Capturing Carbon Dioxide from Air

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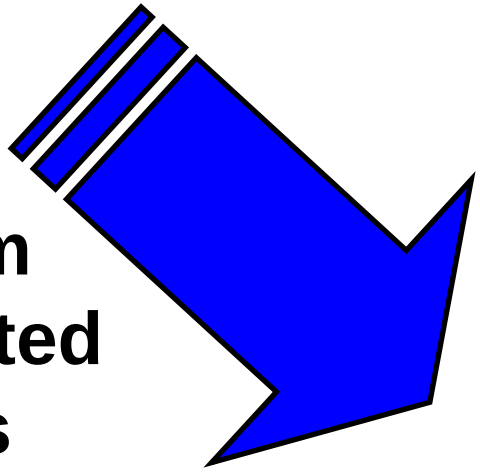
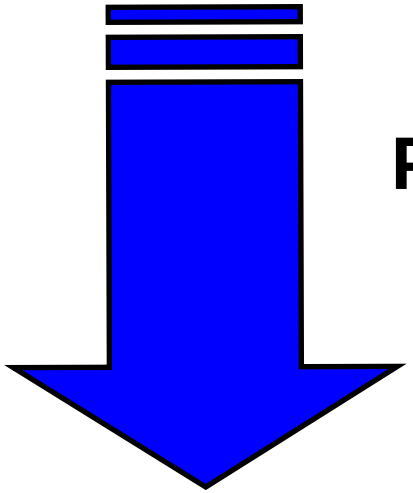
LENFEST CENTER FOR SUSTAINABLE ENERGY
THE EARTH INSTITUTE AT COLUMBIA UNIVERSITY

Net Zero Carbon Economy



CO_2 from concentrated sources

CO_2 extraction from air



Permanent & safe disposal

The Substitution Principle

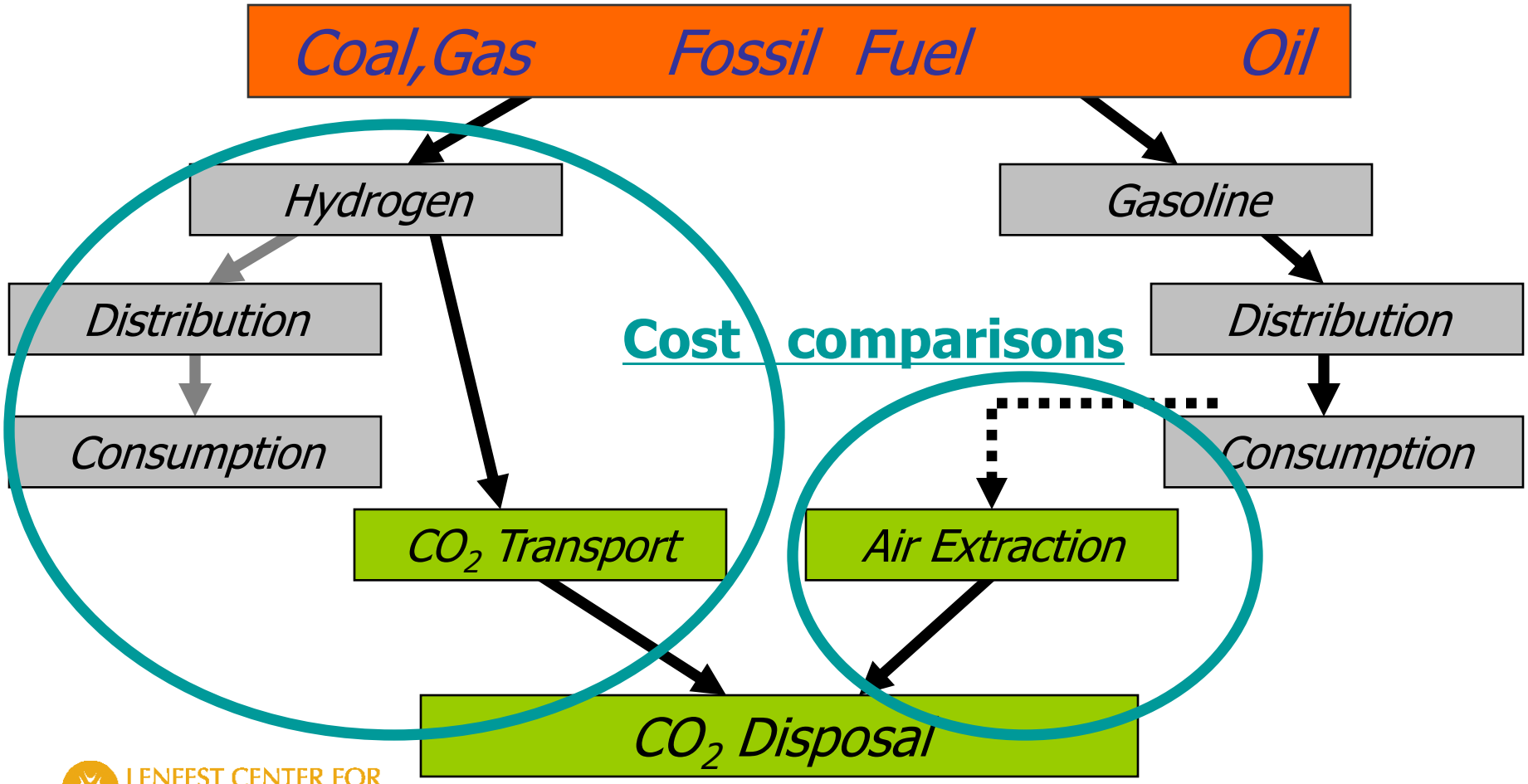
- All CO_2 is equal
- Combustion and capture cancel out
  - No need to co-locate
- Air is a perfect transport system
  - Mixing times are fast, weeks to months
- Air is an excellent storage buffer
  - Annual emissions are 1% of stored CO_2

