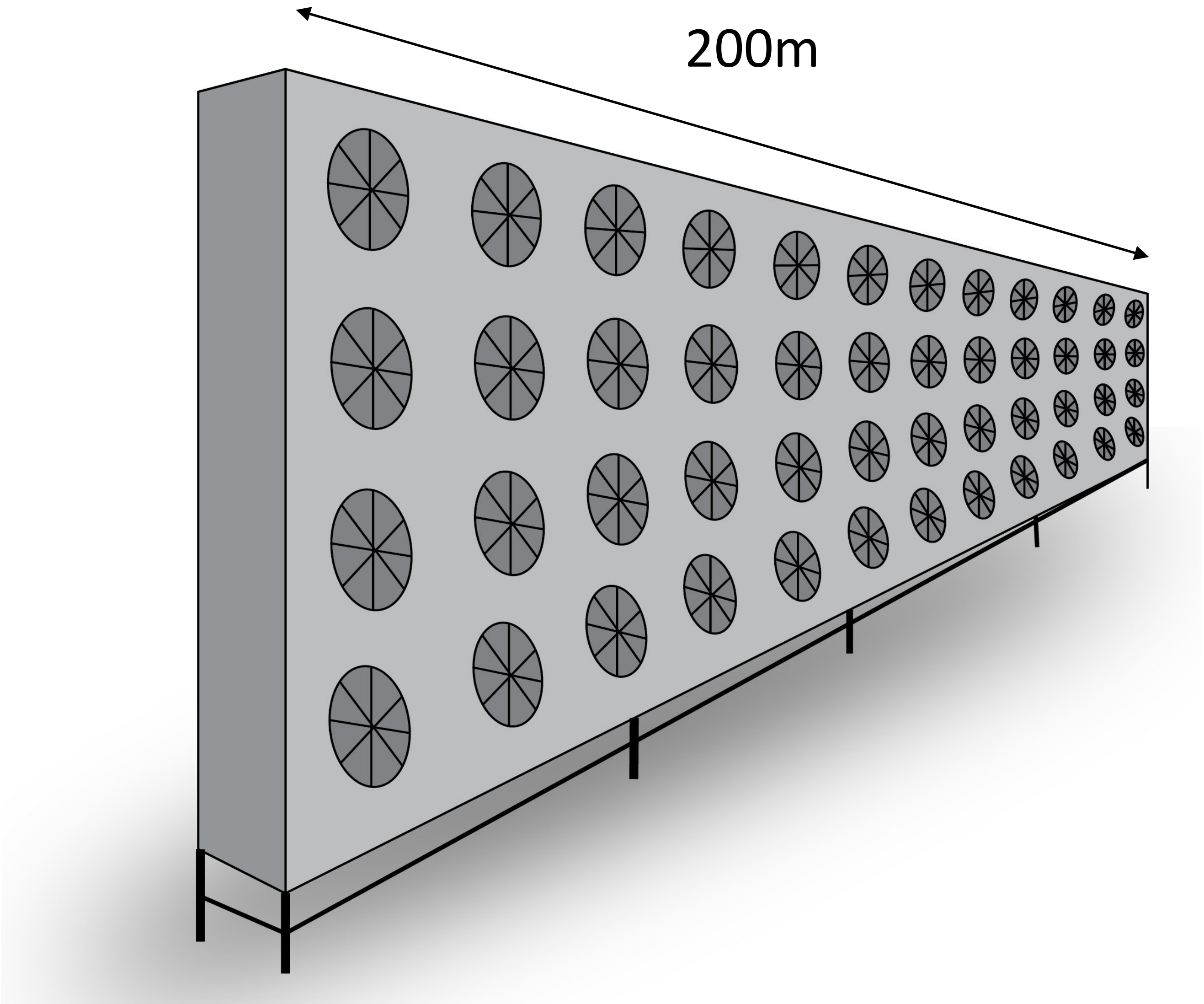


CO_2-loaded solvent out

