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3D-Printing of Porous Electrodes for Electrochemical CO_2 Reduction

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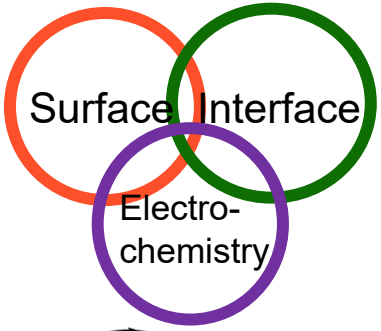
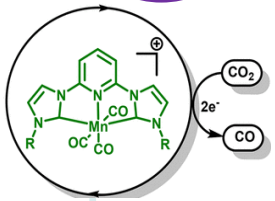
WAGENINGEN UNIVERSITY & RESEARCH

Research Concepts & Applications



- Fabrication and Synthesis
- Characterizations

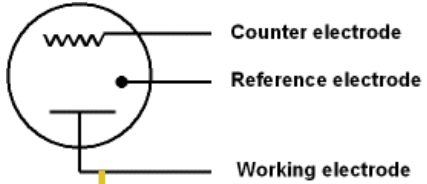


I. Electrocatalysts

- CO_2 electrochemical conversion

II. Corrosion

- Corrosion of electrocatalysts
- Corrosion inhibition



III. Electrochemical Sensors

- Electrochemical impedance spectroscopy (EIS)

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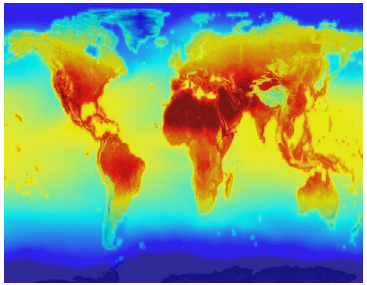
CO_2 - Climate change!