Air Capture: A Different Paradigm

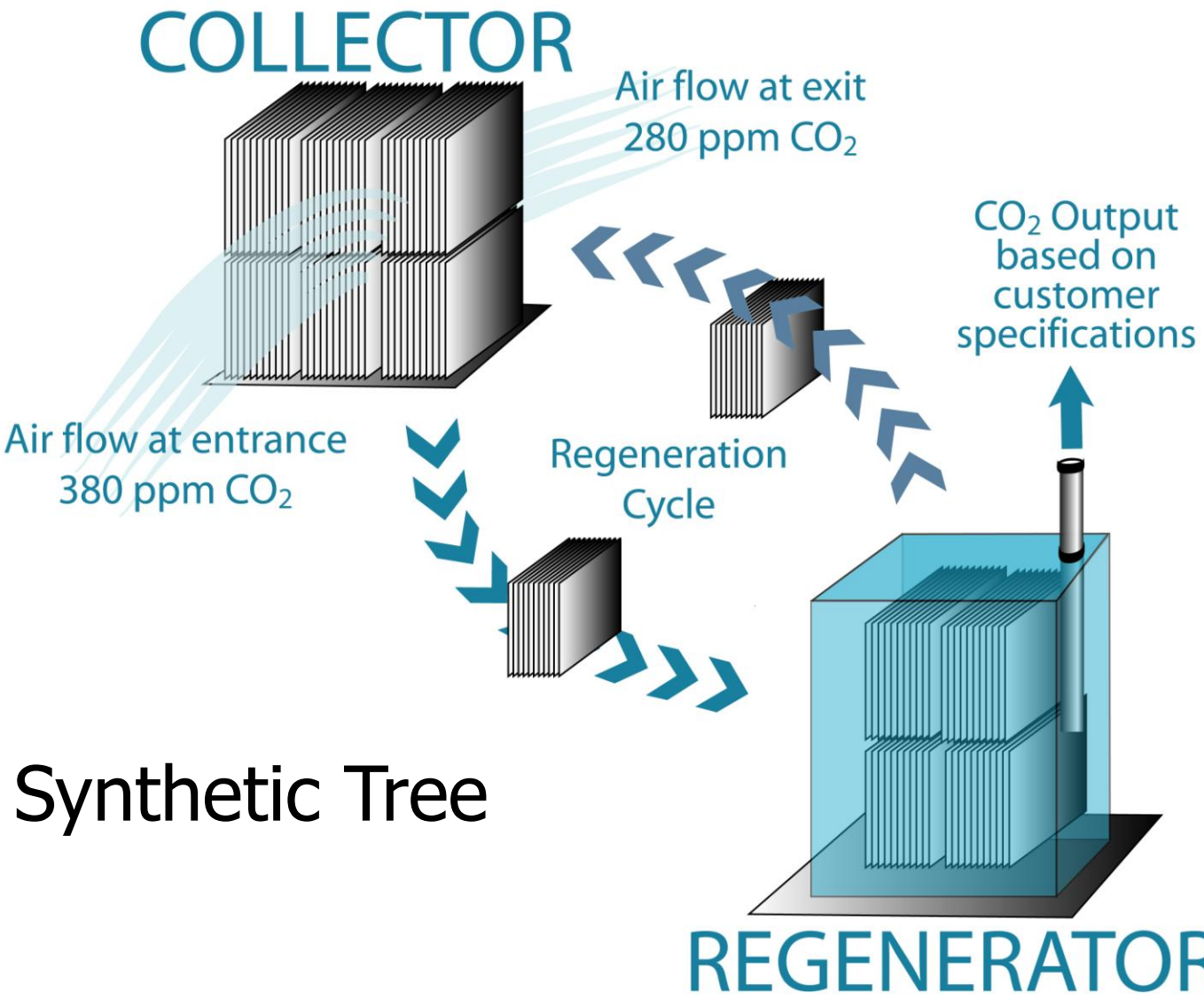
- Leave existing infrastructure intact
- Retain quality transportation fuels
- Eliminate shipping of CO_2
- Open remote sites for CO_2 disposal
- Enable fuel recycling with low cost electricity

Separate sources from sinks in space and time

Hydrogen or Air Extraction?



