Electrolysis and Redox Flow Batteries: Combining the Two Worlds

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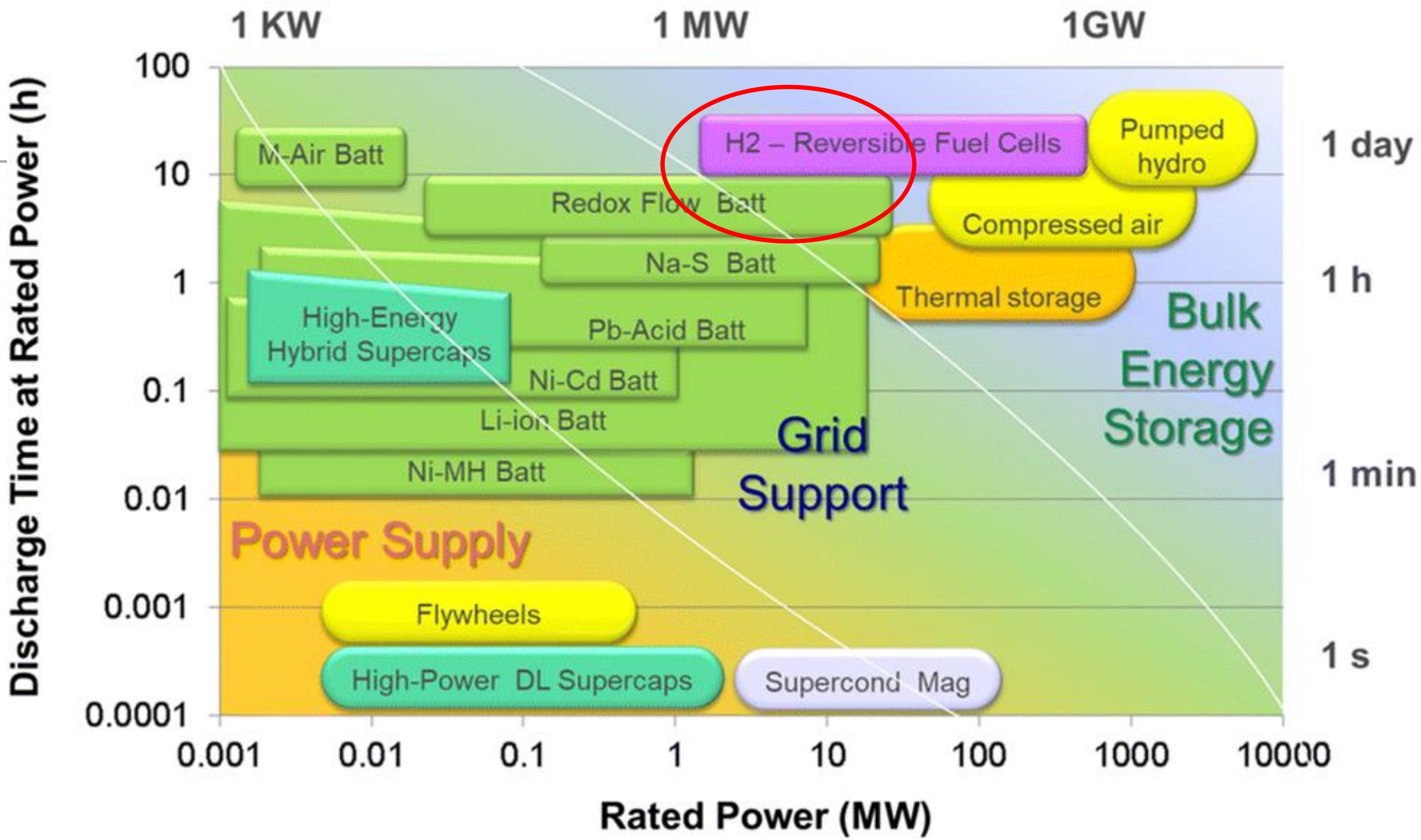
Energy Storage Systems



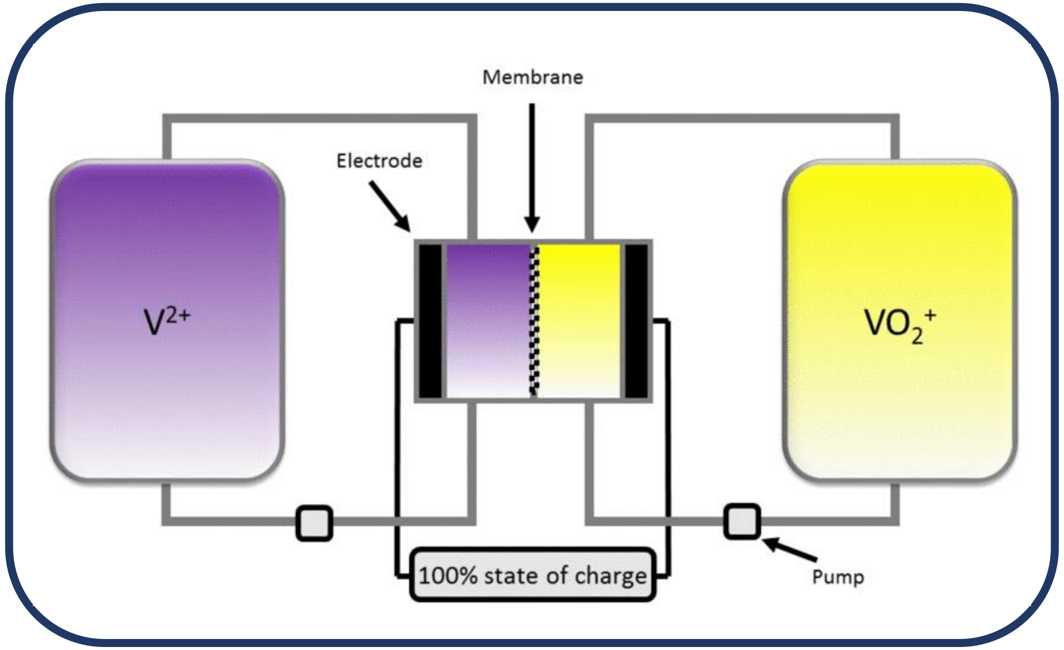
Sustainable Energy Fuels, 2023, **7**, 5473-5482

Are aqueous flow batteries a better solution for grid scale?

NON-FLAMMABLE

Negolyte

Posolyte



Anode Reaction:

$V^{2+} \rightarrow V^{3+} + e^-$

$E^0 = -0.26$ V vs SHE

Cathode Reaction:

$VO_2^+ + e^- + 2H^+ \rightarrow VO^{2+} + H_2O$

$E^0 = 1$ V *vs* SHE

ENERGY DENSITY $\approx 20\ Wh/kg$

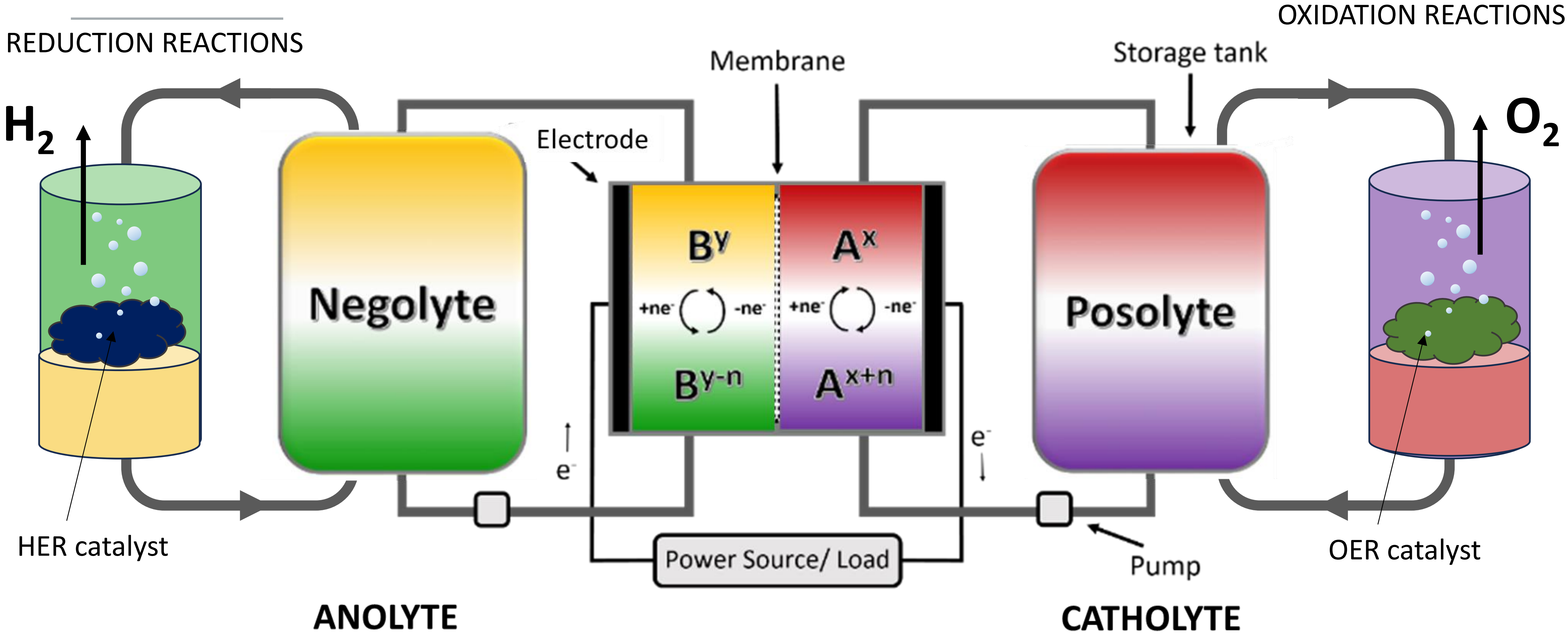
$E_{cell} = 1.26$ V
Low Cell Voltage

Vanadium concentration
1.5 – 2 M, 3 M H_2SO_4

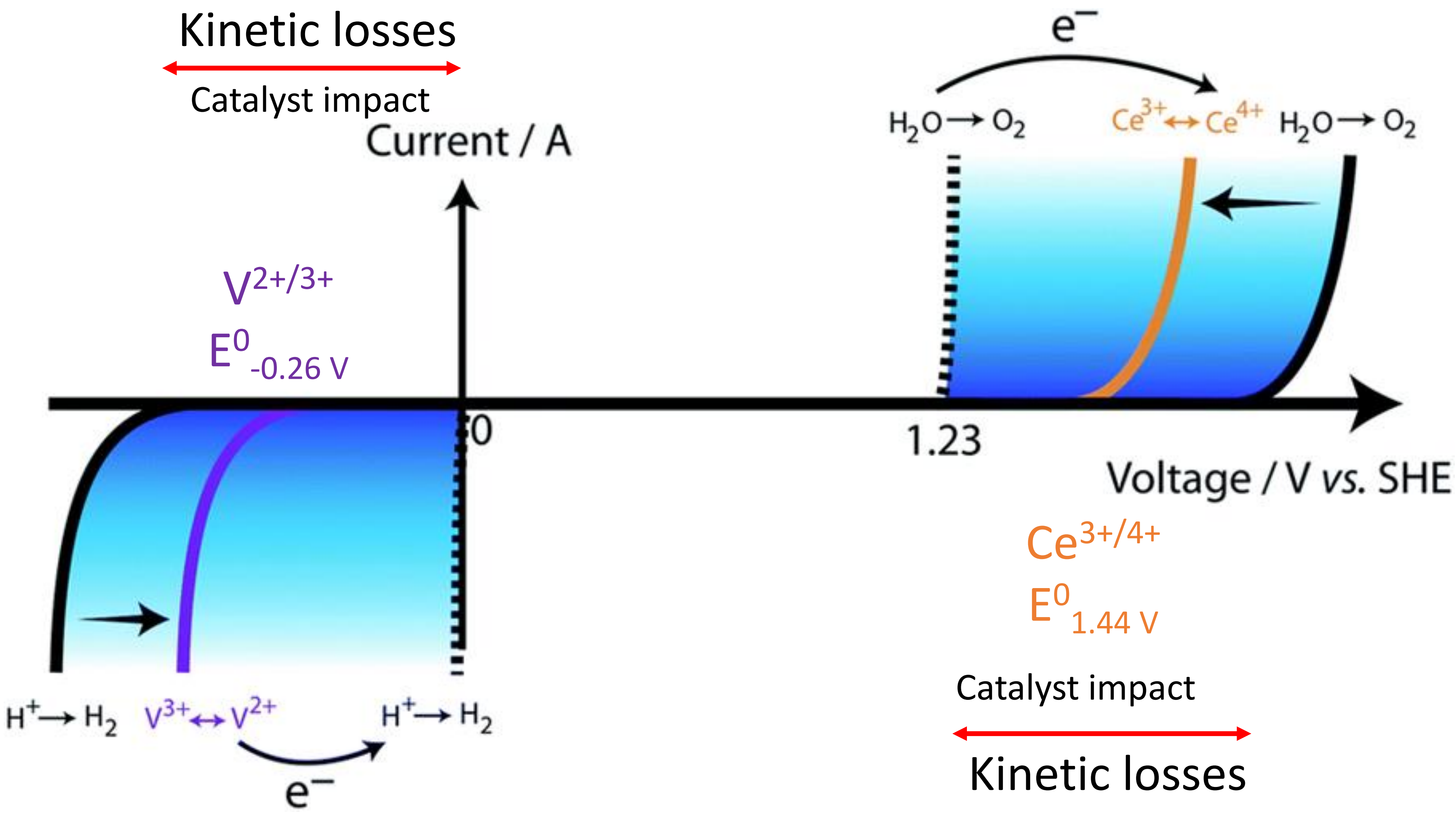
Low energy density solutions means huge volumes to achieve MWh capacities