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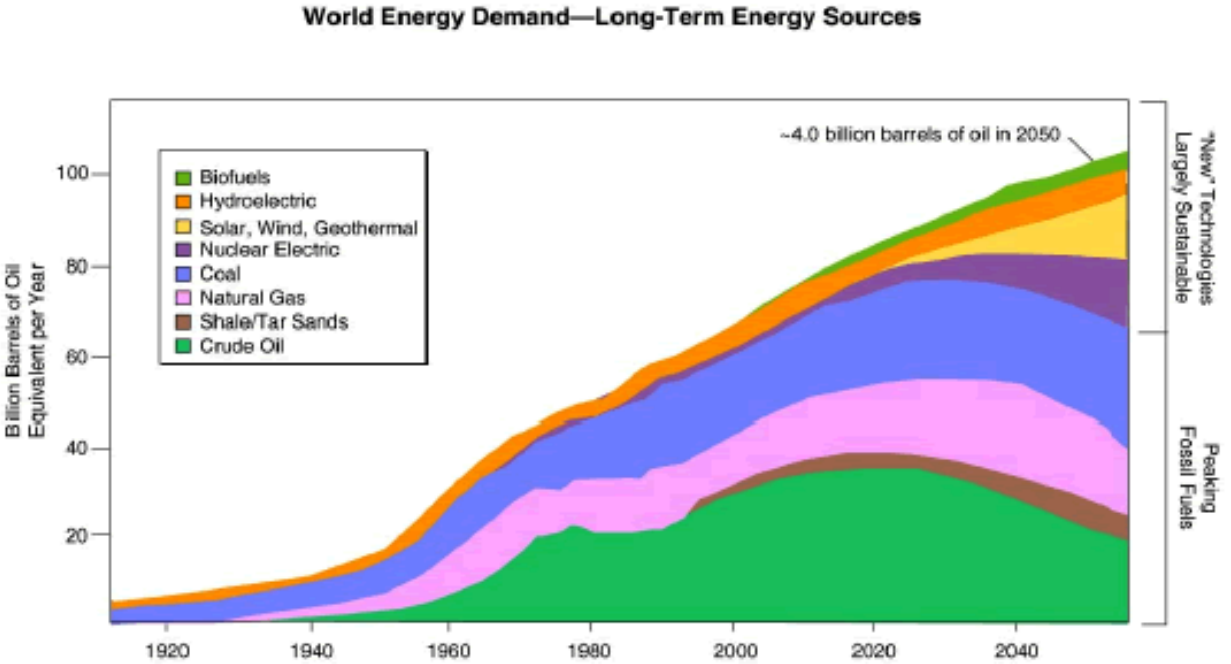
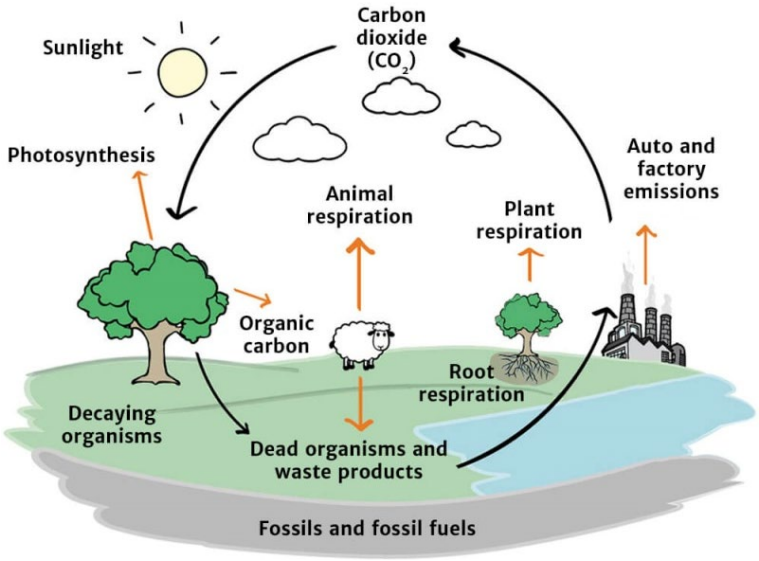
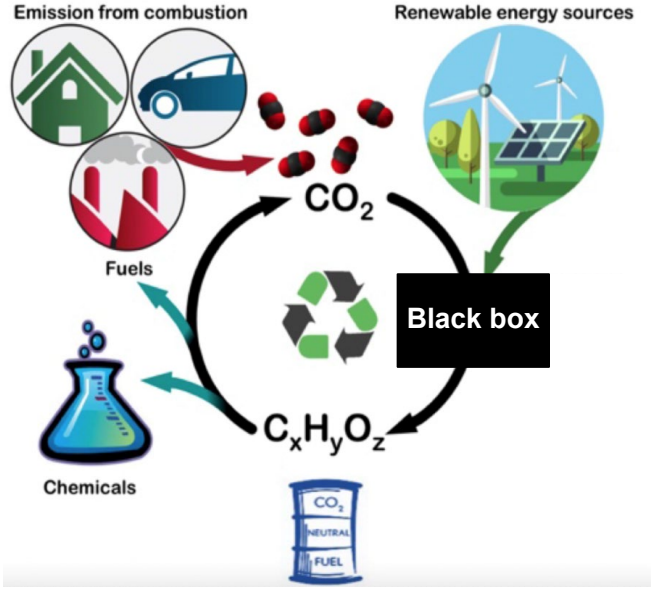
Long-term global energy generation



“Carbon Cycle”

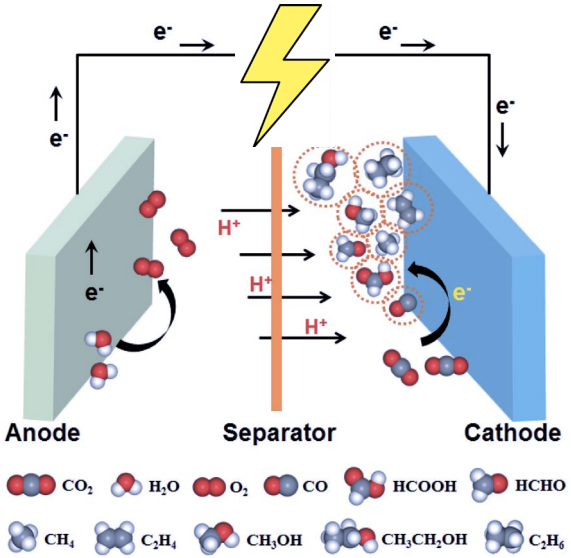
Let’s learn from the nature!





