

Direct Air Capture

Jen Wilcox

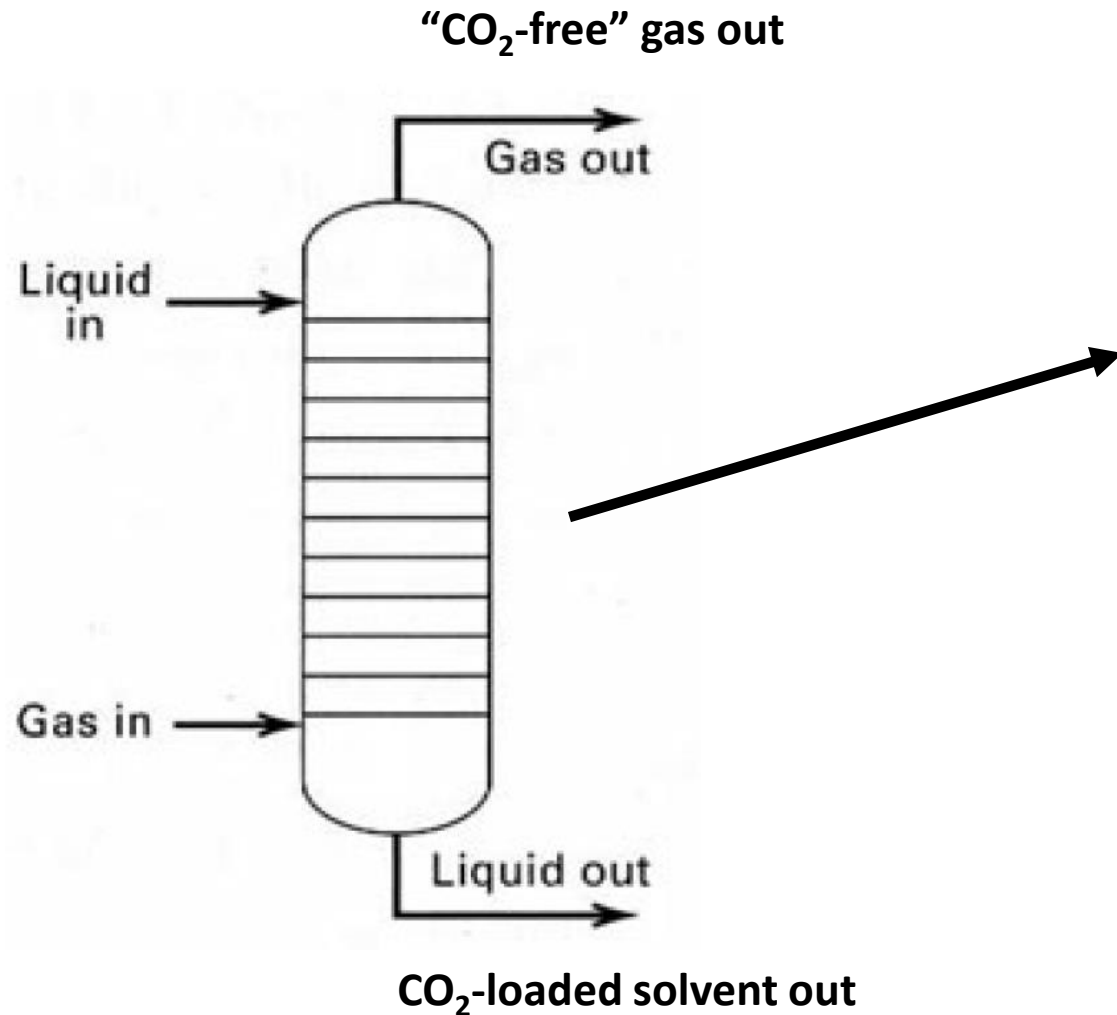
Chemical Engineering
Worcester Polytechnic Institute

Workshop on DAC
DOE, Washington, DC
July 24th, 2019



What Does Scrubbing CO₂ from a Point Source Look Like?

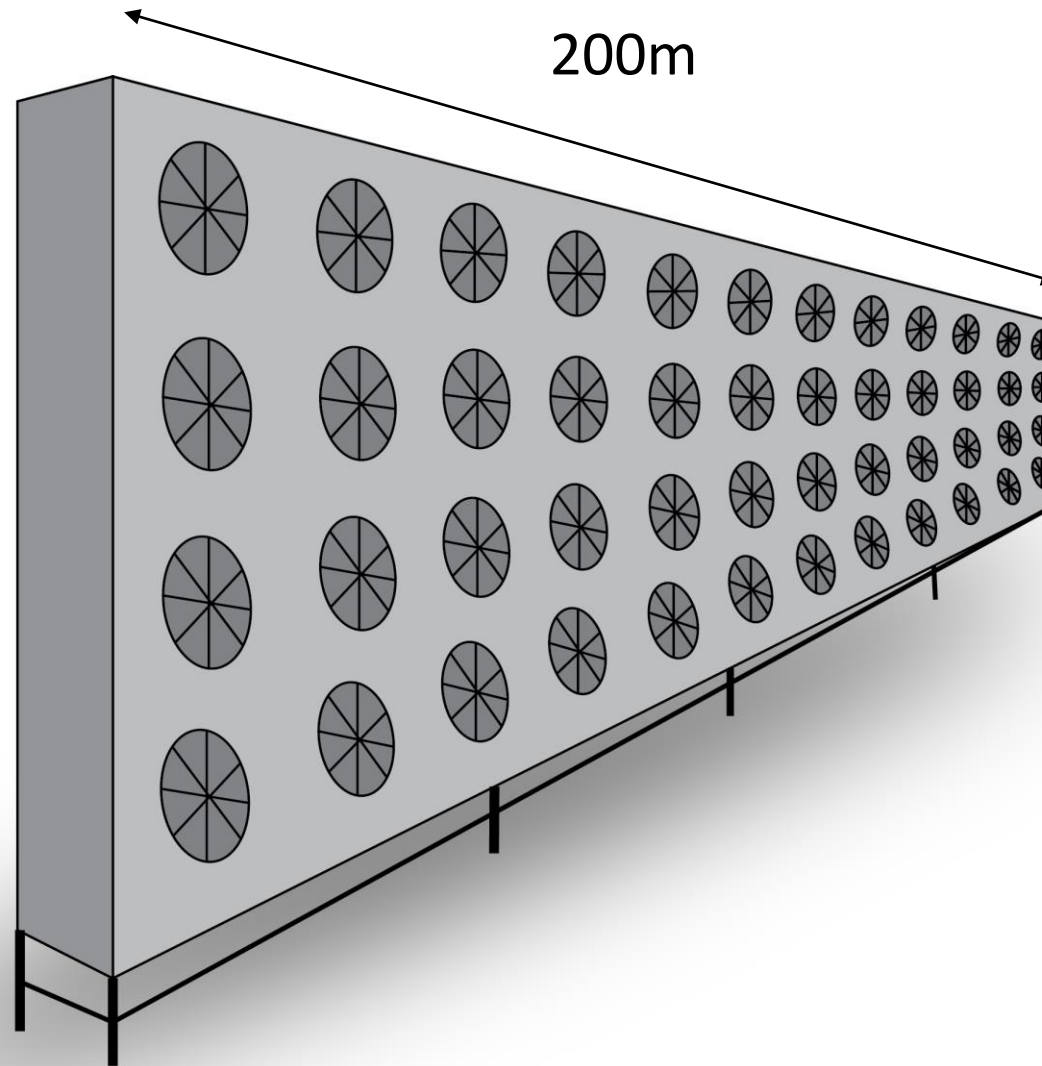
First patent filed by Bottoms in 1930!