Air Capture: Collection & Regeneration



Synthetic Tree

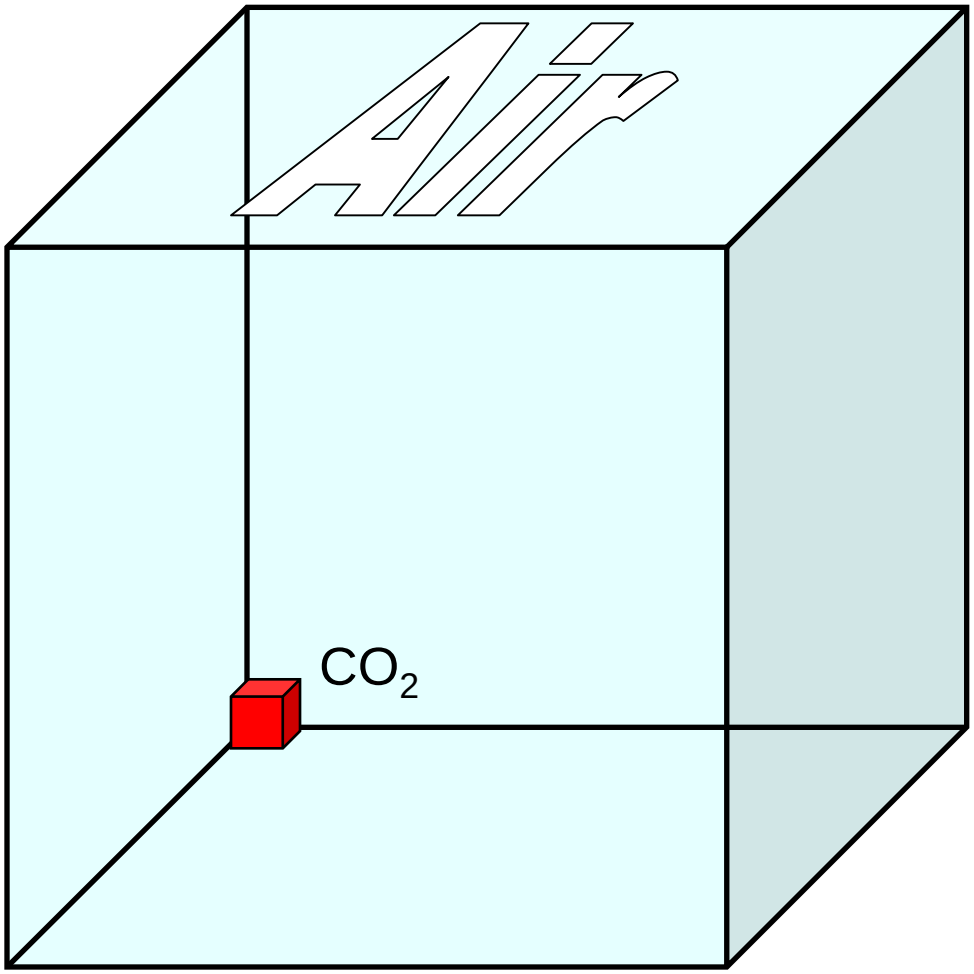
Courtesy GRT

Challenge: CO_2 in air is dilute

- Energetics limits options
  - Work done on air must be small
    - compared to heat content of carbon
    - 10,000 J/m^3 of air
- No heating, no compression, no cooling
- Low velocity 10m/s (60 J/m^3)

Solution: Sorbents remove CO_2 from air flow

CO_2 Capture from Air



1 m³of Air

40 moles of gas, 1.16 kg

wind speed 6 m/s

$$\frac{mv^2}{2} = 20\,\mathrm{J}$$

0.015 moles of CO_2

produced by 10,000 J of gasoline

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Volumes are drawn to scale

How much wind?

(6m/sec)