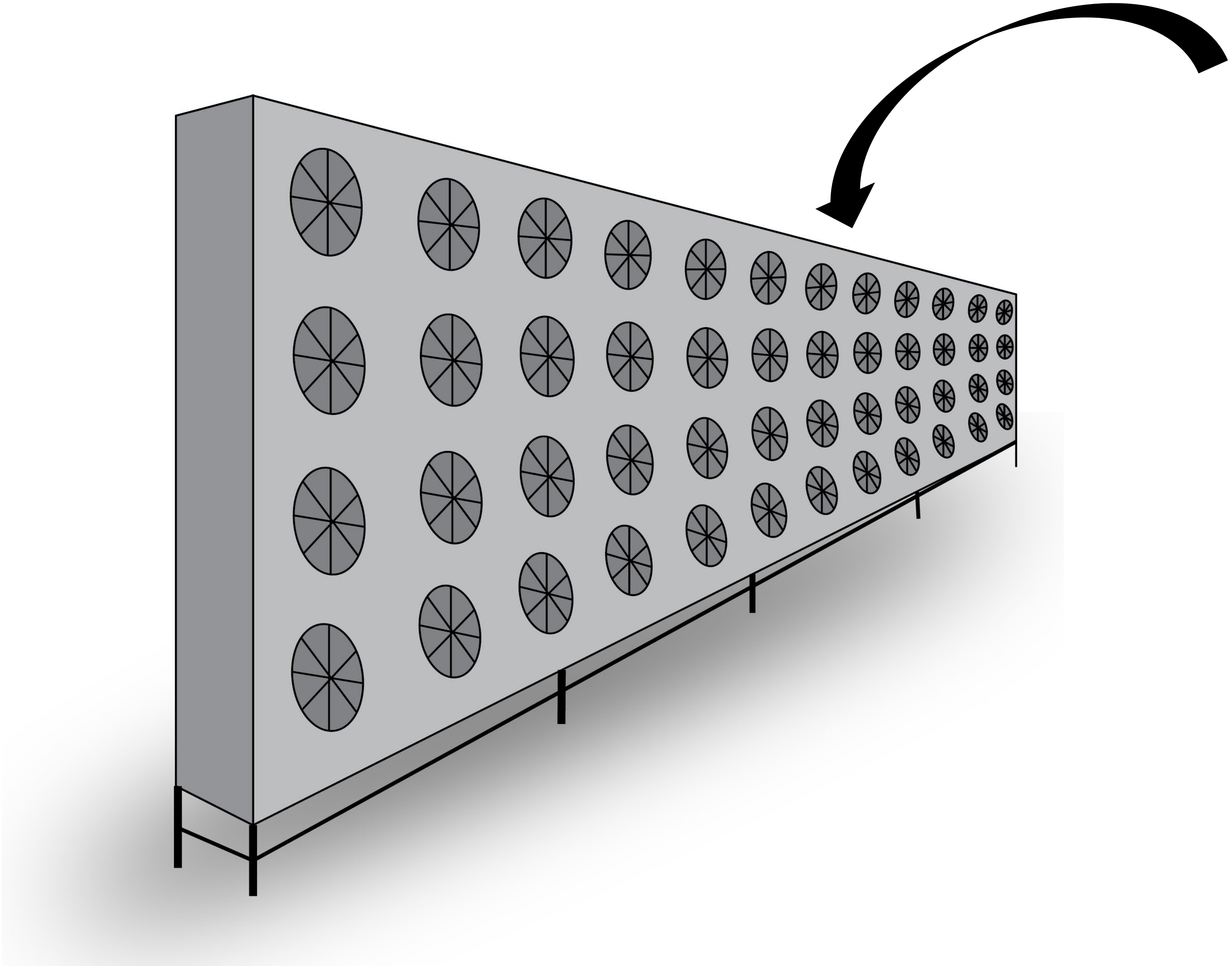
Petra Nova – 1.4 Mt CO_2/year
115 Meters Tall Absorber

