Reuse Project Overview

Dr. Athanasios Papadopoulos

CERTH
CENTRE FOR
RESEARCH & TECHNOLOGY
HELLAS

Reuse

Funded by
the European Union

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No. 101172954. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union.

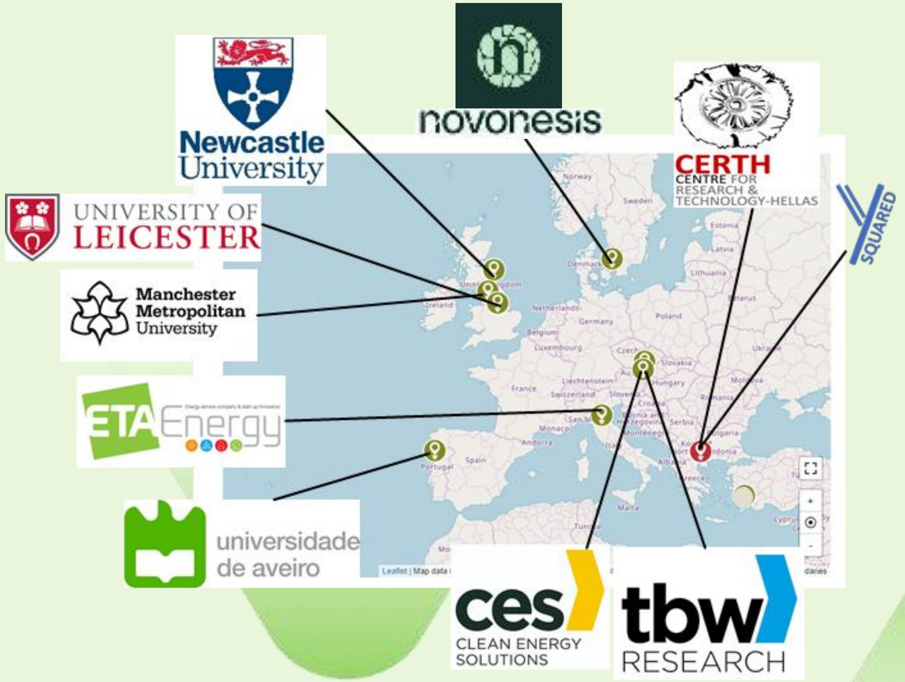
REUSE

Reuse

A HORIZON EUROPE project- ID: 101172954, DOI: 10.3030/101172954, (01/10/2024-31/09/2027)

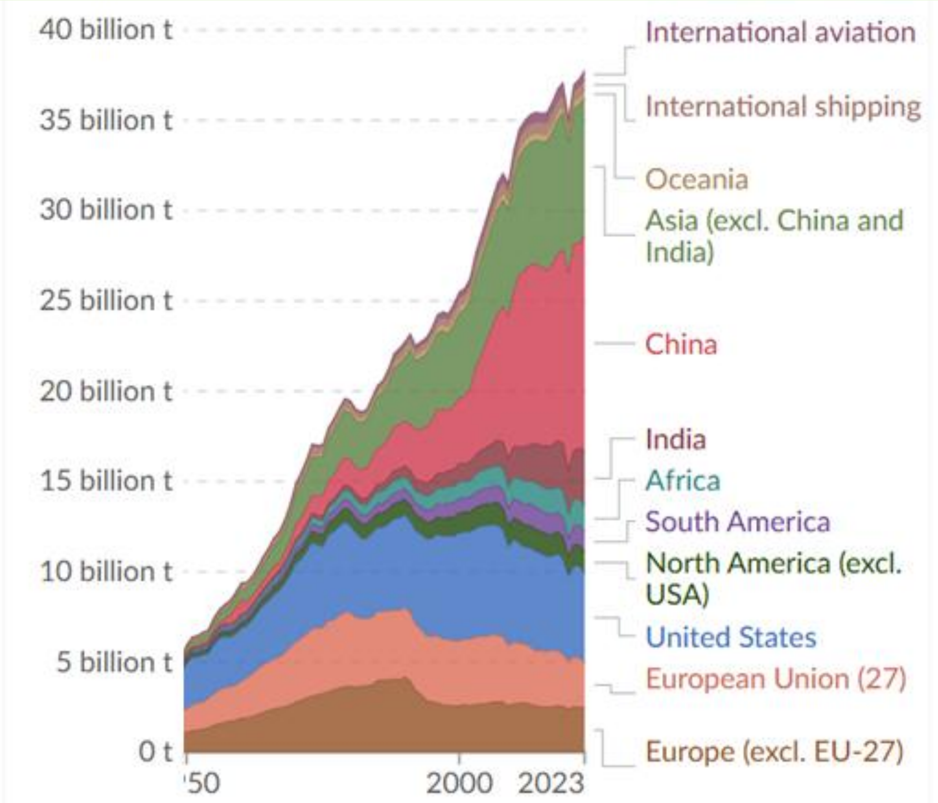
HORIZON-CL5-2024-D3-01-05 - Development of carbon fixation technologies for biogenic flue gases