$6CO_2 + 6H_2O + energy \rightarrow C_6H_{12}O_6 + 6O_2$

The black box: Electrocatalysts



Reduction:

$CO_2+2H^++2e^-\rightleftarrows CO+H_2O$

Oxidation:

$2H_2O\rightleftarrows O_2+4H^++4e^-$

Compatative reduction:

$2H_2O+2e^-\rightleftarrows H_2+2OH^-$

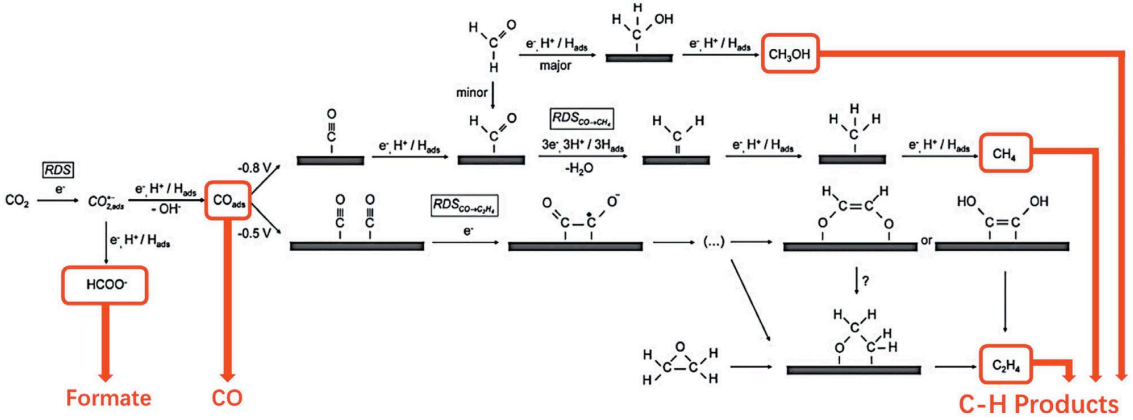
Zhang et al., Adv. Sci. (2018) 5, 1700275.

Thermodynamic & Kinetic Considerations

Y. Hori, electrochemical CO_2 reduction on metal electrodes, Modern Applications of Electrochemical Technology, No42, Springer, NY (2008).

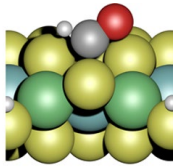
$2H^+ + 2e \rightarrow H_2$	E^0_{SHE}=-0.41
$CO_2 + 2H^+ + 2e \rightarrow HCOOH$	E^0_{SHE}= -0.61
$CO_2 + 2H^+ + 2e \rightarrow CO + H_2O$	E^0_{SHE}= -0.53
$CO_2 + 4H^+ + 4e \rightarrow C + 2H_2O$	E^0_{SHE}= -0.20
$CO_2 + 4H^+ + 4e \rightarrow HCHO + H_2O$	E^0_{SHE}= -0.48
$CO_2 + 6H^+ + 6e \rightarrow CH_3OH + H_2O$	E^0_{SHE}= -0.38
$CO_2 + 8H^+ + 8e \rightarrow CH_4 + 2H_2O$	E^0_{SHE}= -0.24

