Reuse Project Overview

CCUS in Action" – A Deep Dive into the Future of Carbon Capture and Utilization

Online Webinar-22/05/2025

Reuse



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.

Dr. Athanasios Papadopoulos



CERTH ENTRE FOR RESEARCH & TECHNOLOGY IELLAS

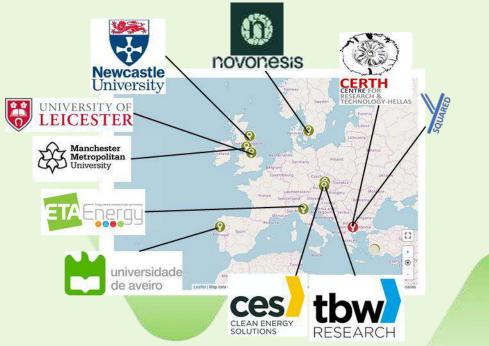
REUSE



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 CO₂ Capture in a Rotating Packed Bed and Electrocatalytic CO₂ Reduction to Useful Products





CO₂ emissions - Facts

40 billion t

35 billion t

30 billion t

Reuse



- By 1990 this had almost quadrupled, reaching more than 20.10⁹ t CO_2/y .
- Emissions have continued to grow rapidly; we now emit over 35 $\cdot 10^{9} \text{ t CO}_{2}/\text{y}.$
- Europe's contribution is $5 \cdot 10^9$ t CO₂/y in 2023
- Europe, USA, America, Africa, India- slow decrease
- China, Asia- steep increase
- In 2023 China emitted about 10.109 t CO₂ = SUM(EU and USA)!
- All Asia emitted 20.10⁹ t CO₂ = 2 x SUM(EU and USA)!



Asia (excl. China and India) 25 billion t China 20 billion t India 15 billion t Africa South America North America (excl. 10 billion t USA) United States 5 billion t European Union (27) 0 t Europe (excl. EU-27) 2000 2023 50

International aviation

International shipping

Oceania

EU targets



The first climateneutral continent by 2050

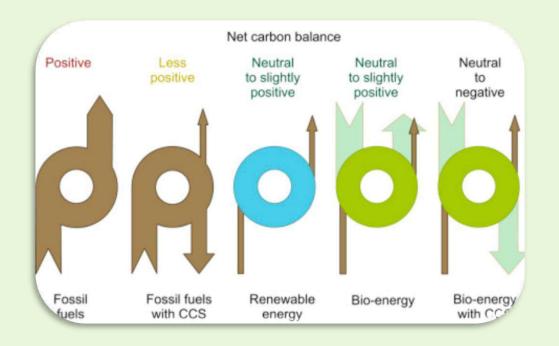
At least 55% less

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).