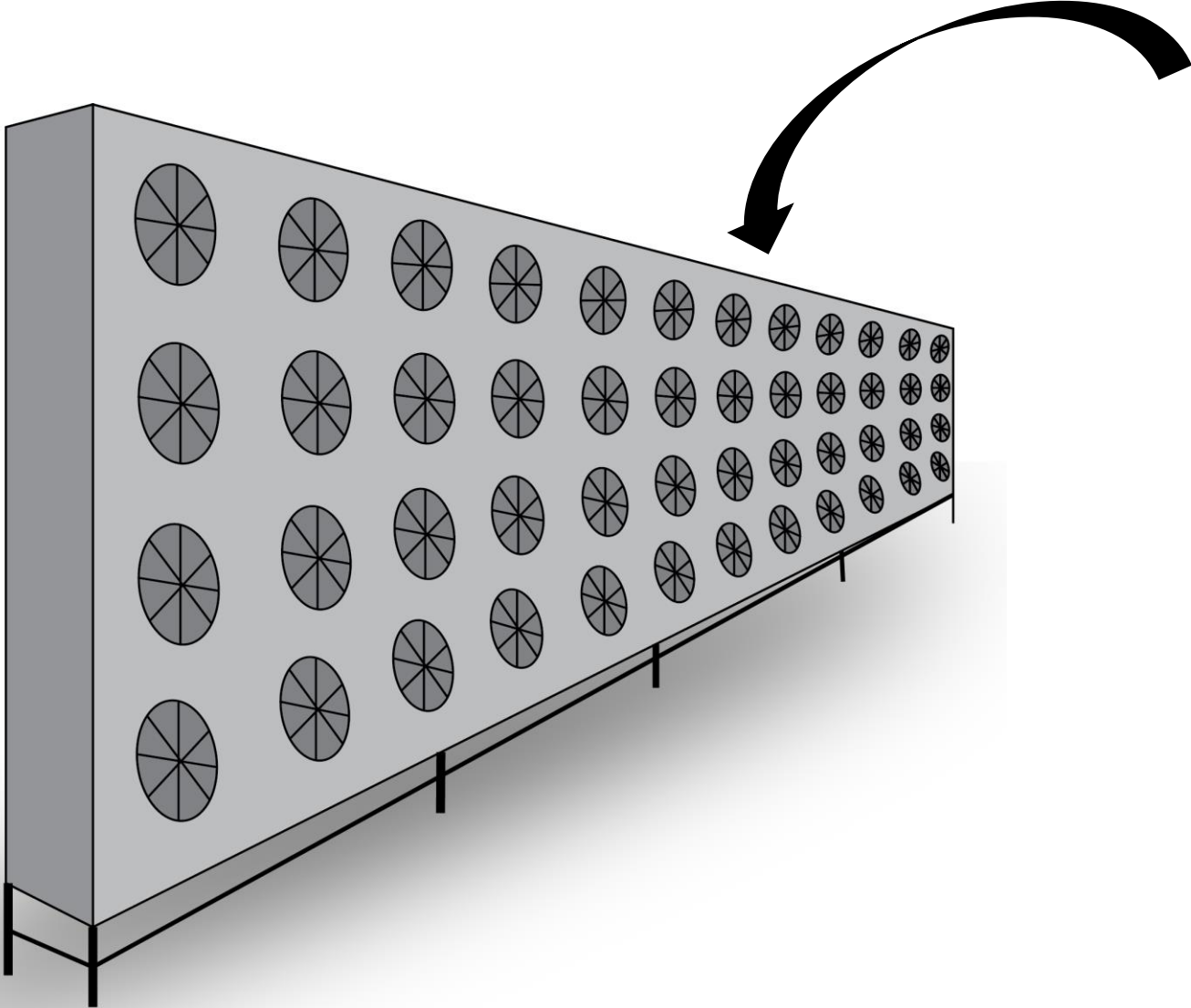
**Petra Nova – 1.4 Mt CO₂/year
115 Meters Tall Absorber**

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 CO₂-grabbing chemicals



Solvents rely on structured packing with solvent flow over the packing

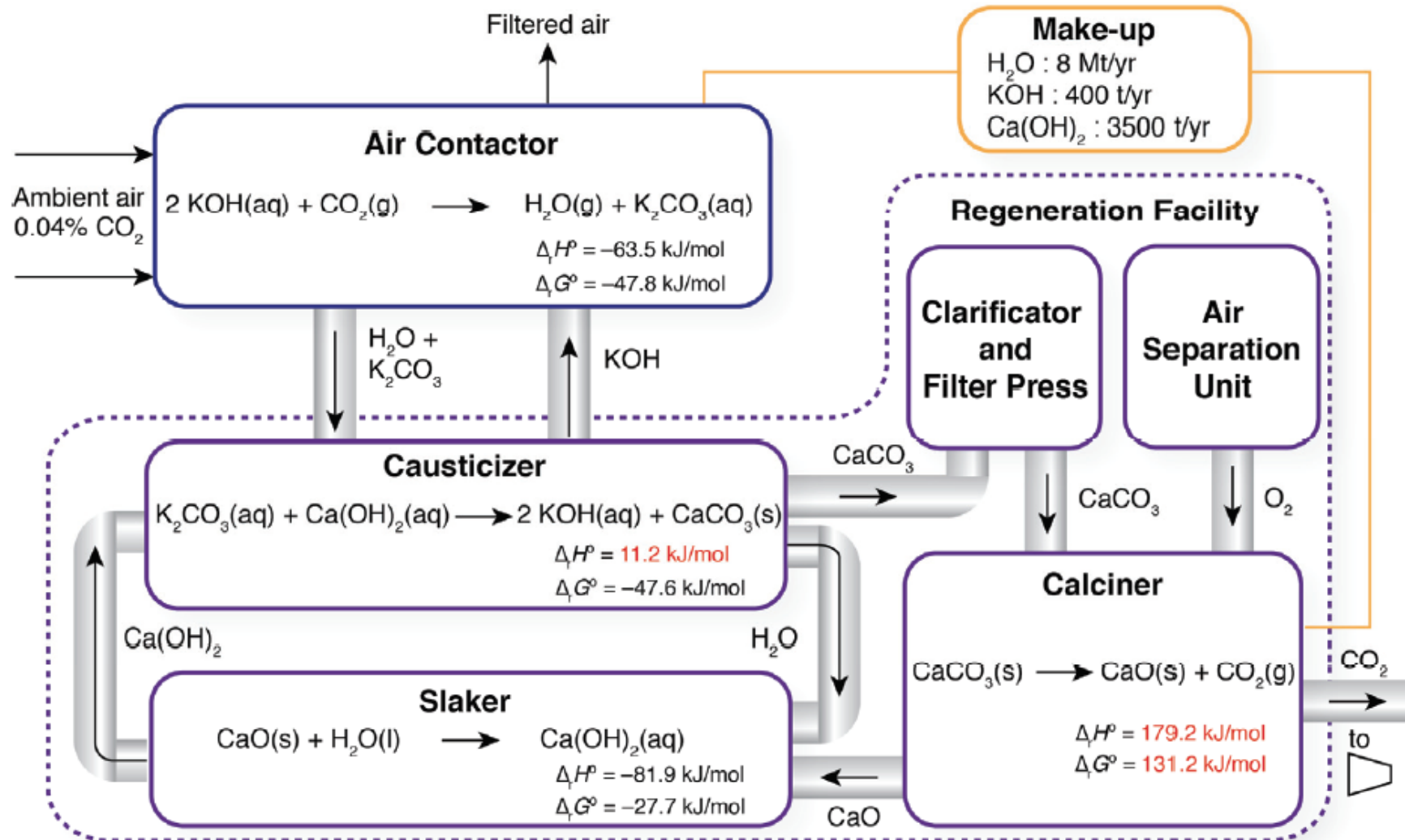


Solid sorbents rely on a honey-comb structure with chemicals (amines) bound to structure