Enzymatic CO_2 Capture in a Rotating Packed Bed and Electrocatalytic CO_2 Reduction to Useful Products



CO_2 emissions - Facts

Reuse



- 1950 the world emitted $6 \cdot 10^9$ t CO_2/y.
- By 1990 this had almost quadrupled, reaching more than $20 \cdot 10^9$ t CO_2/y.
- Emissions have continued to grow rapidly; we now emit over 35 $\cdot 10^9$ t CO_2/y.
- Europe's contribution is $5 \cdot 10^9$ t CO_2/y in 2023

- Europe, USA, America, Africa, India- slow decrease
- China, Asia- steep increase

- In 2023 China emitted about $10 \cdot 10^9$ t CO_2 = SUM(EU and USA)!
- All Asia emitted $20 \cdot 10^9$ t CO_2 = **2** x SUM(EU and USA)!

Hannah Ritchie and Max Roser (2024) - "CO_2 emissions" Published online at OurWorldinData.org. Retrieved from: 'https://ourworldindata.org/co2-emissions' [Online Resource]

EU targets

Reuse

The first climate-neutral continent

by 2050

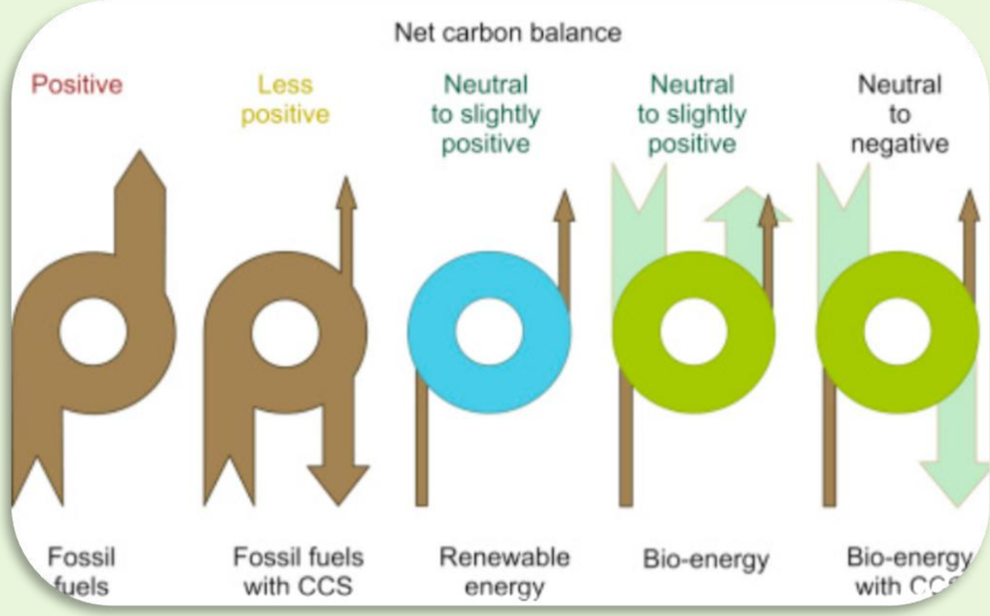
At least 55% less

net greenhouse gas emissions by 2030, compared to 1990 levels

- The European Green Deal (EGD) establishes the objective of becoming climate neutral in 2050.
- This objective requires a greenhouse gas emissions reduction of 55% by 2030.
- This in turn requires significantly higher shares of renewable energy sources (RES).
- The current EU target of at least 32% RES by 2030, set in the Renewable Energy Directive (REDII), is not sufficient and needs to be increased to 38-40%, according to the Climate Target Plan (CTP).

