SAND2019-15490PE

Memzyme Technology for Cost-Effective CO_2 Separations in Enhanced Oil Recovery

Technology Commercialization Fund Project: TCF-17-13314

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DOE Project Kickoff Meeting
November 18, 2019

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Acknowledgment

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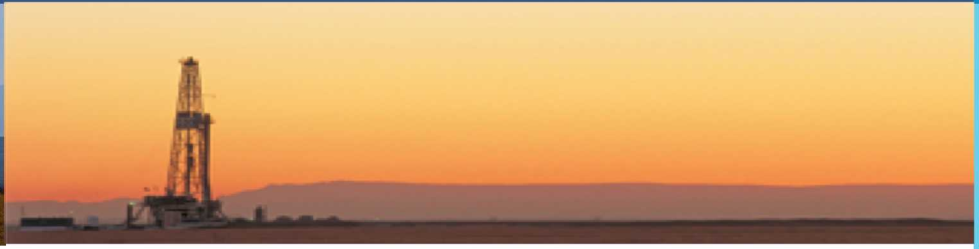
This material is based upon work supported by the Department of Energy under Award Number TCF-17-13314.

Memzyme for Carbon Capture

Sandia National Laboratories





Dr. Susan Rempe
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Principal Investigator

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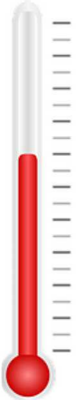
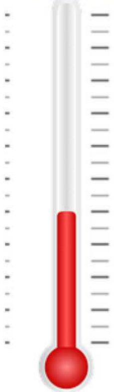
U. New Mexico
Experimental Lead

