Direct Air Capture

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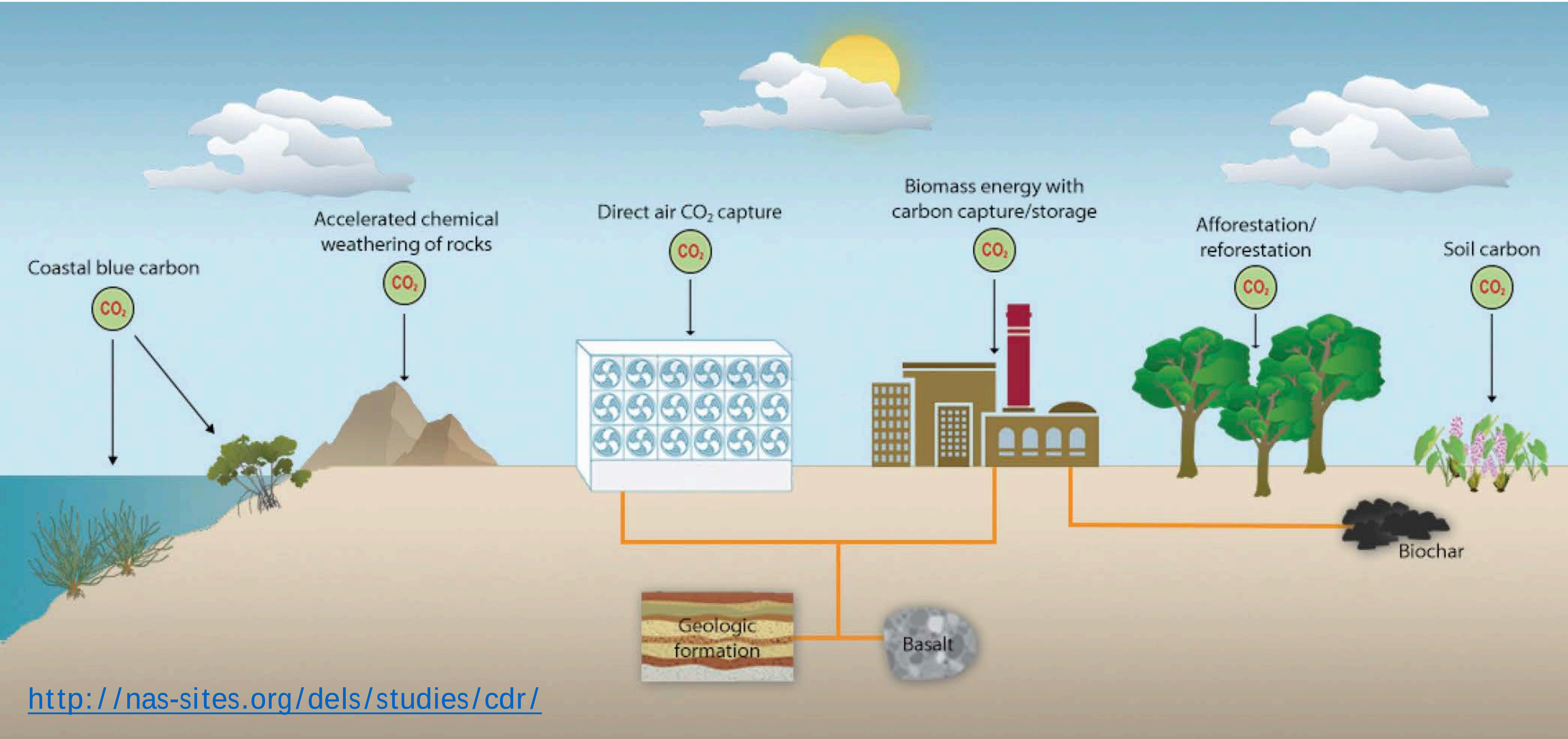
WPI

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

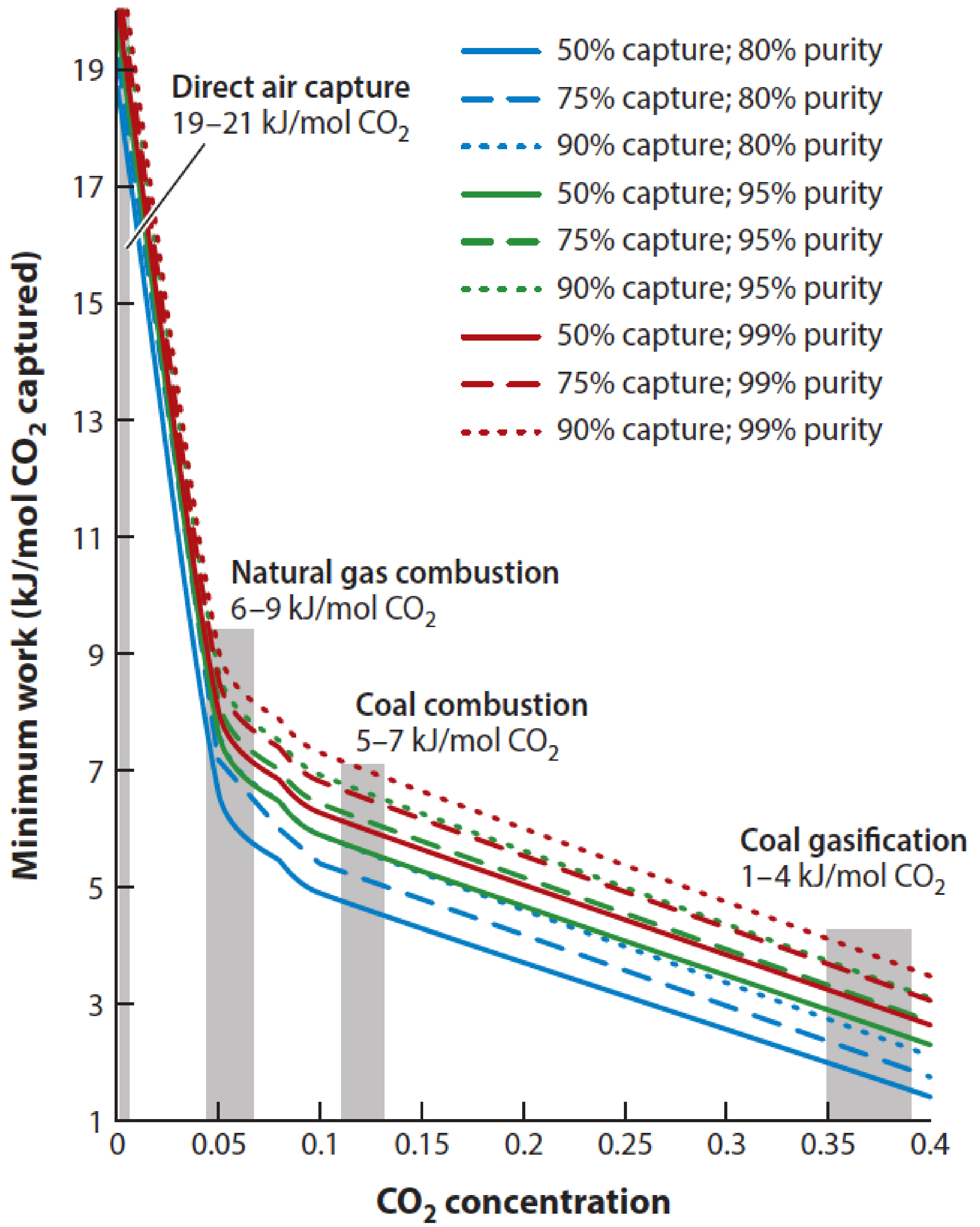
Cons:

- 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

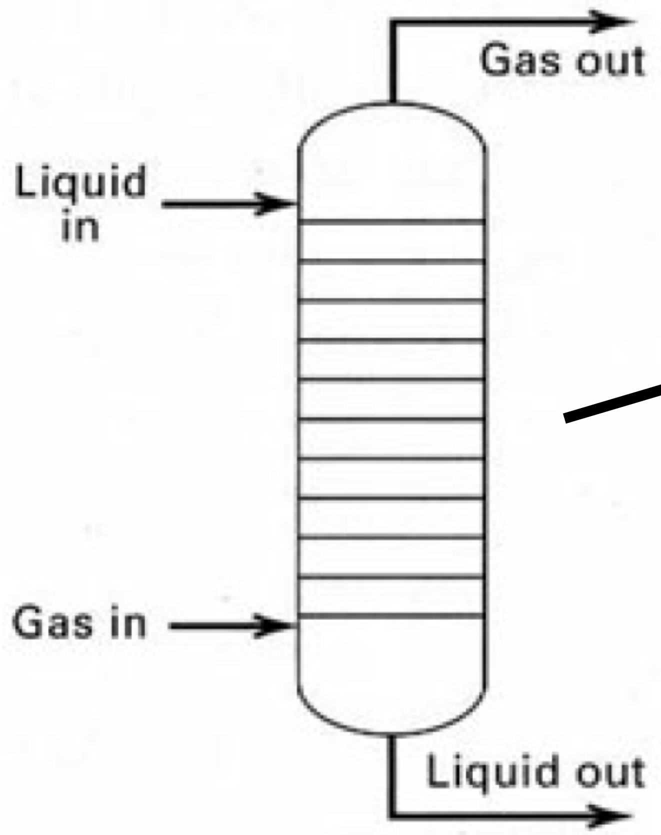


Reference: Wilcox, Carbon Capture, 2012

What Does Scrubbing CO_2 from a Point Source Look Like?

First patent filed by Bottoms in 1930!