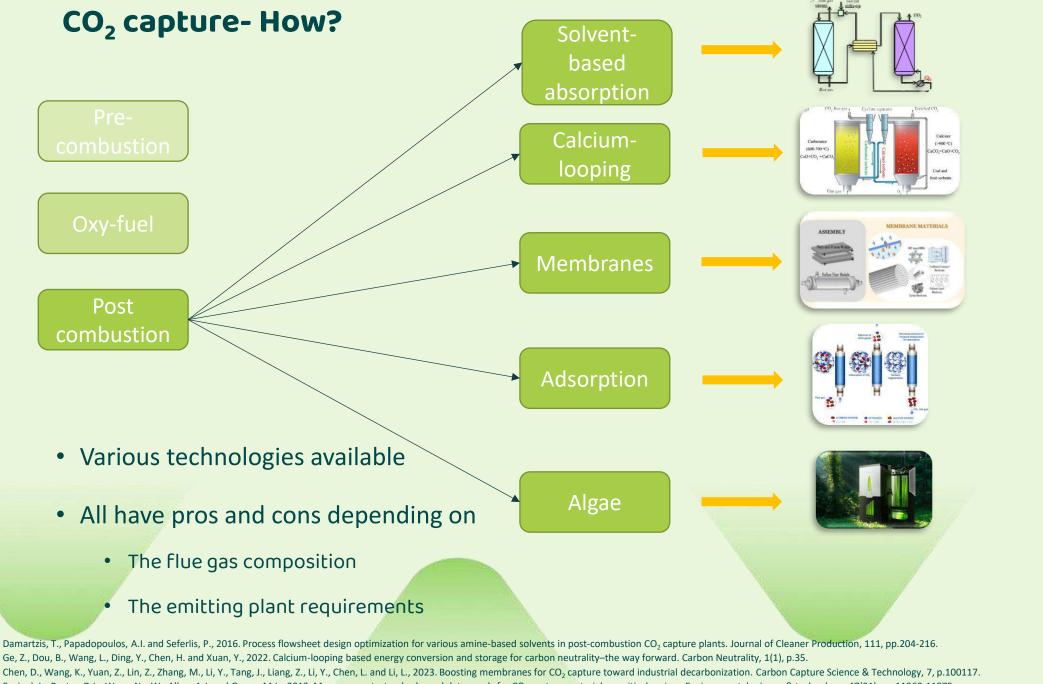


Biomass-derived emissions





- 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



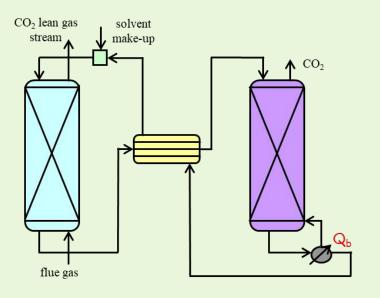


6

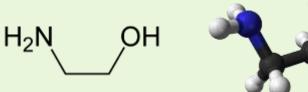
Reuse

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 CO₂ 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 CO₂ 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:

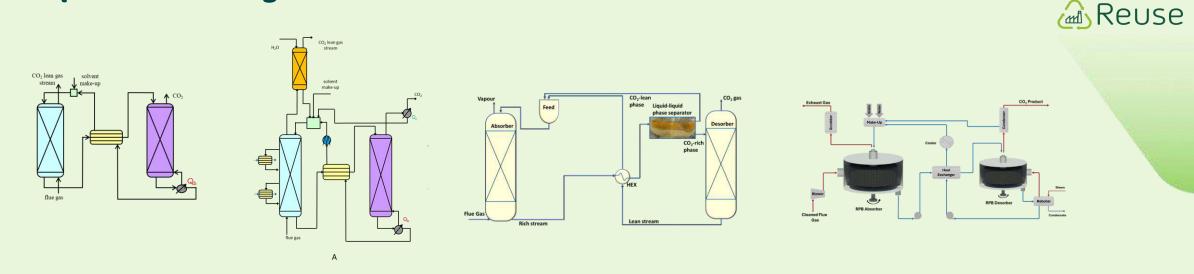
- High stripping energy
- High heat of absorption
- Solvent vapor losses due to high vapor pressure