Imagine a future …

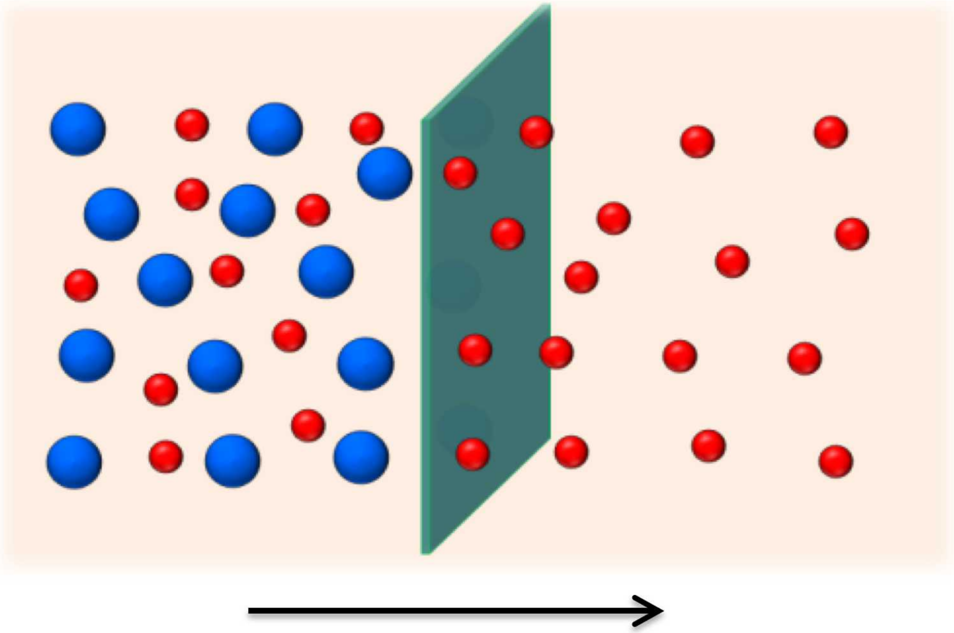
+1.4 F





Membrane with unique function

N_2, O_2, CO_2



Selective → useable CO_2

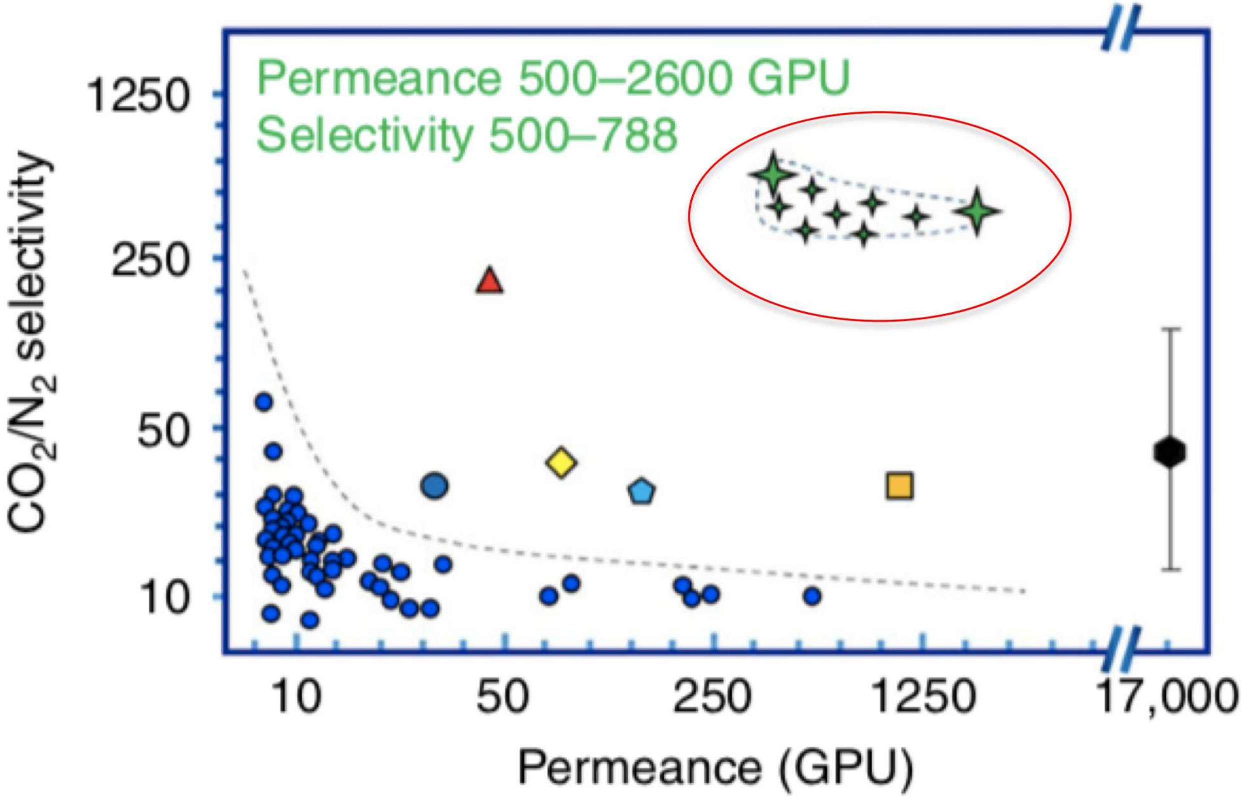
(>500 CO_2/N_2)

Rapid → less membrane

(2600 GPU)

Fu, et al. *Nature Commun*. 9:990 (2018)

