Enzymatic Carbon Capture

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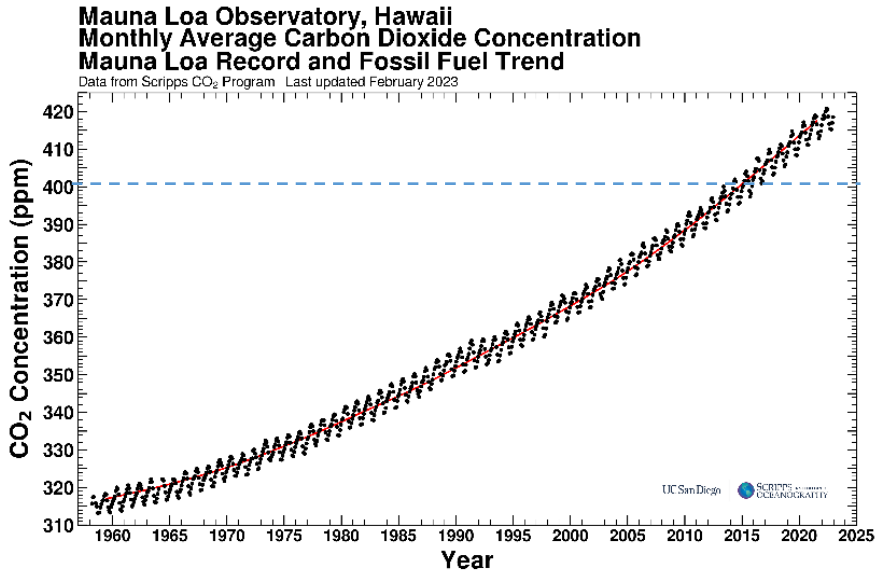
ENZYNOV'2 Biocitech Paris-Romainville, France

Global primary energy consumption by source

Our World in Data

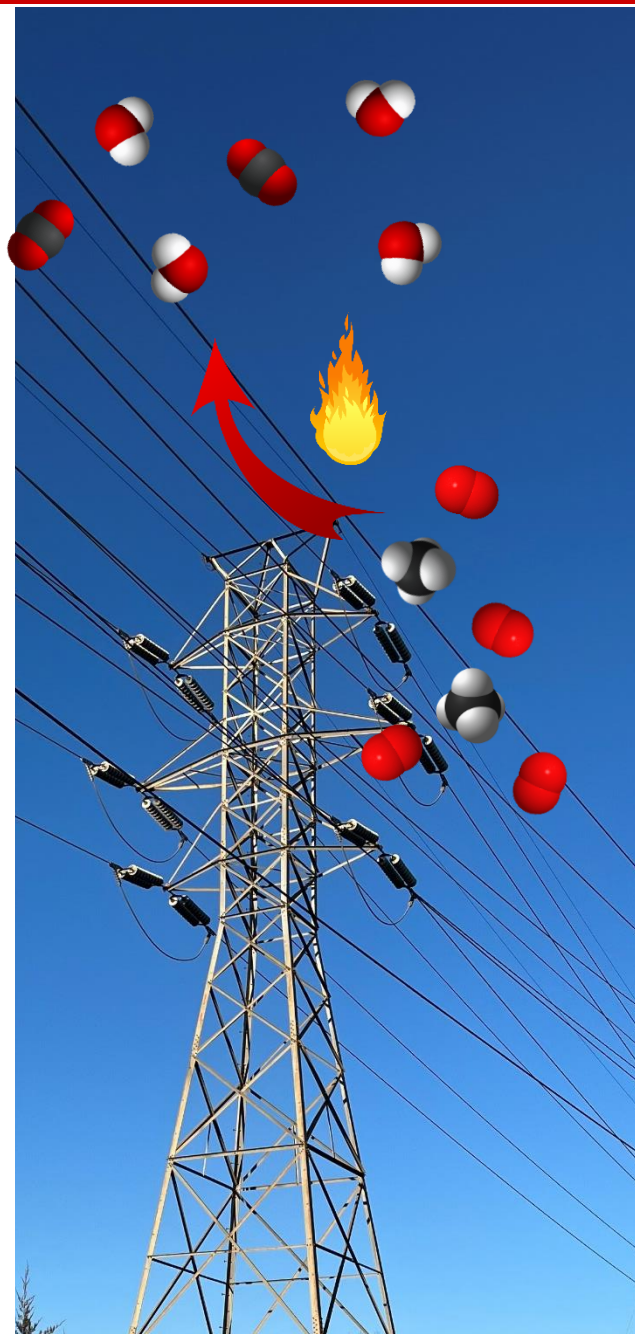
Primary energy is calculated based on the 'substitution method' which takes account of the inefficiencies in fossil fuel production by converting non-fossil energy into the energy inputs required if they had the same conversion losses as fossil fuels.