175MW/700MWh vanadium redox flow battery project in China

Sustainable flow batteries with useful **chemical potentials**

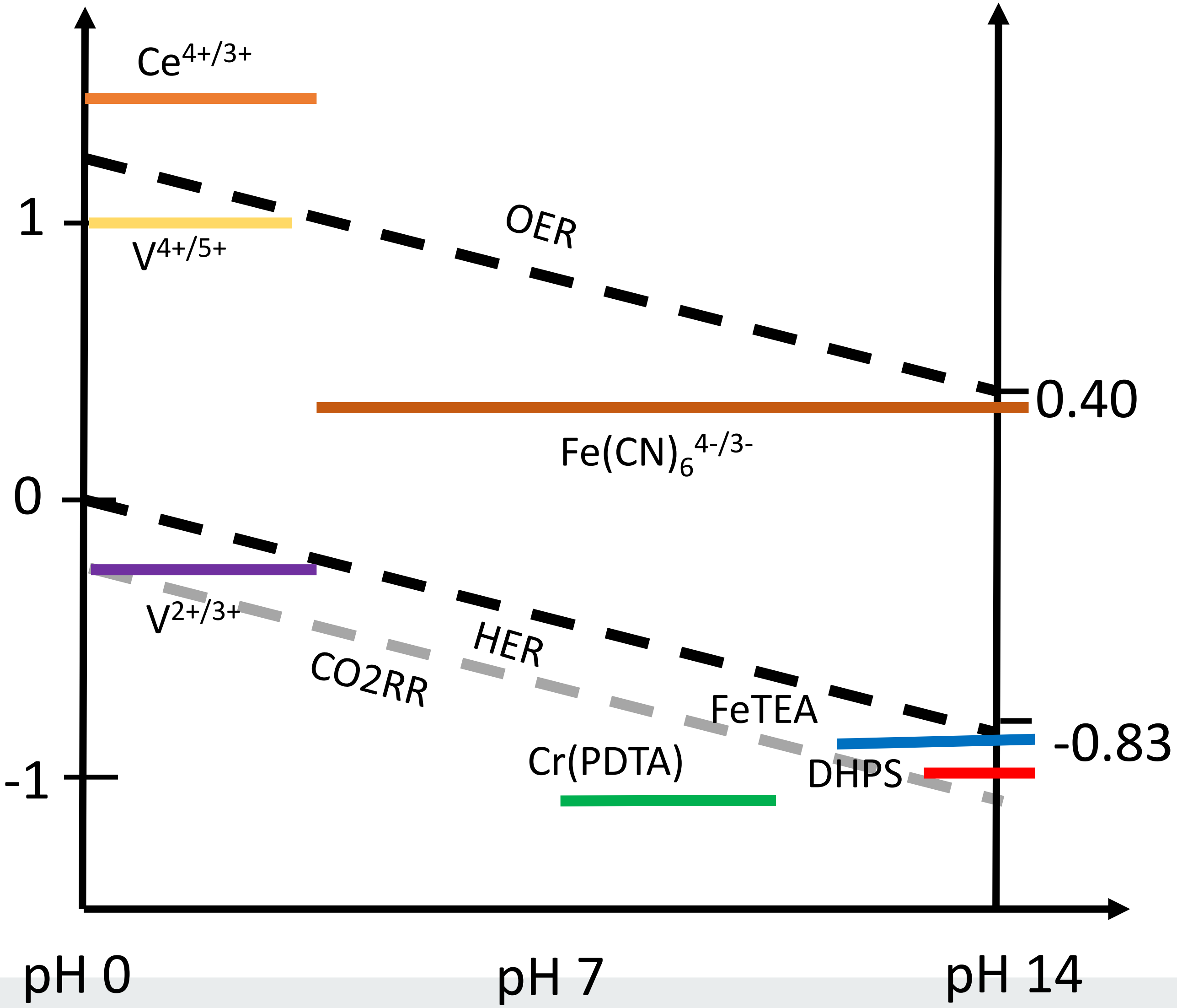


Balance of available energy and reaction kinetics



Amstutz, Toghill, Girault et al., ***Energy Environ. Sci.***, 2014, **7**, 2350

Decoupled Flow Battery Projects



My projects to date:

Acid pH - POC

V/Ce flow battery for water splitting

Alkaline pH

HER and *alternative* oxidation

- CrPDTA /$Fe(CN)_6$ (pH 8)
- FeTEA and analogues
- Phenazine analogues
- vs $Fe(CN)_6$

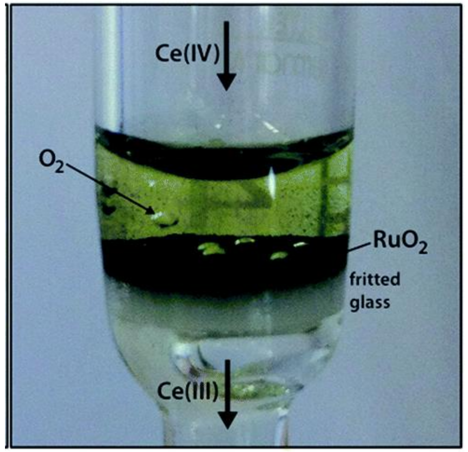
CO_2 reduction

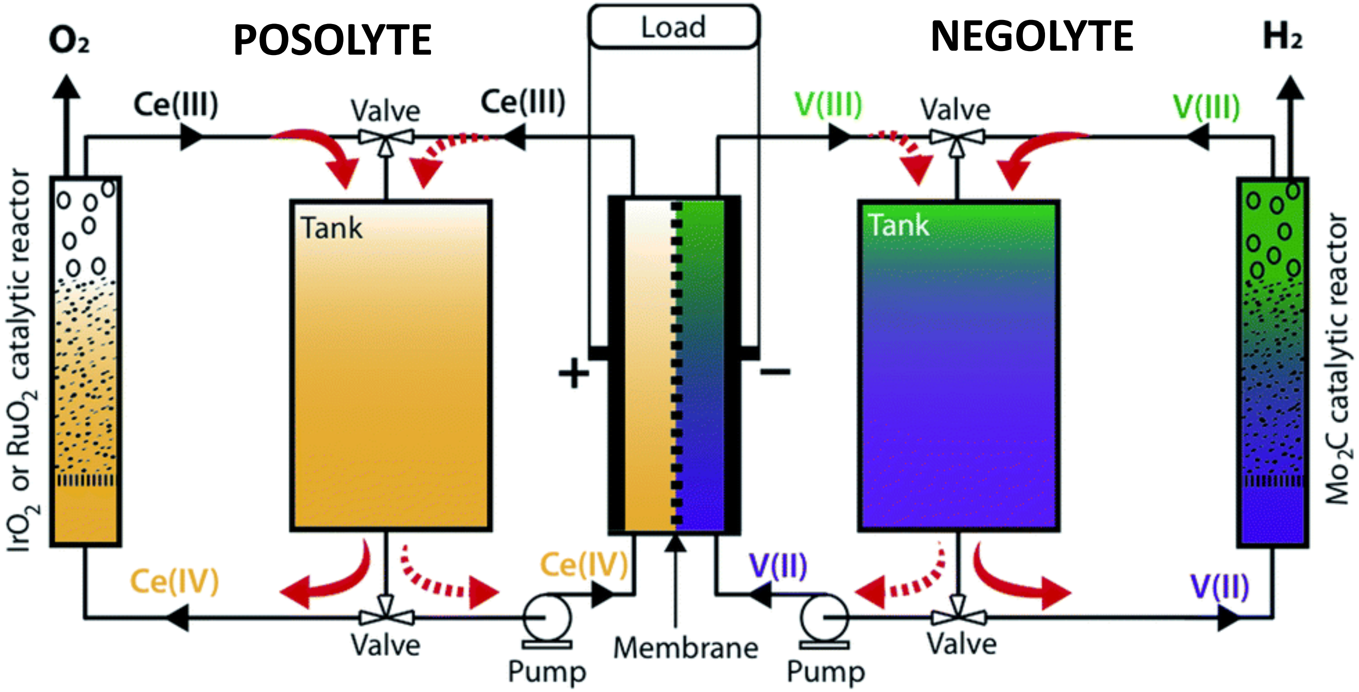
pH 8 – CrPDTA /$Fe(CN)_6$

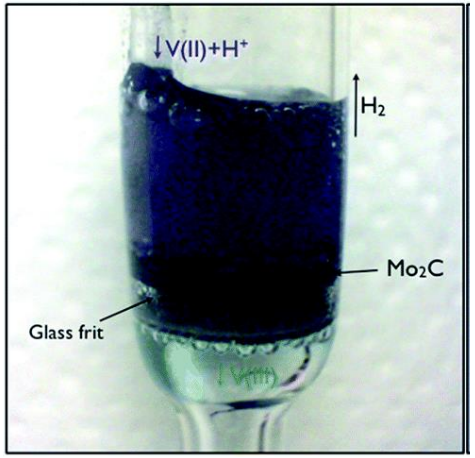
- Bi to formate
- Au to syngas

Original example was the Dual Circuit V-Ce battery developed for decoupled water splitting

Lancaster University







Mean **oxygen** conversion was 78 ± 8%

Ce-V redox flow battery : conventional electrochemical discharge

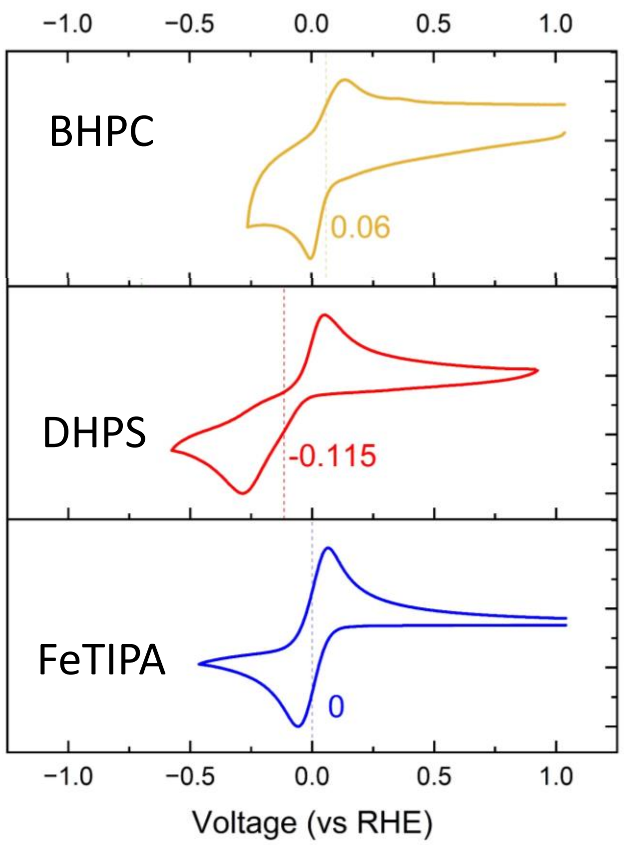
Dual-circuit system : discharge via two catalysed chemical reactions