0.2 m^2 for CO_2

Wind area that carries 22 tons of CO_2 per year

50 cents/ton of CO_2 for contacting

Wind area that carries 10 kW of wind power

80 m^2 for Wind Energy

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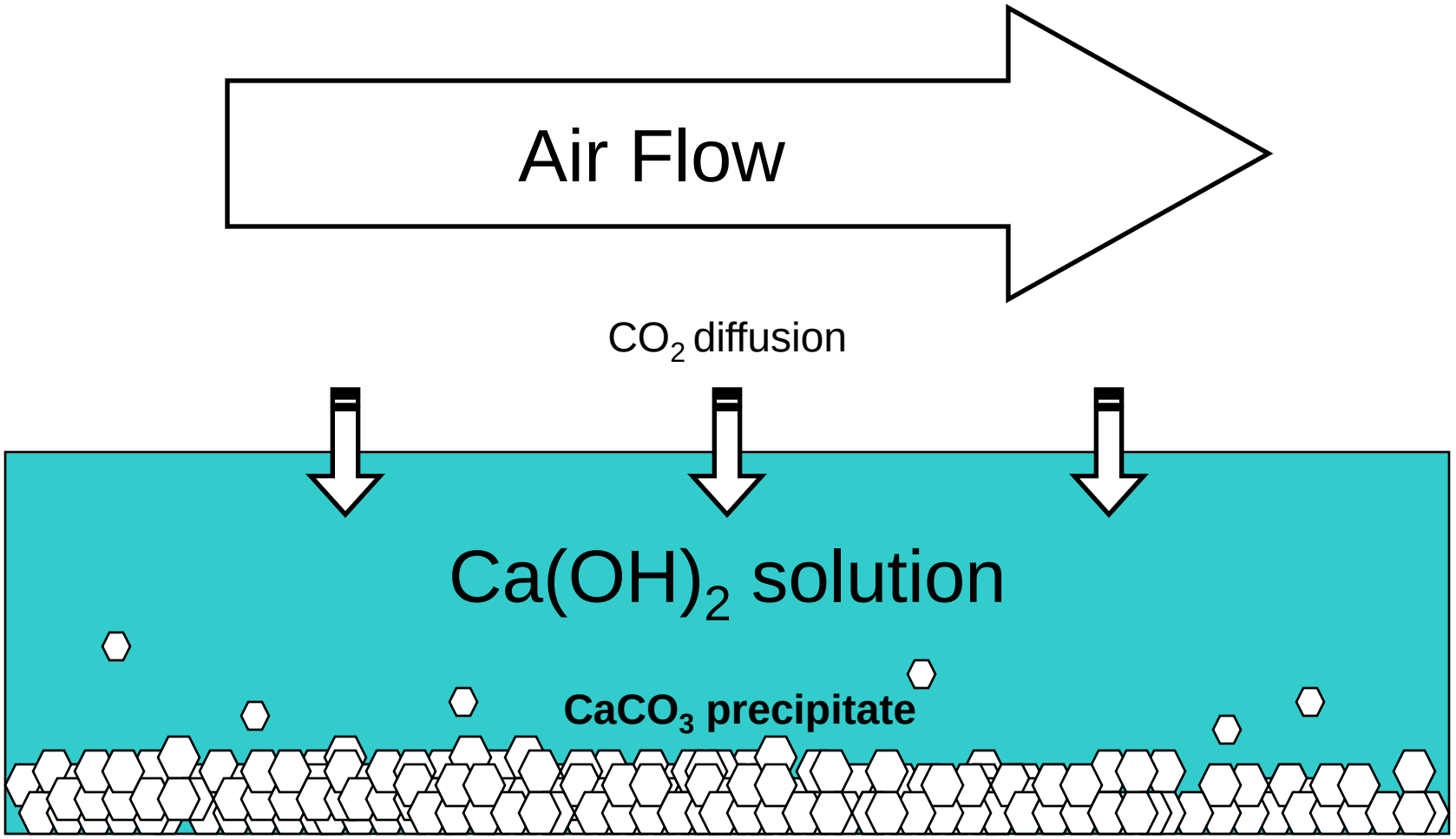
$Ca(OH)_2$ as an absorbent