Membrane with unique function

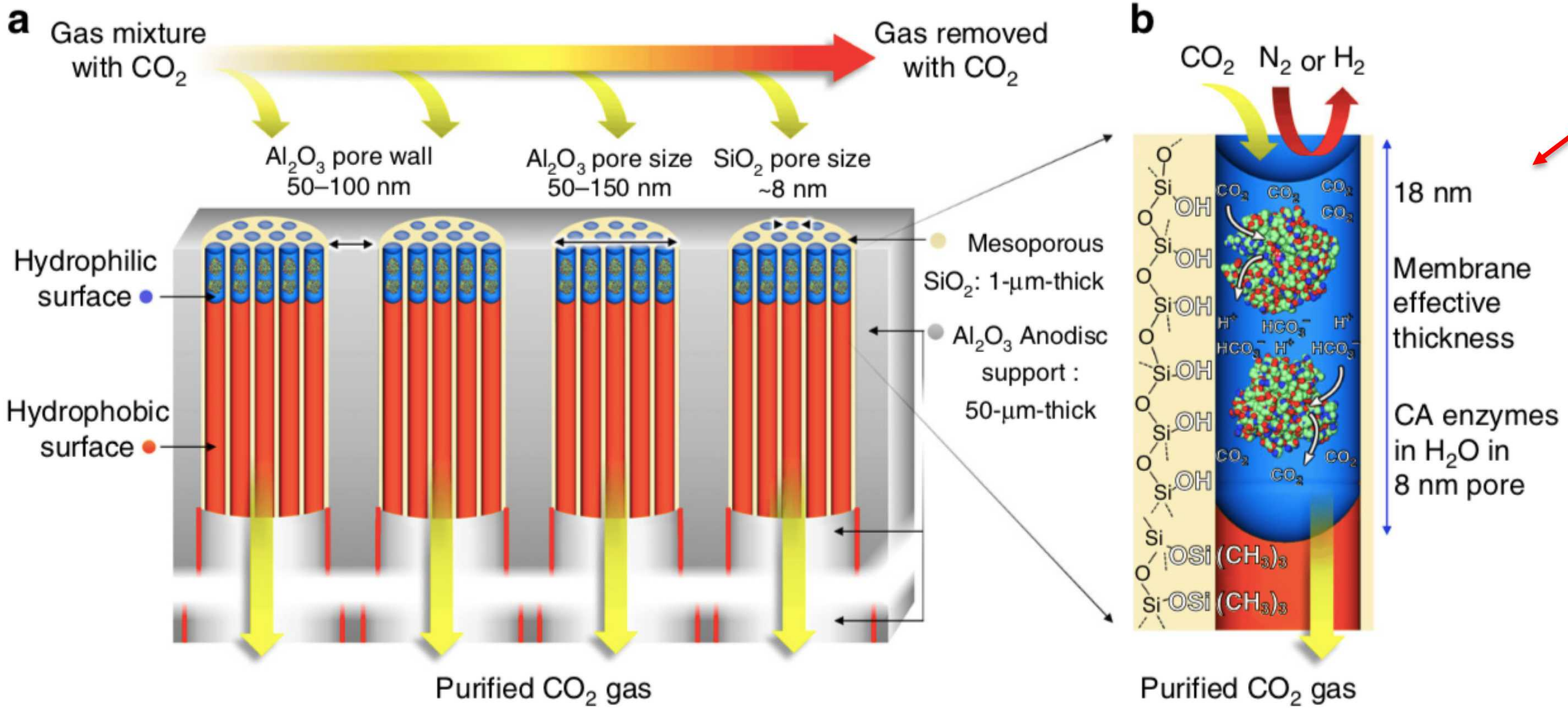


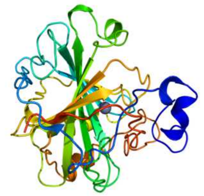
Green stars: Fu, et al. *Nature Commun*. 9:990 (2018)

1 GPU = 10^{-6} cm^3(STP)/(cm^2 s cmHg)
= 3.35 x 10^{-10} mol/(m^2 s Pa)

Red triangle: Trachtenberg, et al. DOE Project DE-FC26-07NT43084, Carbozyme (2011)
Black hexagon: -43 C, Zhou, et al. *Angew. Chem. Int. Ed*. 53:3492 (2014)
Others: see references in Fu, et al.

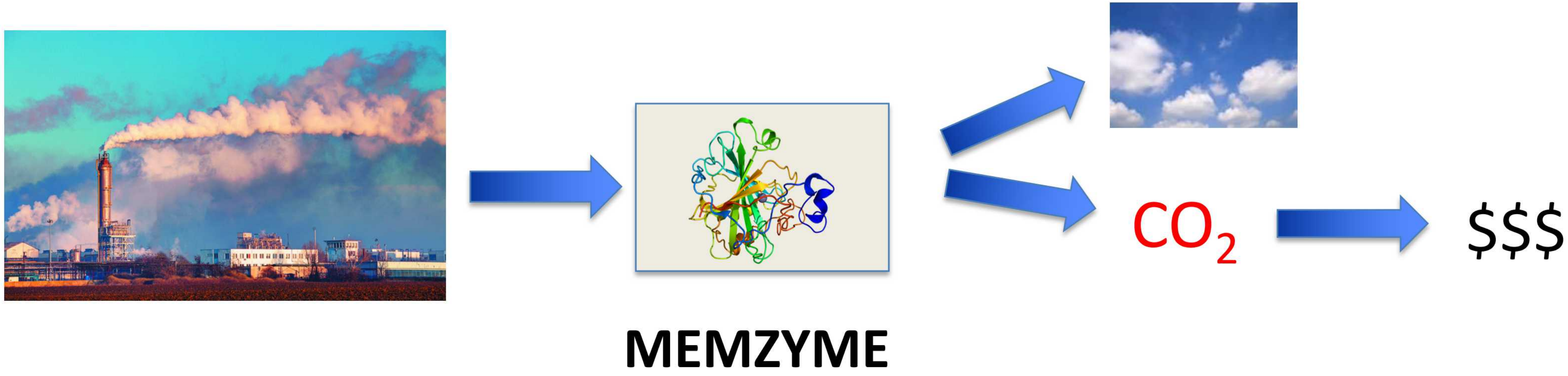
Membrane with unique structure





Fu, et al. *Nature Commun*. 9:990 (2018)