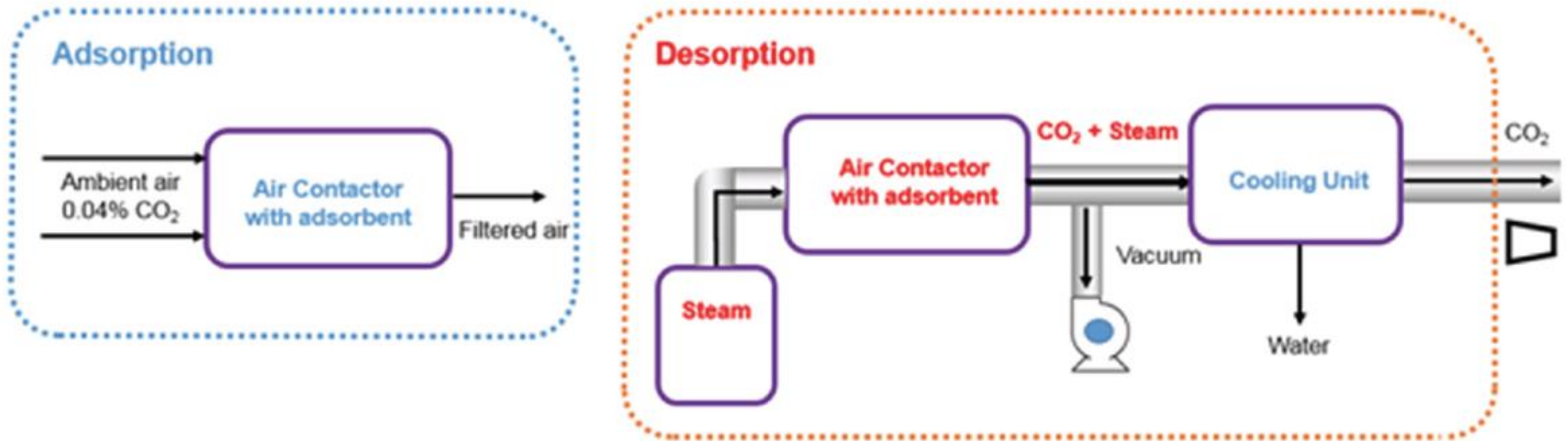


System Differences – Liquid Solvents

Carbon Engineering



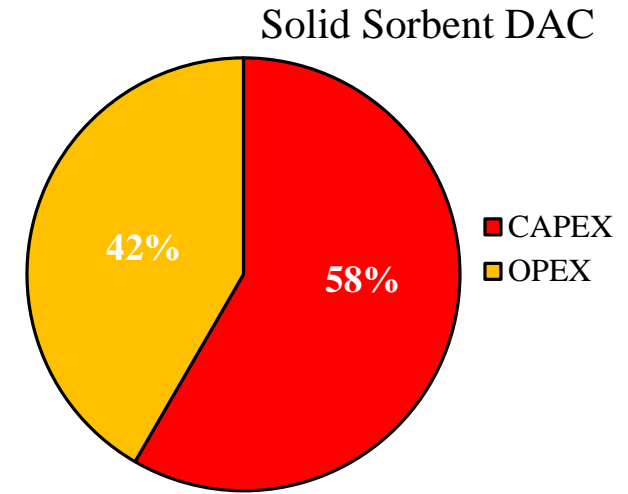
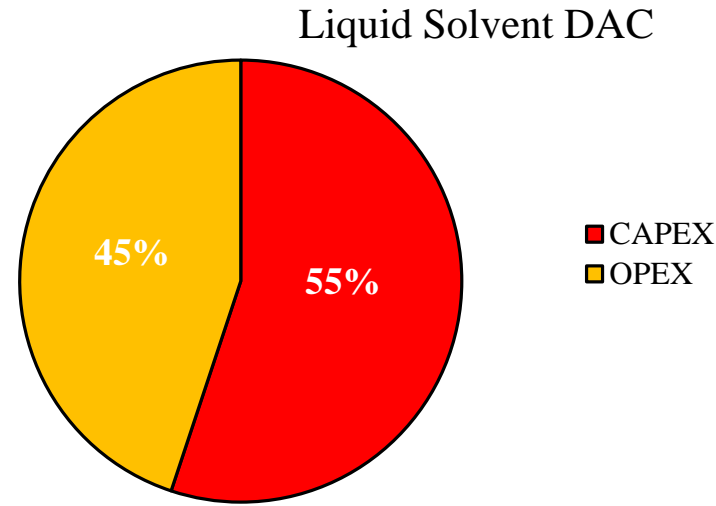
System Differences – Solid Sorbents Global Thermostat and Climeworks



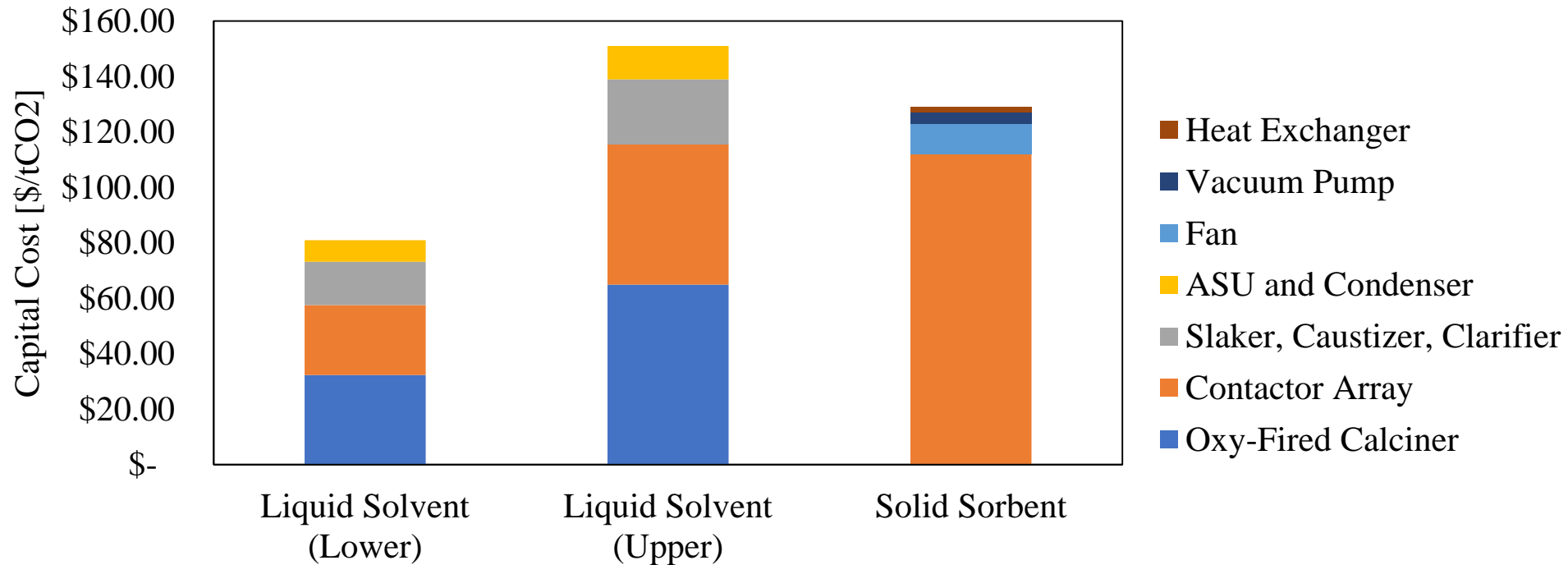
To Design a DAC Plant, you First Need to Design a Power Plant