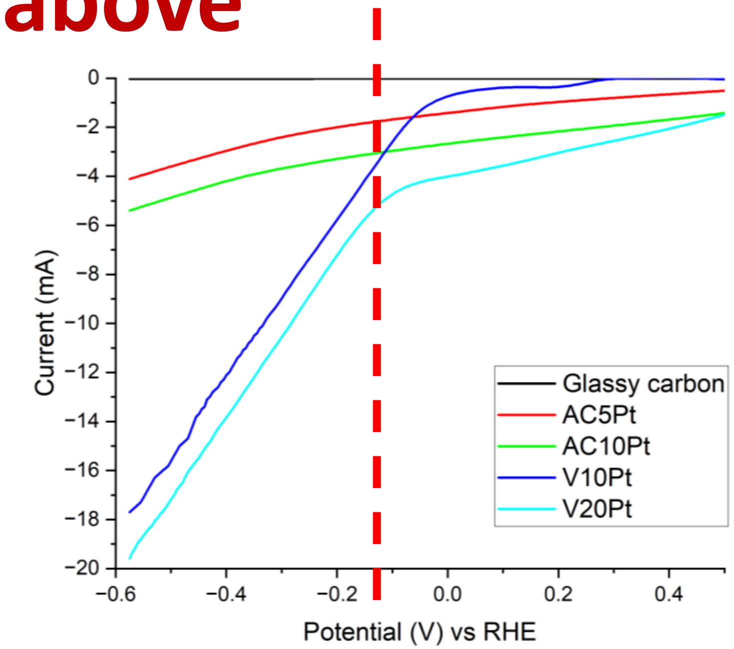
Mean **hydrogen** conversion was 96 ± 4%

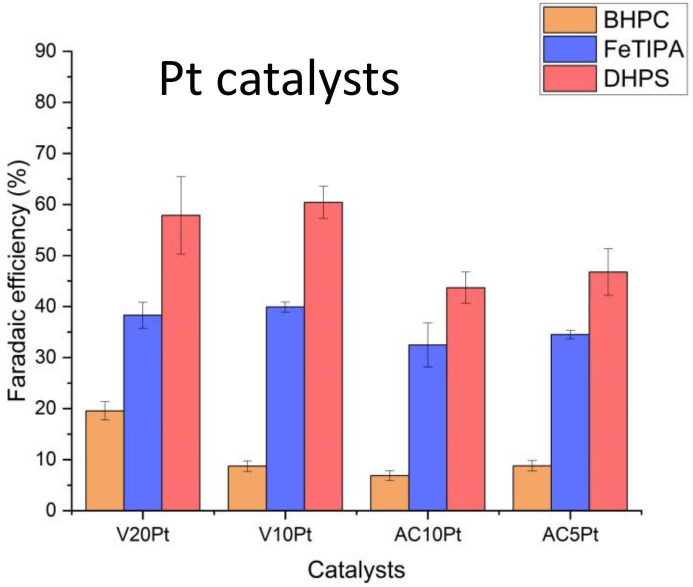
Amstutz, Toghill, Girault et al., ***Energy Environ. Sci.***, 2014, **7**, 2350

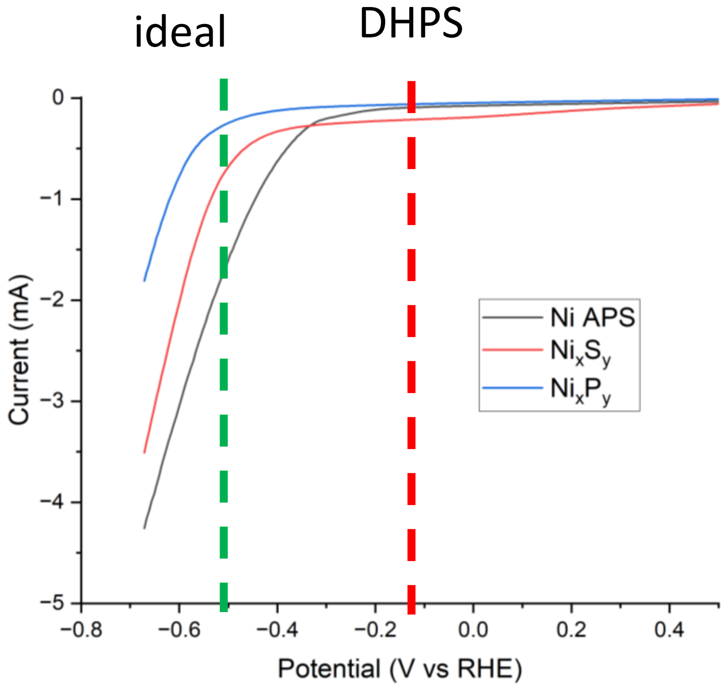
Redox flow battery for hydrogen generation. Patent No. WO2013131838A1 (2013).