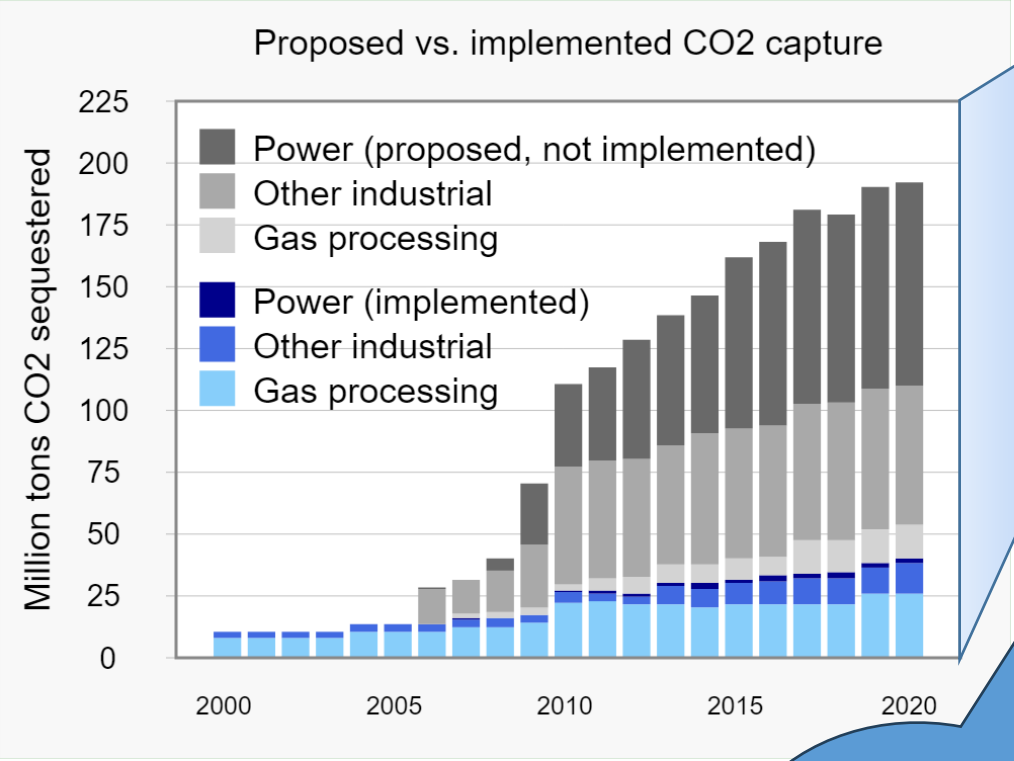
A Big Urgent Problem

Source: Our World in Data based on Vaclav Smil (2017) and BP Statistical Review of World Energy

OurWorldInData.org/energy • CC BY



Carbon Capture Use & Storage



Abdulla et al. (2021) *Environ. Res. Letters*: https://doi.org/10.1088/1748-9326/abd19e

Point Source Capture

Capture
Capturing CO_2 from fossil or biomass-fuelled power stations, industrial facilities, or directly from the air.

Use
Using captured CO_2 as an input or feedstock to create products or services.

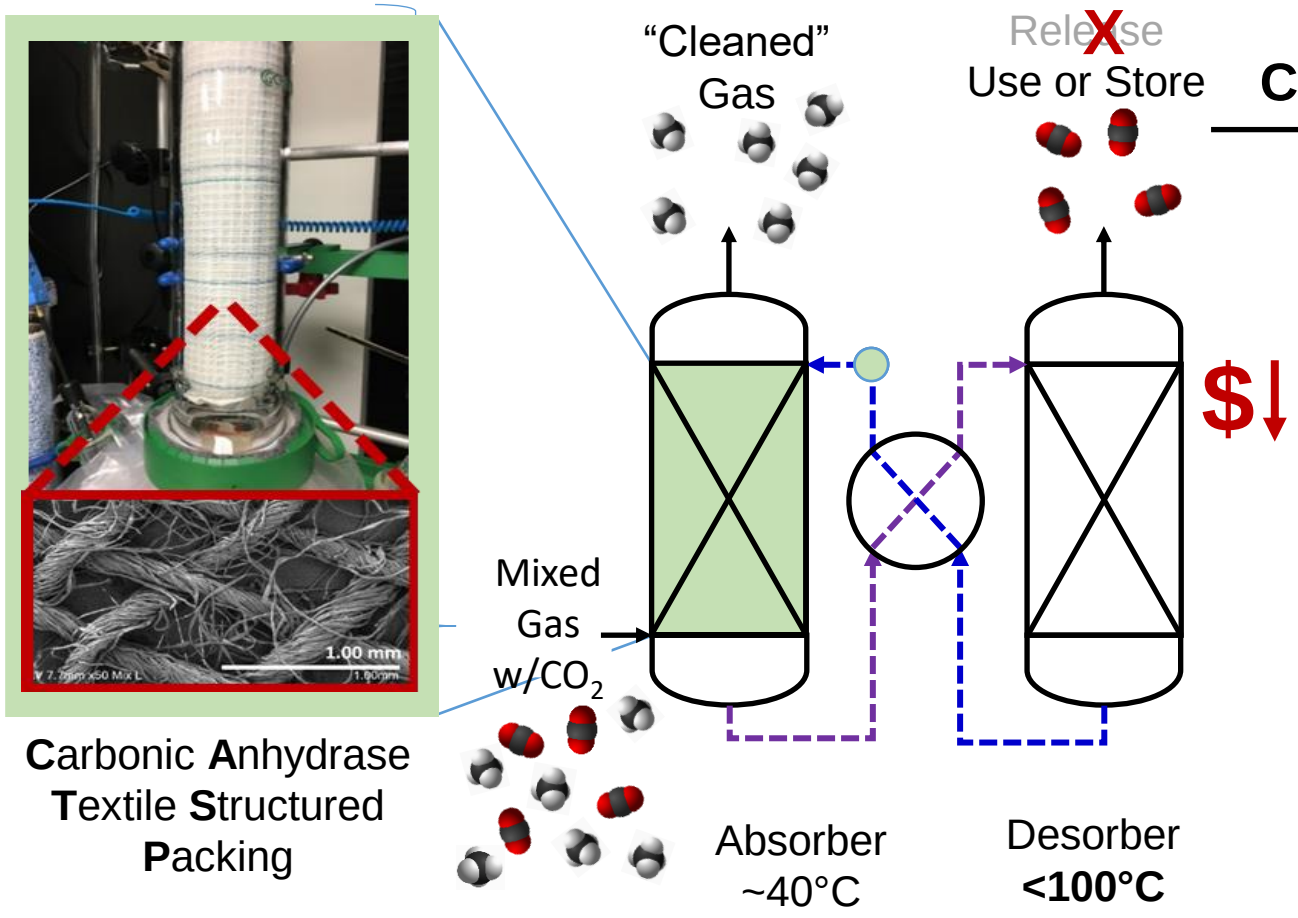
Transport
Moving compressed CO_2 by ship or pipeline from the point of capture to the point of use or storage.

Storage
Permanently storing CO_2 in underground geological formations, onshore or offshore.