https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en
https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52021PC0557

Biomass-derived emissions



- ➢Biomass will be a key energy carrier to accomplish energy and climate targets
- ➢Biomass combustion systems may enable the decarbonization of various sectors as they allow for highly efficient use of sustainable biomass residues
- ➢The combination of biomass with carbon capture and utilization or storage can result to net zero or negative systems

Quader, M.A. and Ahmed, S., 2017. Bioenergy with carbon capture and storage (BECCS): Future prospects of carbon-negative technologies. In Clean energy for sustainable development (pp. 91-140). Academic Press.

CO_2 capture- How?

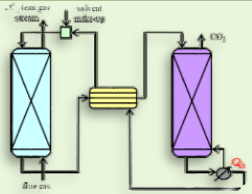
Reuse

Pre-combustion

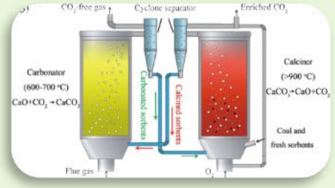
Oxy-fuel

Post combustion

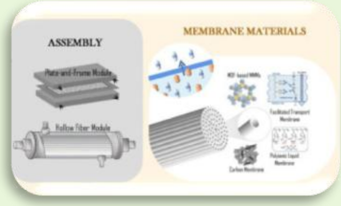
Solvent-based absorption



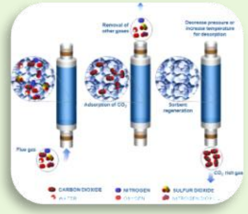
Calcium-looping



Membranes



Adsorption

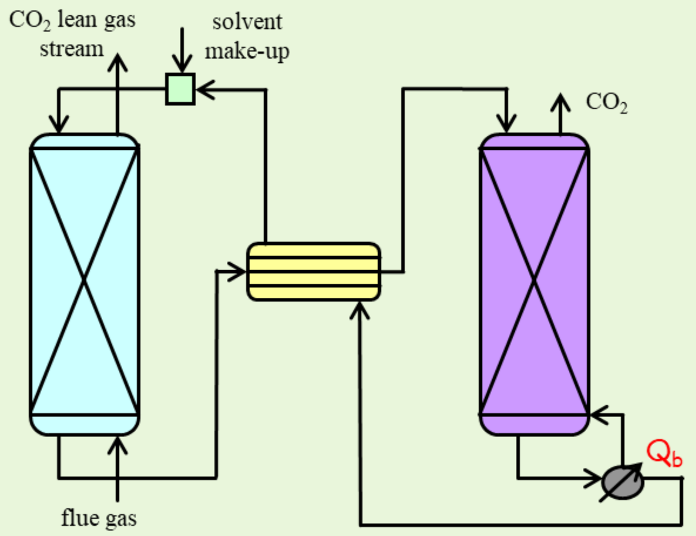


Algae

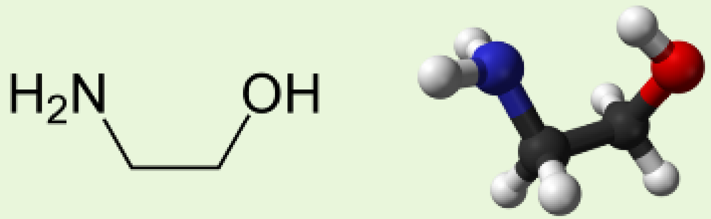
- Various technologies available
- All have pros and cons depending on
  - The flue gas composition
  - The emitting plant requirements

Damartzis, T., Papadopoulos, A.I. and Seferlis, P., 2016. Process flowsheet design optimization for various amine-based solvents in post-combustion CO_2 capture plants. Journal of Cleaner Production, 111, pp.204-216.
Ge, Z., Dou, B., Wang, L., Ding, Y., Chen, H. and Xuan, Y., 2022. Calcium-looping based energy conversion and storage for carbon neutrality–the way forward. Carbon Neutrality, 1(1), p.35.
Chen, D., Wang, K., Yuan, Z., Lin, Z., Zhang, M., Li, Y., Tang, J., Liang, Z., Li, Y., Chen, L. and Li, L., 2023. Boosting membranes for CO_2 capture toward industrial decarbonization. Carbon Capture Science & Technology, 7, p.100117.
Espinal, L., Poster, D.L., Wong-Ng, W., Allen, A.J. and Green, M.L., 2013. Measurement, standards, and data needs for CO_2 capture materials: a critical review. Environmental science & technology, 47(21), pp.11960-11975.
https://newatlas.com/environment/algae-fueled-bioreactor-carbon-sequestration/