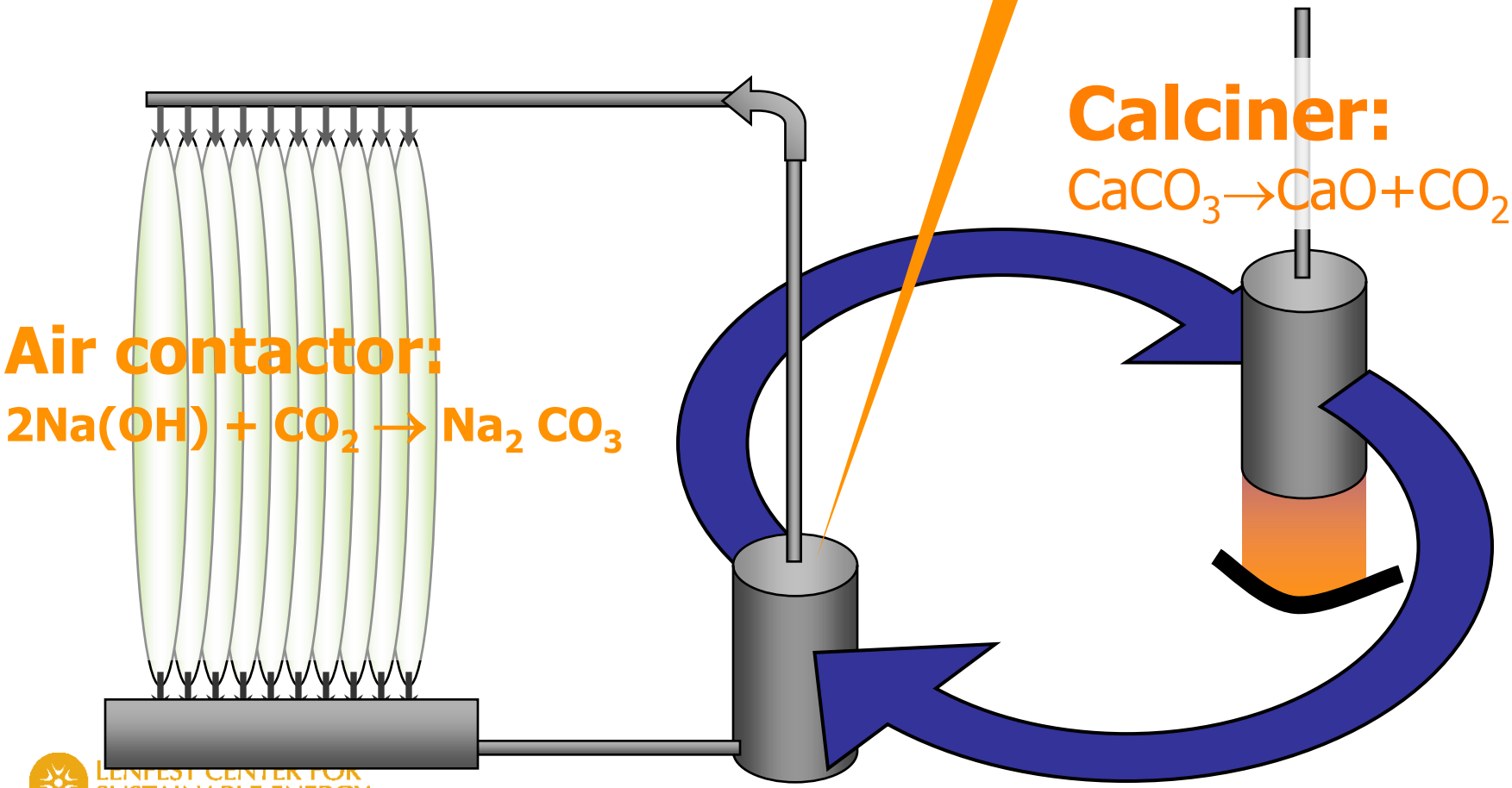


CO_2 mass transfer is limited by diffusion in air boundary layer

A First Attempt

Ion exchanger:

$Na_2CO_3 + Ca(OH)_2 \rightarrow 2Na(OH) + CaCO_3$



Lime Based Air Capture

- is feasible, but awkward
  - Reaction kinetics is good
  - Binding energy is far too large
  - Sodium hydroxide is difficult to use

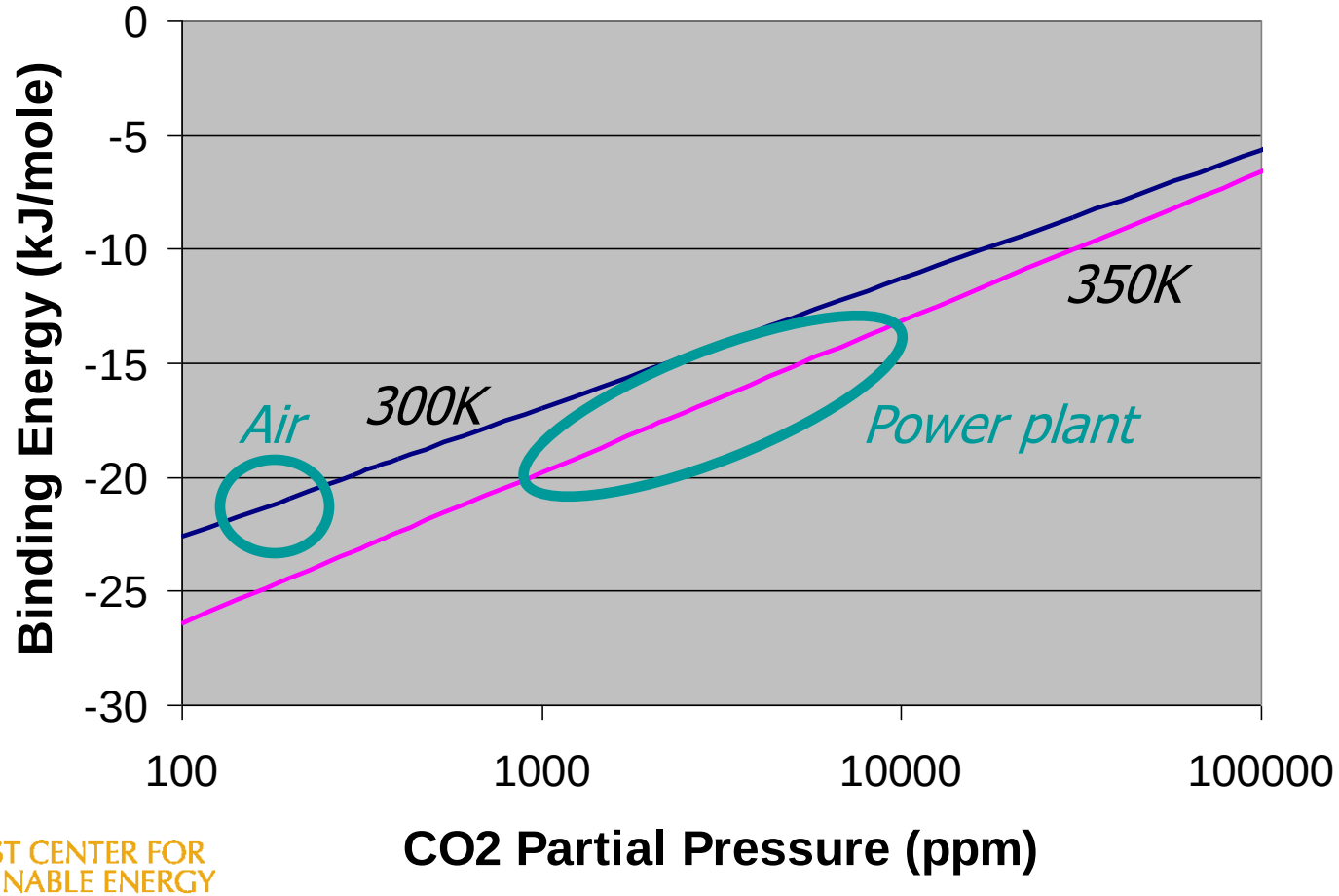
Proof of Principle vs. Practical Implementation?