Direct Air Capture Contactor Looks Very Different

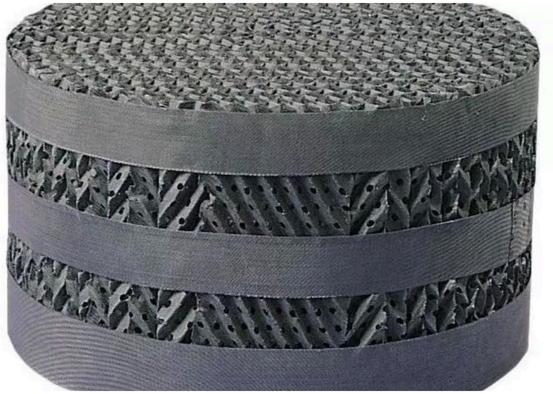
need 10 of these to capture 1 $MtCO_2$ per year



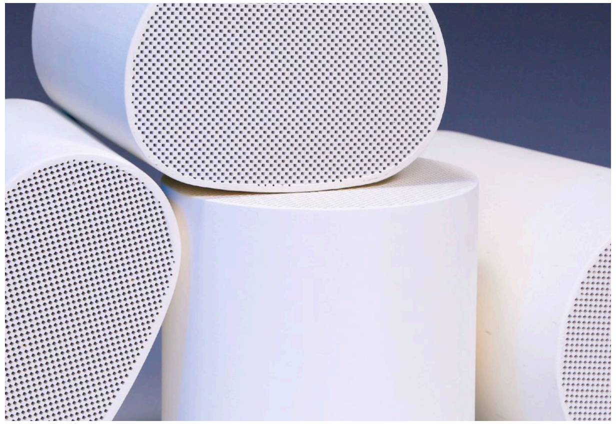
Today's technologies are based on liquids or solid materials containing CO_2-grabbing chemicals



Solvents rely on structured packing with solvent flow over the packing



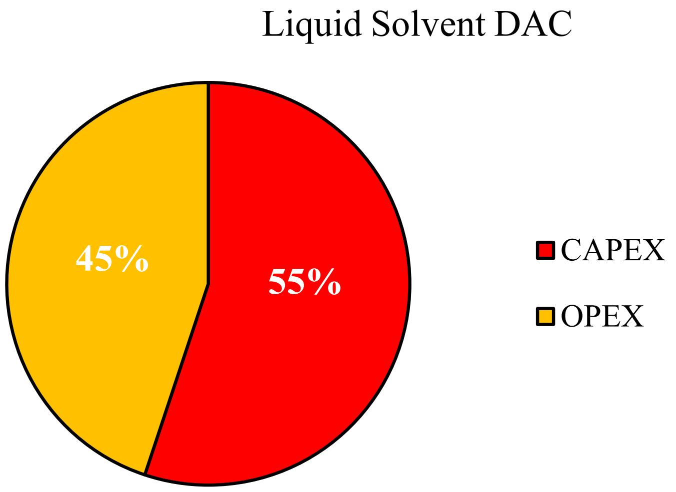
Solid sorbents rely on a honey-comb structure with chemicals (amines) bound to structure