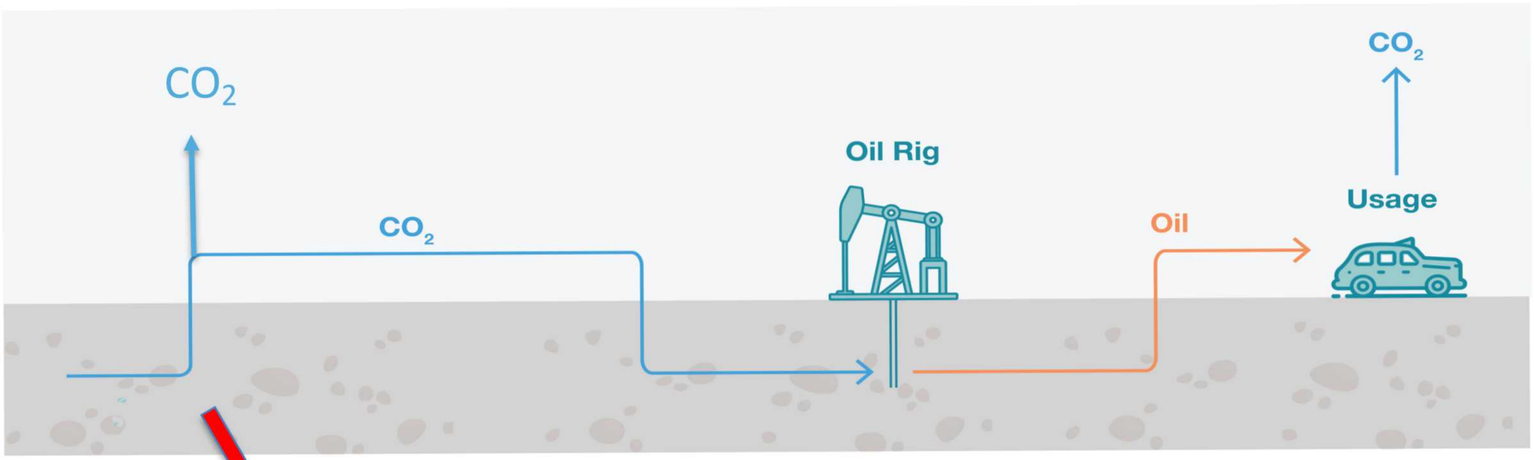
Commercialization Value



At lab-scale, our modular, rechargeable filters separate CO_2 from nitrogen rapidly (2600 GPU) **and** selectively (>500), creating the potential to make carbon capture from power plant emissions profitable while restoring our climate.

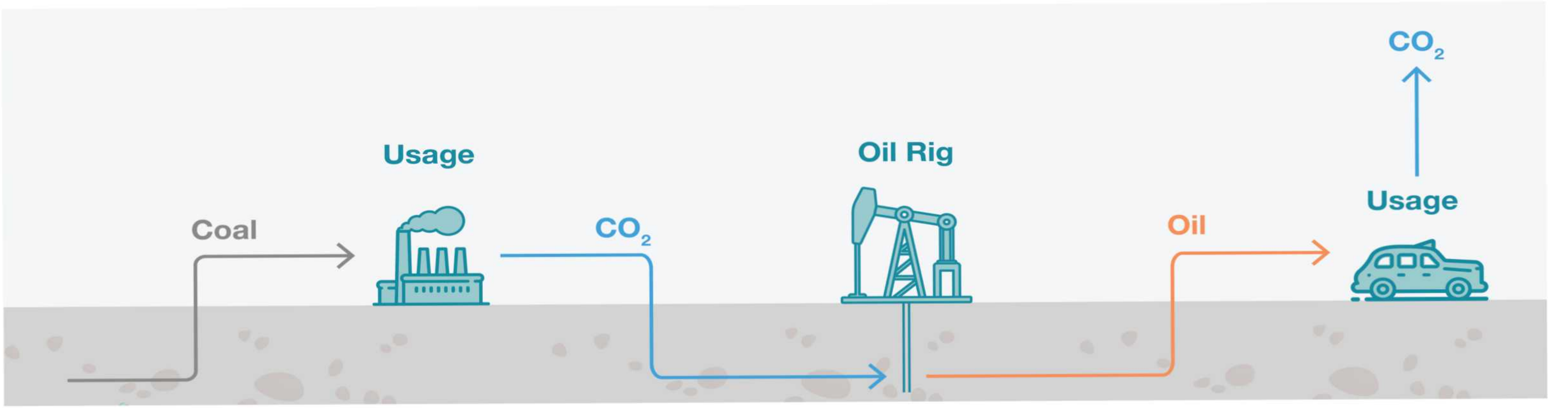
Oil & tax credits drive CO_2 capture

Natural CO_2



tax credit ($35/t caught & utilized)
($50/t caught & stored)