Search for a Better Sorbents

- Good reaction kinetics
  - Reach air side transport limit
- Low binding energy
  - Comparable to flue gas capture
- Small environmental footprint
- Failsafe designs

Sorbents designed for flue gas scrubbing are strong enough to capture CO_2 from air

Sorbent Choices



Why Air Capture Works

- Comparison with capture of wind energy in a windmill
  - Front end collector is small and low cost
  - Verified by our design
  - Big cost is in the regenerator

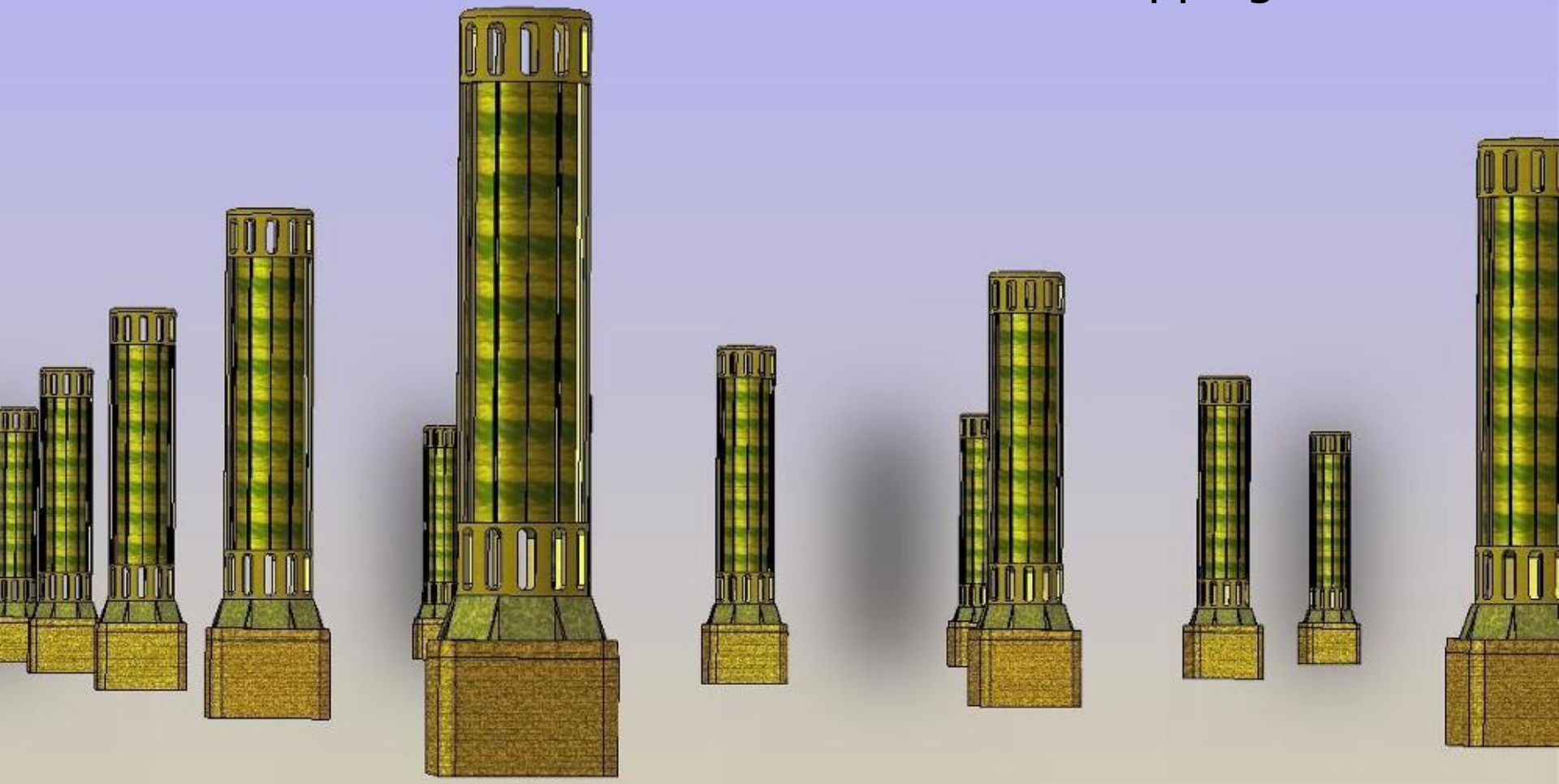
- Comparison with flue stack capture of CO_2 in a power plant
  - Sorbent strength in flue stack and air capture device are the same
  - Back end regenerator cost is the same as in flue stack capture
  - Front end cost is much larger than for flue stack, but it is very small