Solvent-based absorption-desorption



Monoethanolamine (MEA)



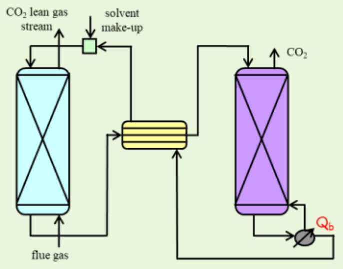
- Pros:
  - Well-established technology
  - Easy to meet conditions
  - Easily retrofitted onto existing plants
- Cons:
  - High capital costs
  - 40% cost penalties to plant operation
  - 70% due to solvent regeneration

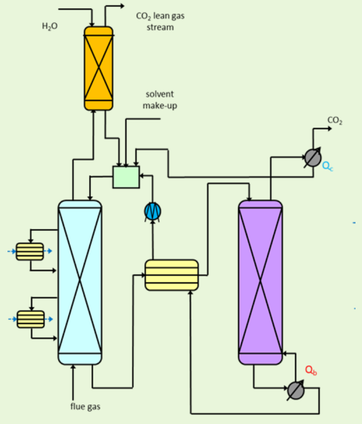
- MEA:
  - High stripping energy
  - High heat of absorption
  - Solvent vapor losses due to high vapor pressure

New and considerably improved solvents and processes required

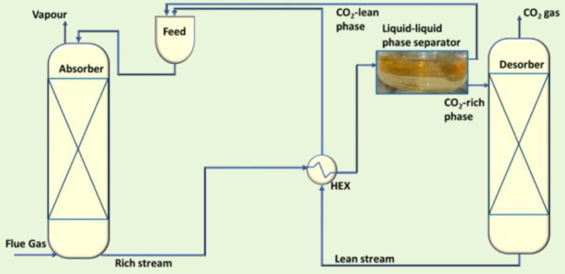
Damartzis, Papadopoulos, Seferlis, 2016, Process flowsheet design optimization for various amine-based solvents in post-combustion CO_2 capture plants, *Journal of Cleaner Production*, 111(A), 204-216.