"CO_2-free" gas out

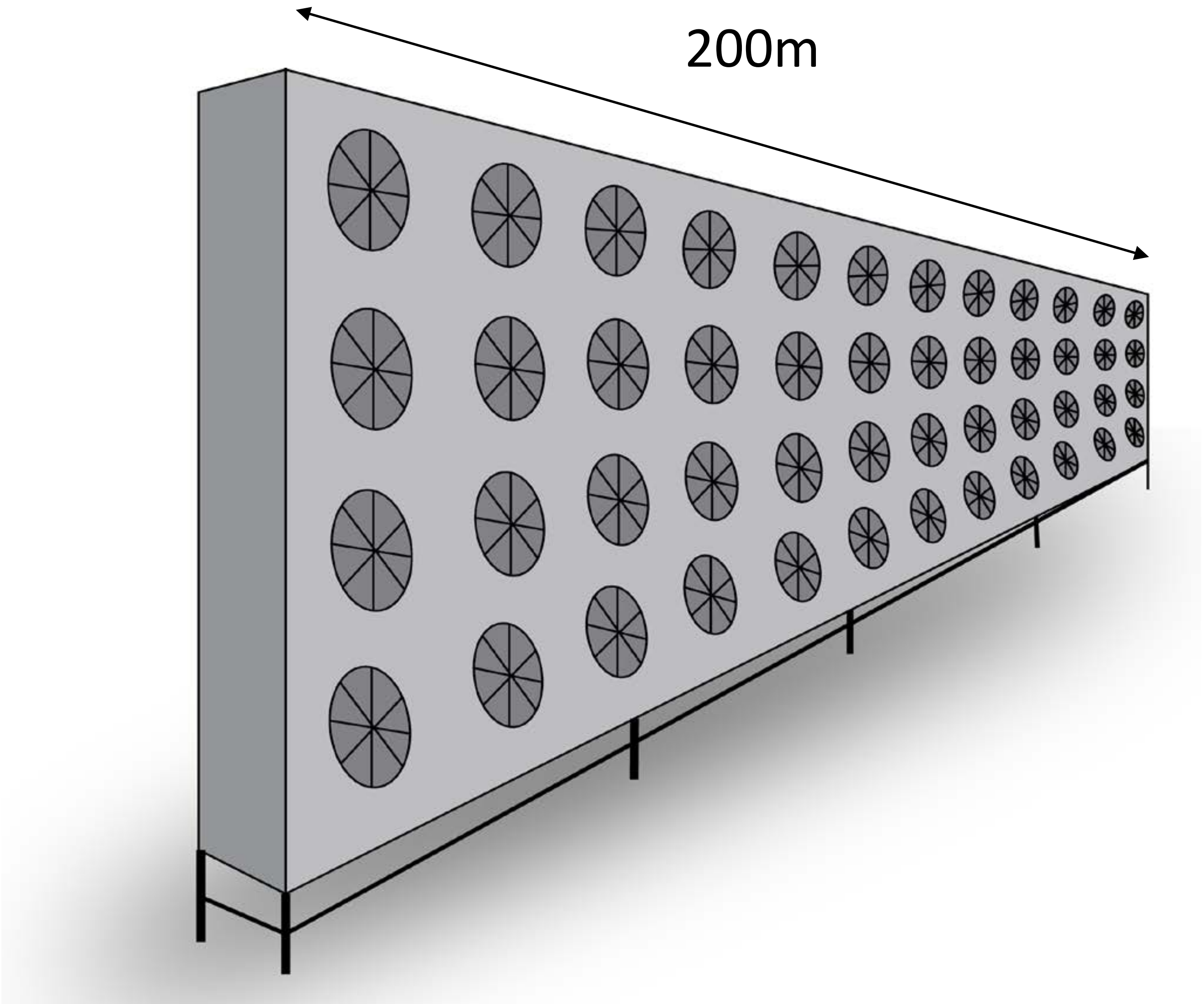


CO_2-loaded solvent out

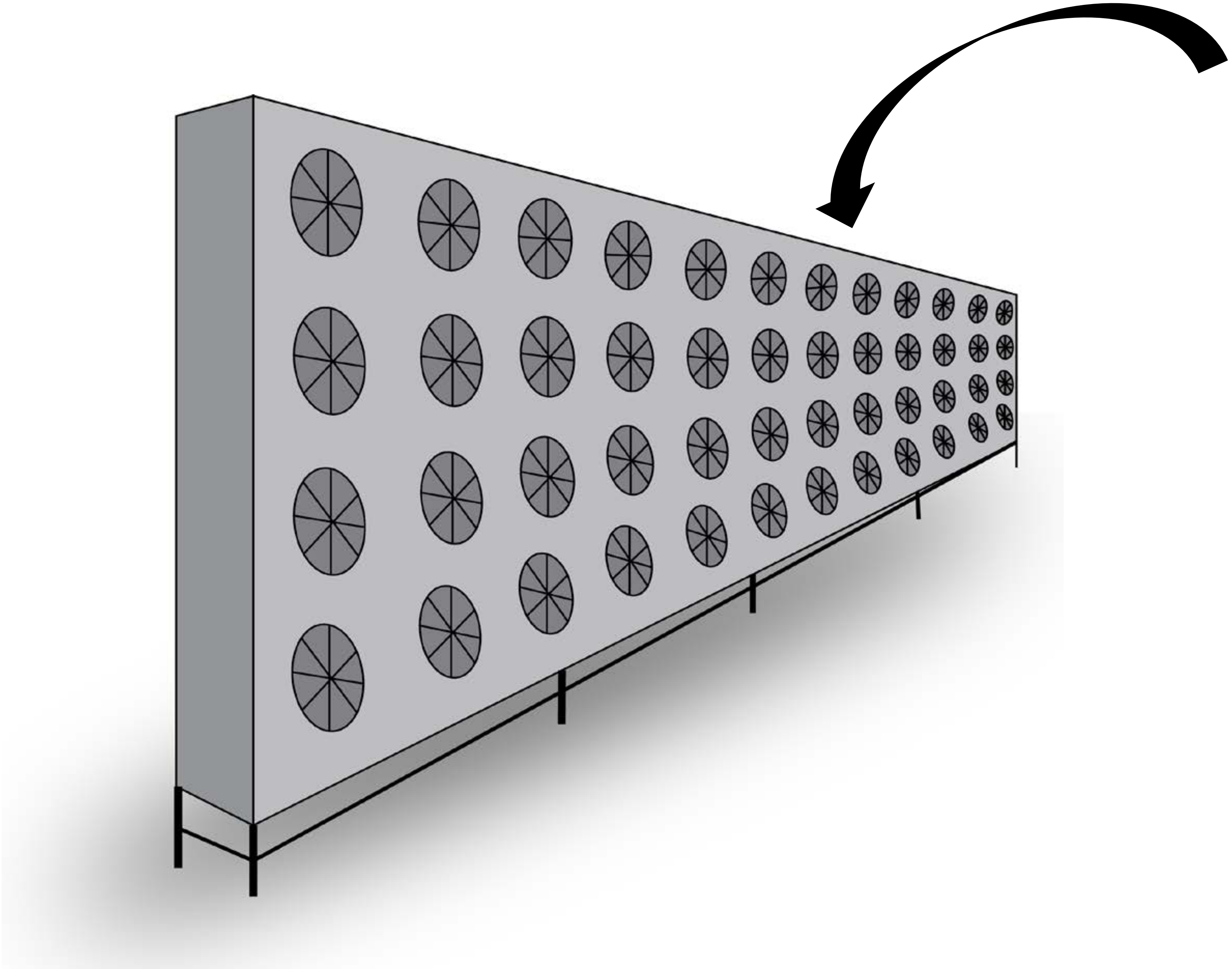
Petra Nova – 1.4 Mt CO_2/year
115 Meters Tall Absorber

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



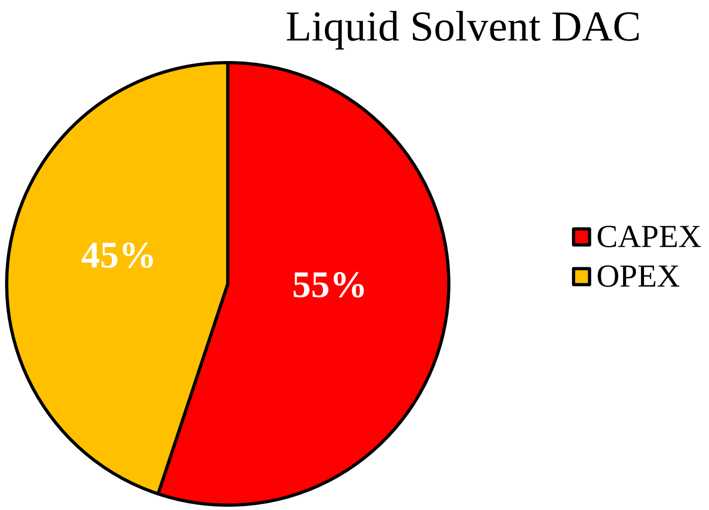
Solvents rely on structured packing with solvent flow over the packing

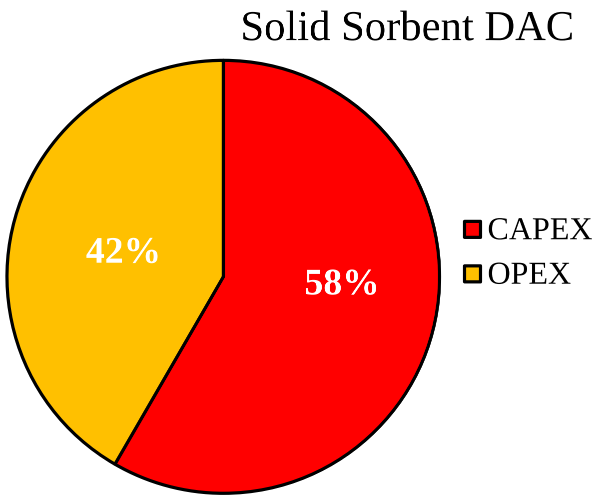
Solid sorbents rely on a honey-comb structure with chemicals (amines) bound to structure

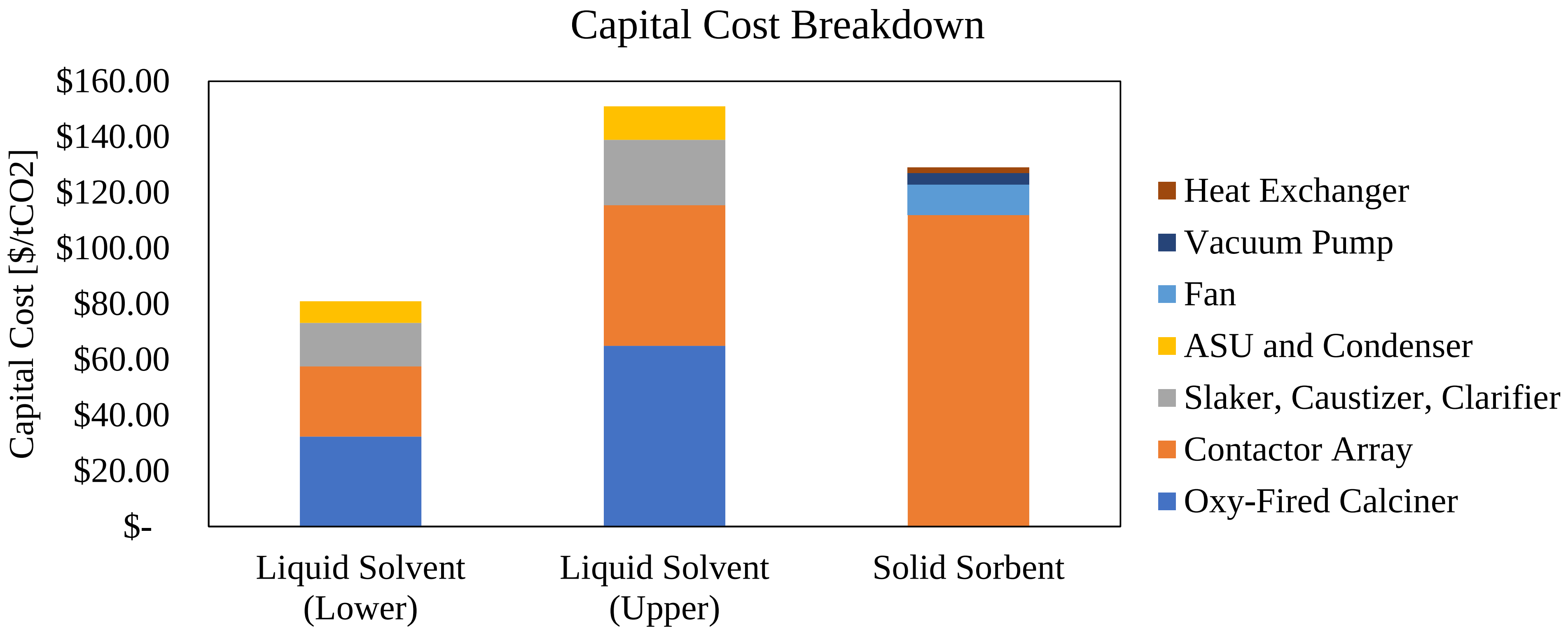
To Design a DAC Plant, you First Need to Design a Power Plant