- 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

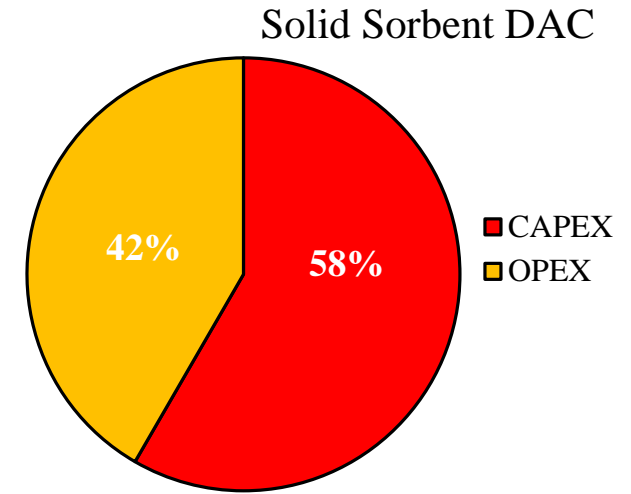
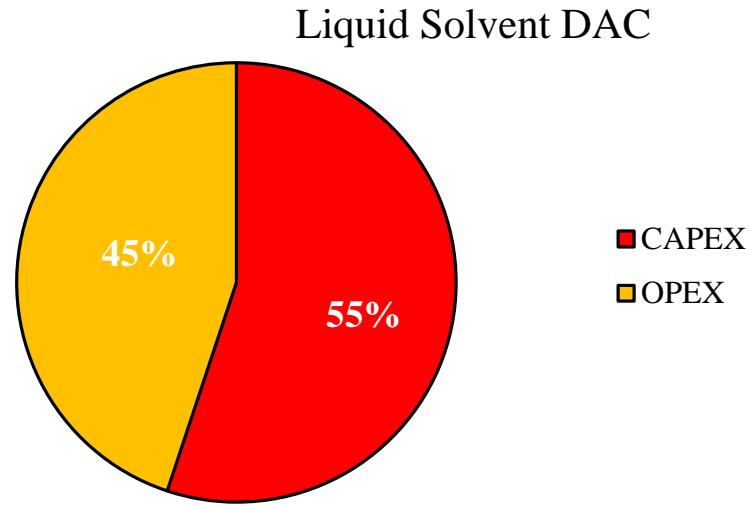
Cost Differences CAPEX