Direct Air Capture

IEA (2021) About CCUS, Technology Report: https://www.iea.org/reports/about-ccus

Reactive Absorption Carbon Capture



Carbonic **A**nhydrase **T**extile **S**tructured **P**acking

Conventional Carbon Capture Schematic

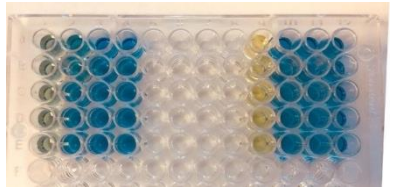
The Sleipner field in the North Sea. (Photo: Harald Pettersen / Equinor ASA)

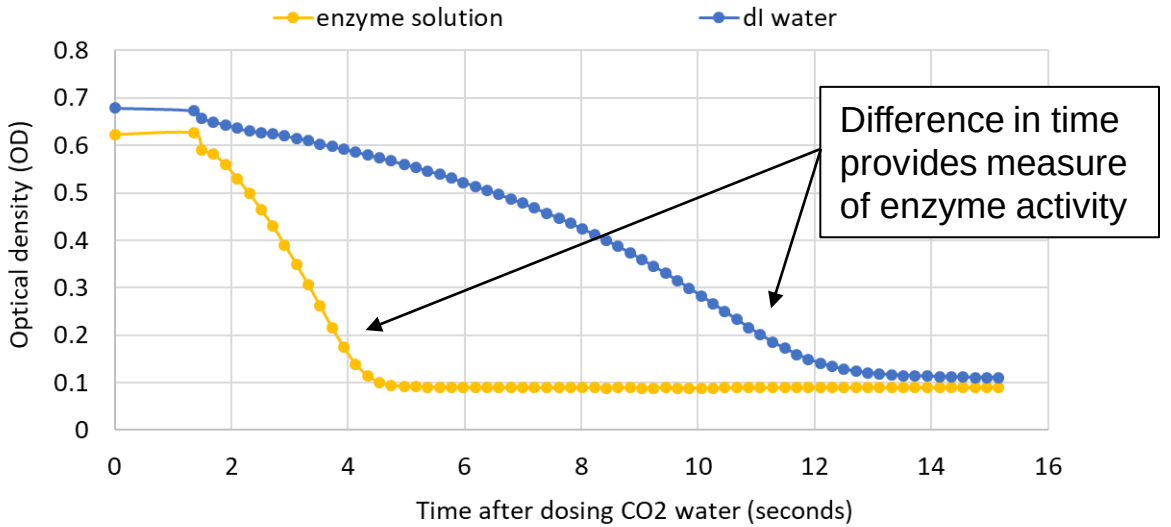
- CO_2 separated from natural gas is injected into the Utsira aquifer under the North Sea
- ~1Mt CO_2/y since 1996 by Statoil of Norway
- The benchmark for geological CO_2 storage

Aq. K_2CO_3 solvent – slow rxn

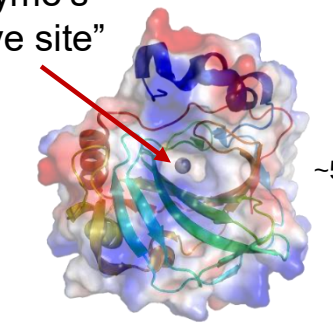
- ΔH_{abs} 27 kJ/mol CO_2
- **Requires a catalyst!**

Carbonic Anhydrase Reaction Catalysis





Zinc in the enzyme's "active site"



Carbonic anhydrase

Image credit: Vlad Lunin

CO_2 hydration → **pH change** → **Color change of indicator** (Bromothymol blue)

pH ↓

$$CO_2 + H_2O \leftrightarrow HCO_3^- + H^+$$

$H^+ + {}^-OH \rightarrow H_2O$

CO_2 becomes "captured" as soluble bicarbonate ion

Alkaline buffer neutralizes the released proton

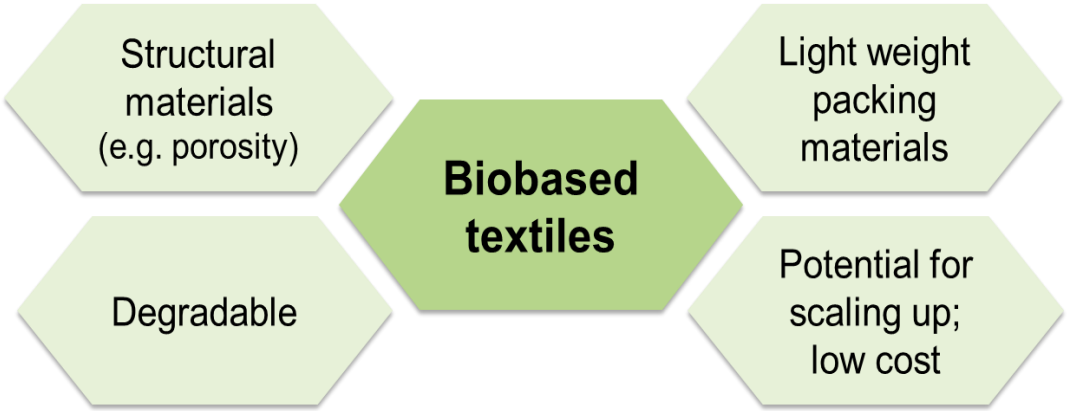
Textiles + Enzymes = Biocatalytic Textiles

"Structural materials"

- **Flexible materials**
- **Large surface area**
- **Transport water**

"Biochemical catalysis"

- **High efficiency**
- **Use less toxic solvents**
- **Sustainable**



immobilization →

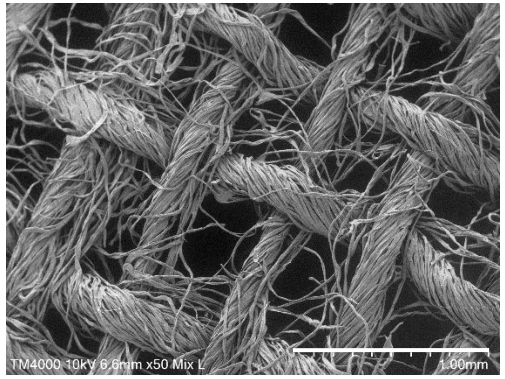
- **Reuse the biocatalysts**
- **Improve functionality**
- **Position the biocatalysts**
- **Versatile modular design**