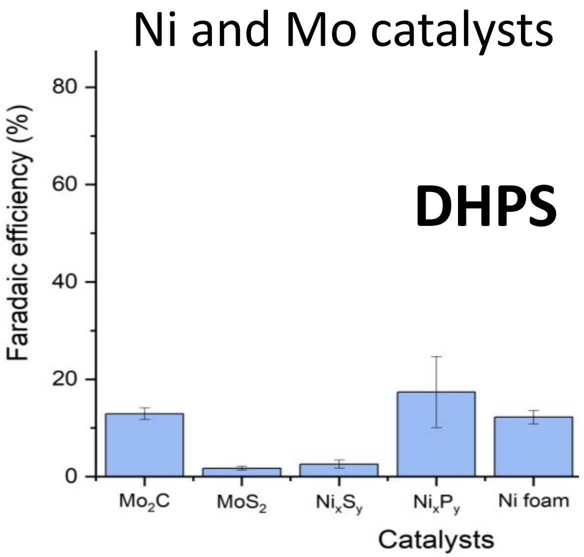
HER in pH 14 and above



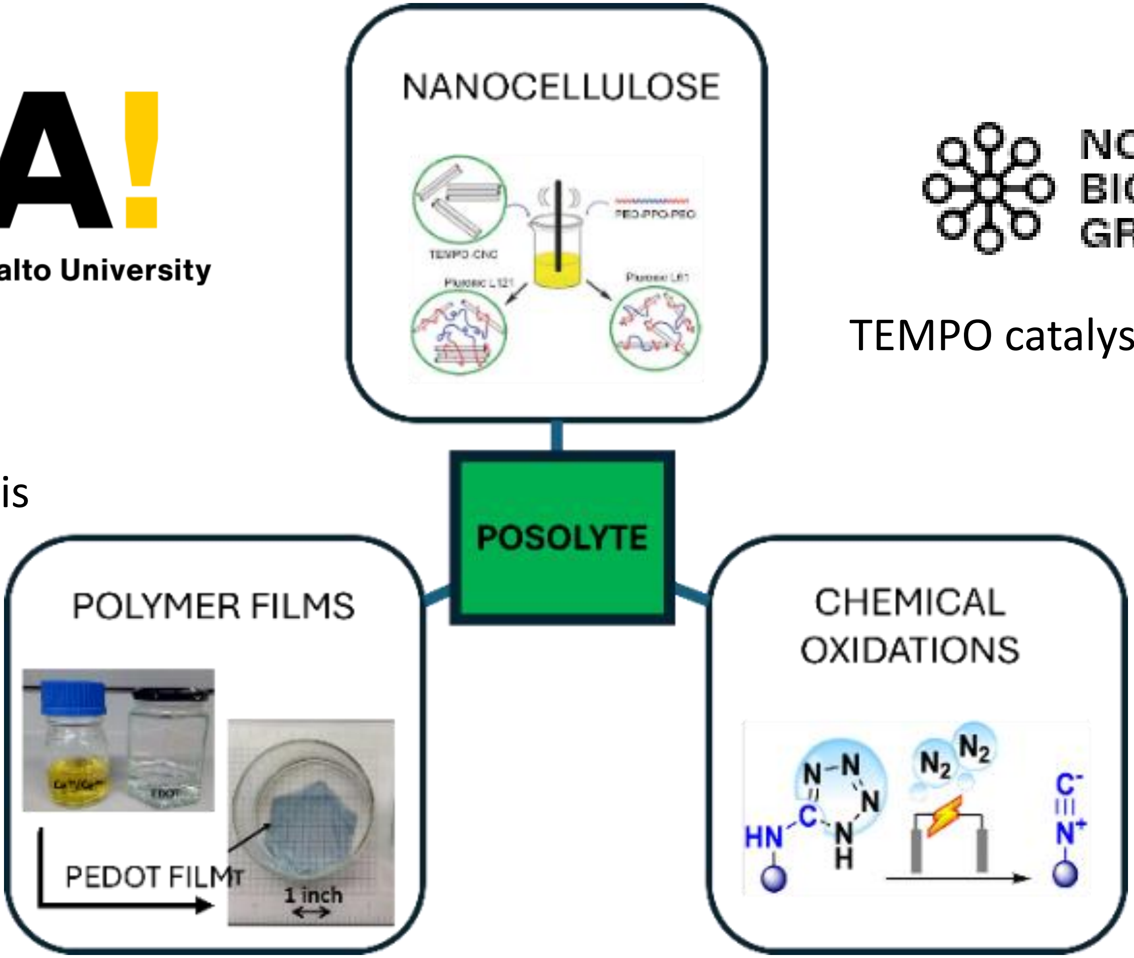








Use the posolyte to produce valuable chemicals

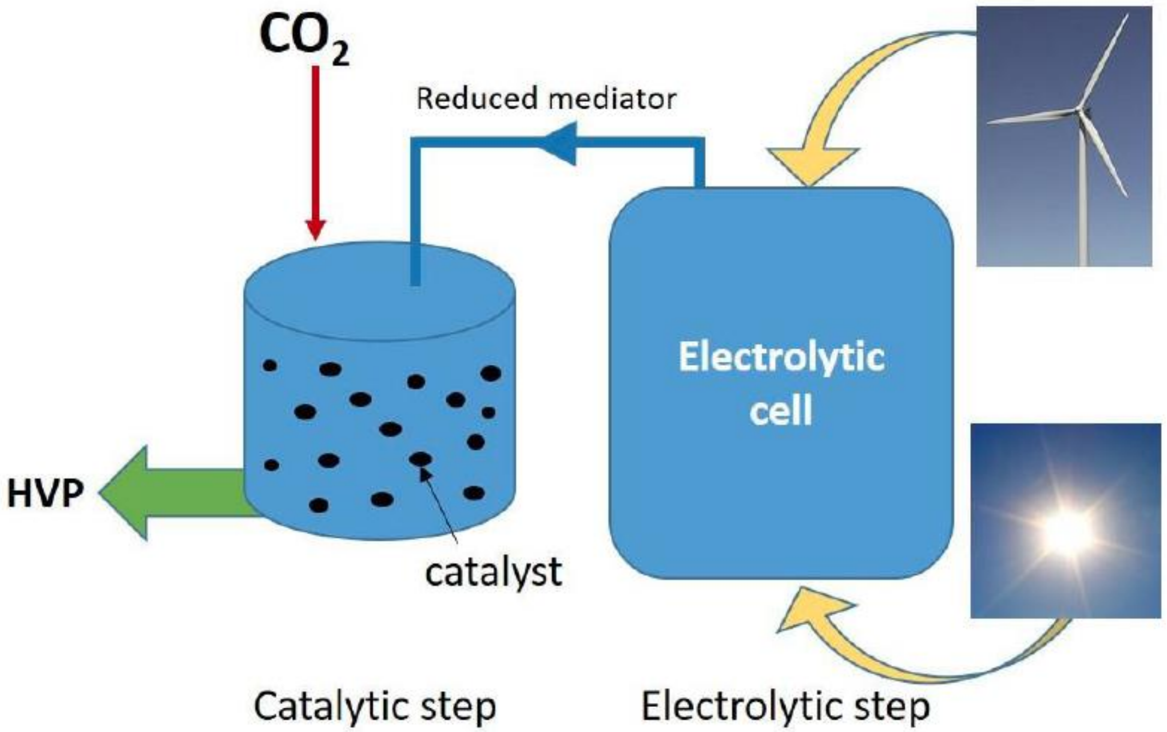


TEMPO catalysed nanocellulose production

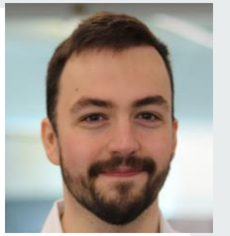
Biphasic polymer film synthesis using a sacrificial oxidant

Pharmaceutical chemical synthesis

Decoupled Electrochemical CO_2 Reduction to High Value Products



Cr(PDTA) – a suitable redox mediator for CO2RR



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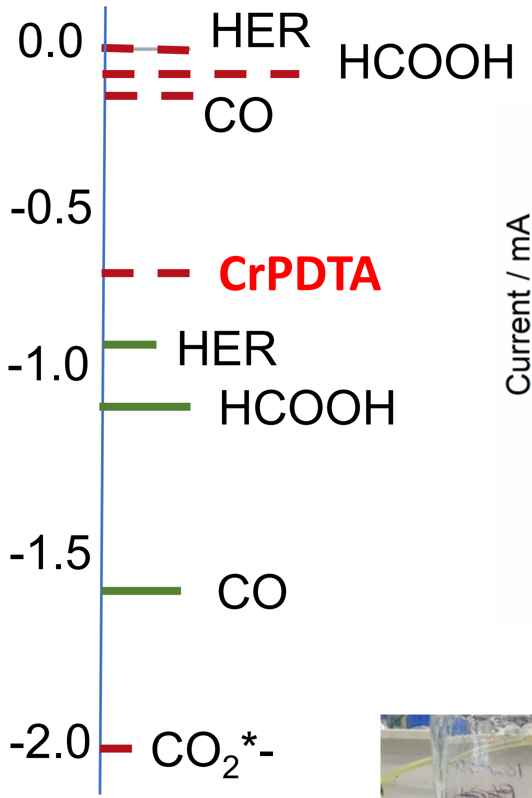
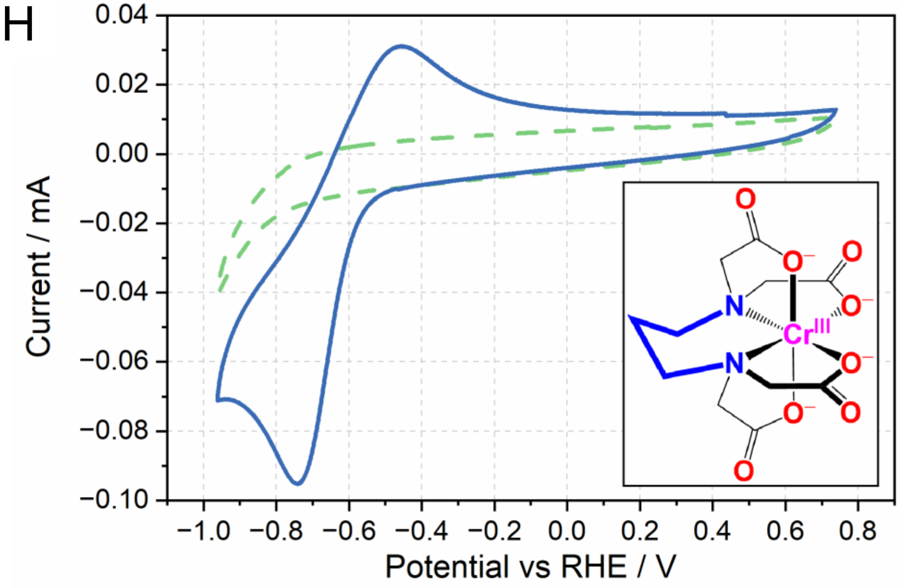
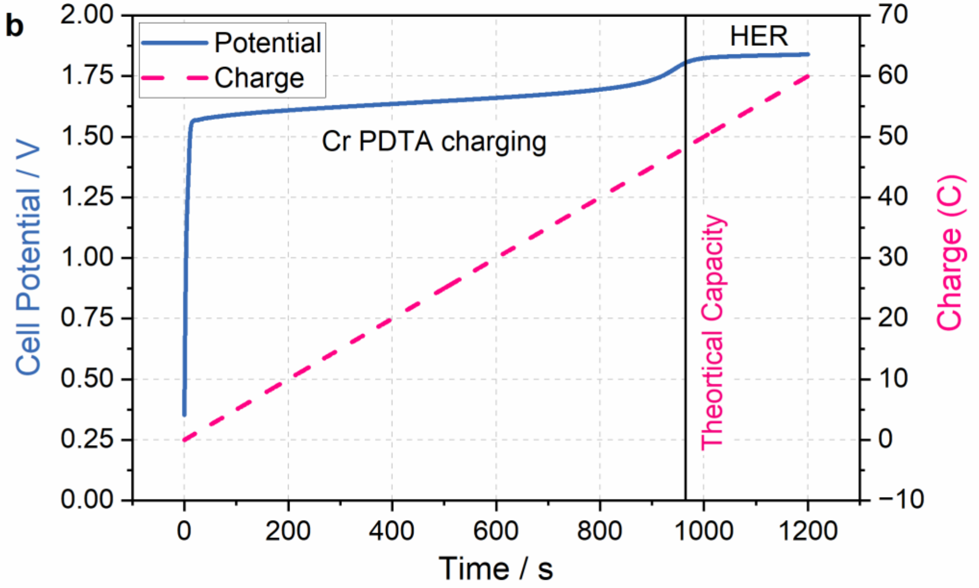
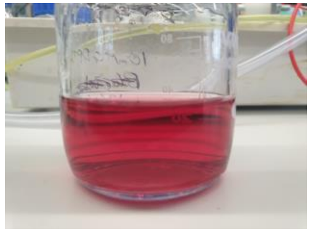
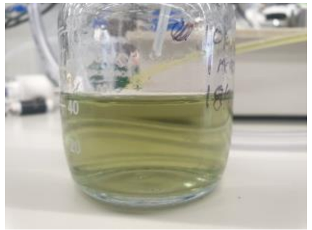
0.5 M $KHCO_3$, pH 8.5, cycled vs potassium ferrocyanide in excess