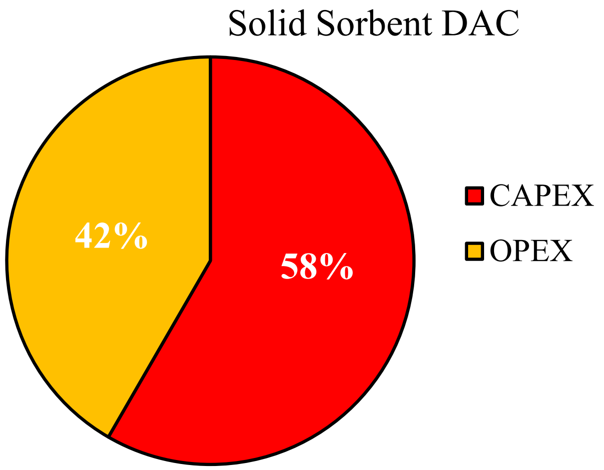


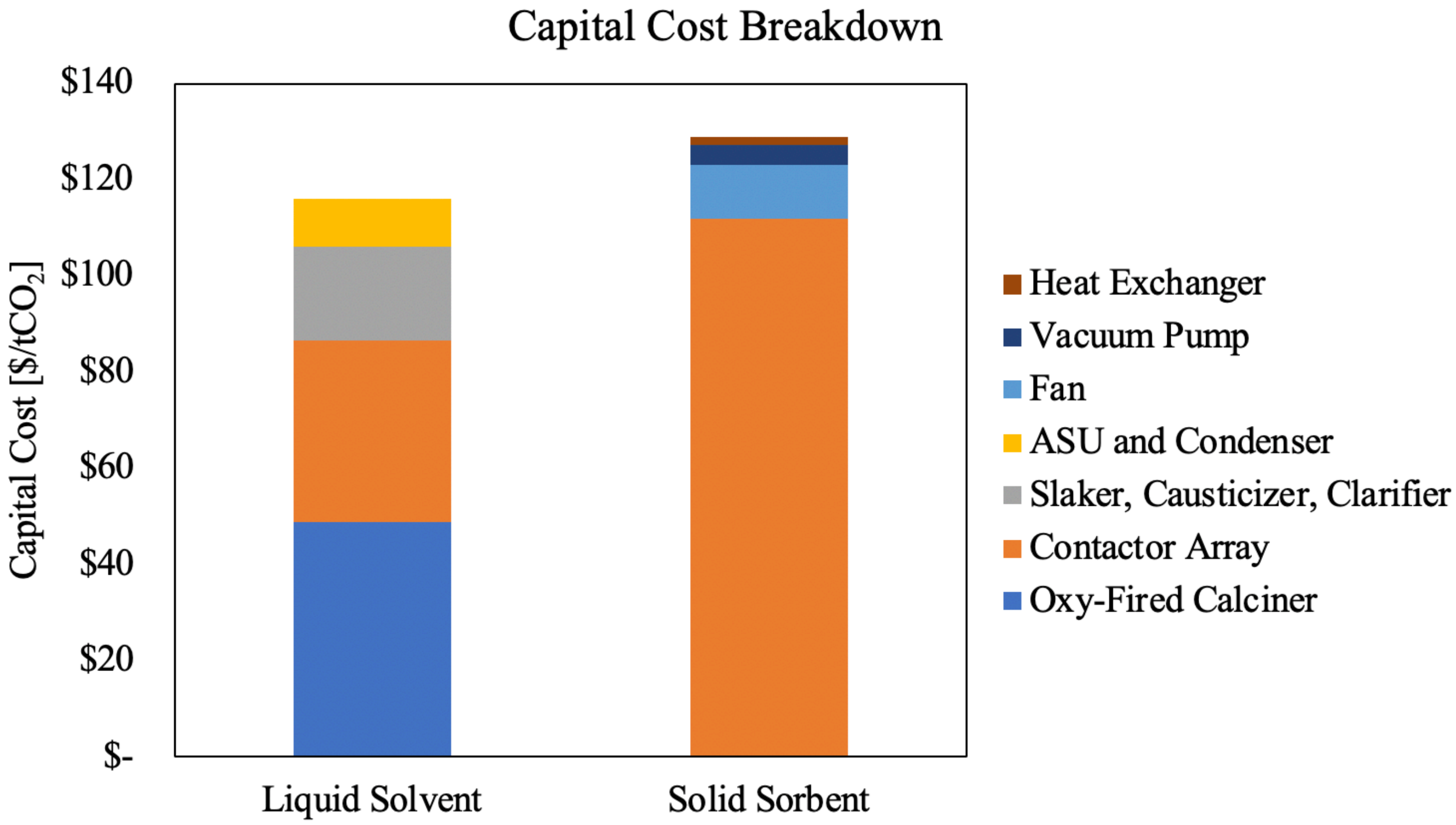
To Design a DAC Plant, you First Need to Design a Power Plant

- 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 $MtCO_2$/yr from air requires 300-500 MW of power!
- Choosing which energy resource to fuel the DAC plant will dictate the net CO_2 removed