GRT's approach to air capture

- GRT in Tucson has developed a sorbent process that is energetically efficient, always carbon positive
- GRT plans to provide small factory produced units for air capture
- GRT will begin with physical CO_2 markets

Together with Allen Wright & Gary Comer, I helped found GRT to develop air capture technology. I am now a member of the company

Small factory produced units can be packed into a standard 40 foot shipping container



GRT's Vision

The first of a kind

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Collection and Regeneration

Collection

- Natural wind carries CO_2 to collector
- CO_2 binds to surface on ion exchange sorbent materials

Regeneration

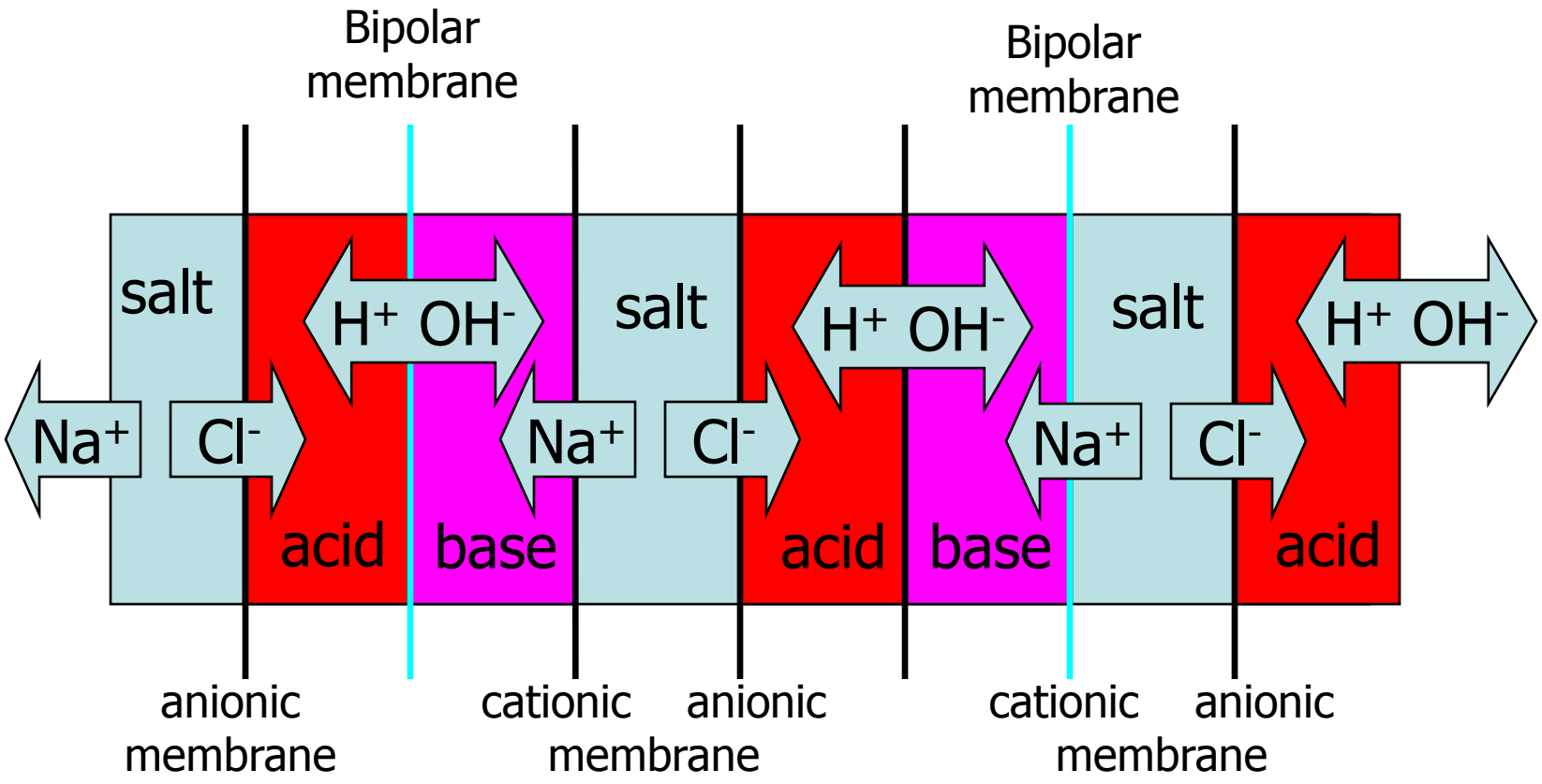
- CO_2 is recovered with:
  - liquid water wash
  - or carbonate solution wash
  - or low-temperature water vapor
  - plus optional low grade heat
- Regenerated sorbent is reused many times over