All values are close to the H_2 evolution potential



Yin, et al. Trends in Chemistry, November, Vol. 1, No. 8

Practical Challenges



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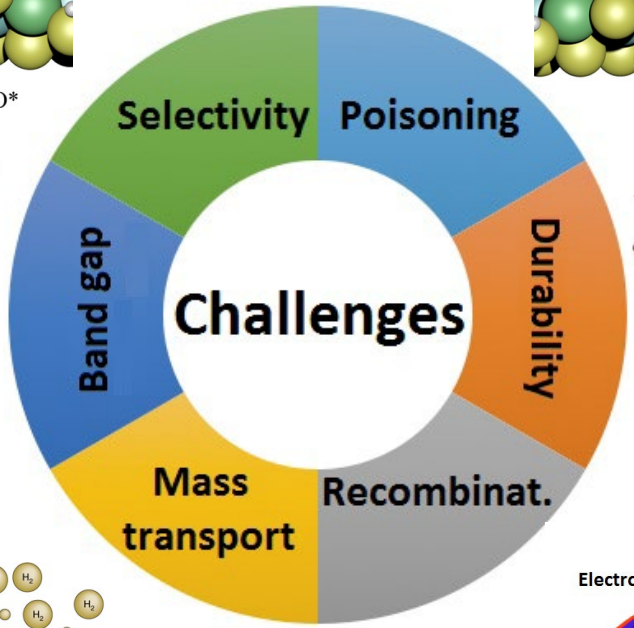
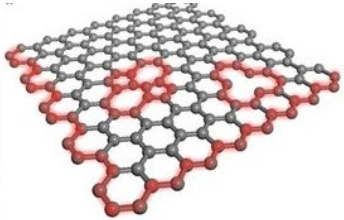
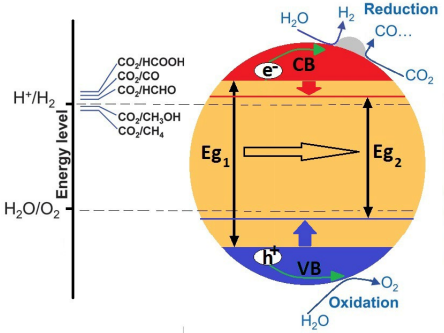
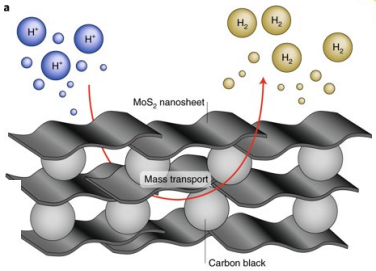
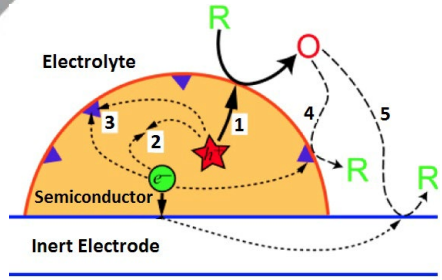
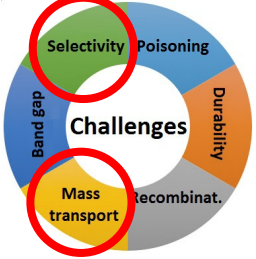




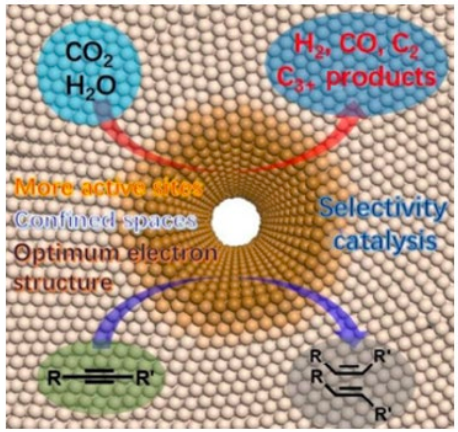






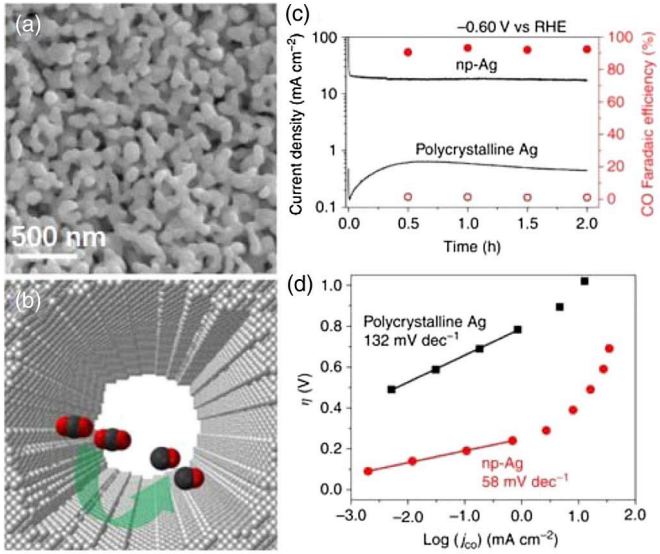


Additive Manufacturing to Enhance CO_2 RR Efficiency



Porous Metal Nanocrystalline Catalysts

Min et al, CCS Chem.2022, 4, 1829–1842.