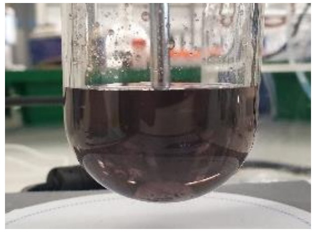




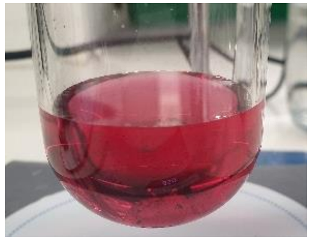




Charge electrolytically



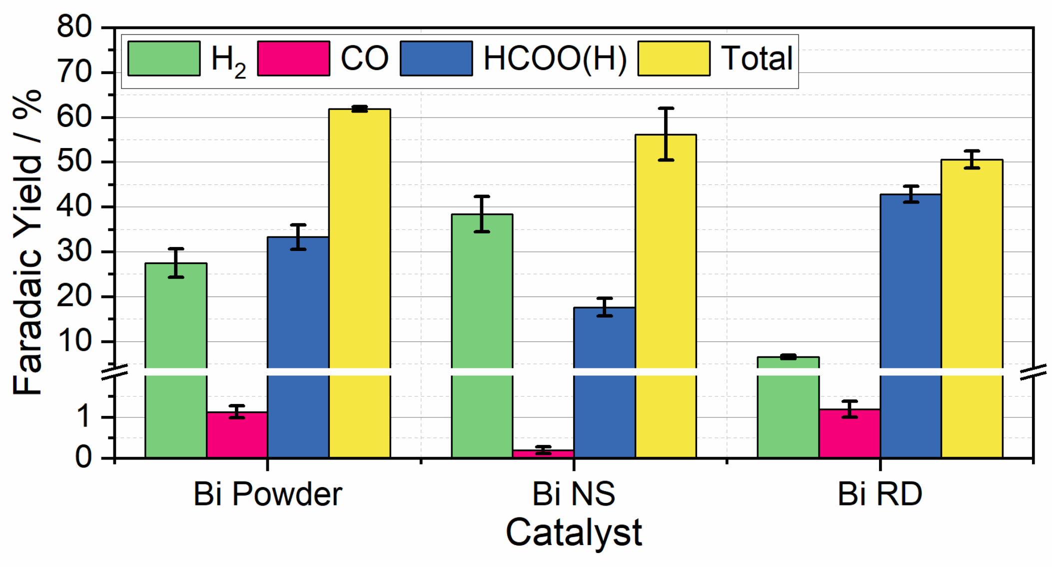
Add CO_2 and catalyst

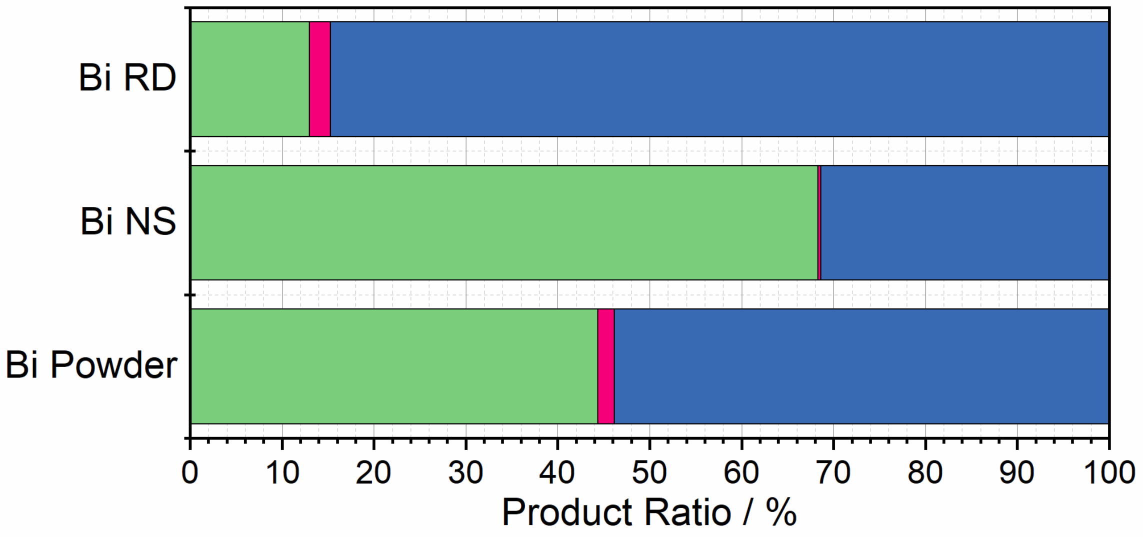


Discharge chemically

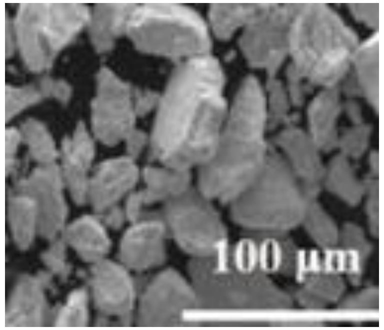
Marshak, Joule **2019**, *3*, 2503, *Inorg. Chem.* 2022, 61, 23, 8752