Making & Pretesting Biocatalytic Textiles

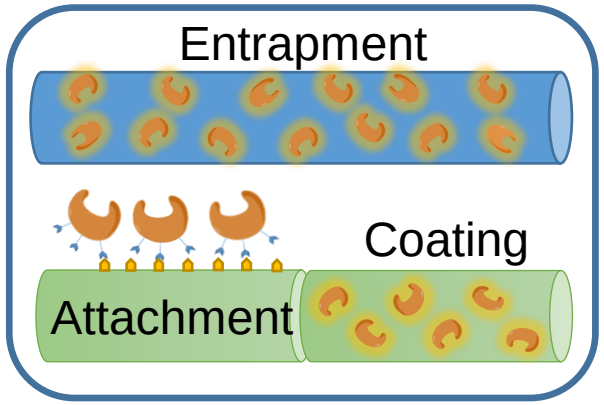
Carbonic anhydrase

+

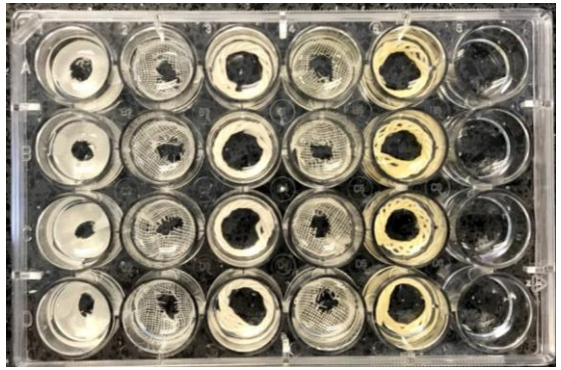
Textile yarns

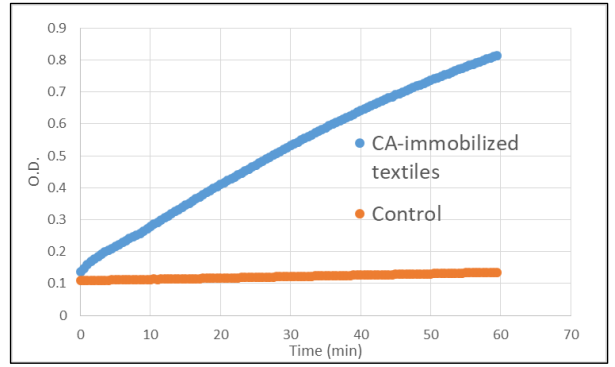


Enzyme Immobilization Methods

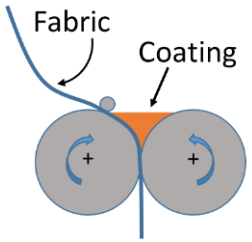


Immobilized Enzyme Activity Assessment



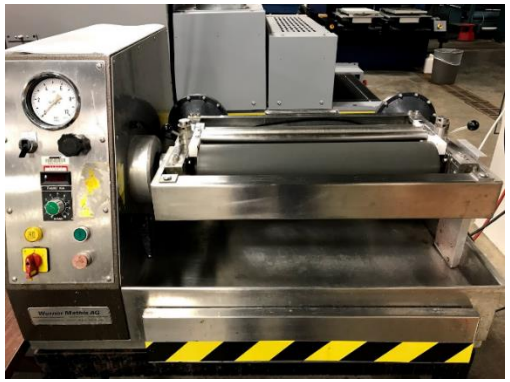


Ester hydrolysis → **Color change of substrate** (Colorless to yellow)