- 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

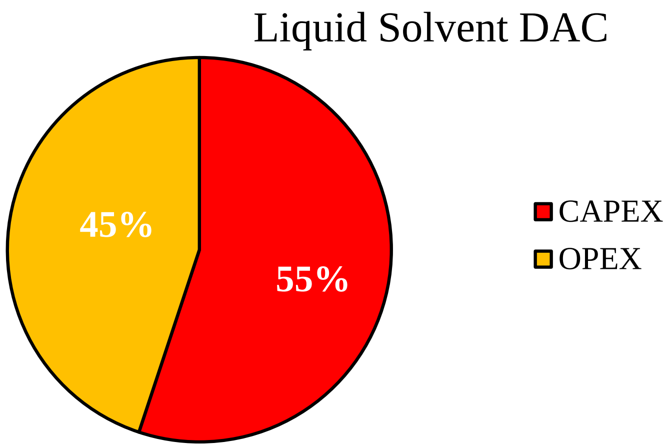


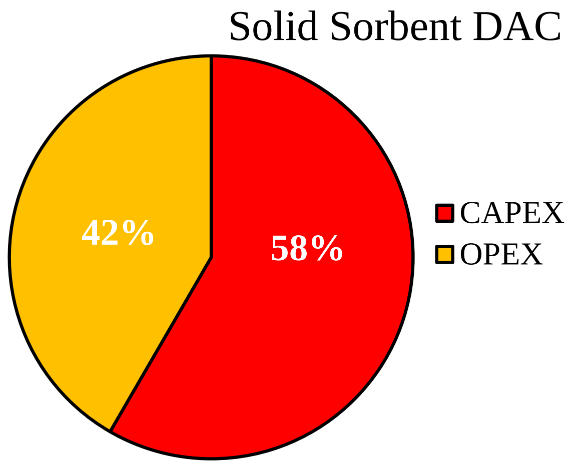


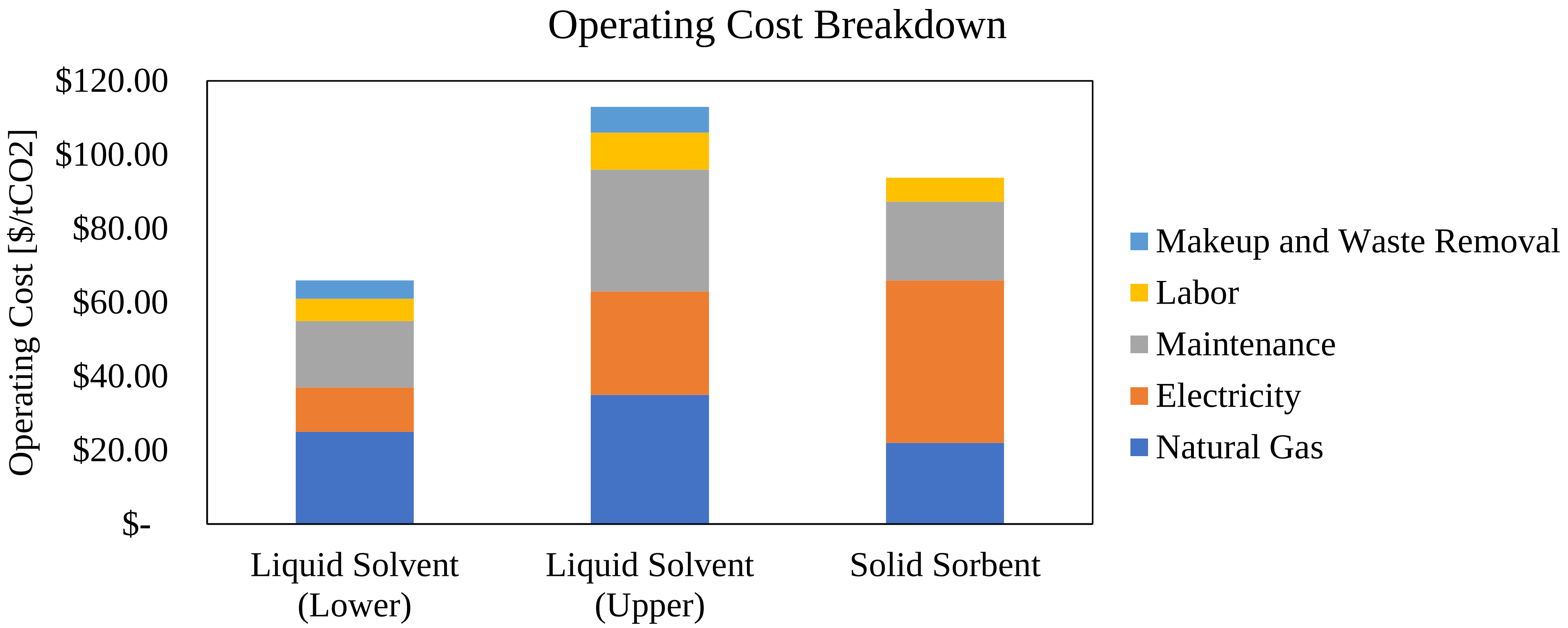


Reference: Pacala et al., NASEM, 2019

Cost Differences OPEX







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

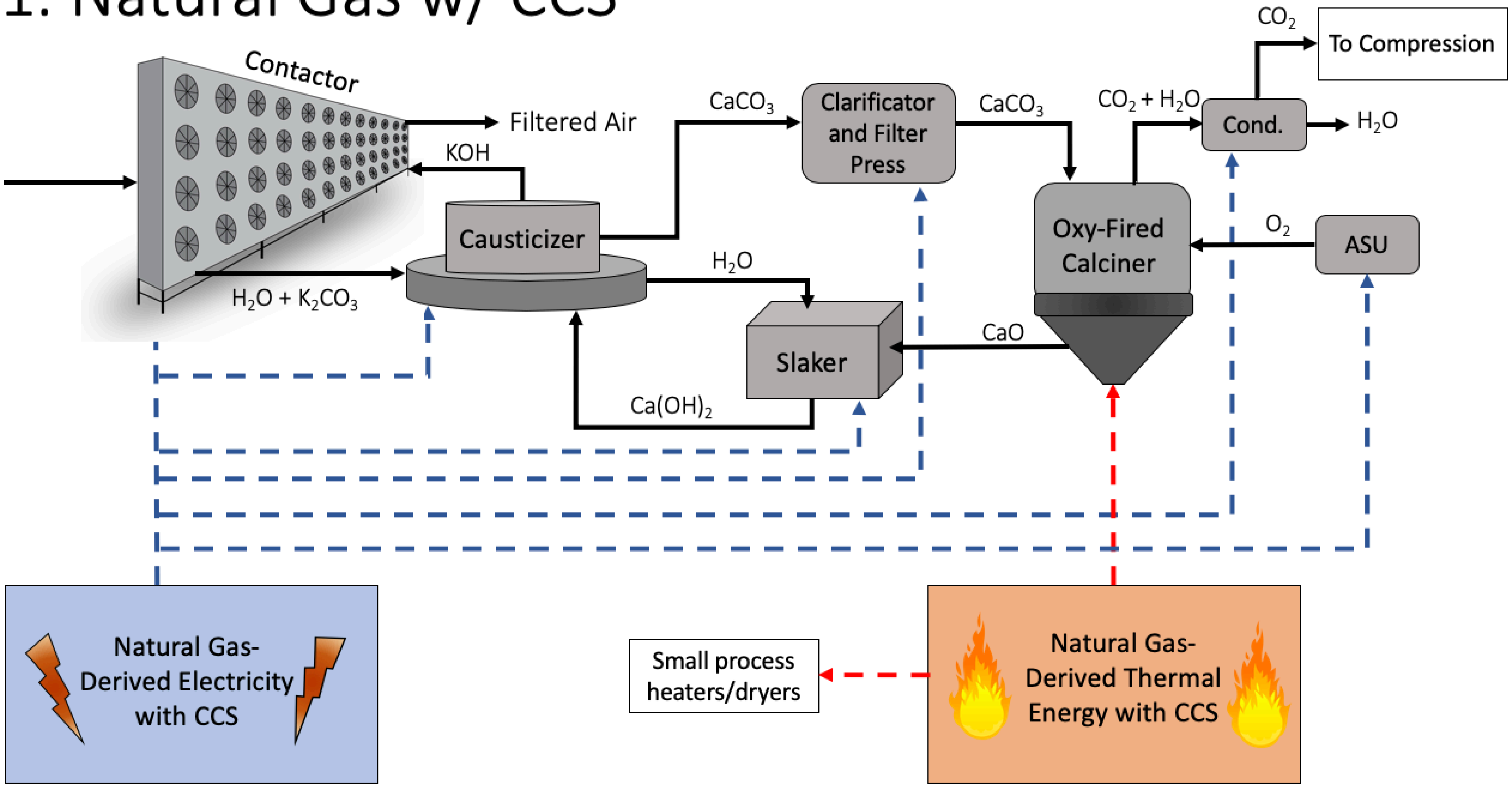
Where does a $20 billion investment and a cost reduction down to $100/t$CO_2$ get us?

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.

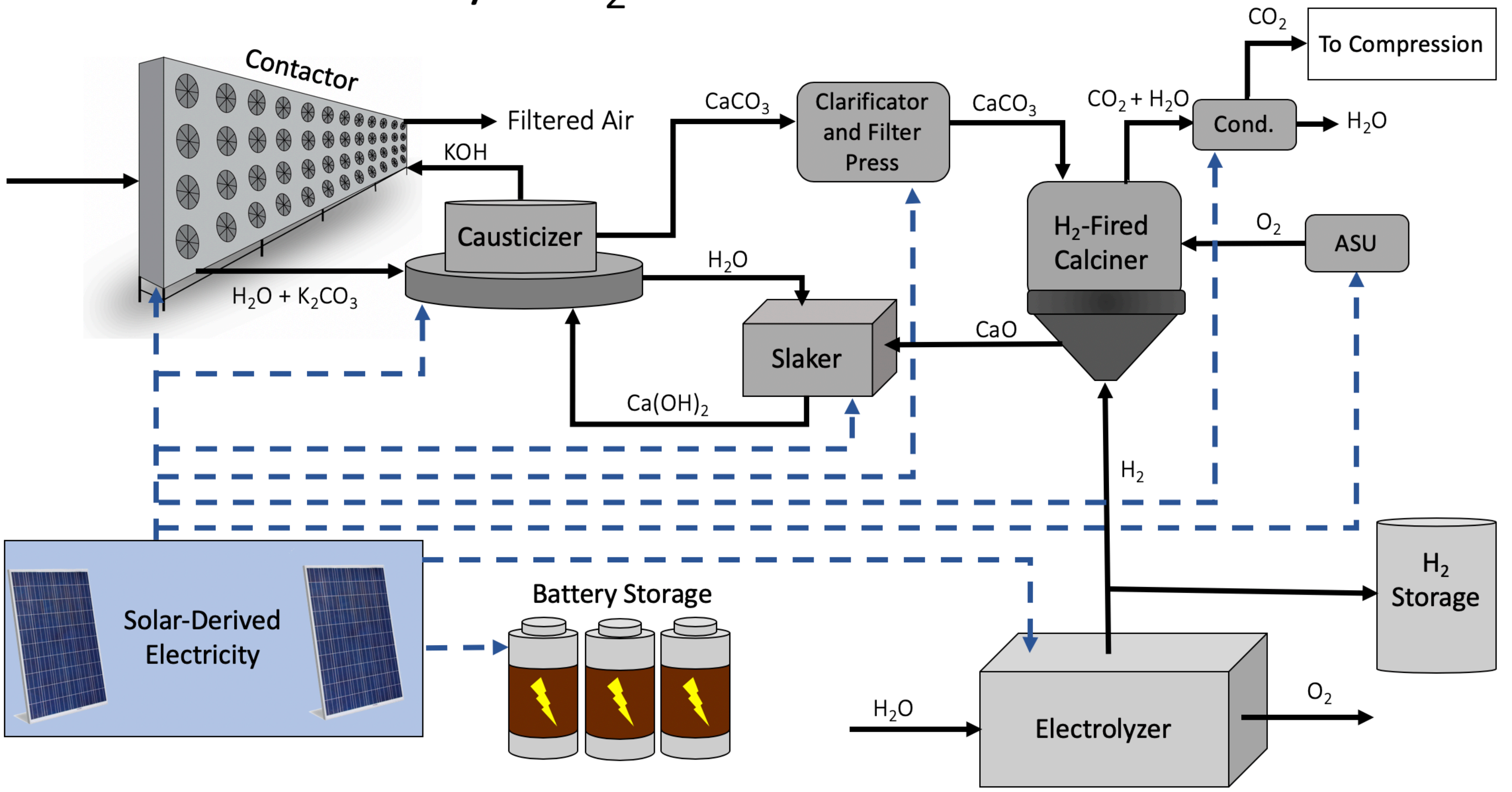
Consider 2 Different Energy System Scenarios

