High-performance carbon capture membrane made of atom-thick filter





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Impact of increasing CO₂ emissions on climate and industry

Source: IPCC 6th Assessment Report

Commercial solution: CO₂ absorption by liquid amines

Membrane-based solution: CO₂ permeation by a selective film

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Atom-thick porous graphene film for sieving gases

Gases can be separated based on their relative size

	Kinetic diameter (Å)
Не	2.60
H ₂	2.89
CO ₂	3.30
02	3.46
N_2	3.64
CH4	3.80

Nature Communications 2018, 9, 2632 Carbon **2019**, 153, 458 Science Advances 2019, 5, eaav1851 Energy & Environmental Sciences 2019, Scientific Reports **2019**, 5, 5202 Advanced Functional Materials 2020, 30 Journal of Membrane Science 2020, 612 Journal of Membrane Science **2021**, 618, 118745 Carbon **2021**, 173, 980

- ~Atom-thick pores \rightarrow Ultrafast CO₂ transport
- ~Å-scale pores \rightarrow Selective CO₂ transport over N₂

Flux $\propto Hexp(\frac{-E_{barrier}}{k_{B}T})$

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Journal of Membrane Science **2021**, 624, 119103 Journal of Membrane Science 2021, 637, 119628 Science Advances **2021**, 7, eabf0116 PNAS **2021**, 118, e2022201118 ACS Nano **2021**, 15, 13230 Industrial & Engineering Chemistry Research, 2021, 60, 16100 JACS Au, **2022,** 2, 723 Angewandte Chemie, **2022**, 61, e202200321 Accounts Mater. Res. 2022, 3, 1073

Patent Application WO2018/177533A1 Patent Application WO2019/175162A1 Patent Application WO2020/011892A1 Patent Application EP20166877 Patent Application EP20174809

Simple scalable chemistry for introducing CO₂sized pores in graphene

Pores are formed by flowing ozone over graphene + energy (heating)

That's it

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Huang, Villalobos, Li, Bondaz, Agrawal, Advanced Materials, 2022 (In press)

Visualization of pore formation inside an electron microscope

Ozone

Proof-of-principle on formation of CO₂-selective pores by oxidation

EPFL Attractive performance of graphene membrane for postcombustion capture

Energy Environ. Sci., **2019**, 12, 3305–3312 Science Advances **2021**, 7, eabf0116 ACS Nano **2021**, 15, 13230 PNAS **2021**, 118, e2022201118

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EPFL Rapid advance in the scale-up of the technology in last four years

Millimeter scale (2018)

Centimeter scale (2021)

Nature Communications **2018**, 9, 2632 Science Advances 2019, 5, eaav1851 Carbon 2019, 153, 458–466. Journal of Membrane Science 2020, 612, 118406. Ind. Eng. Chem. Res, **2021**, 60, 16100

Journal of Membrane Science **2021**, 618, 118745 Science Advances **2021**, 7, eabf0116

ACS Nano **2021**, 15, 13230

Meter scale (10 kg CO₂/day) (Ongoing)

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Schweizerische Eidgenossenschaft Confédération suisse Confederazione Svizzera Confederaziun svizra

Swiss Federal Office of Energy SFOE

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Large area graphene on low-cost Cu foil by CVD

Reduction in cost of the material by 100fold

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Thank you

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http://epfl.ch/labs/las