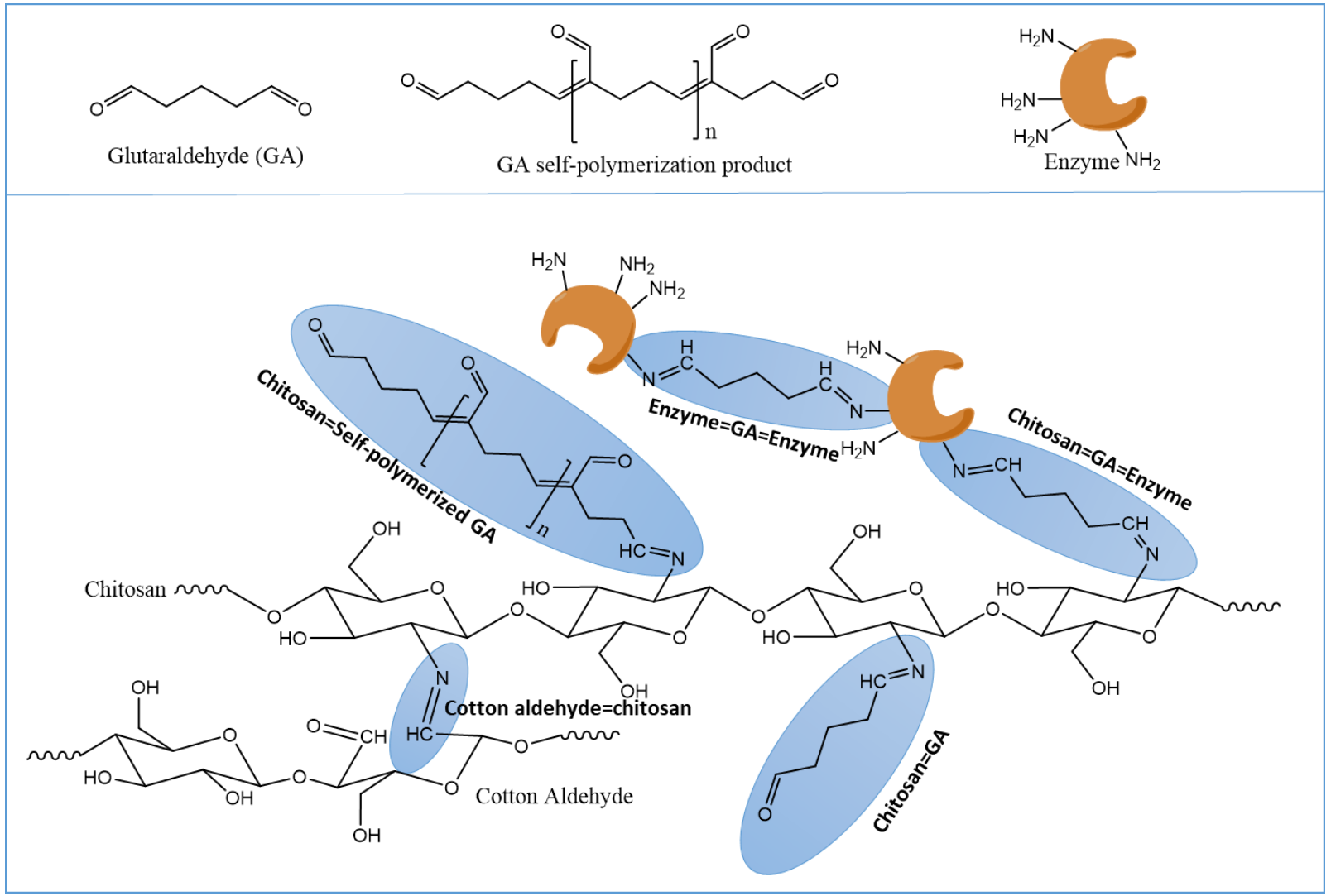


Scale-up

Coating Application by Padding on Textiles



TSP Module

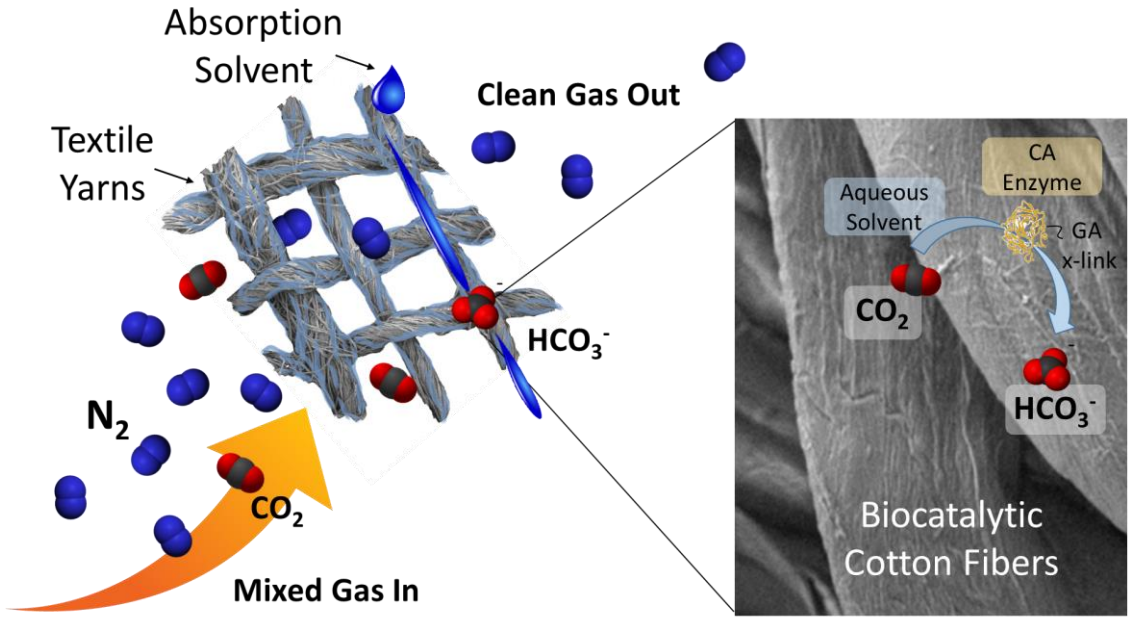


Shen et al. (2022) Catalysts

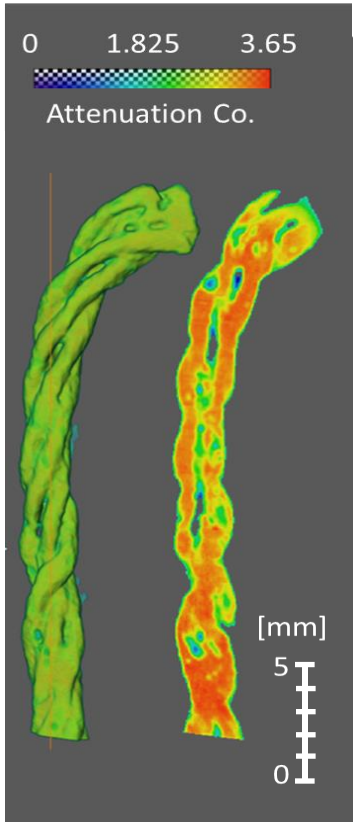
Enzyme Immobilization Chemistry

What's Happening inside the CATSP?

CATSP = Carbonic Anhydrase Textile Structured Packing



Shen et al. (2022) Catalysts



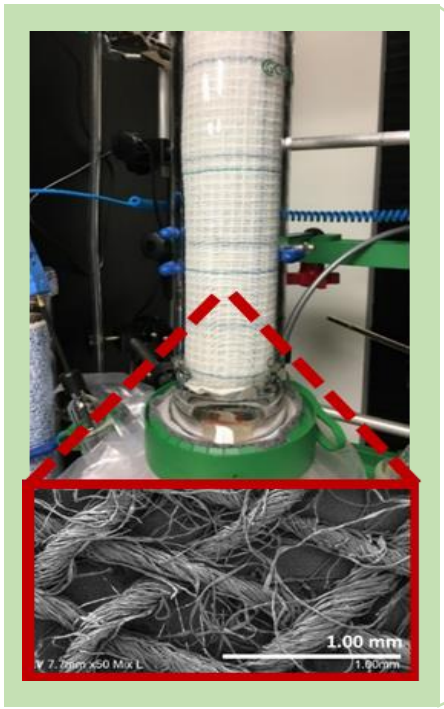
Yuan et al. (2021) Adv. Mat. Int.