Cost Differences - CAPEX







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

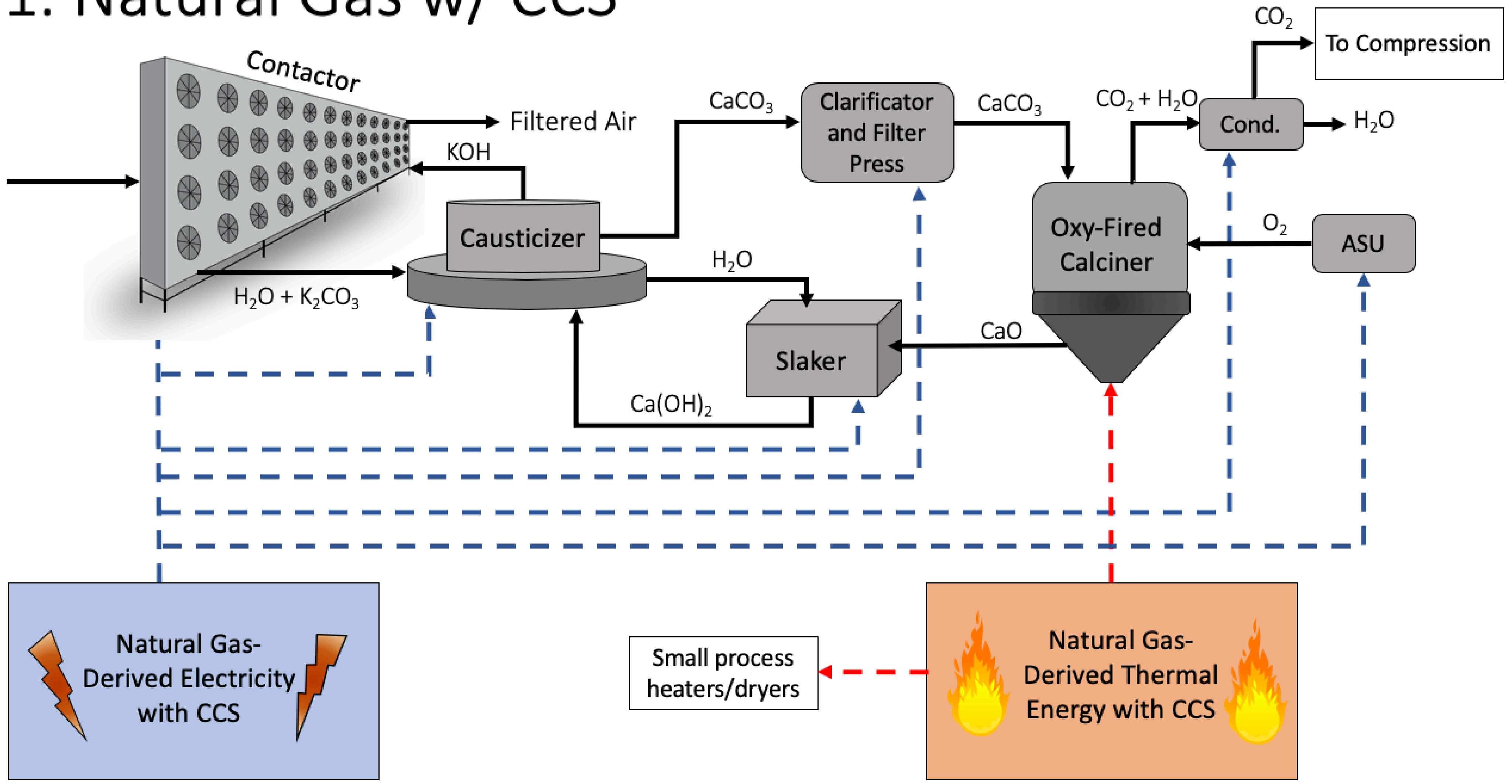
Where does a \$20 billion investment and a cost reduction down to \$100/tCO_2 get us?

This would mean building 200 synthetic forests each capturing 1 MtCO_2 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.