1. Natural Gas w/ CCS

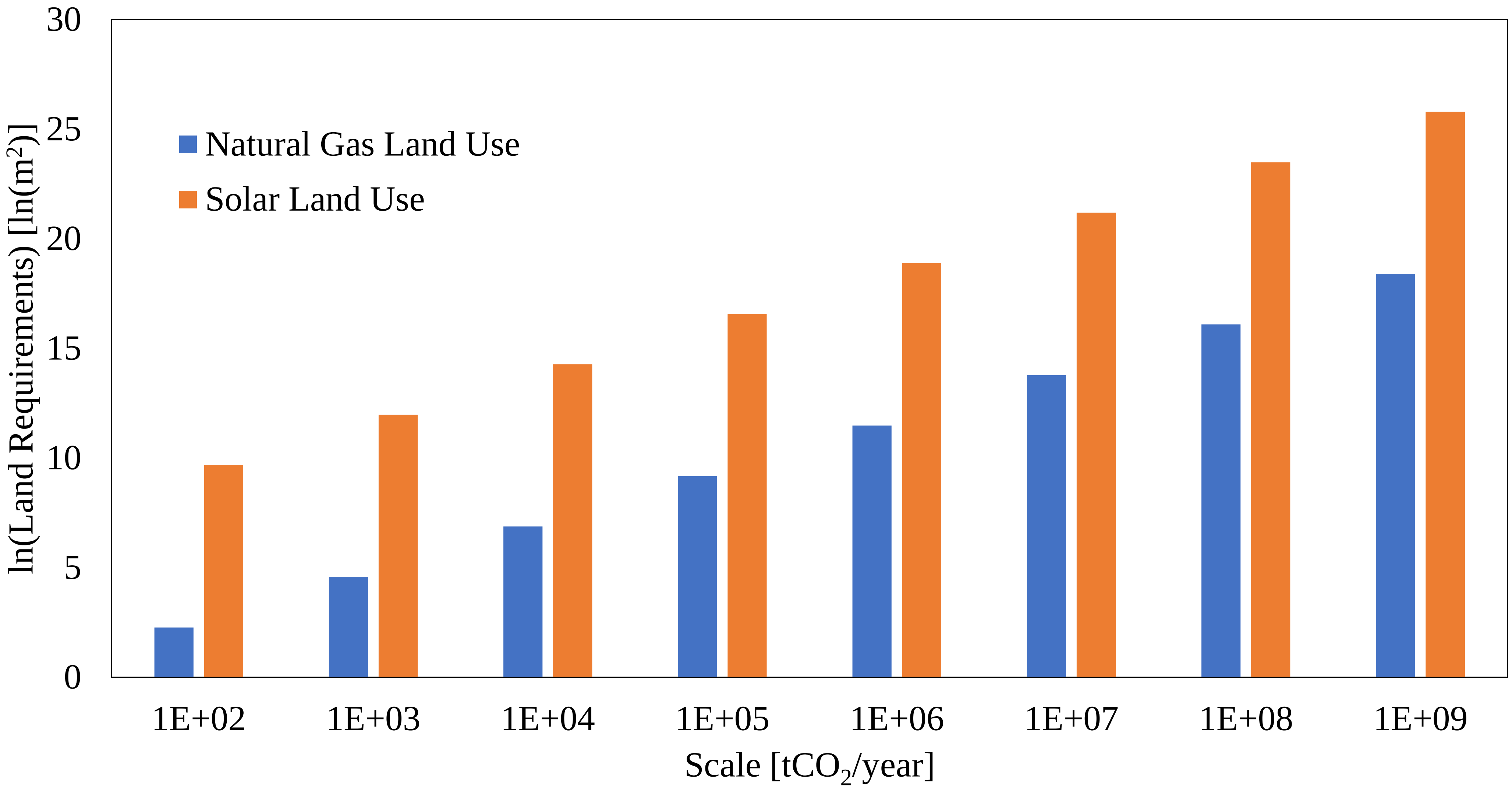


Consider 2 Different Energy System Scenarios

2. Solar Electricity + H_2-Fired Kiln



Natural gas and solar land requirements



Capturing 200 million tonnes from the air?

Powered by natural gas with CCS?

200 DAC plants = 1/2 land area of Washington D.C. roughly 37 mi^2

Powered by solar and H_2?

The size of Maryland roughly 12,400 mi^2

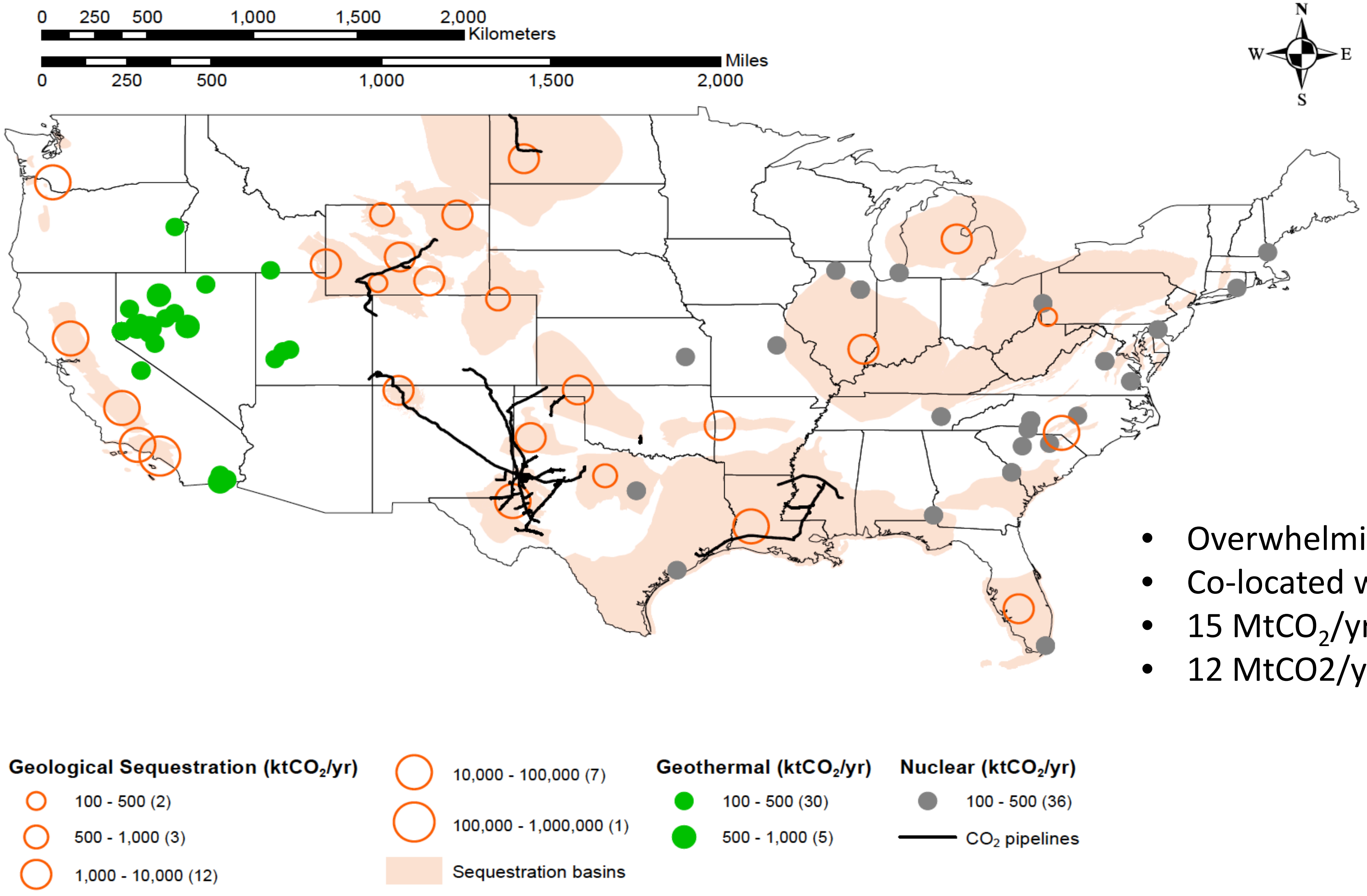
DAC Siting Low-Carbon Available Thermal Energy

Results of a Recent Study from Our Team

- Regardless of the technology (solvent or sorbent), the energy distribution is 80% thermal and 20% electric for DAC
- Solid sorbent selected due to low-quality of thermal energy required (i.e., 100 °C)
- Thermal we're considering from 3 pathways:
  - Geothermal – "waste" heat
  - Nuclear – 5% slipstream of steam
  - Stranded natural gas - avoided flare gas
- Beneficial Reuse: EOR and beverage bottling industry
- Geologic Storage: USGS basin-level storage
- Ultimate Goal: delivered cost of compressed CO_2 at 99% purity in light of 45Q
- Electricity prices and carbon intensity based upon grid mix of a given DAC site
- Careful of Definitions:
  - Cost of Capture – "break-even cost"
  - Cost of CO_2 Avoided – considering fossil-based energy to fuel DAC
  - Cost of CO_2 Produced – combining point-source capture with DAC
  - Cost of Net Removed CO_2 – true cost from climate's perspective

Reference: Wilcox et al., under review PNAS (2019)