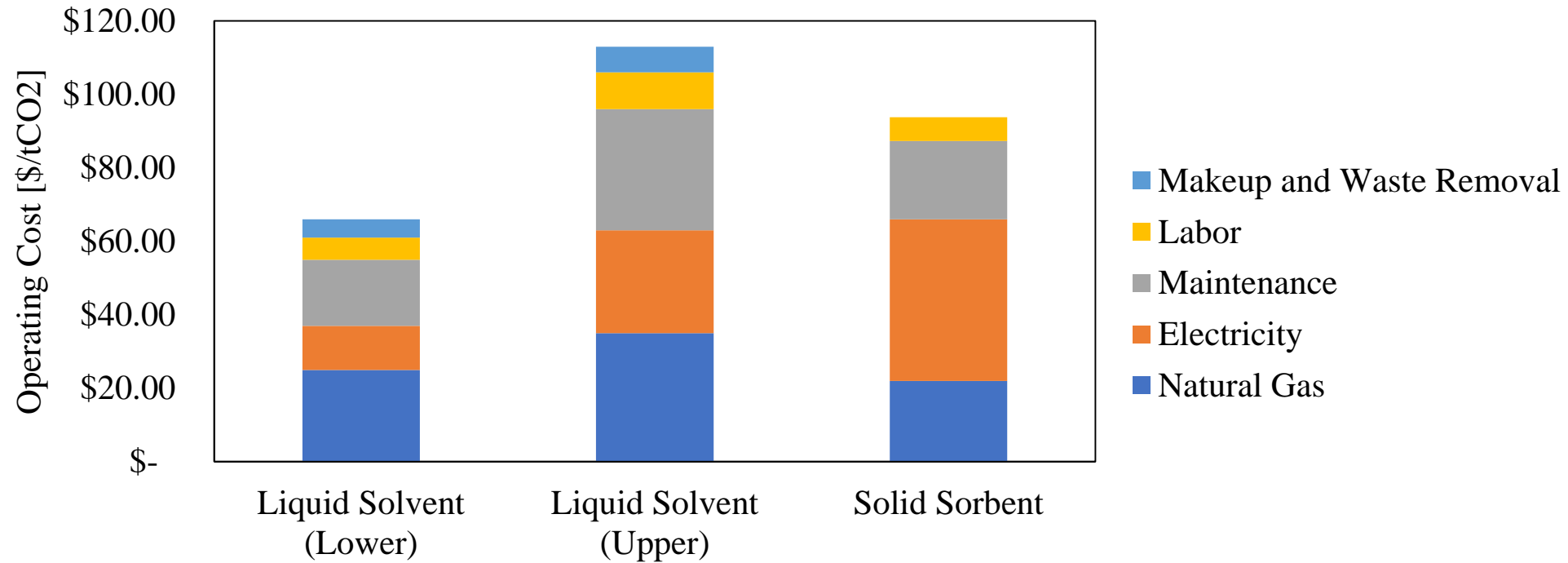
Capital Cost Breakdown



Cost Differences OPEX



Operating Cost Breakdown

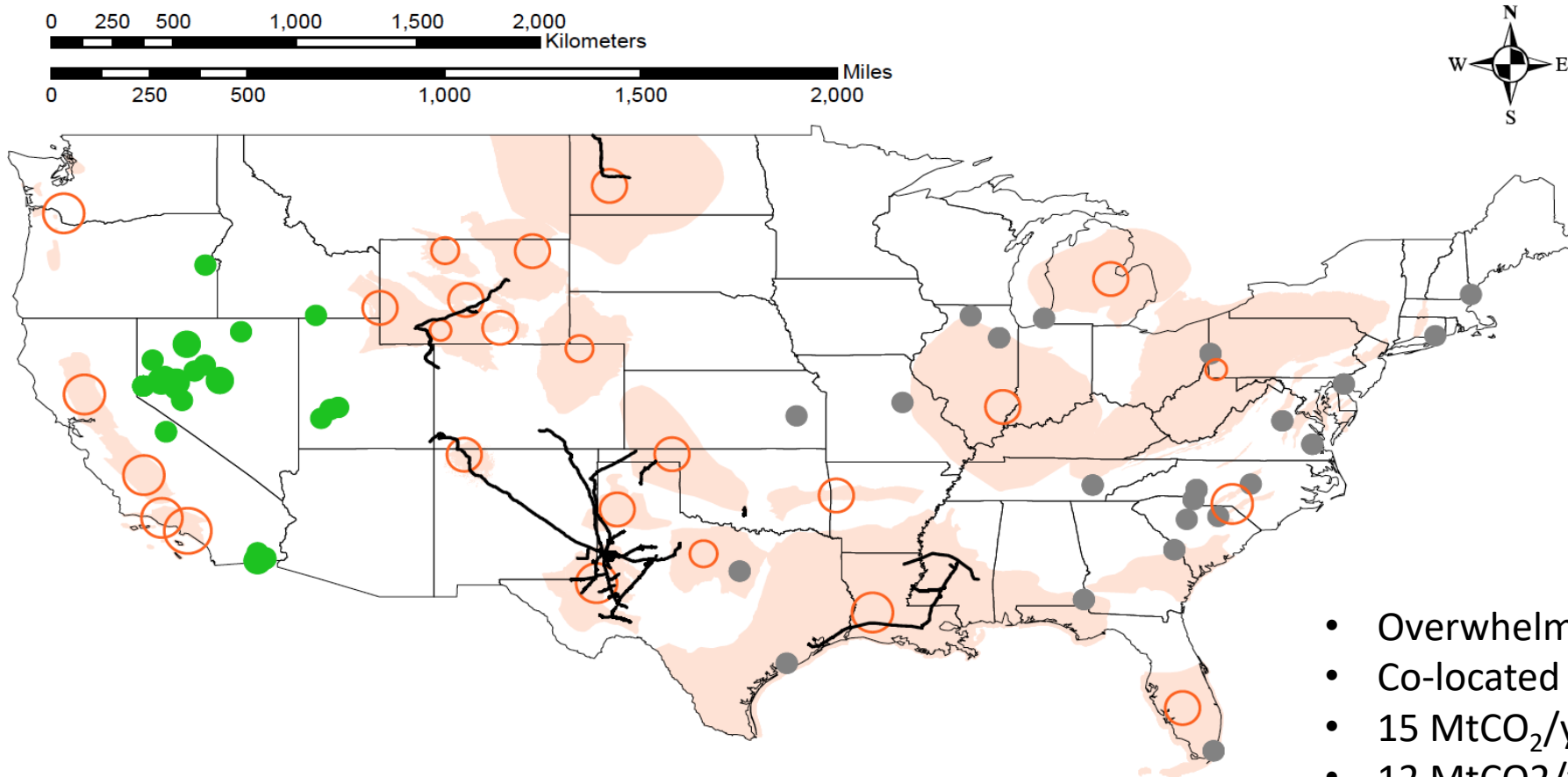


DAC Siting Low-Carbon Available Thermal Energy

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 CO₂ 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 CO₂ Avoided – considering fossil-based energy to fuel DAC
 - Cost of CO₂ Produced – combining point-source capture with DAC
 - Cost of Net Removed CO₂ – true cost from climate's perspective

Geological Sequestration – satisfying the 45Q criteria, i.e., > 100 ktCO₂/yr



0 250 500 1,000 1,500 2,000 Kilometers

0 250 500 1,000 1,500 2,000 Miles



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

Geological Sequestration (ktCO₂/yr)

- 100 - 500 (2)
- 500 - 1,000 (3)
- 1,000 - 10,000 (12)

○ 10,000 - 100,000 (7)

○ 100,000 - 1,000,000 (1)

■ Sequestration basins

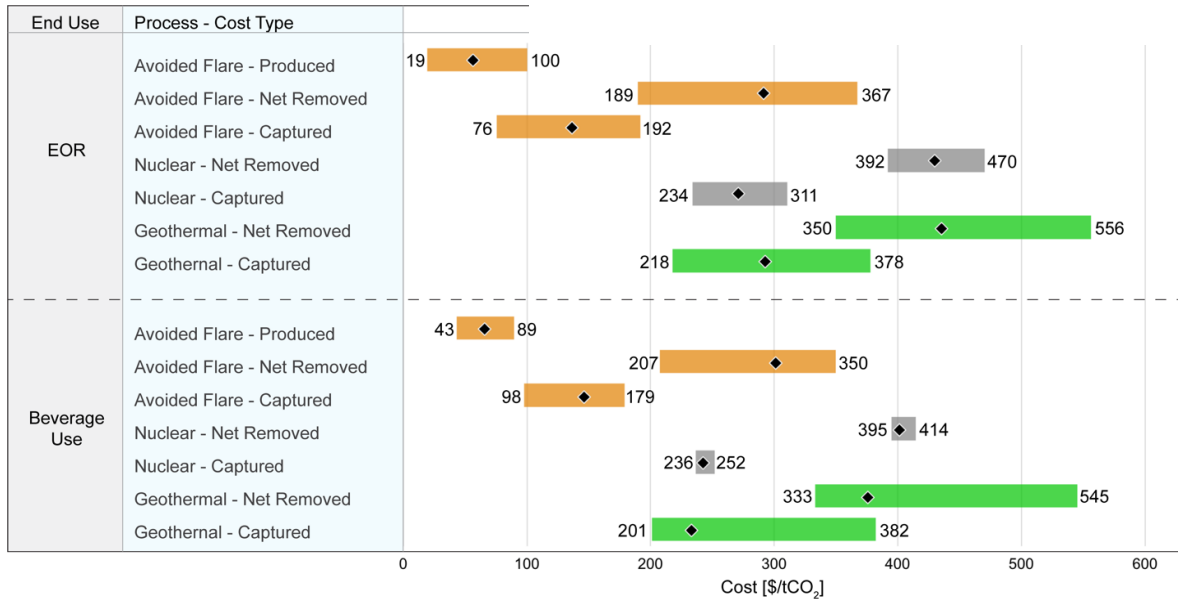
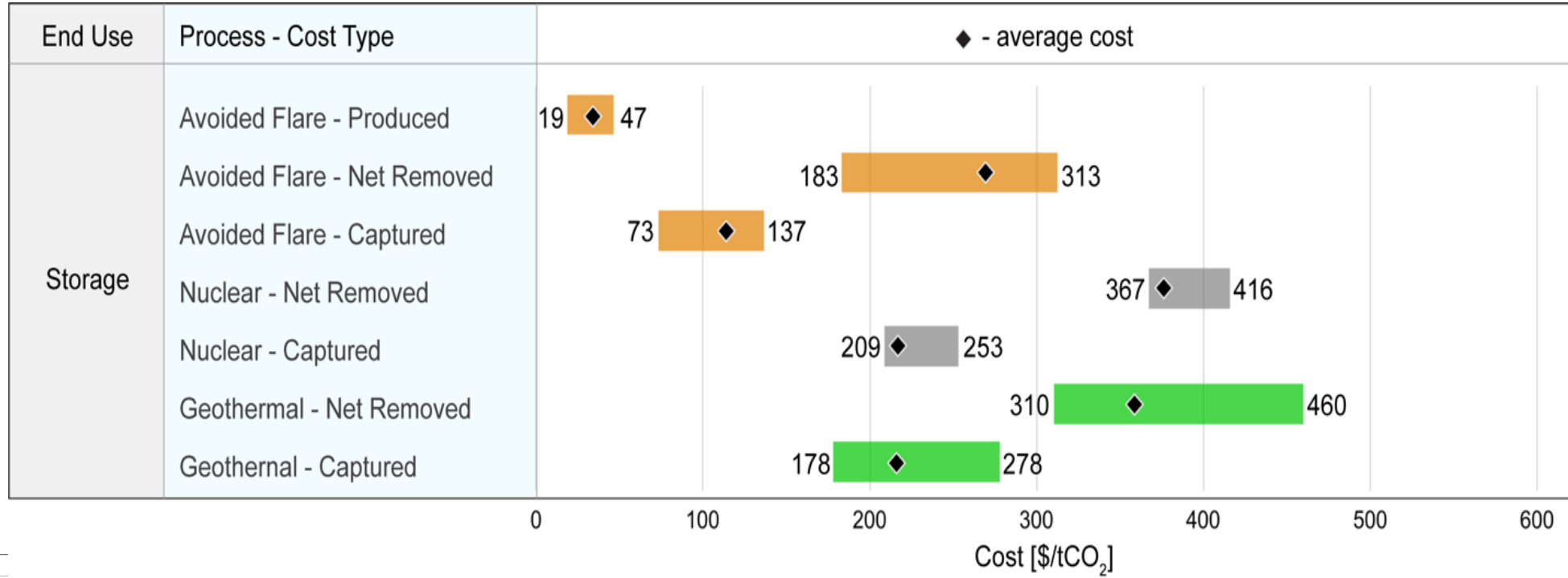
Geothermal (ktCO₂/yr)

- 100 - 500 (30)
- 500 - 1,000 (5)

Nuclear (ktCO₂/yr)

- 100 - 500 (36)
- CO₂ pipelines

Costs of Geologic Storage



Questions?