New and considerably improved solvents and processes required



Reuse

Options to mitigate costs

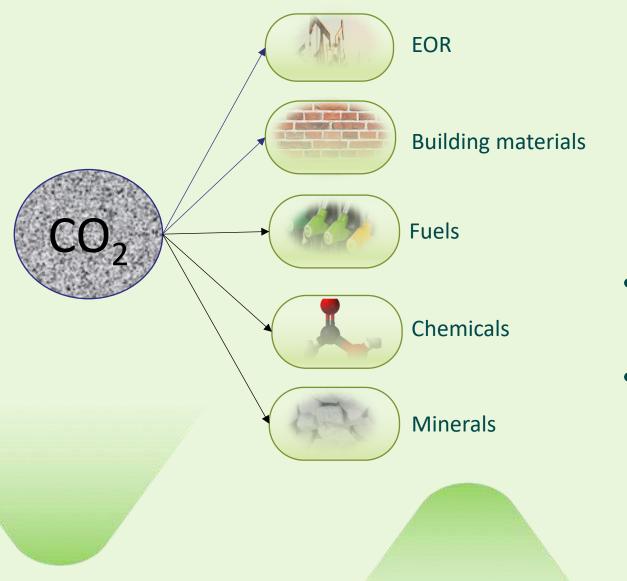


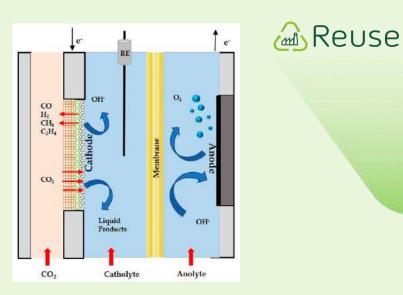
- Packed-bed columns (PB): Standard flowsheet (Absorber-Cross heat exchanger-Desorber)
- **PB**: Modified flowsheets, where the standard scheme is intensified through additional equipment, mainly for energy recovery.
- Phase-change systems: Liquid-liquid phase-separation
- Rotating-packed bed systems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

Nessi, Papadopoulos, Seferlis, 2021, A Review of Pilot and Commercial Plants for Post-Combustion CO₂ 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 CO₂ 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 CO₂- What do we do with it?



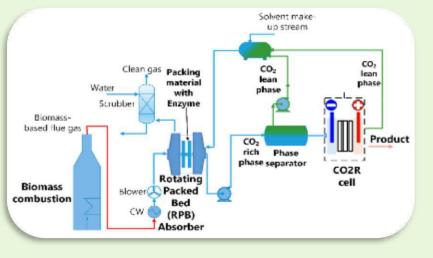


- The are various different technologies for CO₂-to-fuels or chemicals
- Electrocatalytic ones are gaining ground because:
 - They may use renewable energy
 - They require considerably milder conditions than thermo-catalytic ones



Zhong, W., Huang, W., Ruan, S., Zhang, Q., Wang, Y. and Xie, S., 2023. Electrocatalytic reduction of CO₂ 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 CO₂ 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** CO₂ Capture-CO₂R
- Use of RPB for CO₂ 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 CO₂ 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.

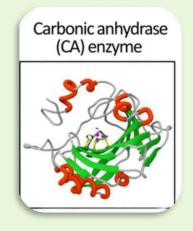
Key innovations- CO₂ absorption



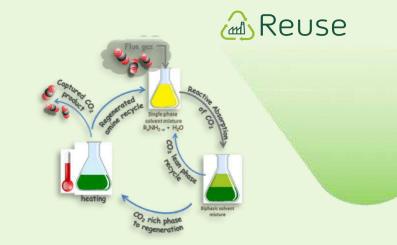


• RPB

- 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 CO₂ 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 into CO₂R cell onto the packing material



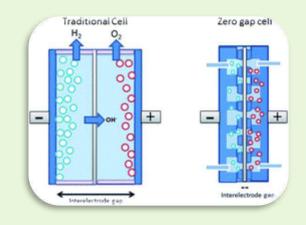
- Phase-change solvent
- Exhibits 2 liquid phases
- One rich in CO₂-> led to CO₂R
- One lean in CO₂-> recycled to absorber
- Delivers more concentrated CO₂



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 CO₂ 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 CO₂ capture: a detailed review. Industrial & Engineering Chemistry Research, 58(13), pp.5088-5111.

Key innovations- CO₂ reduction and gasification



- CO₂R cell
- Design of zero-gap, membrane type flow cells to reduce ohmic losses by decreasing the interelectrode distance.

Catalysts

 Design functionalised carbon surfaces utilising carbon materials with different morphological nature (1D-carbon nanotube, 2D-graphene) via plasma

PLASMA

catalyst-suppor

excited species

dectron

 Design of template free shapecontrolled 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 advancedcatalysts 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.



Reuse

Thank you!

Reuseproject.eu

in REUSE - Horizon Europe Project info@reuseproject.eu



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.



Copyright © REUSE, all rights reserved. This document may not be copied, reproduced, or modified in whole or in part for any purpose. In addition, an acknowledgment of the authors of the document and all applicable portions of the copyright notice must be clearly referenced. Any changes in this document will be notified and approved by the PMB of REUSE