Anthro CO_2

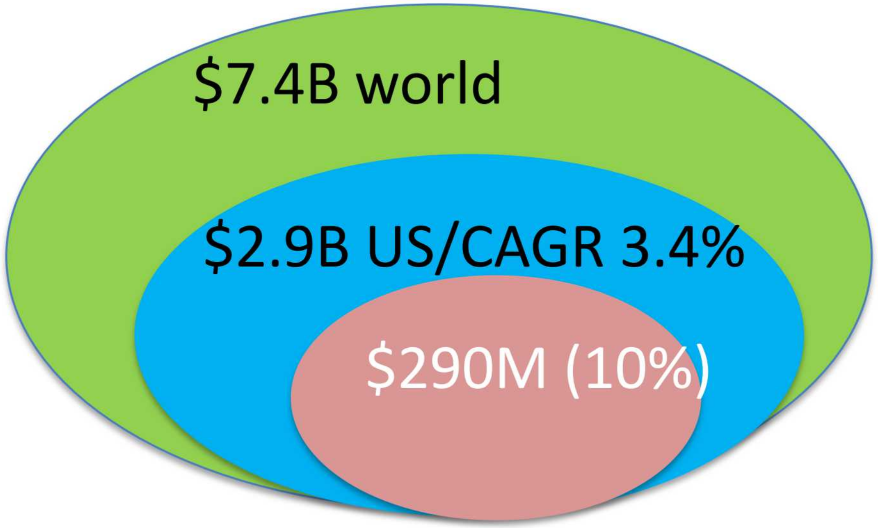


CO_2-enhanced oil recovery (EOR)

CO_2 from coal power plants is marketable

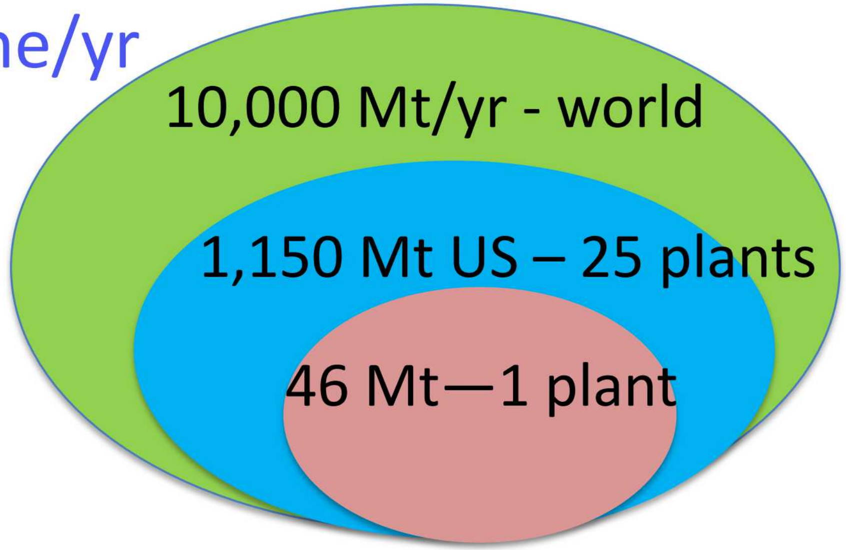
Current CO_2 market

$/yr



CO_2 available w/capture tech.

Volume/yr



Current capture tech is expensive

CO_2-EOR
needs <$20/t at
today's oil prices

Liquid amine absorption
($60/t* – credit = $25/t)

*includes all costs, including compression of separated CO_2

Membranes show promise for low-cost CO_2 capture

Membranes (lab scale)	Flux (GPU)	Selectivity (CO_2/N_2)	Capital ($/$m^2$)	Cost of Separation* ($/t CO_2, 90%)
Memzyme	2600	500+	Low (~$50/$m^2$)	$18
MTR	1000	50	Low ($150/$m^2$)	$32
UOP	60	30	unknown	>$35
Air Liquide	70	30	unknown	>$35

*estimated based on lab-scale performance, membrane fabrication costs, and includes compression

Basic Research Needs for Carbon Capture: Beyond 2020, Appendix A (Fig. 9)
Merkel, T. C., et al. *J. Membr. Sci.* (2010) 359:126

Data taken from reports:

Merkel, T., et al. Membrane process to capture CO_2 from coal-fired power plant flue gas. (*NETL*, 2009).
Casillas, C. et al. Pilot testing of a membrane for post-combustion CO_2 capture. In *Proc. 2015 NETL CO_2 Capture Technology*.
Vora, S.D. *DOE/NETL Advanced Carbon Dioxide Capture R&D Program: Technology Update* (NETL, 2013).
Hasse, et al. CO2 capture by sub-ambient membrane operation. *Energy Procedia* (2013) 37, 993.