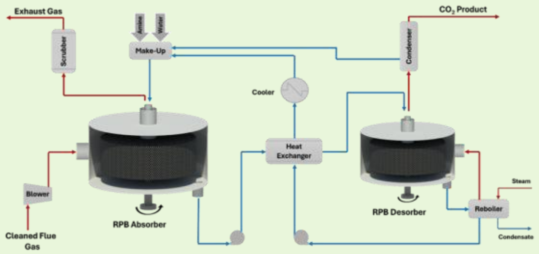
Options to mitigate costs





A

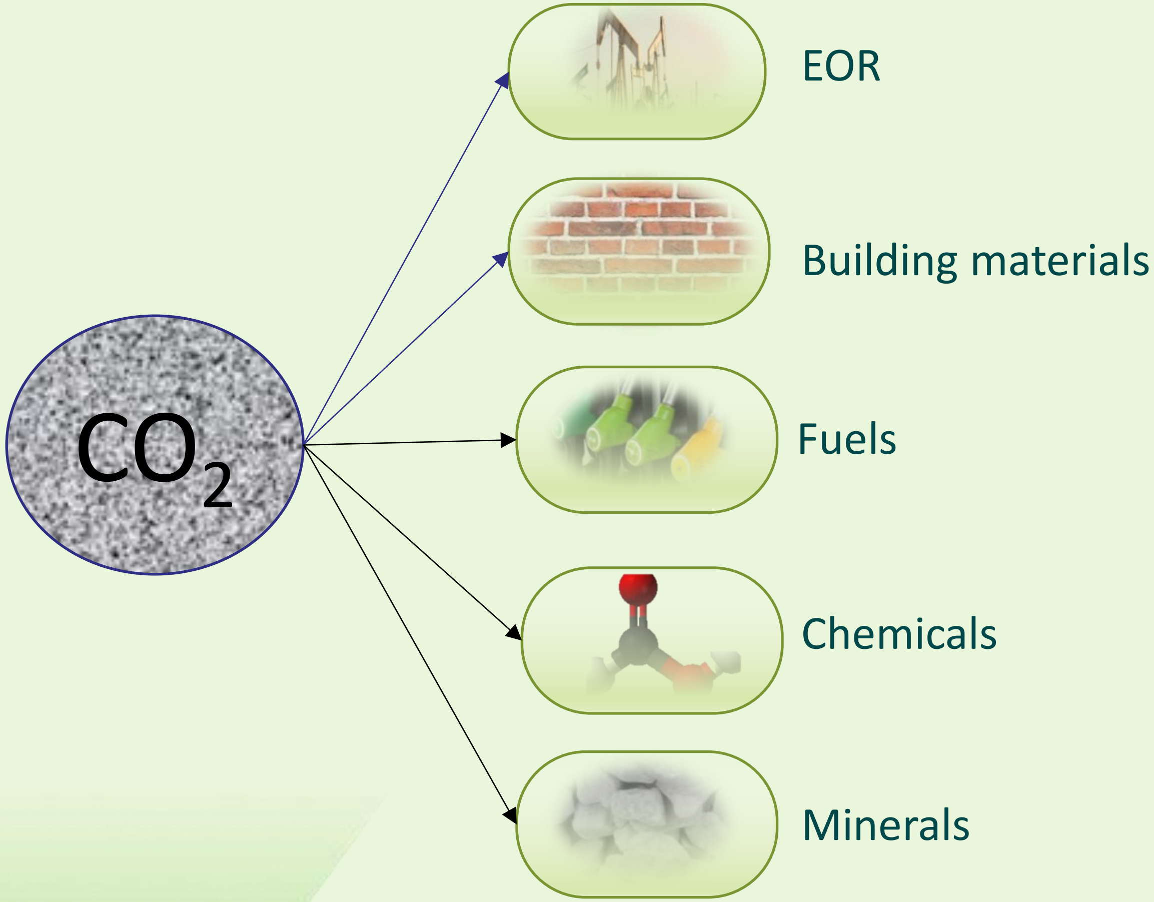


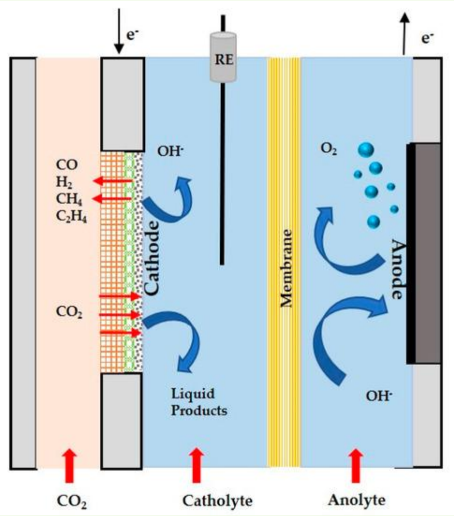


- **Packed-bed columns (PB)**: Standard flowsheet (Absorber-Cross heat exchanger-Desorber)
- **PB**: Modified flowsheets, where the standard scheme is intensified through additional equipment, mainly for energy recovery.
- **Phase-change systems**: Liquid-liquid phase-separation
- **Rotating-packed bed systems (RPB)**: Highly intensified equipment

Nessi, Papadopoulos, Seferlis, 2021, A Review of Pilot and Commercial Plants for Post-Combustion CO_2 Capture: Packed Bed, Phase-Change and Rotating Processes, *International Journal of Greenhouse Gas Control* , 111, 103474
Damartzis, Papadopoulos, Seferlis, 2016, Process flowsheet design optimization for various amine-based solvents in post-combustion CO_2 capture plants, *Journal of Cleaner Production*, 111(A), 204-216.
Kantouros, B., Kazepidis, P., Papadopoulos, A.I., Seferlis, P., Rotating Packed Beds for Post-Combustion CO2 Capture: Holistic Process Modeling and Plant Design (Submitted)

Captured CO_2- What do we do with it?