Lu et al. F. A Selective and Efficient Electrocatalystfor Carbon Dioxide Reduction.Nat. Commun.2014,5, 3242.

- Confined spaces increase the retention time of key intermediates to promote the selective catalysis.
- An increased surface area improves the
- Precise manufacturing of pore size and structure is a value offered by additive manufacturing!

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Objectives:

- Fabrication of porous electrode with improved catalytic performance through the sophisticated precise tuning of interconnected hierarchical pore sizes.
- Combine 3D printing techniques with tailored functional coating to improve the current/power densities of CO_2 electrochemical conversion.
- Fundamental understanding of the impact of material architecture on overall faradaic efficiency, in particular mass transfer limitations.

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The advantages of 3D-printed systems for CO_2 reduction:

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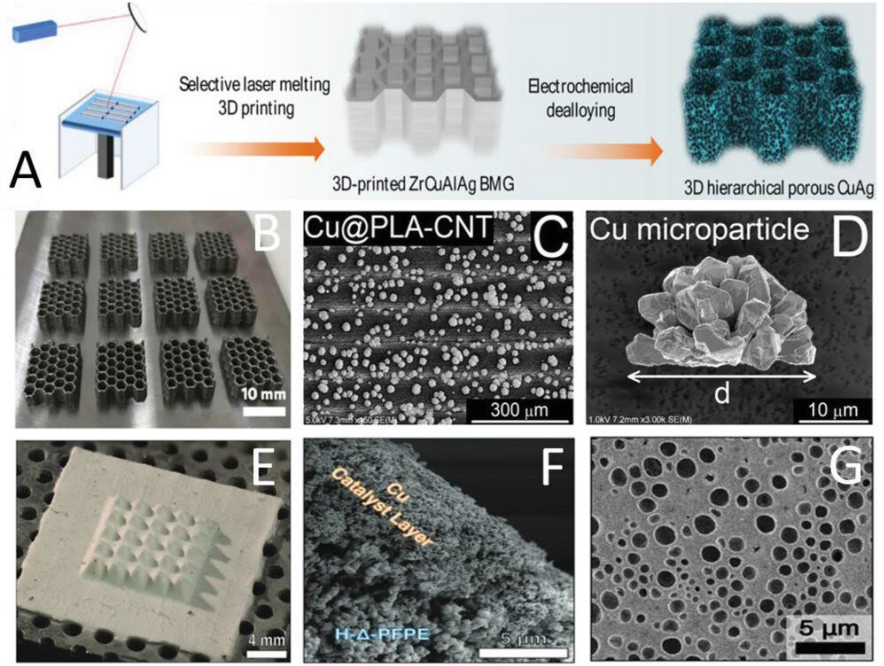
- Complex geometry and distribution control
- Versatility in design
- Scalability and reproducibility
- Minimal waste production
- Cost-effectiveness



Padinjareveetilet et al., Advanced Materials Interfaces 10.8 (2023): 2201734

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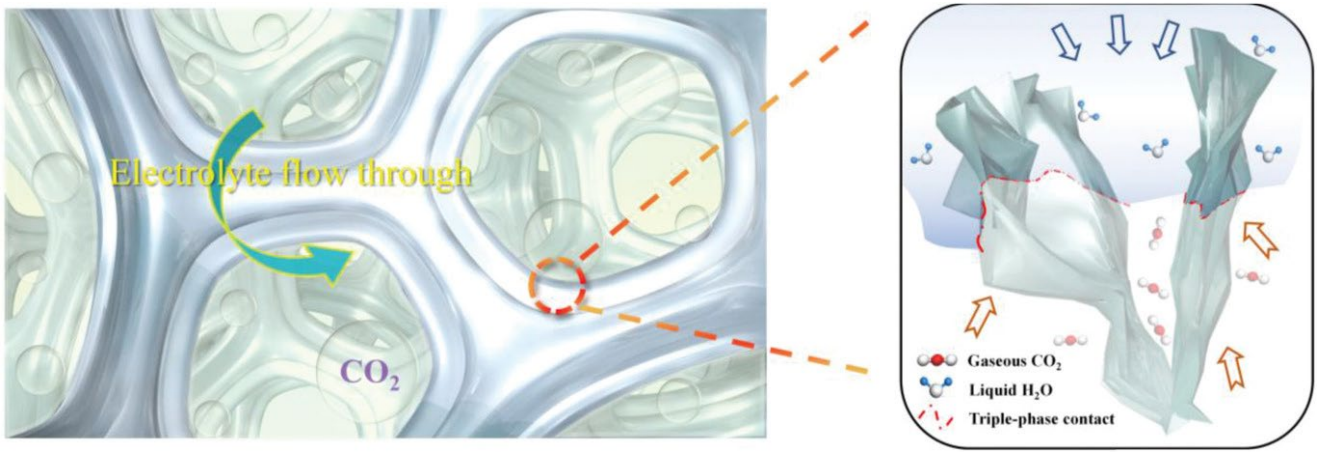
The merits of porous electrode for CO_2 reduction:

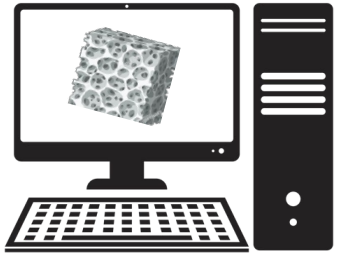


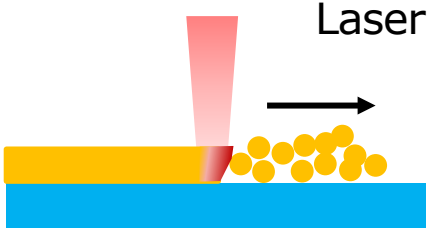
Shi et al., Advanced Science 9.30 (2022): 2204472.

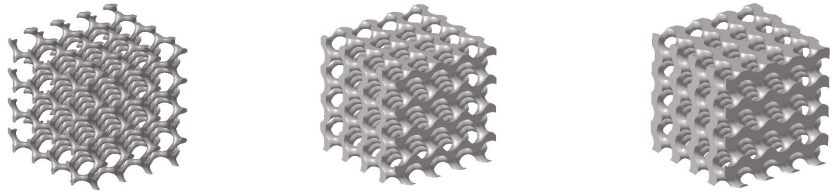
- improved the selectivity for CO_2 reduction,
- increased specific surface area for reactions,
- improved mass transfer properties,
- Reduced overpotential and energy efficiency.

Fabrication of porous substrate

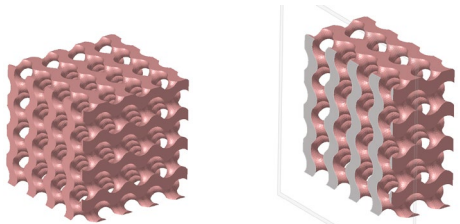
Laser Powder Bed Fusion: LPBF







Porous materials with different pore sizes



Functional coating decoration

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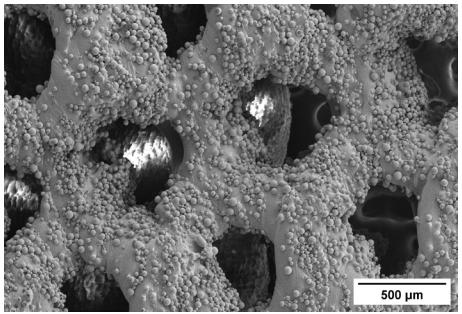
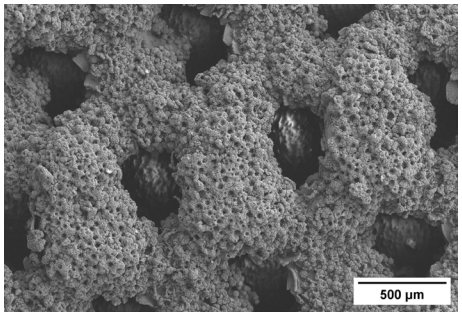
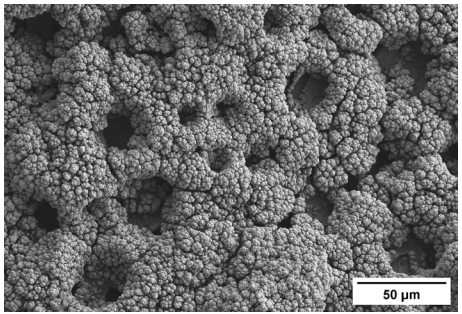
Fabrication of different porous sizes