Memzyme path toward market

Challenge: Maintain Function in Scalable Format with Industrial Gases

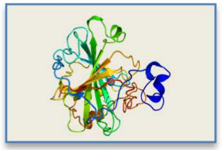
Task 1: Make stronger, scalable supporting material

Task 2: Test compatibility of membrane & support

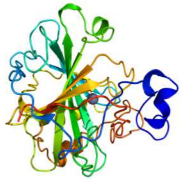
Task 3: Optimize active layers (enzymes, buffers)

Task 4: Optimize selectivity for CO_2 from flue gas

Optimize for flue gas



Make samples



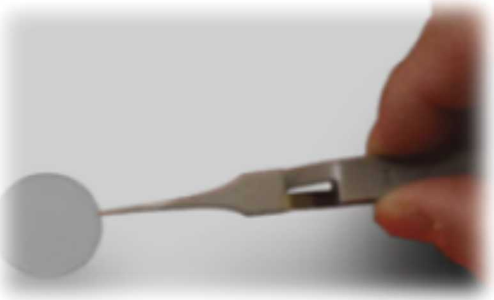
Make raw mat'ls

Design (IP)

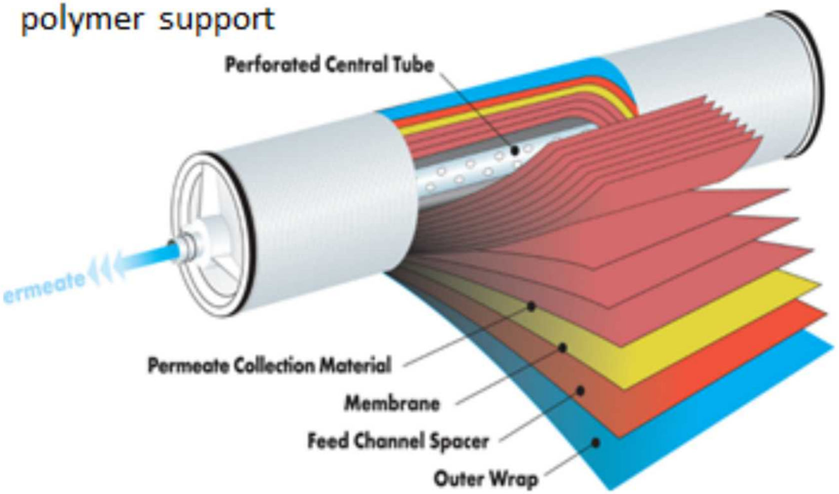
US Patent 9,242,210 (2016)

Task 1: Supporting material

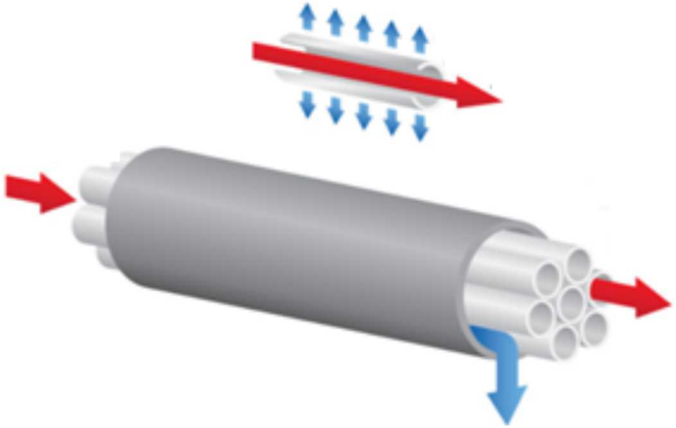
Current lab-scale supports:
Small piece of polymer support and small piece of anodized porous alumina