Textile causes liquid to spread and forces gas to contact ("bump into") the liquid

Enzyme rapidly converts CO_2 into highly soluble bicarbonate ion

Textile guides liquid flow

Biocatalytic Textile Gas-Liquid Contactor



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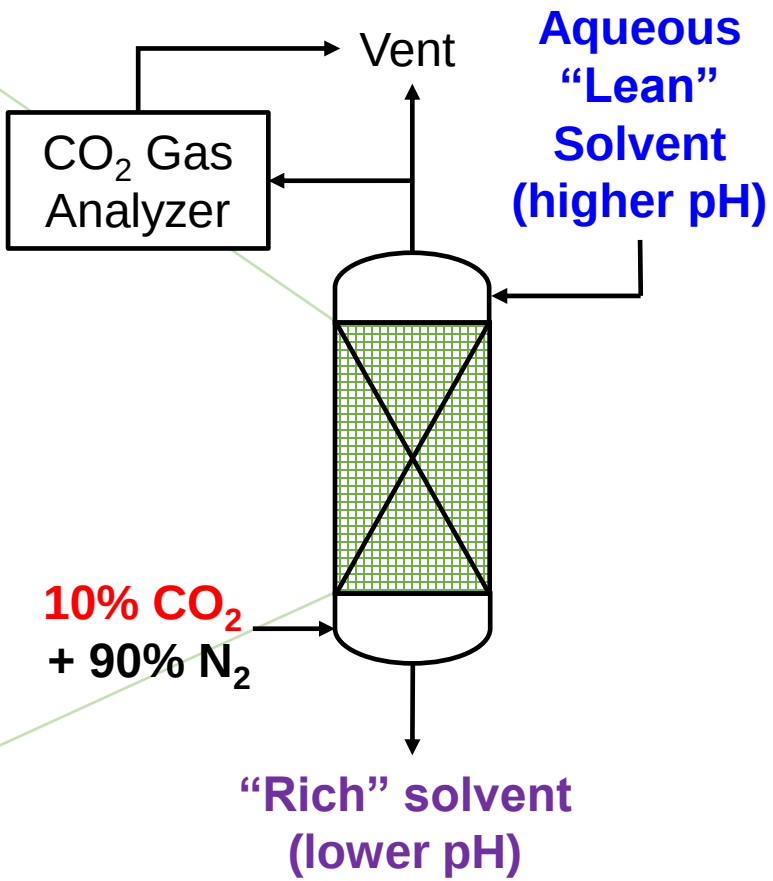
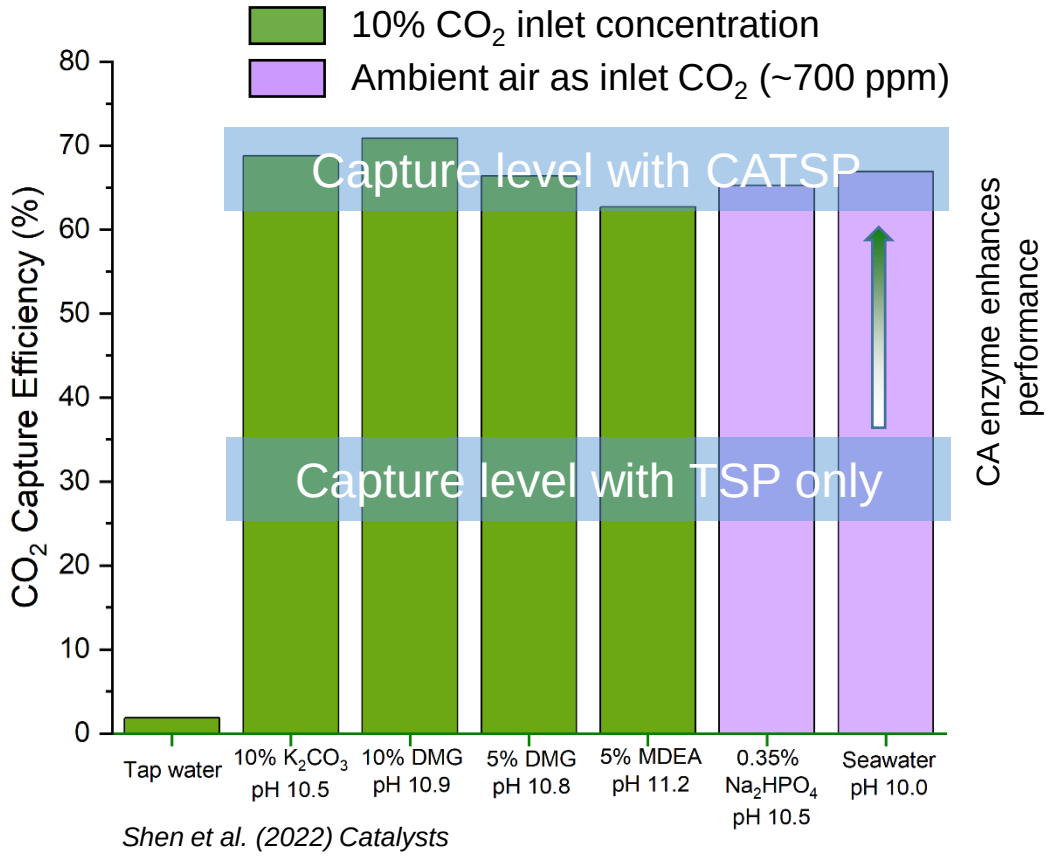