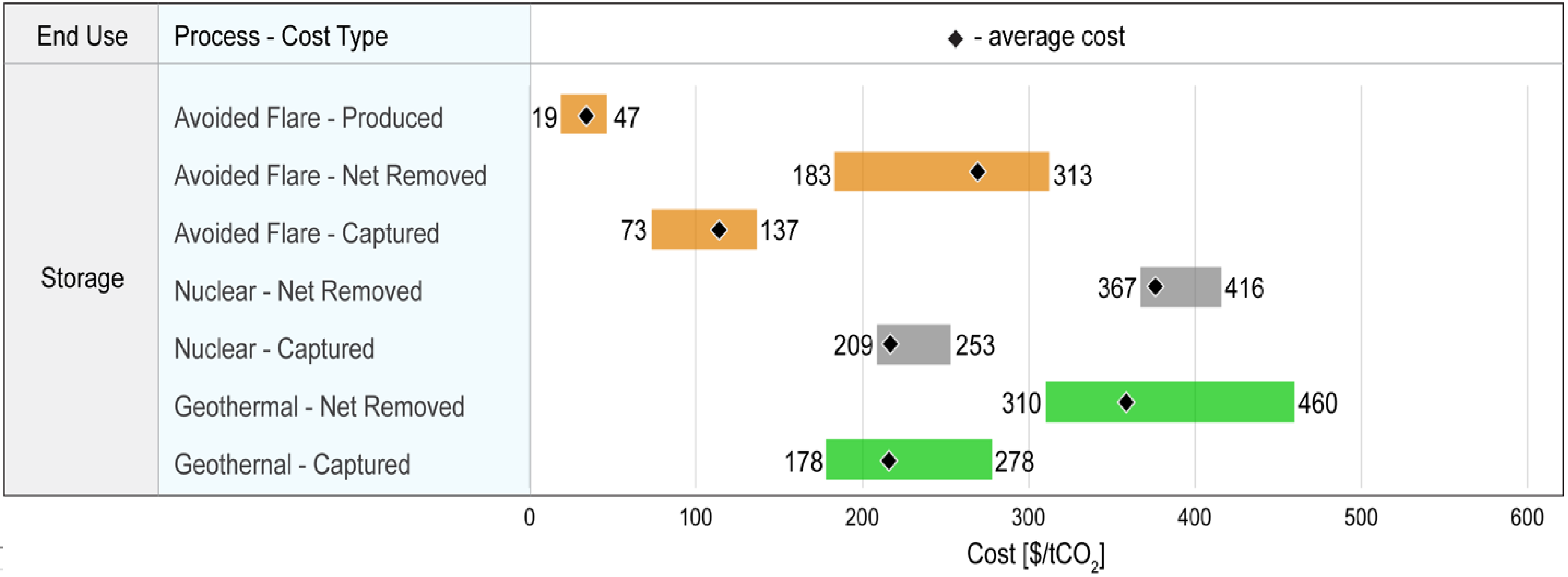
Geological Sequestration – satisfying the 45Q criteria, i.e., > 100 ktCO_2/yr

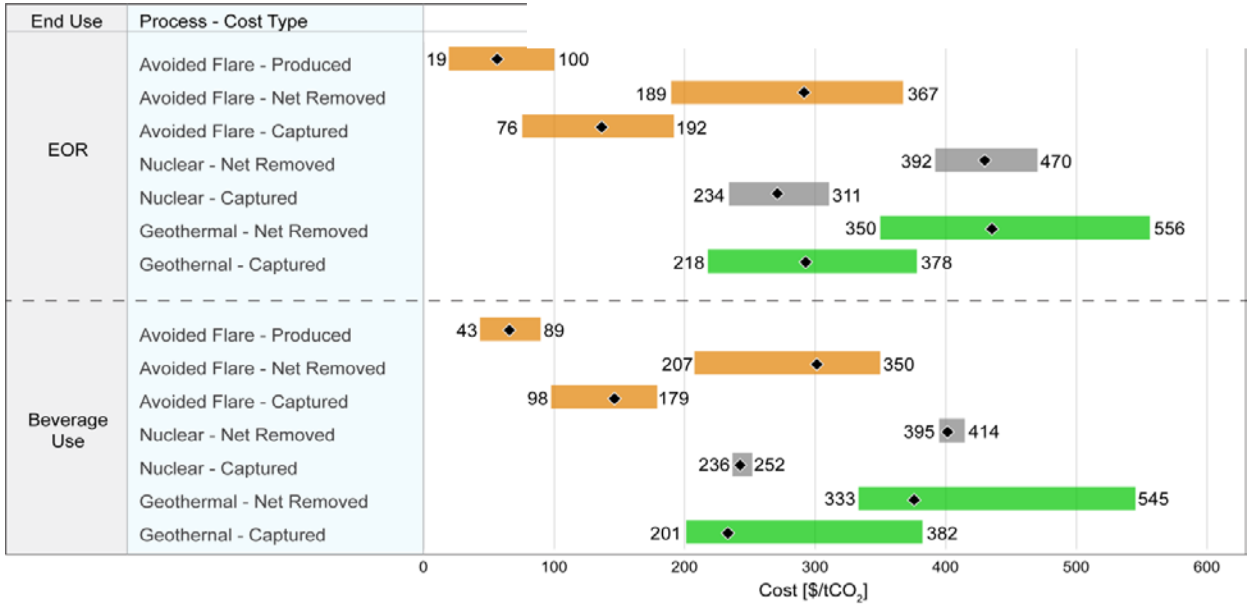


- Overwhelming sequestration potential
- Co-located w/ geothermal and stranded NG
- 15 MtCO_2/yr satisfy 45Q
- 12 MtCO2/yr do not satisfy 45Q

Reference: Wilcox et al., under review PNAS (2019)

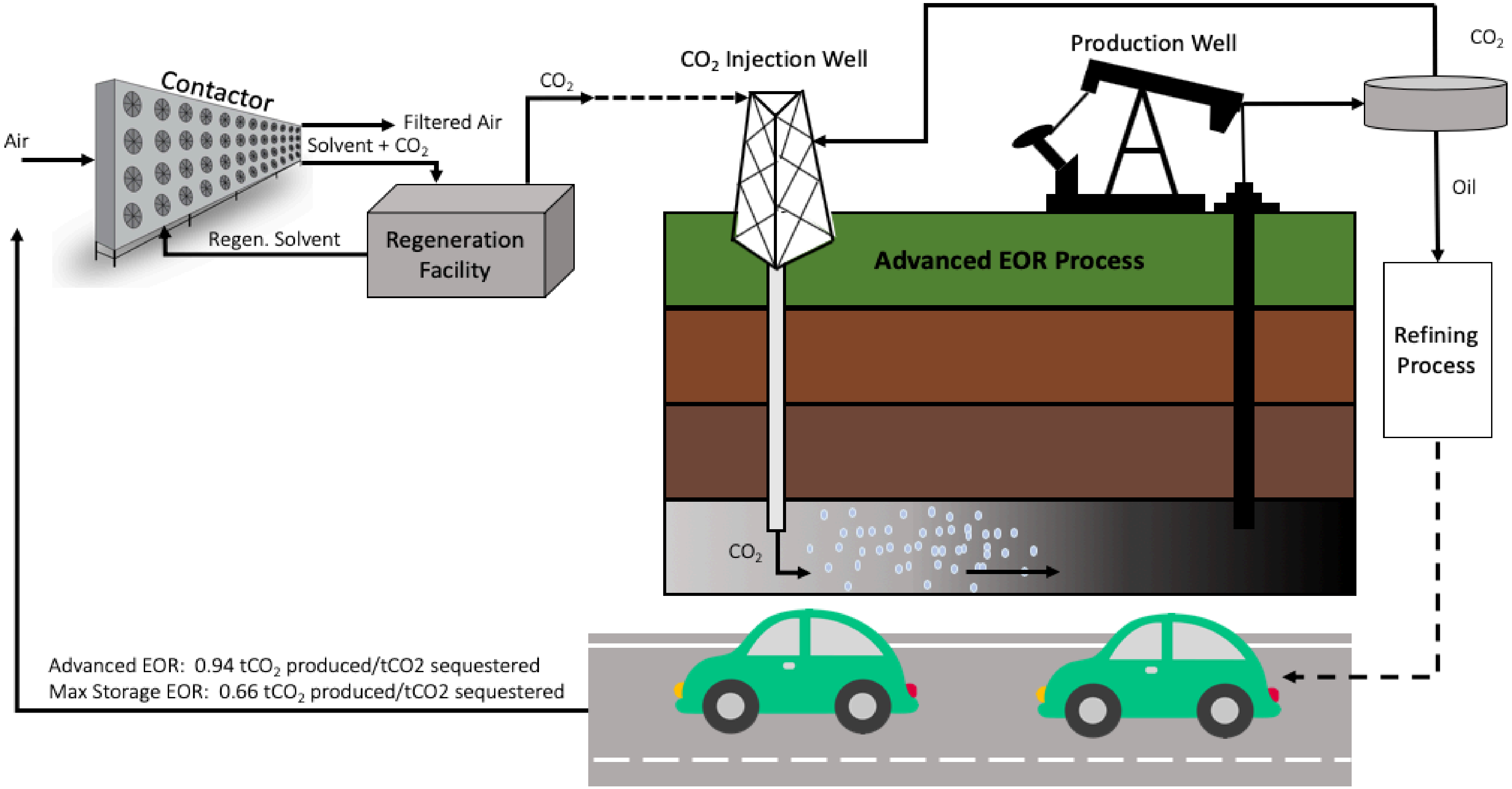
Costs of Geologic Storage





What Would it Take for CO_2-EOR to be Negative?

- CO_2-EOR started in 1972 with the first project in the Permian Basin
- Utilization market is ~ 80 $MtCO_2$/yr compared to 3 $MtCO_2$/yr for beverage industry
- Depends on strategic operational choices, which may shift based on a tax credit or carbon market

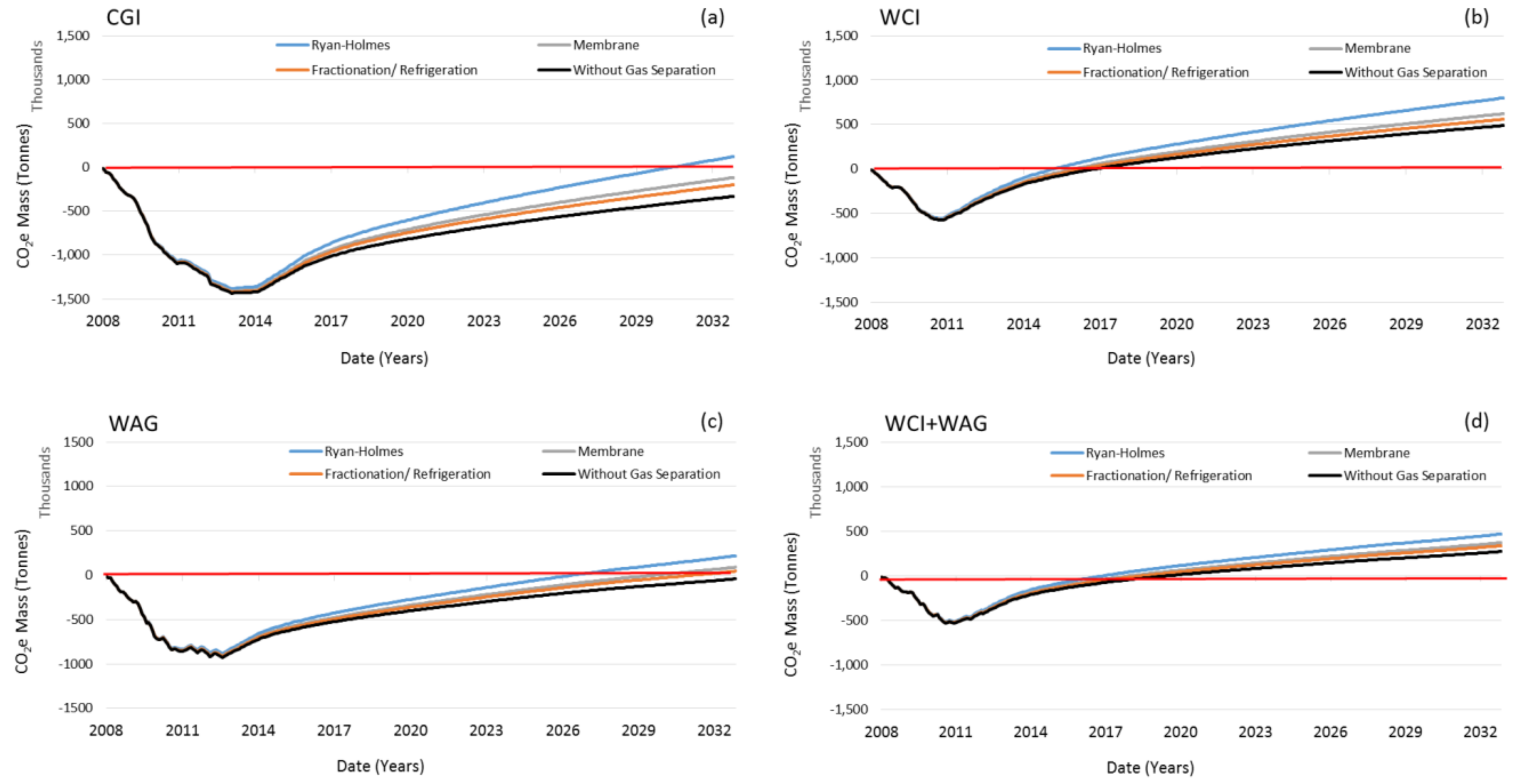


Reference: 2015, IEA Report, Storing CO_2 through Enhanced Oil Recovery

IEA's Maximum Storage EOR+

- Excess CO_2 from the separation facility is injected into an underlying saline aquifer
- Note that all approaches are negative in the early years of the project.