Bismuth nanostructure is crucial to performance and product selectivity



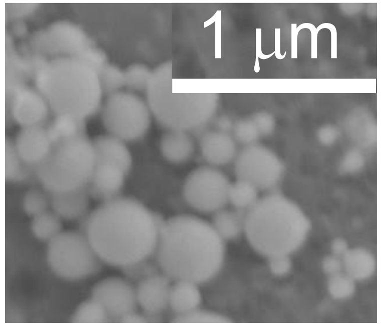


Reported CO_2 active at -0.6 V vs RHE



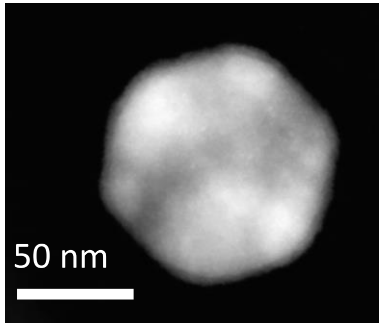
30 mins

Bismuth powder



3 mins

Bismuth nanospheres



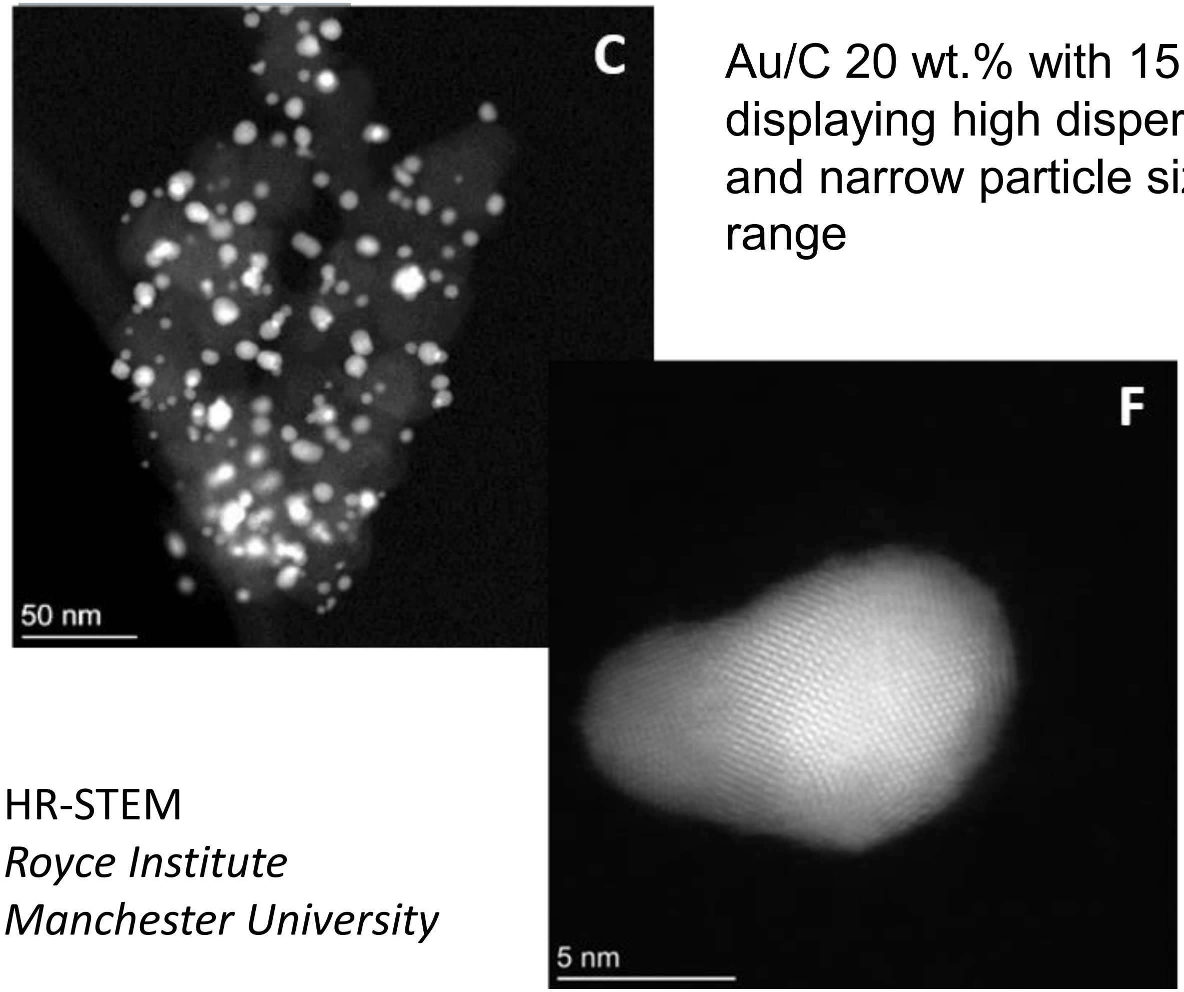
15 mins

Bi rhombic dodecahedron

M. Potter, D.E. Smith, C.G. Armstrong & K. E Toghill, ***EES. Catal.***, 2024, **2**, 379-388

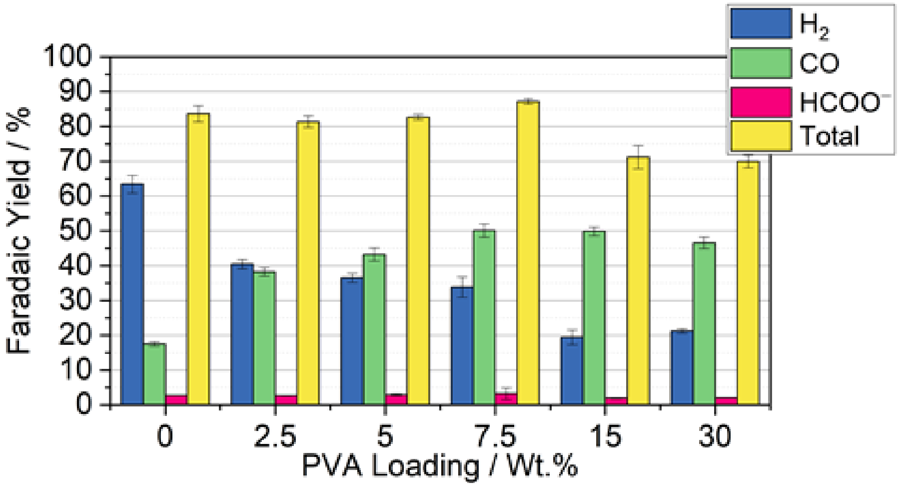
H. Xie et al, *Adv. Mater.* **2021**, 33, 2008373.

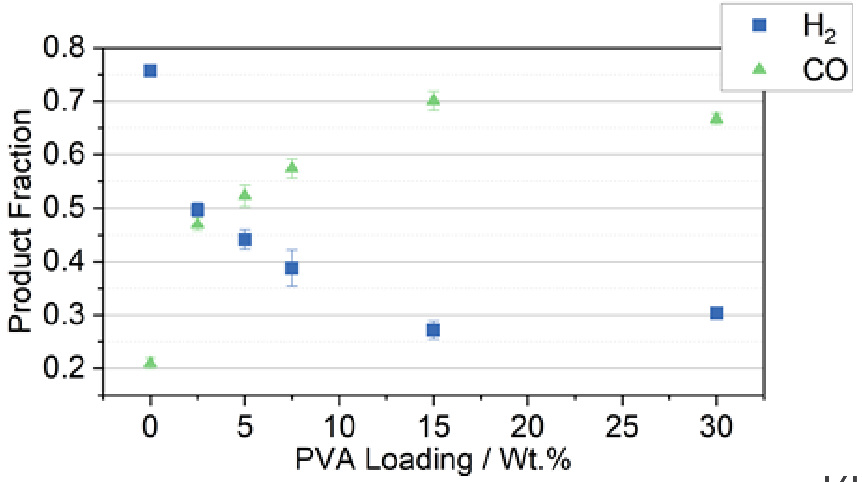
Decoupled Electrochemical CO_2 Reduction: Enabling CO Production



Au/C 20 wt.% with 15 wt.% displaying high dispersity and narrow particle size range

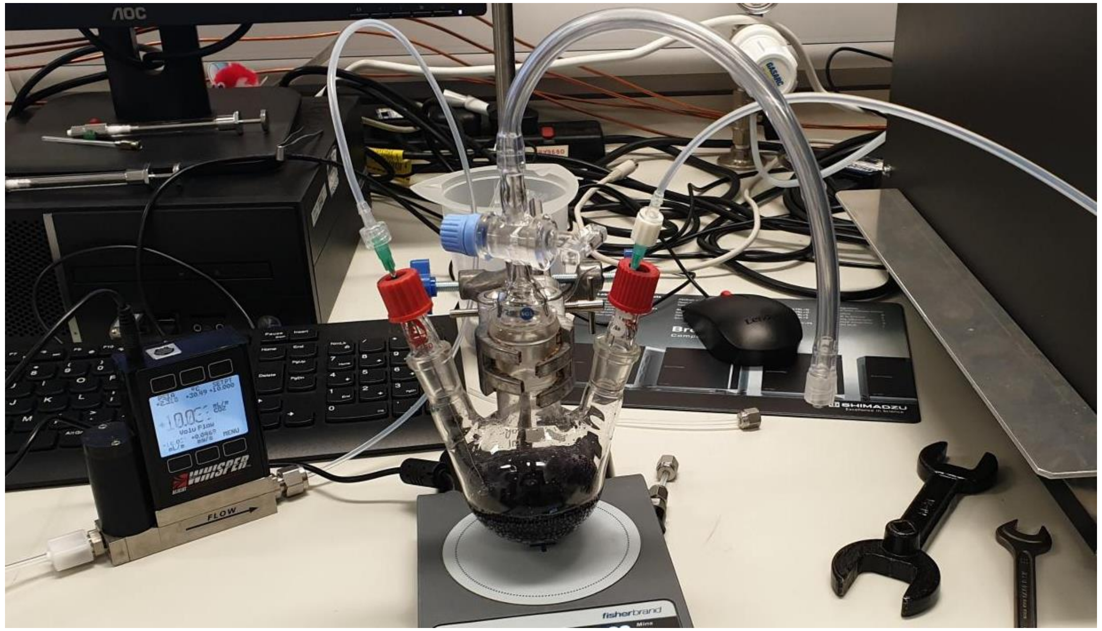
HR-STEM
Royce Institute
Manchester University