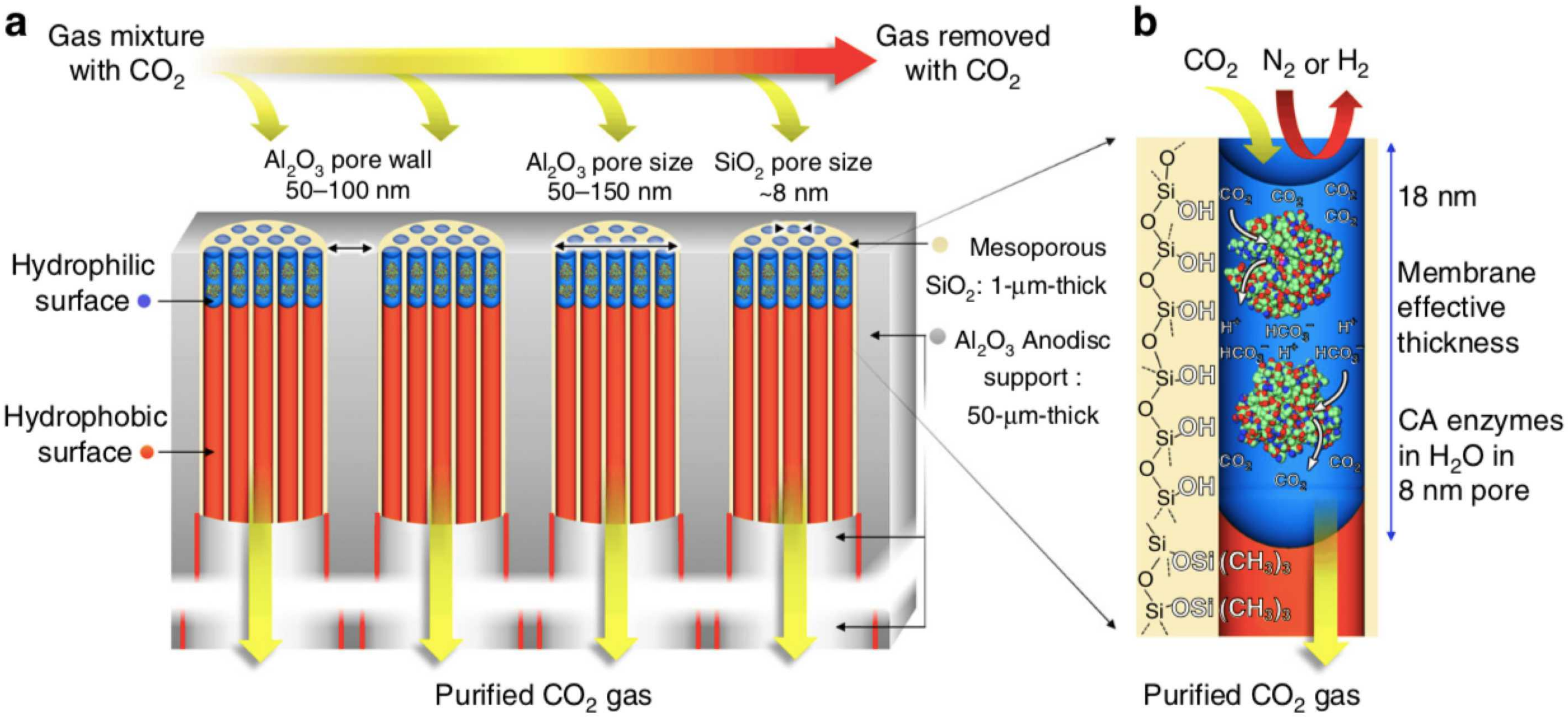
Strategy 1:
Spiral wound by using flexible polymer support



Strategy 2:
parallel tubes by using rigid porous ceramic support



Task 2: Test membrane-support compatibility

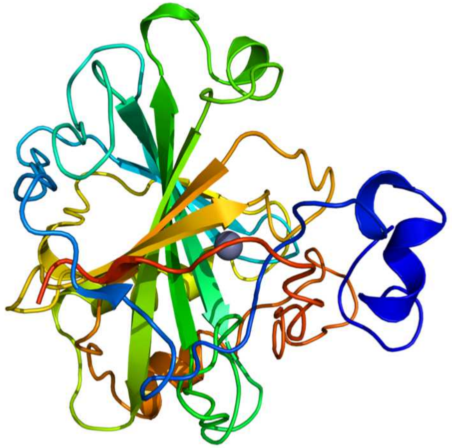


Can the new supporting structure be made compatible with membrane fabrication?

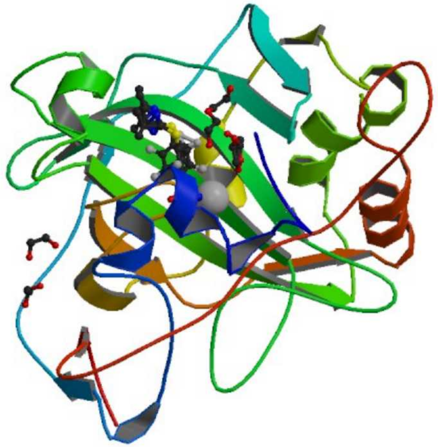
Task 3: Optimize active layer

Incorporate variants, modify buffer

What conditions optimize enzyme lifetime and performance in nanoconfined membrane?