Ti-6Al-4V







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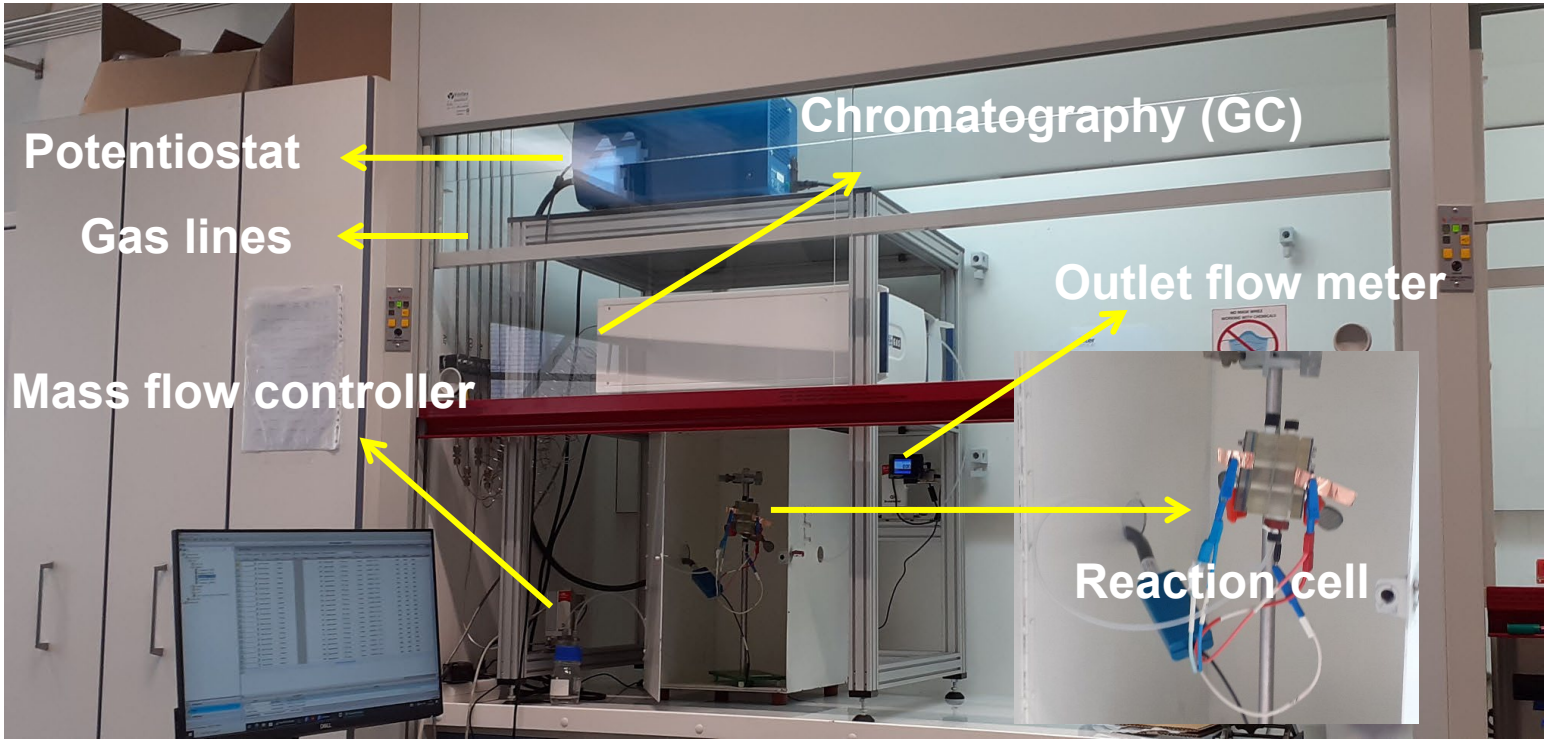
Lab-scale Reactor



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Summary & Next Steps

- Deposition of **Copper** (Cu) nanoparticles onto porous Ti alloy-based substrates through electroless deposition.
- Elucidating the impact of varying **pore size** on the efficiency and resultant products of CO_2 reduction.
- **Understanding** the effects of **pore size** and **co-catalysts** on the product selectivity.

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Thank you for your attention!

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