Courtesy GRT

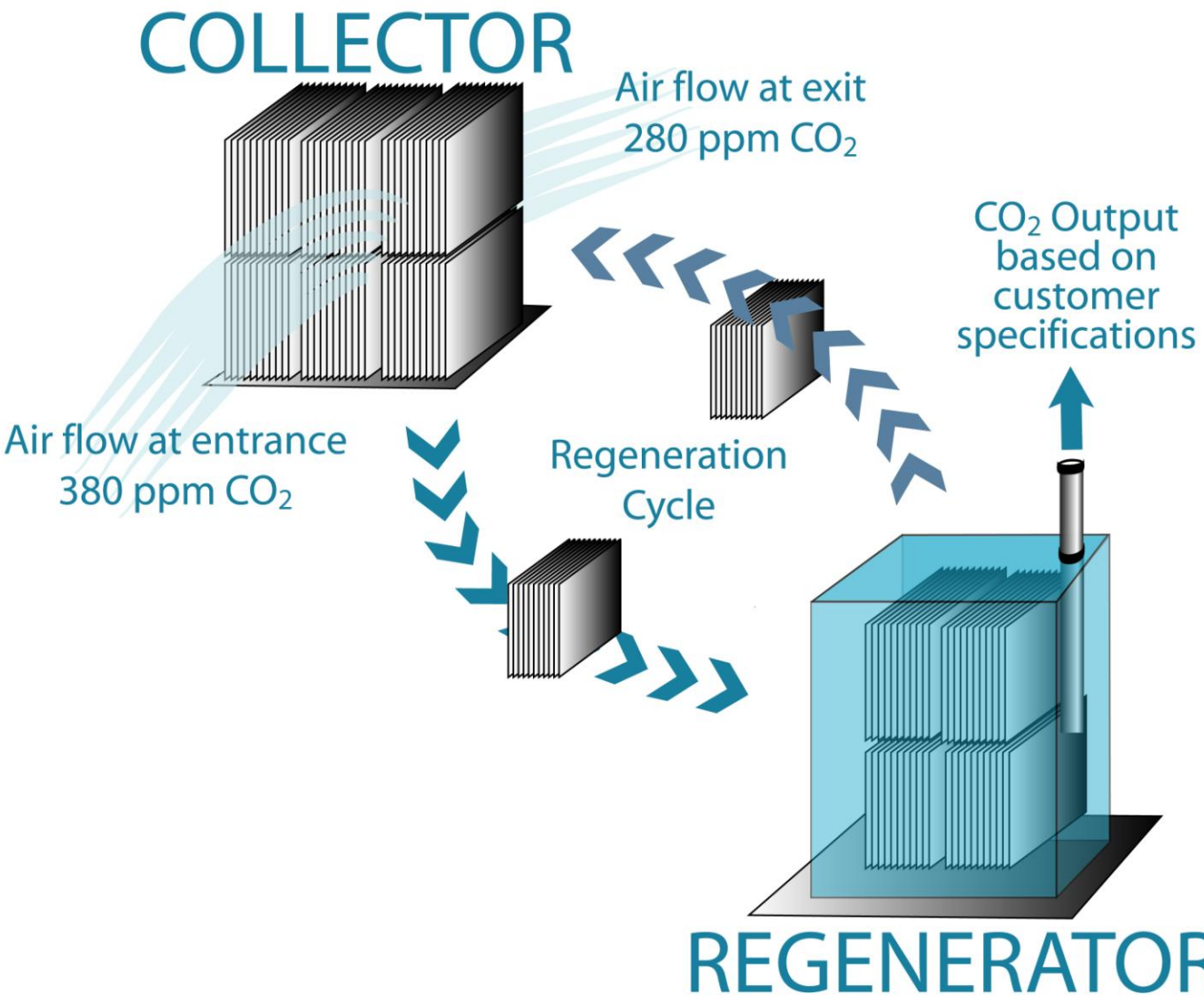
Options for Regeneration

- Pressure Swing
- Thermal Swing
- Water Swing
  - Liquid water – wet water swing
  - Water vapor – humidity swing
- Carbonate wash is a water swing
  - With CO_2 transfer
  - Salt splitter for CO_2 recovery

Salt Splitting - Electrodialysis



Air Capture: Collection & Regeneration



Courtesy GRT

GRT's Carbon, Energy and Water Balance

- Production costs are negligible compared to lifetime capture
- Energy consumption is small (varies with implementation)
  - Low grade heat
  - Electric power
  - Ambient energy
- Water consumption can substitute for energy
  - Water consumption can be 5 to 15 times CO_2 collection
  - Water can be salty or dirty
  - Clean fresh water is produced as by-product
- Indirect emissions depend on energy sources
  - Worst case (electro-dialysis with coal energy) is still carbon positive

Four Stages of Air Capture

- Industrial and commercial CO_2
  - Selling CO_2
- CO_2 capture compensating for emissions
  - Selling Offsets
- CO_2 capture to lower concentrations air
  - Selling more offsets
- CO_2 capture for fuel recycling
  - Selling fuel made from CO_2, water and non-fossil energy

Materially Closed Energy Cycles