More Information:

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

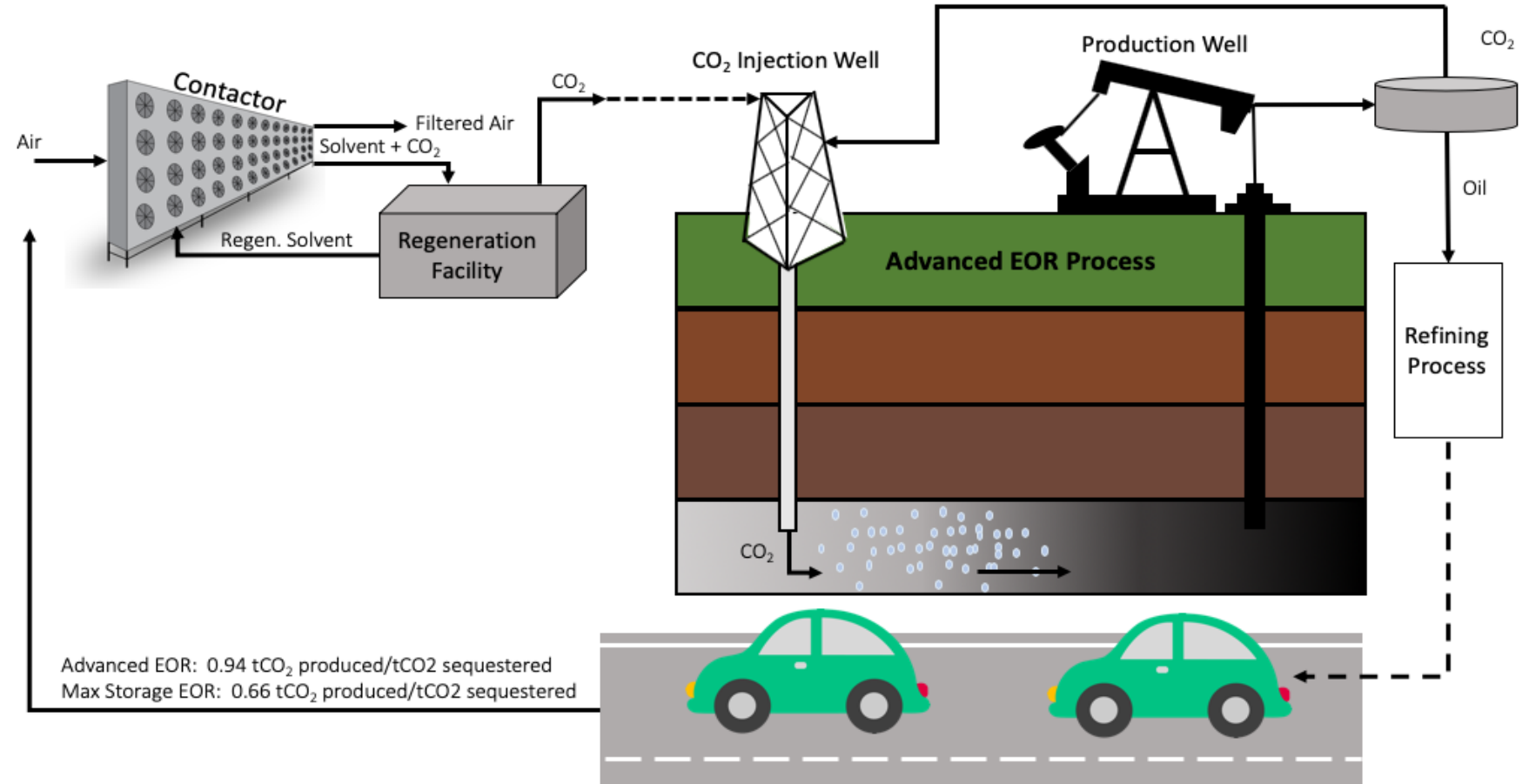
https://www.ted.com/talks/jennifer_wilcox_a_new_way_to_remove_co2_from_the_atmosphere

<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/>

What Would it Take for CO₂-EOR to be Negative?

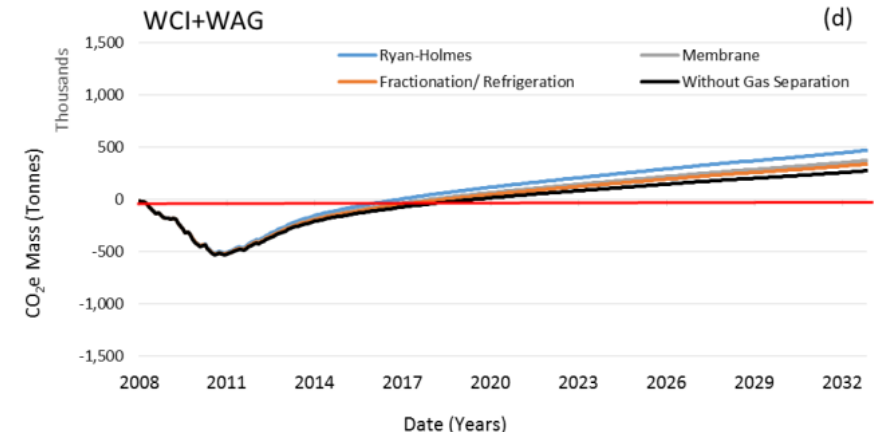
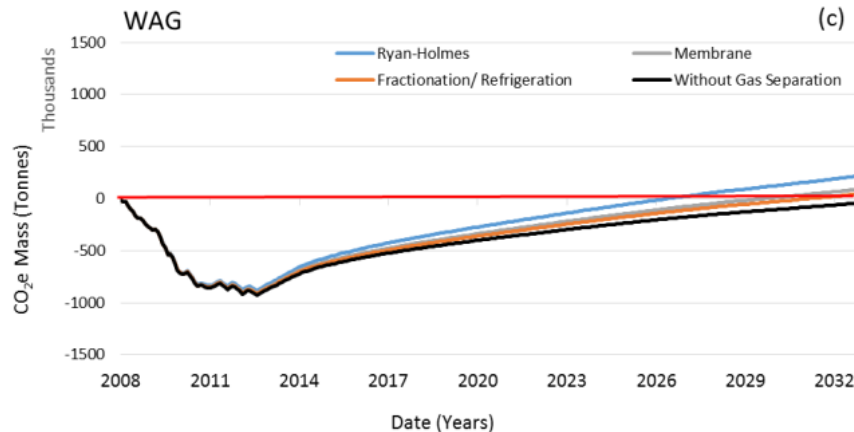
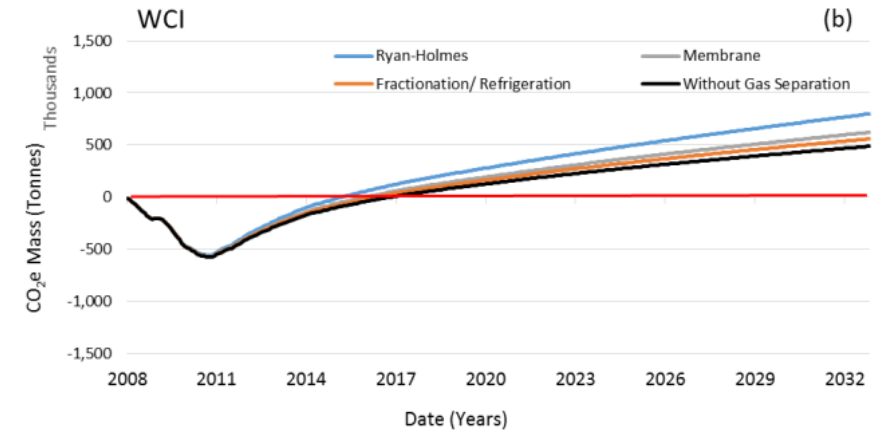
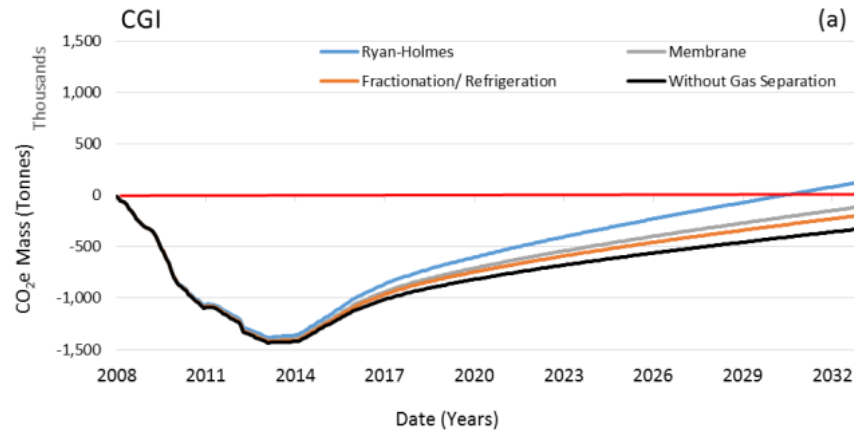
- CO₂-EOR started in 1972 with the first project in the Permian Basin
- Utilization market is ~ 80 MtCO₂/yr compared to 3 MtCO₂/yr for beverage industry
- Depends on strategic operational choices, which may shift based on a tax credit or carbon market