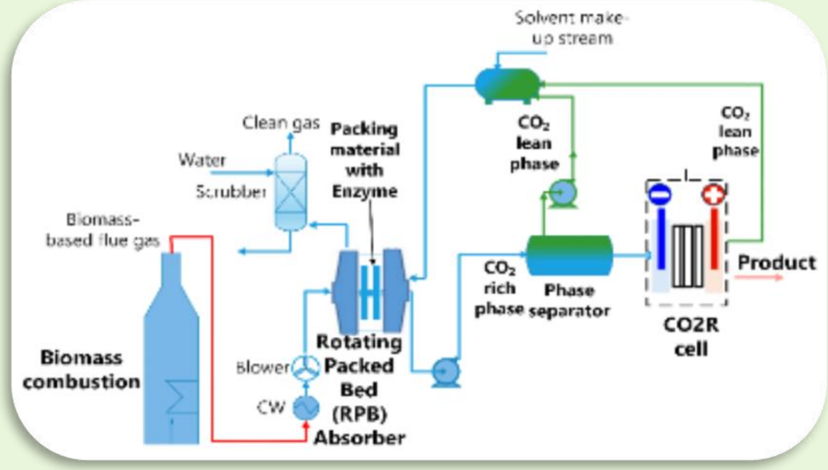




- The are various different technologies for CO_2-to-fuels or - chemicals
- Electrocatalytic ones are gaining ground because:
  - They may use renewable energy
  - They require considerably milder conditions than thermo-catalytic ones

Zhong, W., Huang, W., Ruan, S., Zhang, Q., Wang, Y. and Xie, S., 2023. Electrocatalytic reduction of CO_2 coupled with organic conversion to selectively synthesize high-value chemicals. Chemistry–A European Journal, 29(20), p.e202203228.
Maniam, K.K., Maniam, M., Diaz, L.A., Kukreja, H.K., Papadopoulos, A.I., Kumar, V., Seferlis, P. and Paul, S., 2023. Progress in electrodeposited copper catalysts for CO_2 conversion to valuable products. Processes, 11(4), p.1148.
Hernandez-Aldave, S. and Andreoli, E., 2020. Fundamentals of gas diffusion electrodes and electrolysers for carbon dioxide utilisation: challenges and opportunities. Catalysts, 10(6), p.713.

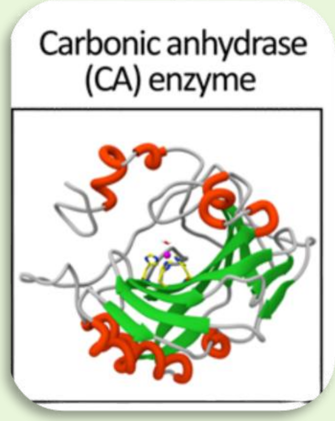
REUSE idea

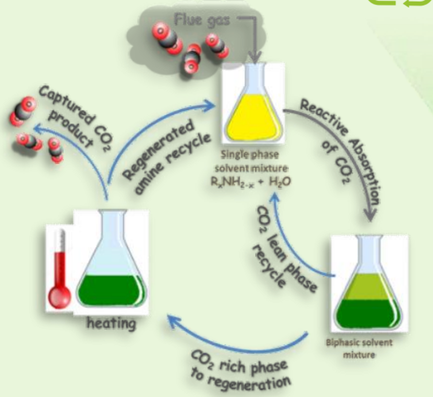


- **Direct** CO_2 Capture-CO_2R
- Use of RPB for CO_2 absorption
- Use of zero-gap electrocatalytic cell for reduction to formic acid
- Combine biomass gasification and demonstrate integrated system

Tzirakis, F., Diaz, L.A., Chararas, I., Molina Montes de Oca, D., Zhao, Z., Seferlis, P., Tsivintzelis, I., Papadopoulos, A.I., 2025, Selection of Solvents for Integrated CO_2 Absorption and Electrochemical Reduction Systems, AICHE Journal, e18734
Sullivan, I., Goryachev, A., Digdaya, I.A., Li, X., Atwater, H.A., Vermaas, D.A. and Xiang, C., 2021. Coupling electrochemical CO2 conversion with CO2 capture. Nature Catalysis, 4(11), pp.952-958.