Bovine C. anhydrase

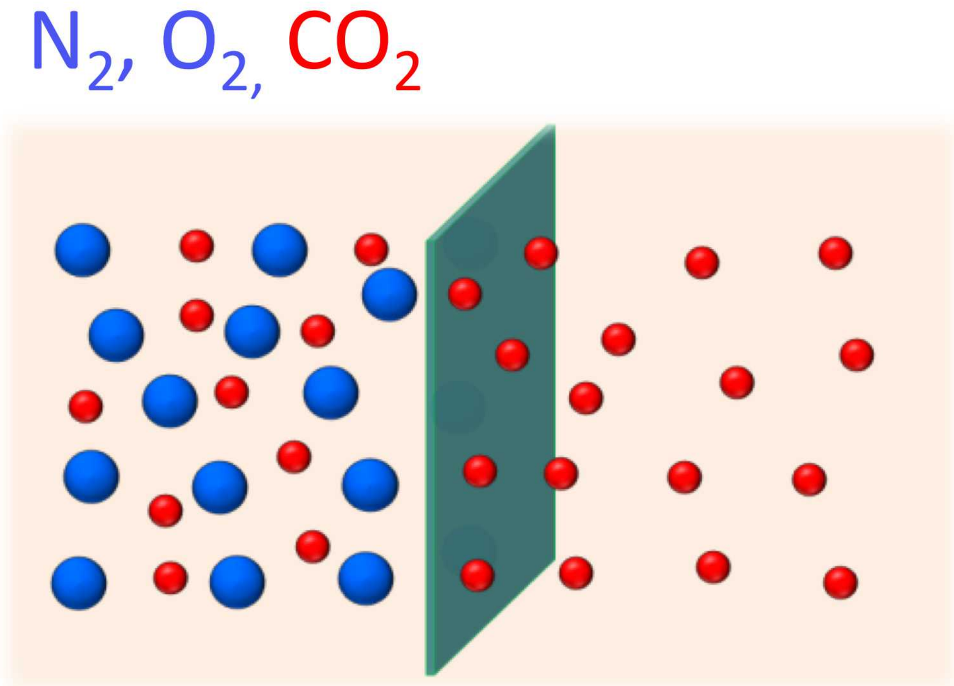


Thermostable, rapid Saz_C.A.

(*Int. J. Mol. Sci.*, 2019 20:1494)

Task 4: Optimize selectivity for flue gas

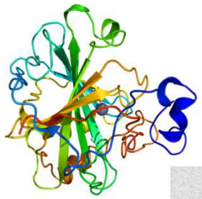
- CO_2 vs N_2 (15:85)
- CO_2 vs O_2 (15:85)
- CO_2 vs SO_x and NO_x
- CO_2 separation with flue gas (60 ^oC)



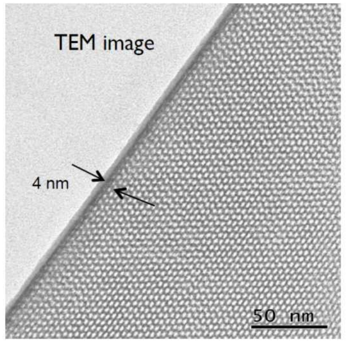
Vary - thickness,

- surface chemistry,
- active layer.

Work flow

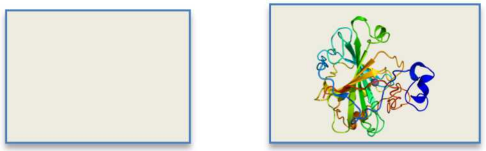


Vary active layer -- enzyme, buffer, storage conditions



Characterize membrane samples (FT-IR, TEM, SEM)

Make samples on support; measure function



TRL 3

TRL 4+

Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4

Budget

Schedule	Year 1	Year 2
DOE TCF Share	$150,000	$150,000
Non-Federal Share	$150,000	$150,000

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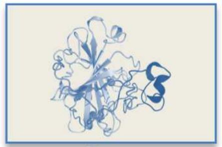
Summary

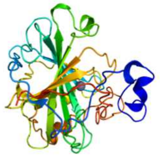
Design (US Patent)

Start-up

Make samples



Make robust, scalable raw materials



Scale up

Implement

LDRD (SNL) Private Funds DOE-TCF Partnerships

2016 2017 2019 2020 2021 2022 2025