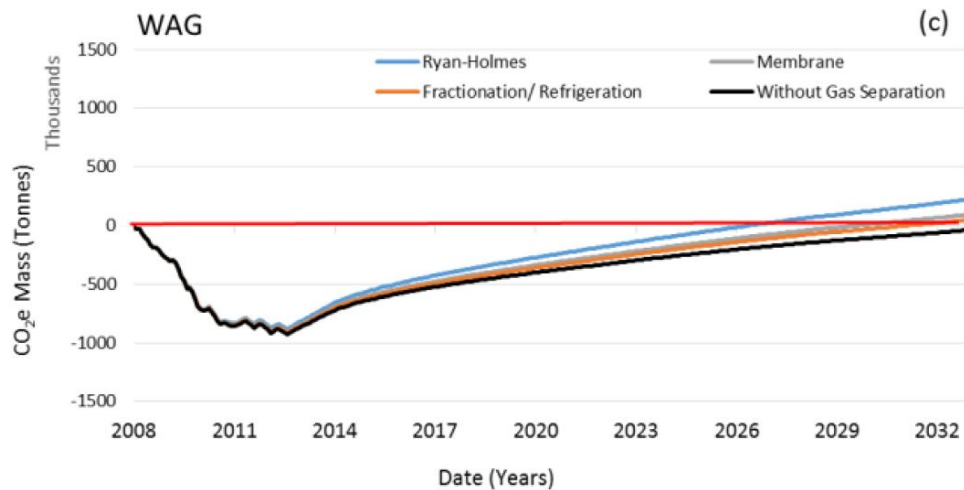
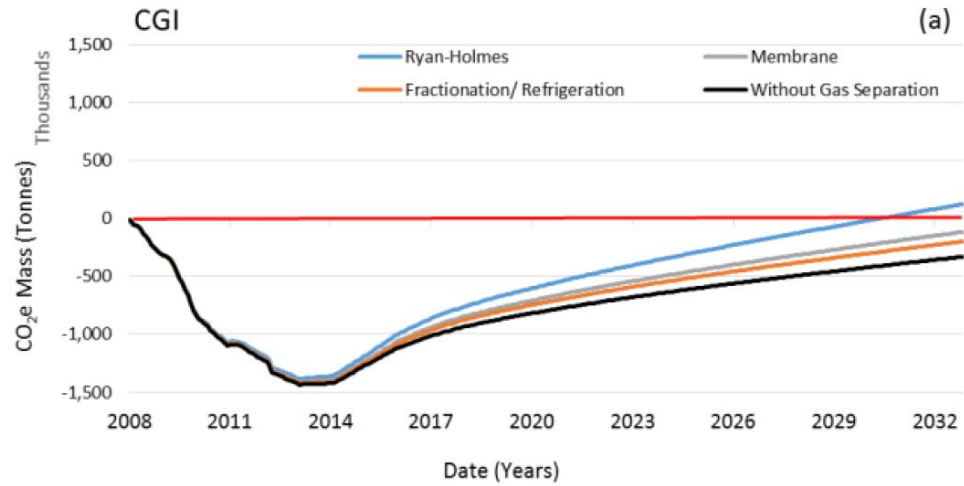
IEA's Maximum Storage EOR+

- Excess CO₂ from the separation facility is injected into an underlying saline aquifer
- Note that all approaches are negative in the early years of the project.

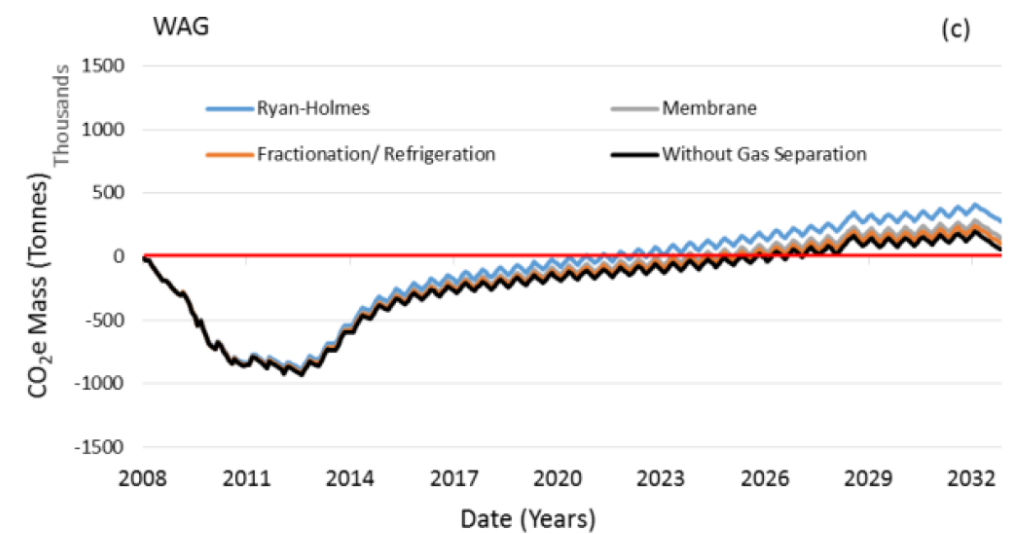
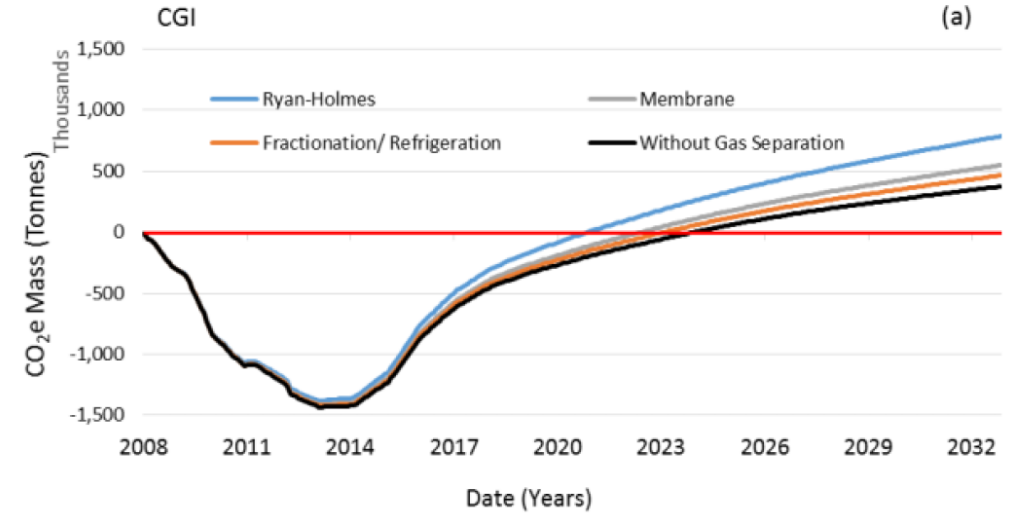
- a) Continuous gas injection
- b) Water curtain injection
- c) Water alternating gas
- d) Hybrid WAG + WCI