Key innovations- CO_2 absorption





- **RPB**
- Short residence time
- 15-20 times lower volume
- Fast mass transfer ×10 -100 and micro-mixing
- Low space footprint

- **Biomimetic absorption with CA**
- Up to 4000 times faster CO_2 hydrolysis than solvent MEA
- Replaces solvent that exhibits fast kinetics
- Need only for solvent that enable high absorption rate
- CA immobilized on fiber (fabric) knitted onto the packing material

- **Phase-change solvent**
- Exhibits 2 liquid phases
- One rich in CO_2-> led to CO_2R
- One lean in CO_2-> recycled to absorber
- Delivers more concentrated CO_2 into CO_2R cell

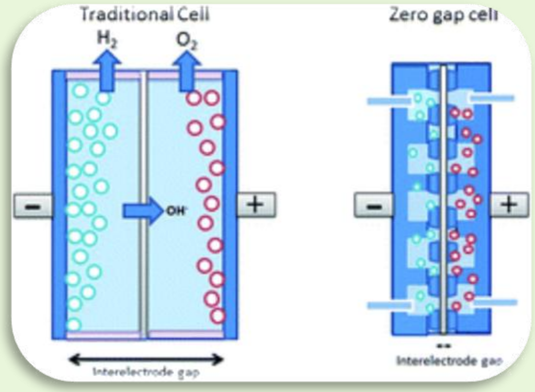
Hendry, J.R., Lee, J.G. and Attidekou, P.S., 2020. Pressure drop and flooding in rotating packed beds. Chemical Engineering and Processing-Process Intensification, 151, p.107908.

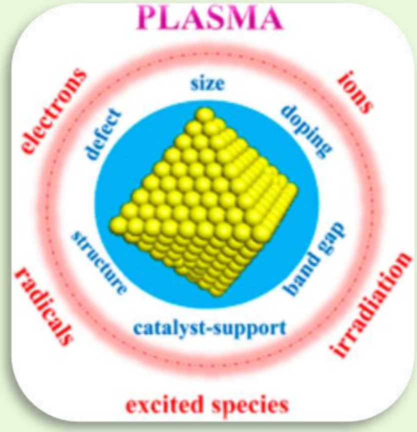
Fu, Y., Jiang, Y.B., Dunphy, D., Xiong, H., Coker, E., Chou, S.S., Zhang, H., Vanegas, J.M., Croissant, J.G., Cecchi, J.L. and Rempe, S.B., 2018. Ultra-thin enzymatic liquid membrane for CO_2 separation and capture. Nature communications, 9(1), p.990.

Papadopoulos, A.I., Tzirakis, F., Tsivintzelis, I. and Seferlis, P., 2019. Phase-change solvents and processes for postcombustion CO_2 capture: a detailed review. Industrial & Engineering Chemistry Research, 58(13), pp.5088-5111.

Key innovations- CO_2 reduction and gasification

Reuse





- **CO_2R cell**
- Design of zero-gap, membrane type flow cells to reduce ohmic losses by decreasing the inter-electrode distance.

- **Catalysts**
- Design functionalised carbon surfaces utilising carbon materials with different morphological nature (1D-carbon nanotube, 2D-graphene) via plasma
- Design of template free shape-controlled tin based catalysts (with or without dopants) via plasma and electrochemical routes on functionalised carbon surfaces that favour selectivity towards FA

- **Gasification**
- Design and test advanced catalysts for tar abatement
- Address variability in biomass gasification
- Combine biomass with wastes

Phillips, R. and Dunnill, C.W., 2016. Zero gap alkaline electrolysis cell design for renewable energy storage as hydrogen gas. RSC advances, 6(102), pp.100643-100651.
Wang, Z., Zhang, Y., Neyts, E.C., Cao, X., Zhang, X., Jang, B.W.L. and Liu, C.J., 2018. Catalyst preparation with plasmas: how does it work?. ACS catalysis, 8(3), pp.2093-2110.

Thank you!

Reuseproject.eu

REUSE - Horizon Europe Project

info@reuseproject.eu

Cite as: A. I. Papadopoulos, REUSE Project Overview, In 1st REUSE Workshop, 01 July, 2025

Funded by the European Union

This project has received funding from the European Union's Horizon Europe research and innovation programme under grant agreement No. 101172954. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union.