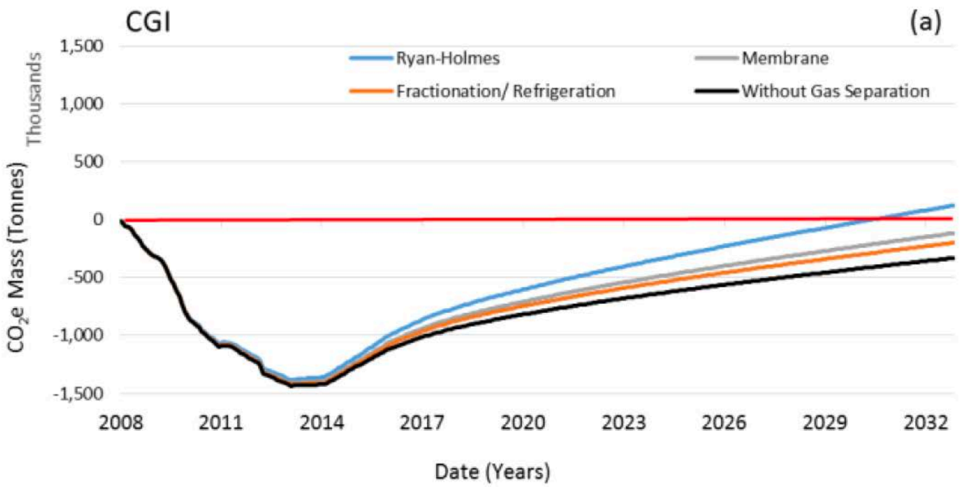
a) Continuous gas injection
b) Water curtain injection
c) Water alternating gas
d) Hybrid WAG + WCI

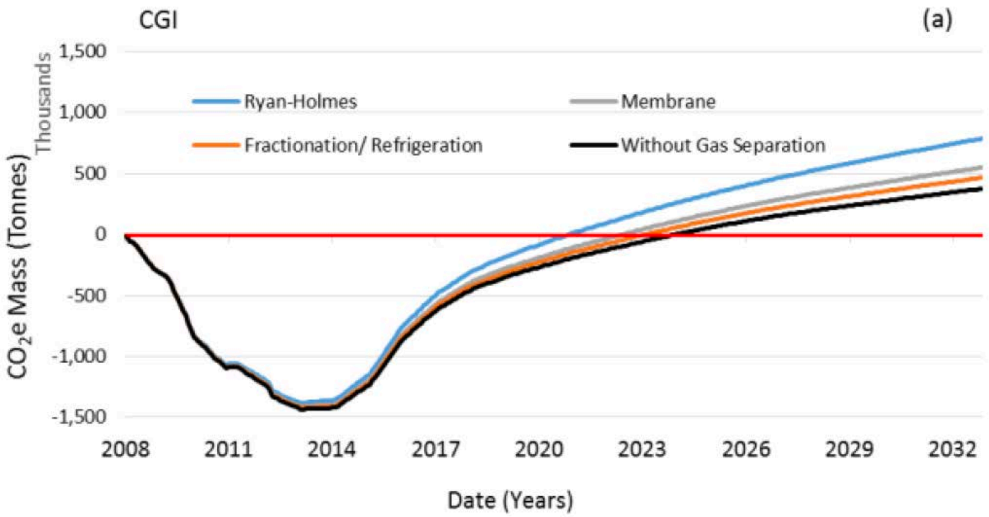


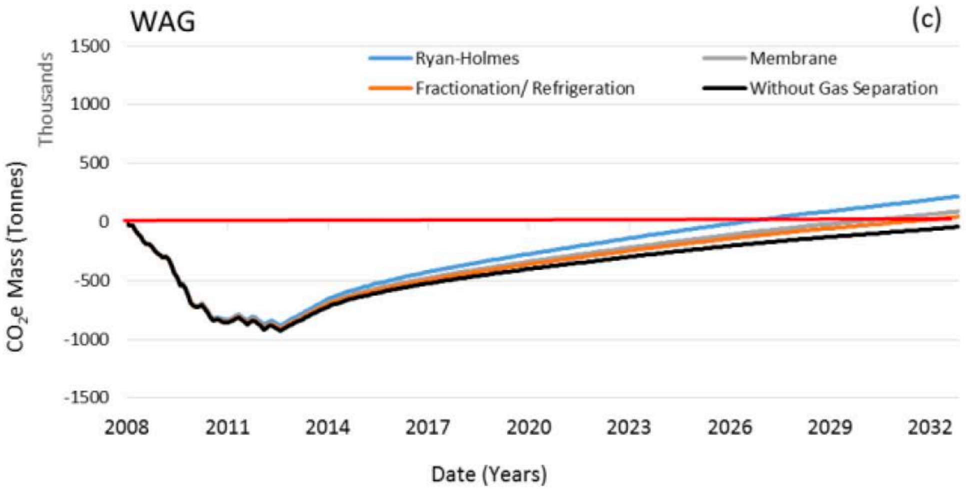
Reference: Nunez-Lopez, *Frontiers Climate, Negative Emissions Technologies*, 2019; Study associated w/ Cranfield field, a 3,000m deep reservoir in Mississippi

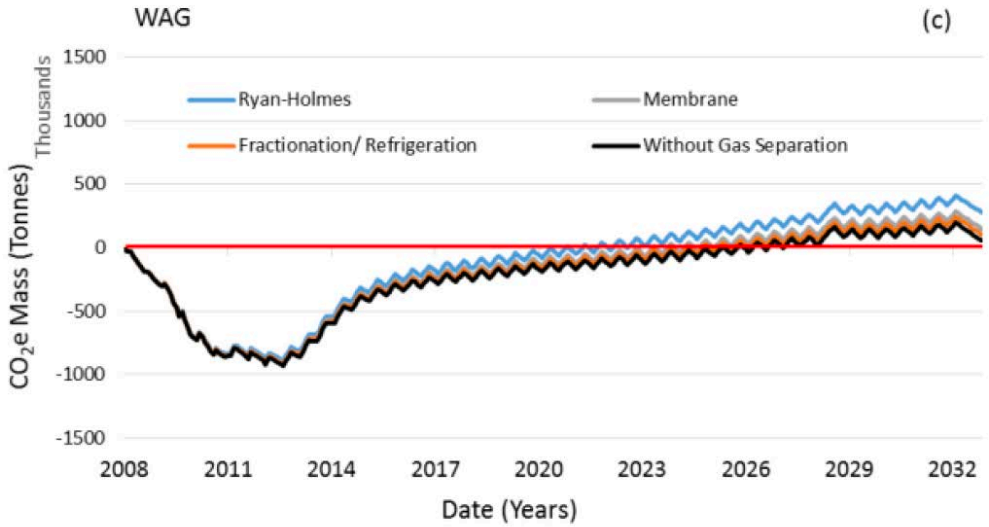
IEA's Maximum Storage EOR+

"Conventional EOR"









Reference: Nunez-Lopez, *Frontiers Climate, Negative Emissions Technologies*, 2019

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:

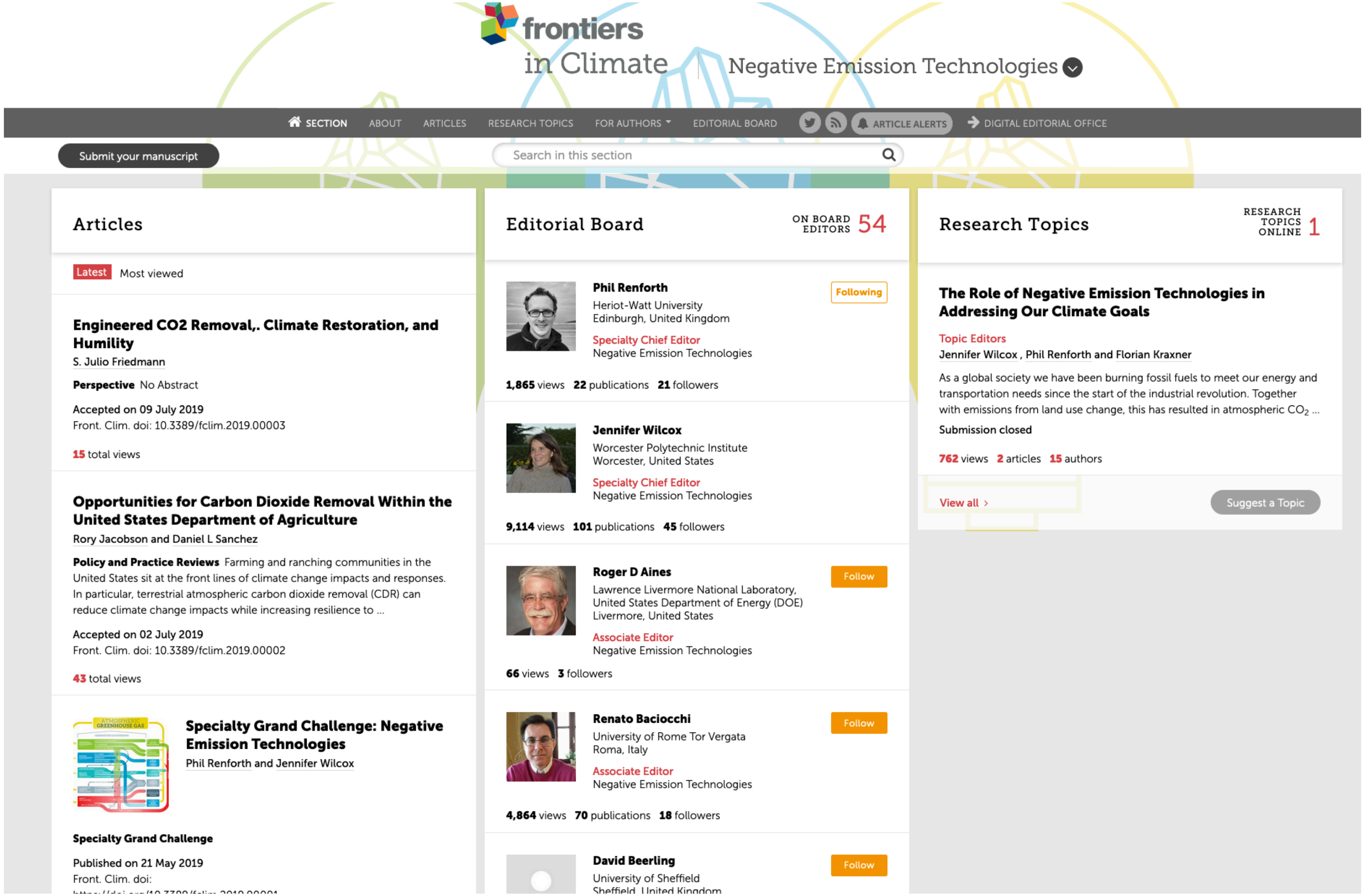
https://users.wpi.edu/~jlwilcox/

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/

Study will be published in New Journal on NETs – Open-Access



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https://www.frontiersin.org/journals/climate/sections/negative-emission-technologies#