Flow-through Absorber Schematic

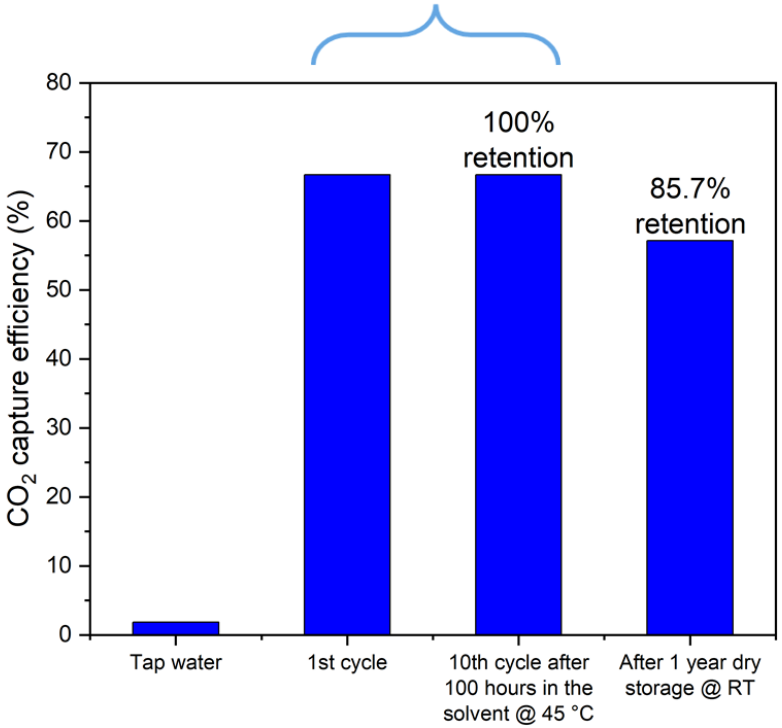


Shen et al. (2022) Catalysts

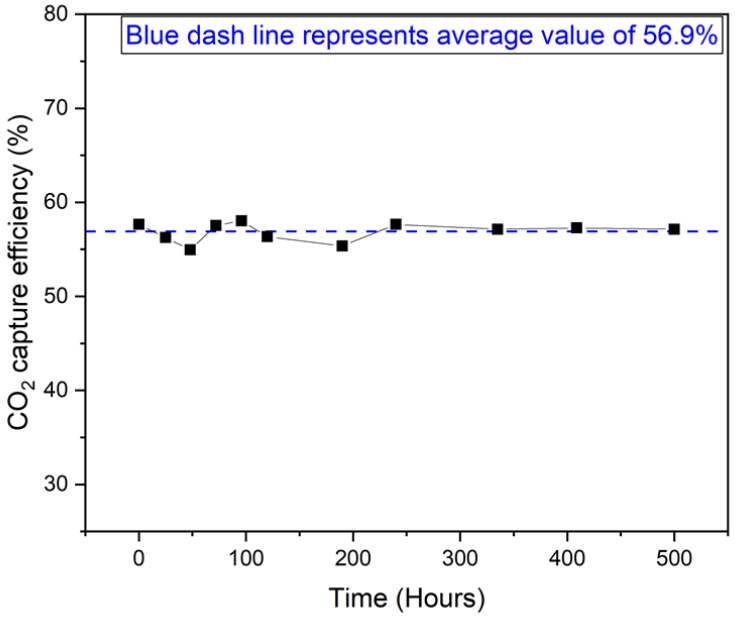
CATSP contactor works for both flue gas and direct air using benign solvents

CATSP-Gen2 Durability & Versatility

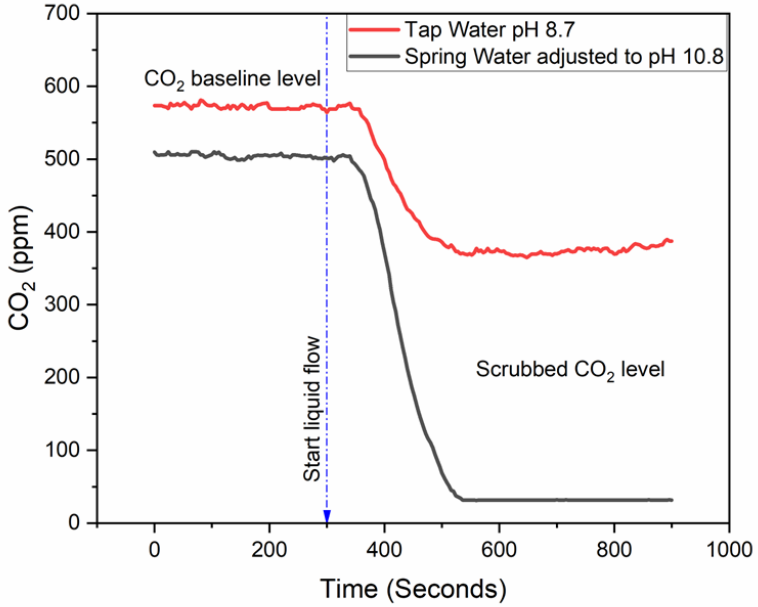
During 71 days*



Single module result – stack modules to increase capture efficiency*



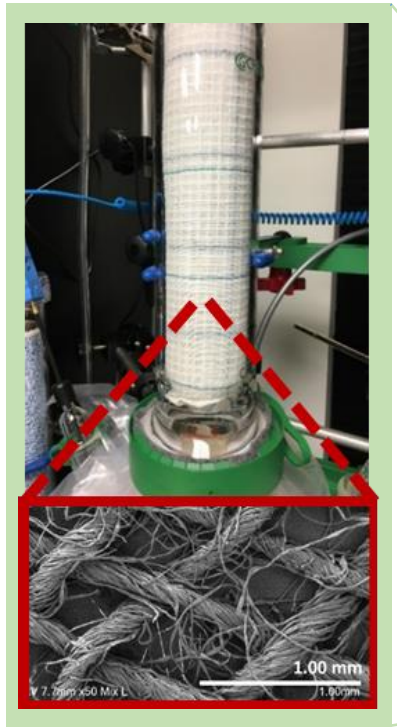
Deep levels of DAC are possible



*J. Shen, Y. Yuan, S. Salmon. *Catalysts* 2022, 12(10): 1180. https://doi.org/10.3390/catal12101108

Textile filters with CA attached to their surface improve gas-liquid contact for fast CO_2 removal; system works best at elevated pH

“Drop-in” or Enabler for “DAC-DSU”