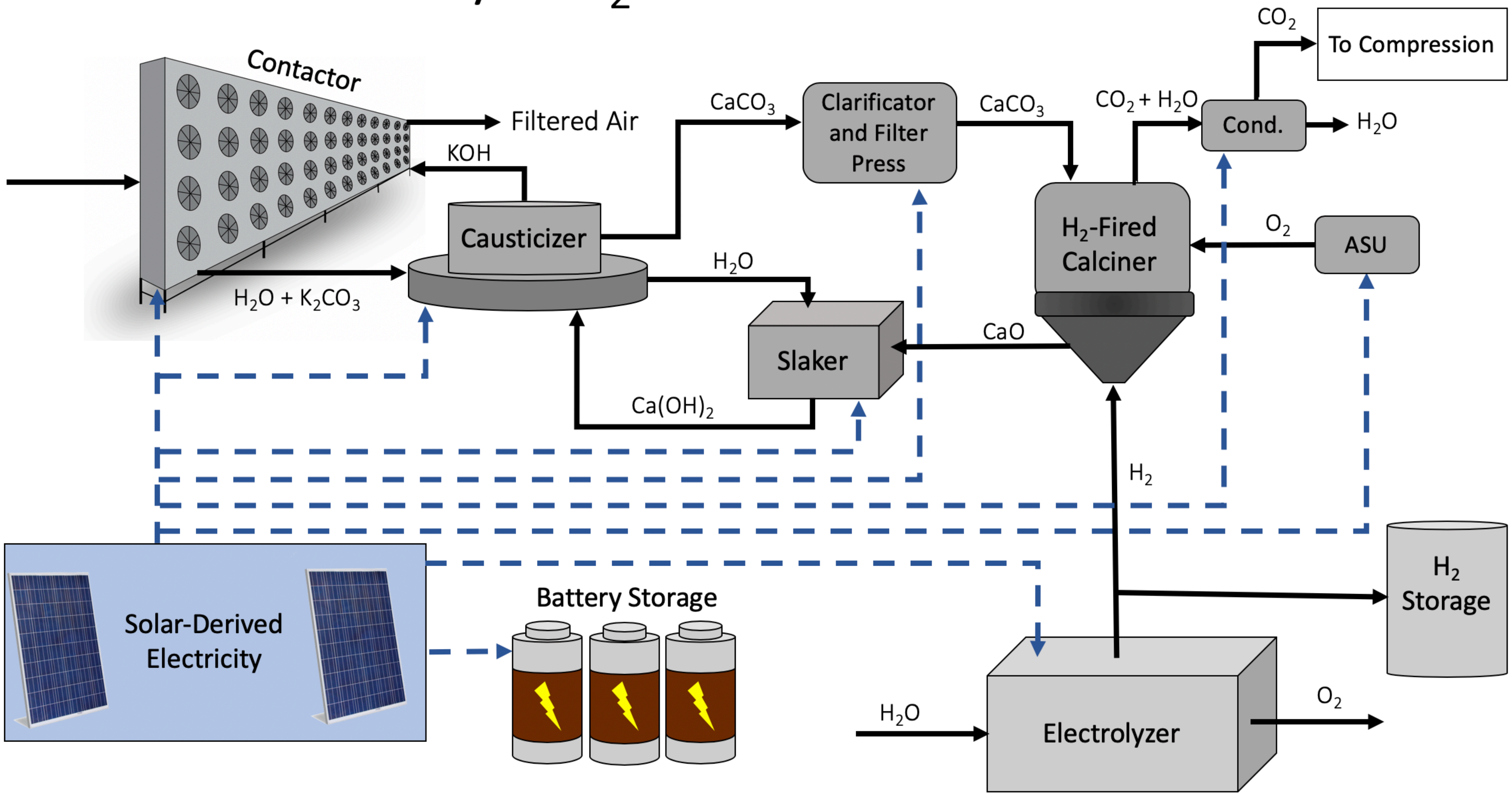
Consider 2 Different Energy System Scenarios

1. Natural Gas w/ CCS



Consider 2 Different Energy System Scenarios

2. Solar Electricity + H_2-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 mi^2

Powered by solar and H_2?

The size of 1/10 of CA roughly 12,000 mi^2

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 < $MtCO_2$/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 $MtCO_2$/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 CO_2 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/