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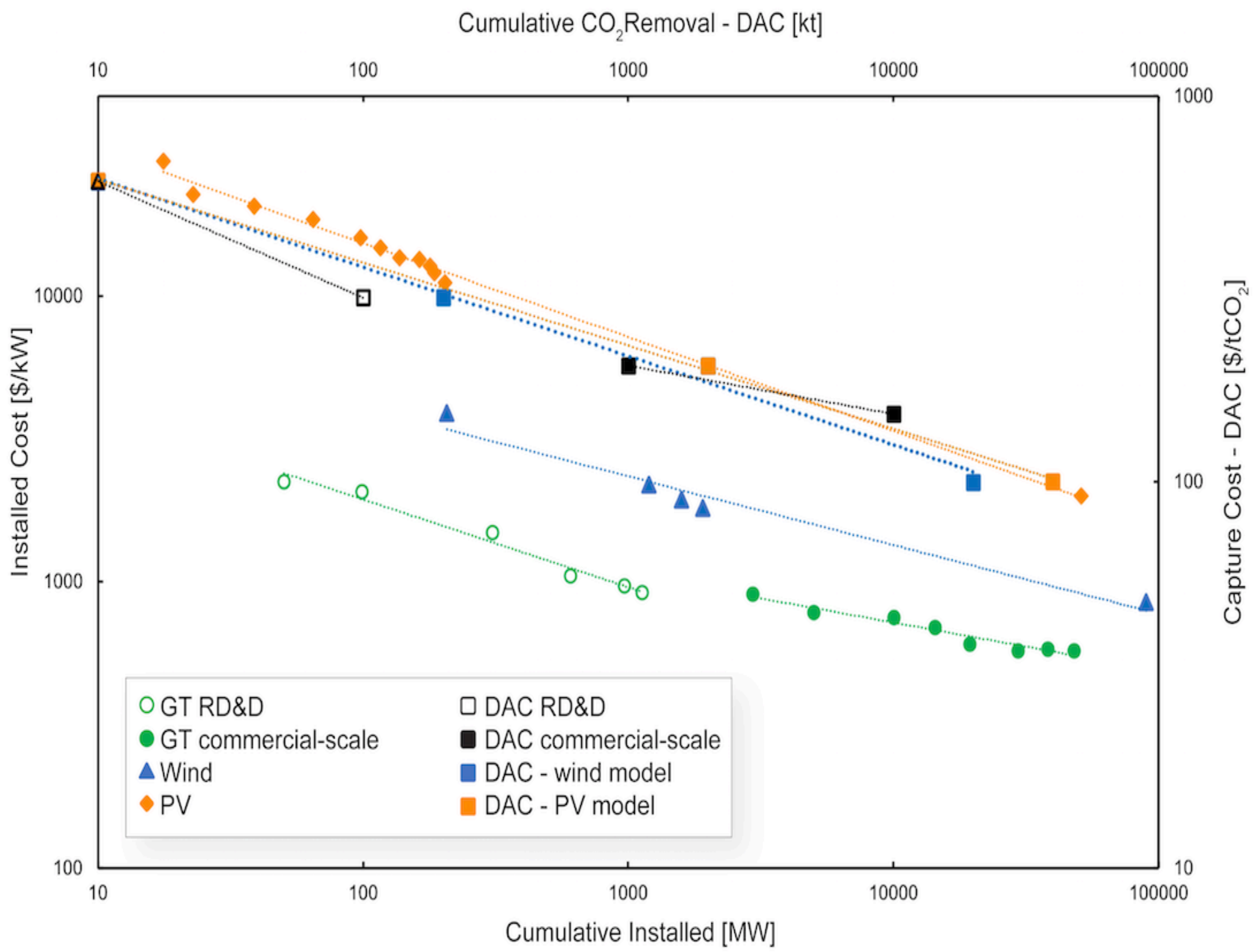
How Might we Get to a Gigaton by Mid Century?

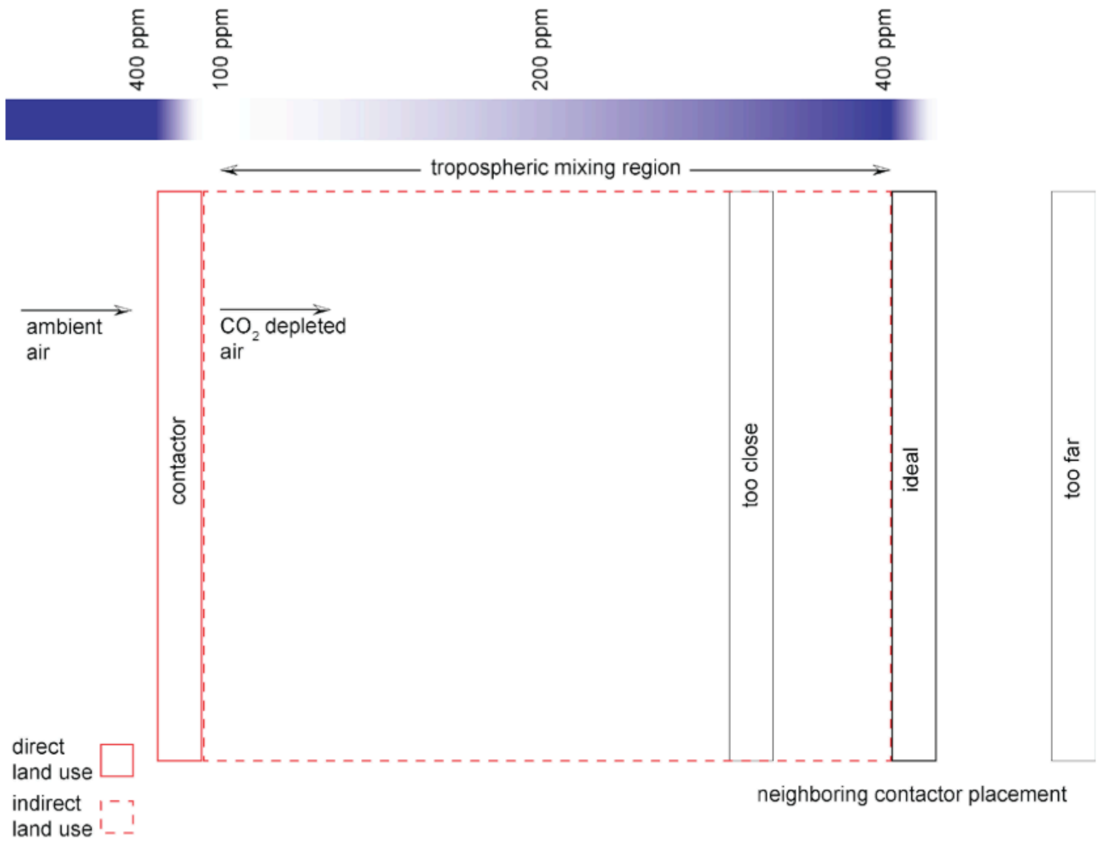


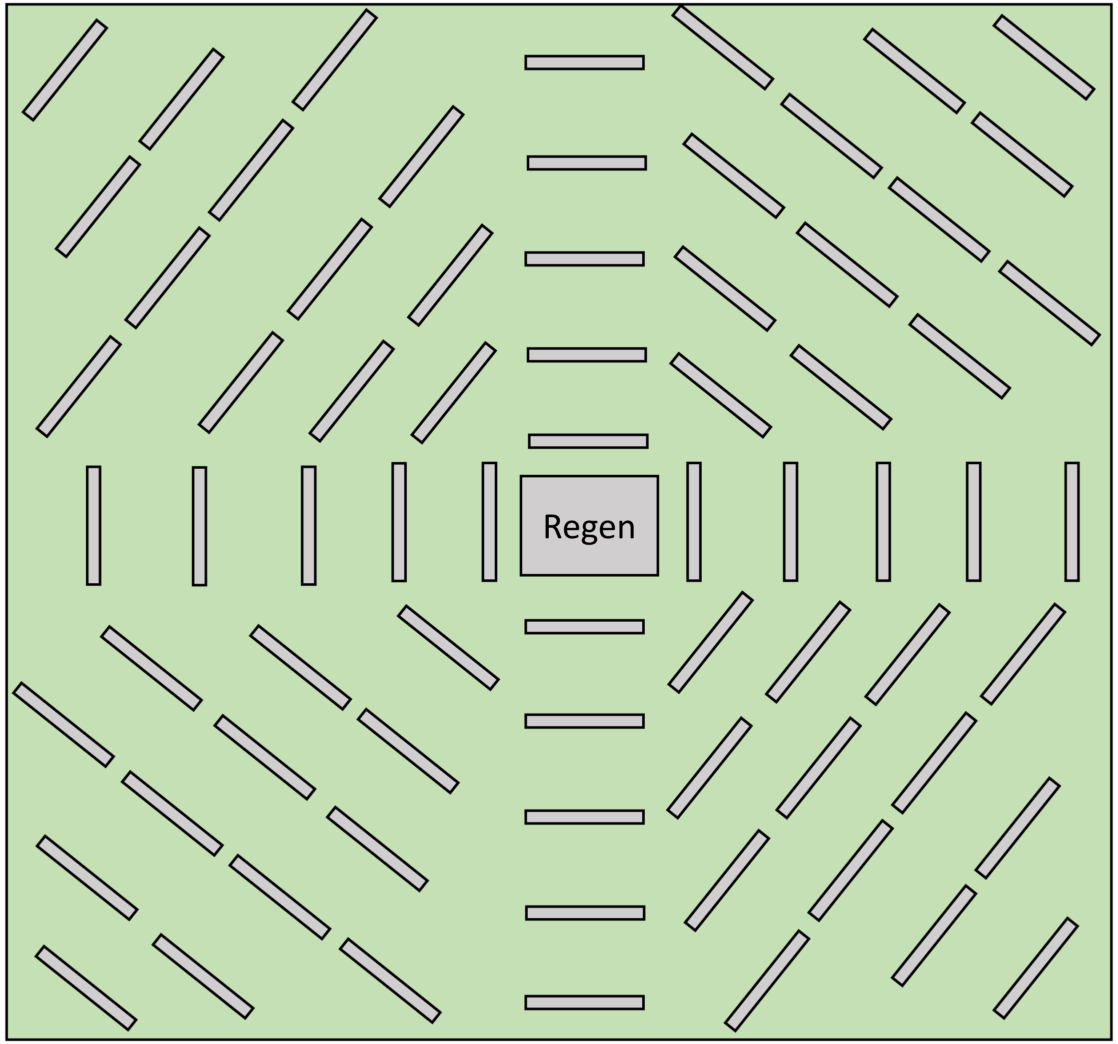
Technology	Experience Rate (%)
PV	25
Wind	18
Gas Turbine RD&D	23
Gas Turbine -commercial	12
DAC – learning by doing	
RD&D	23
commercial	9
DAC – wind model	17
DAC – solar model	25