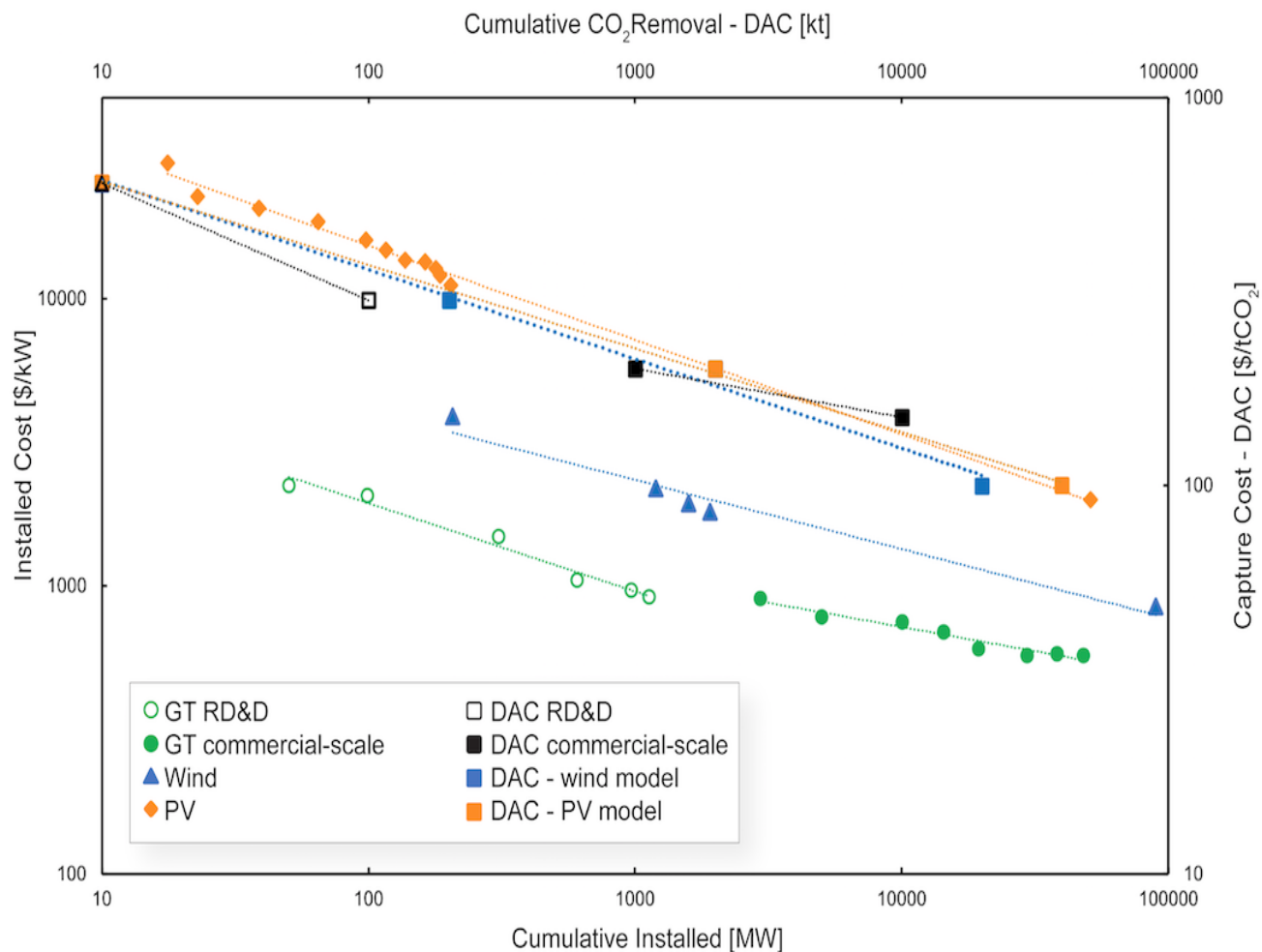
IEA's Maximum Storage EOR+



“Conventional EOR”



Today DAC is Taking Place at the Kiloton Scale How Might we Get to a Gigaton by Mid Century?

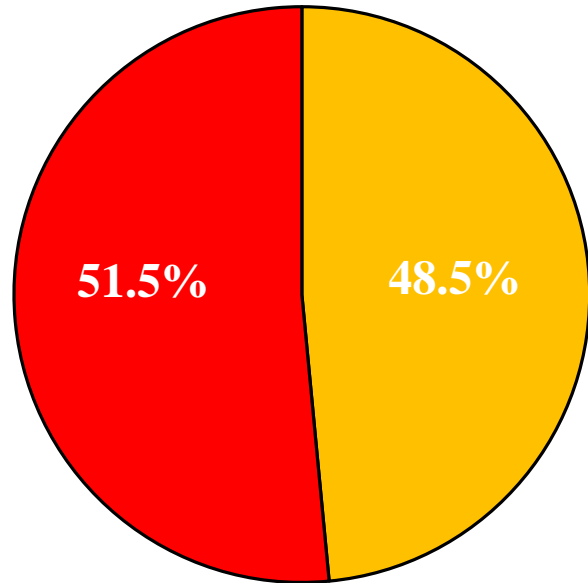


Technology	Experience Rate (%)
PV	25
Wind	18
Gas Turbine RD&D	23
Gas Turbine -commercial	12
DAC – learning by doing RD&D	23
commercial	9
DAC – wind model	17
DAC – solar model	25

- 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

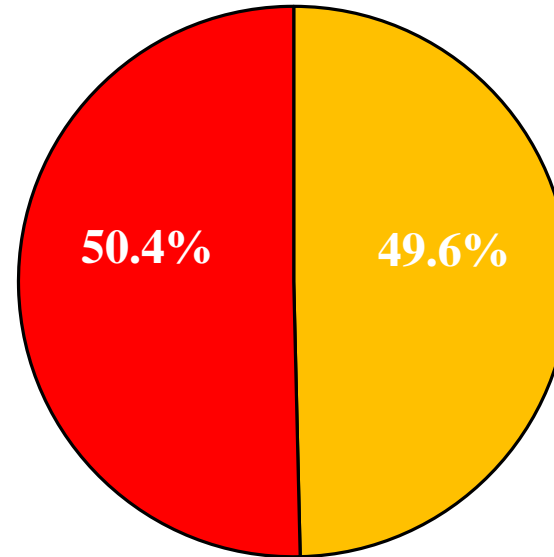
Comparison to Point Source Capture (amine scrubbing)

SCPC Power Plant



■ OPEX
■ CAPEX

NGCC Power Plant



■ OPEX
■ CAPEX