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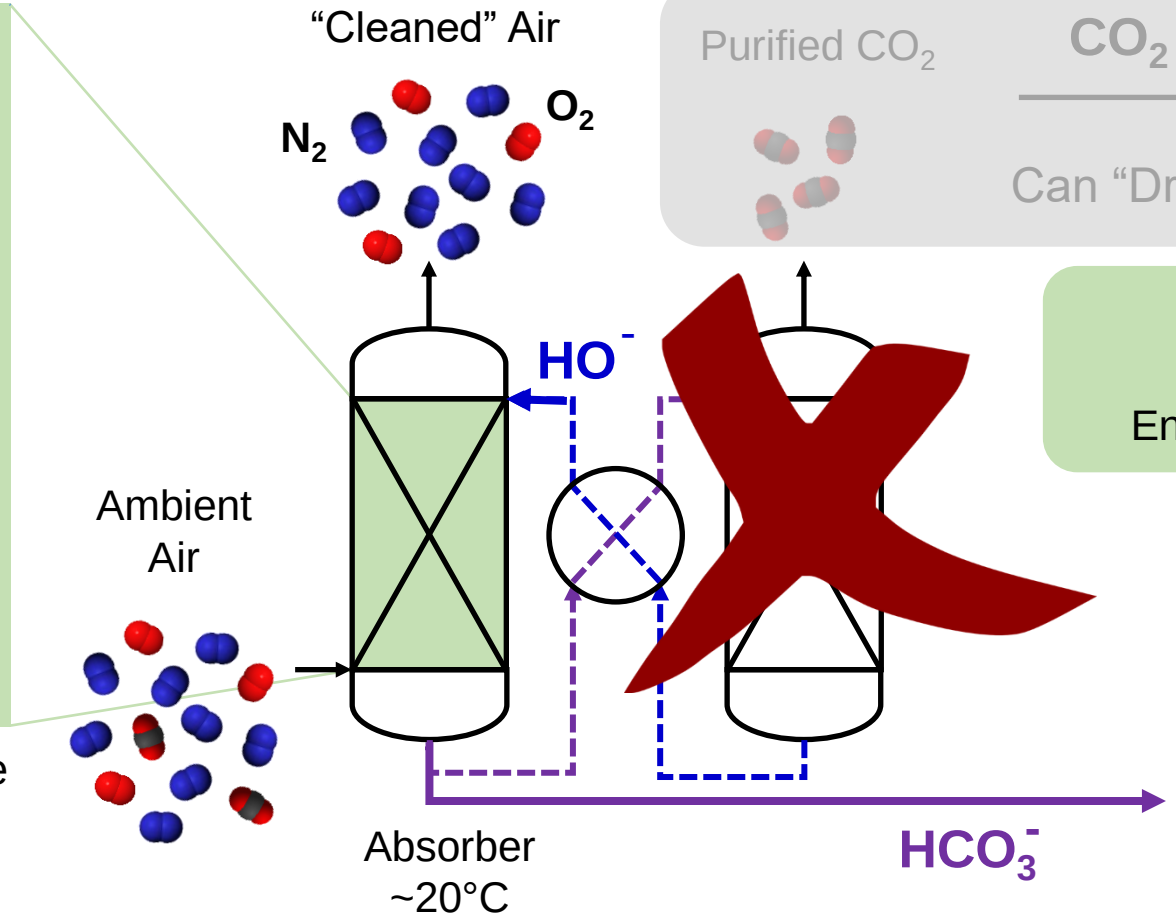


Purified CO_2 → CO_2 → Use or Storage

Can “Drop-in” to Conventional Processes

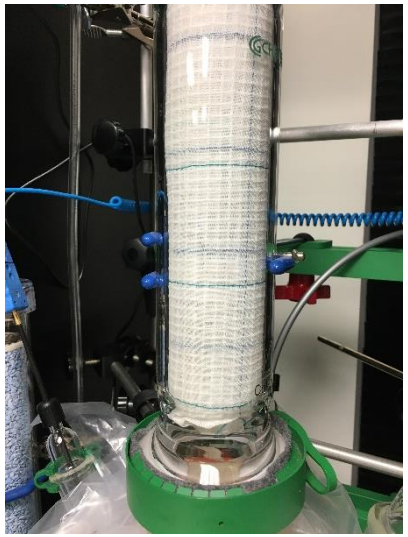
OR
Eliminate Desorption Stage!
Enable Direct Use of Inorganic Carbon!

Combined Capture & Use

- Neutralize industrial effluents (alkali + M^{2+})
- Enhance algae growth (biofuels & feed)
- Electrochemical reduction (platform chemicals)

Enables use of solvents that can ***expand*** CO_2 ***utilization*** options

Paths to Scale-up



Lab scale
(NCSU)

Now

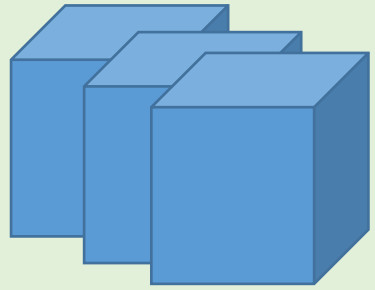
Small bench-scale*
(UK-CAER)

Near-term

Small field scale**
(Biogas upgrading)

Long-term

Full commercial scale***



Develop modular designs for rapid deployment

* Bench-scale CO_2 Capture Unit at University of Kentucky's Center for Applied Energy Research: https://netl.doe.gov/sites/default/files/netl-file/J-Thompson-UKY-CAER-Increased-Mass-Transfer.pdf
** Biogas Upgrading – Technical Review, Energiforsk: http://vav.griffel.net/filer/C_Energiforsk2016-275.pdf
*** Petra Nova Commercial-scale CO_2 Capture Project: https://www.nrg.com/case-studies/petra-nova.html

Thank you!

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Textile Biocatalysis Research
https://sites.textiles.ncsu.edu/textile-biocatalysis/

Biocatalyst Interactions with Gases (BIG) Collaboration
https://biocat.ncsu.edu/