- PV Model - $100 by 2040 – 40 MT – 1 Gt by 2050
- Wind Model - $100 by 2050 – 20 MT – 1 Gt 2070
- Conventional - $100 by 2060 – 100 MT - 1 Gt 2070

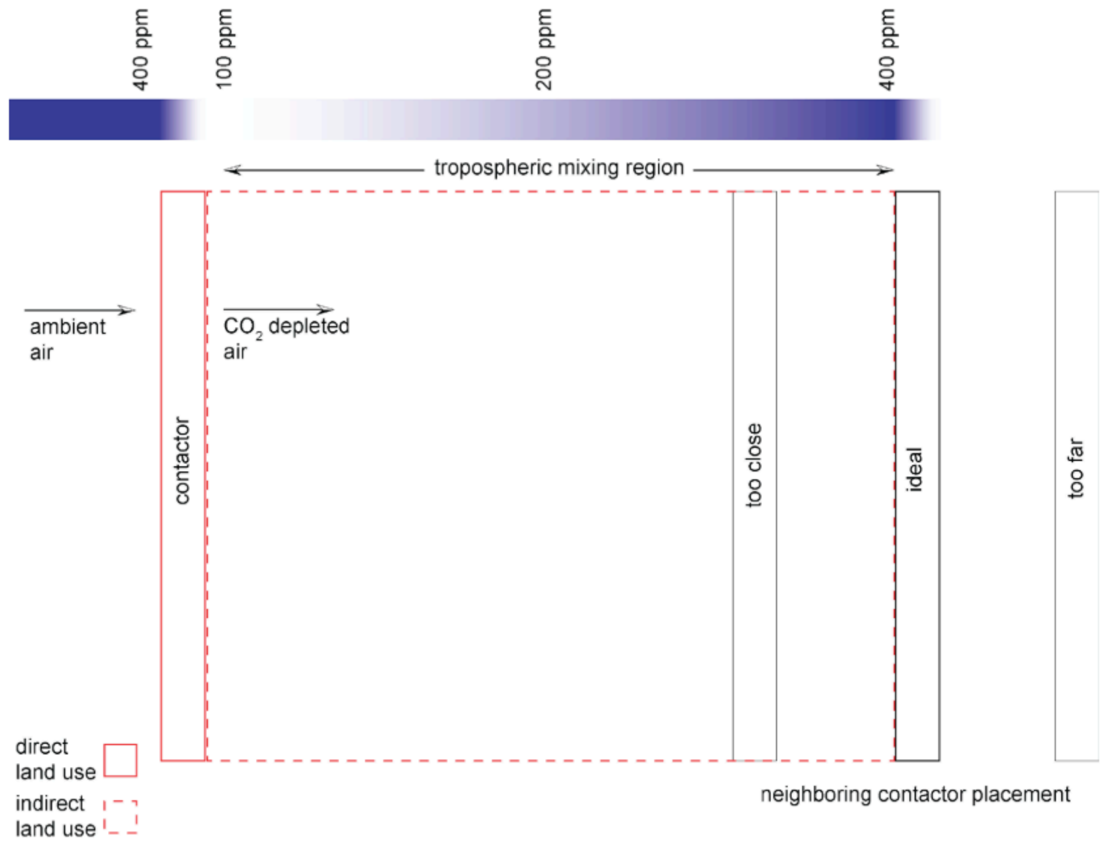
Reference: Wilcox et al., under review PNAS (2019)

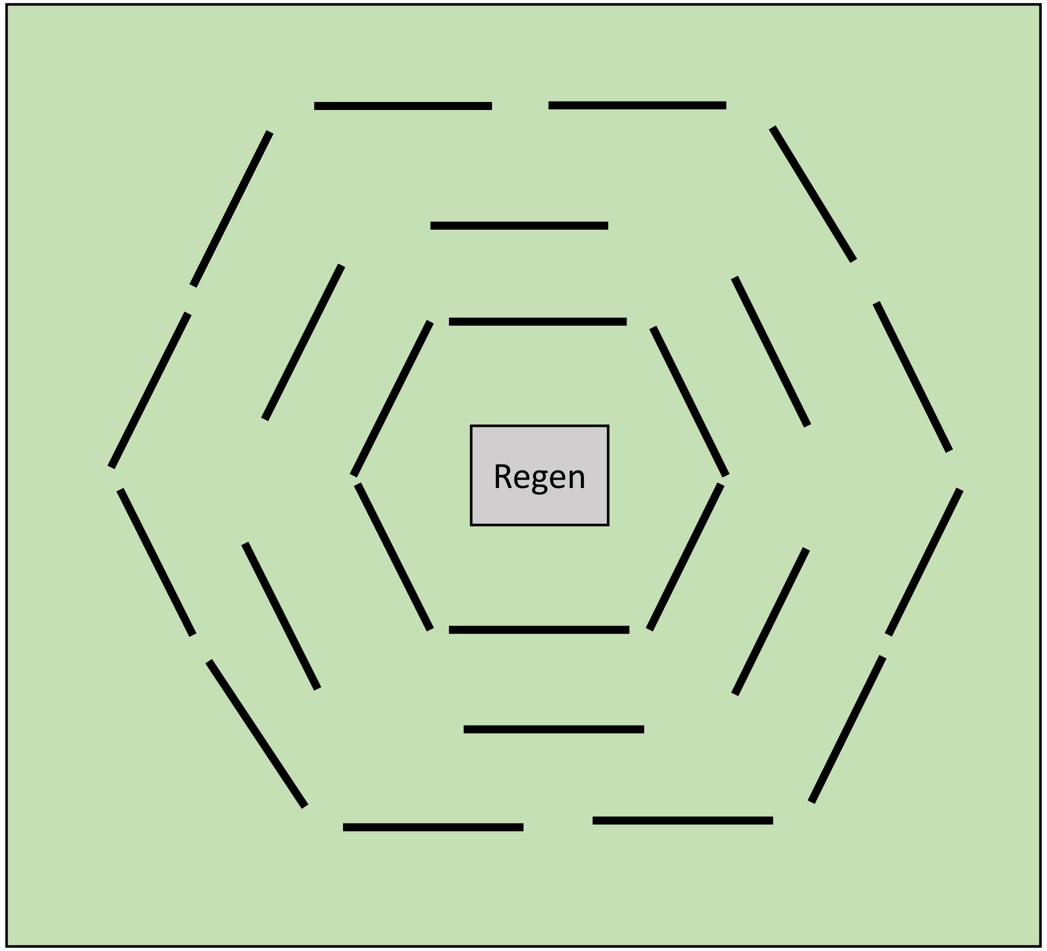
OPT 1 Spacing DAC Contactors and Indirect Land Use



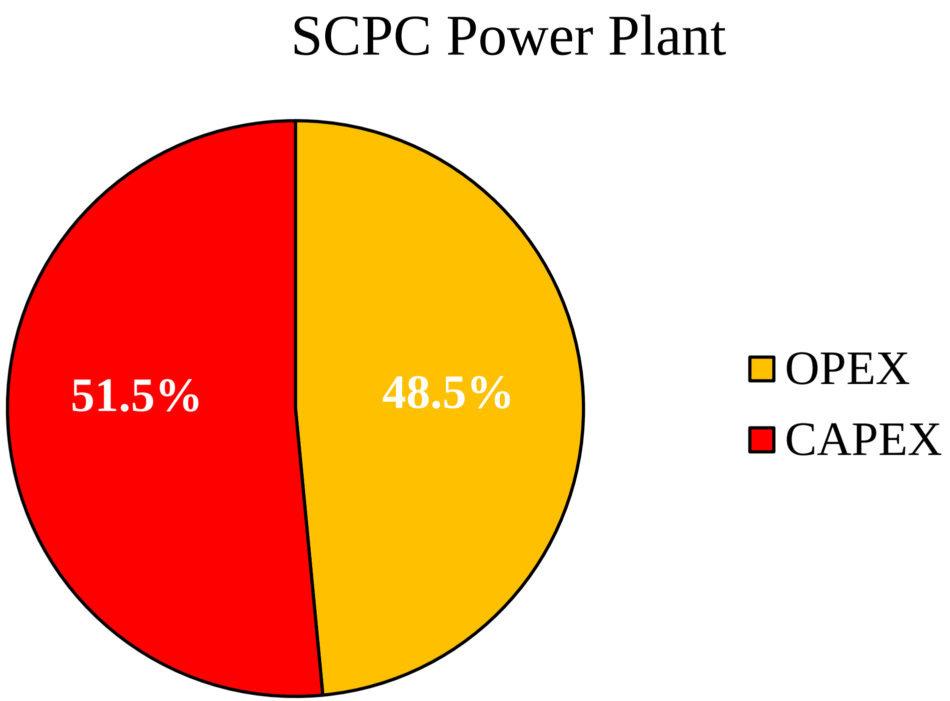


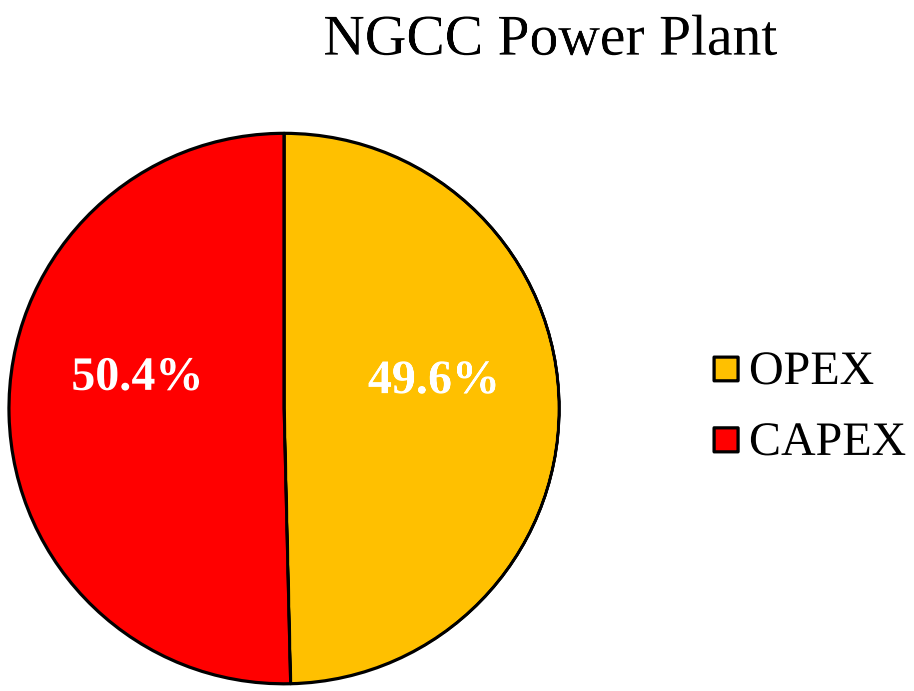
OPT 2 Spacing DAC Contactors and Indirect Land Use





Comparison to Point Source Capture (amine scrubbing)





Reference: Integrated Environmental Control Module, developed by Ed Rubin