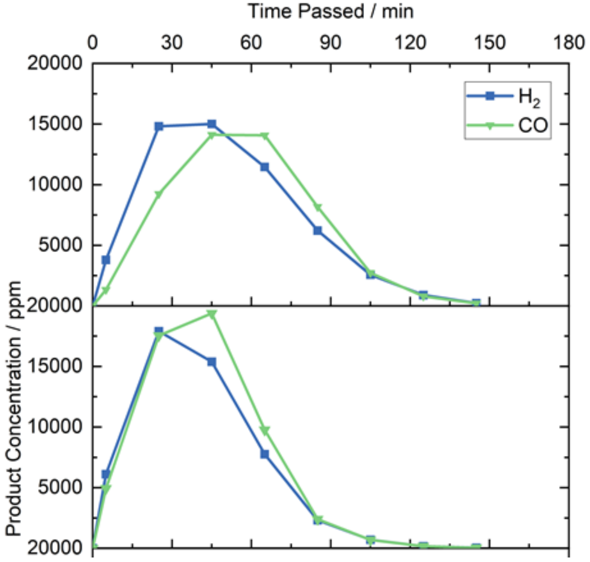


Manuscript submitted, Mark Potter PhD thesis, Lancaster University 2025

Decoupled Electrochemical CO_2 Reduction:
Towards Scaled Syngas Production



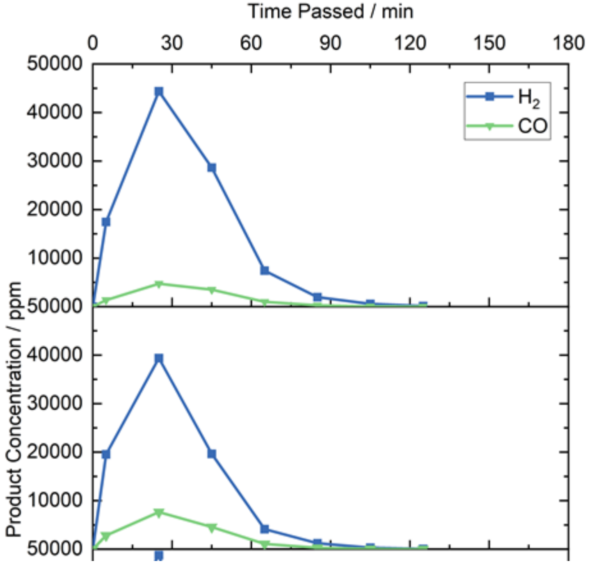
- 1:1 H_2 to CO
- FY of 42.4 ± 2.3 %, 43.0 ± 1.2 %, and 3.5 ± 0.1 %
- H_2, CO and HCOO(H) respectively
- Total of 88.8 ± 1.1 %



Product specific current density 11.9 mA mg^{-1}

← Catalyst as powder

1:1 H_2 to CO
SYNGAS



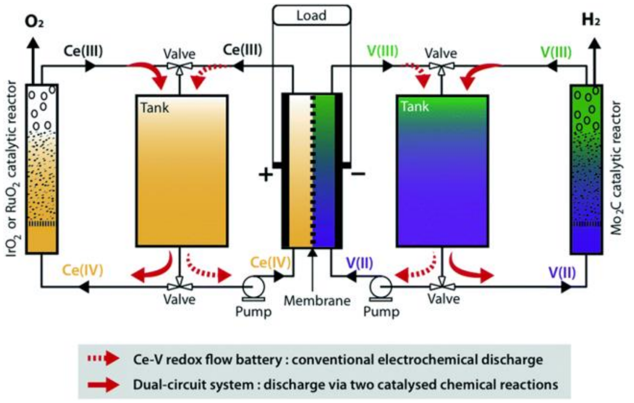
Catalyst as dispersion →

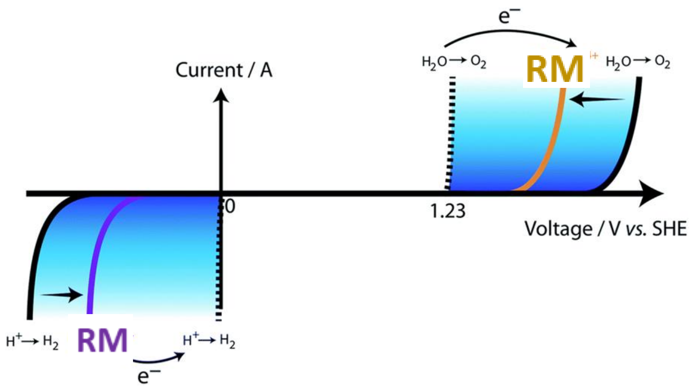
7:1 H_2 to CO

Manuscript submitted, Mark Potter PhD thesis, Lancaster University 2025

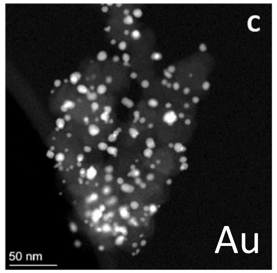
CONCLUSIONS: Combining Electrolysis and Redox Flow Batteries

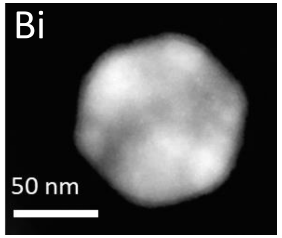
ACIDIC pH HER/OER

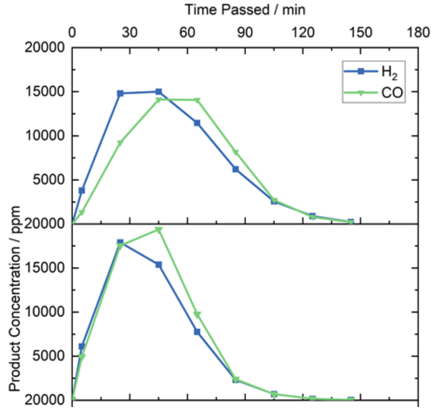




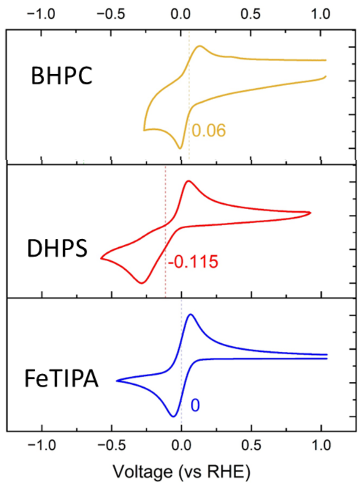
CO_2 REDUCTION



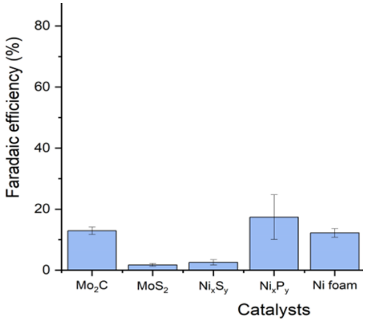


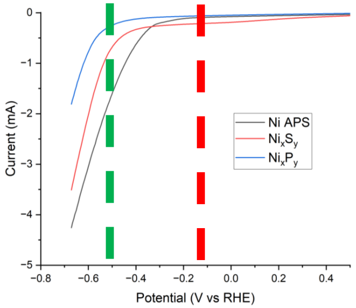


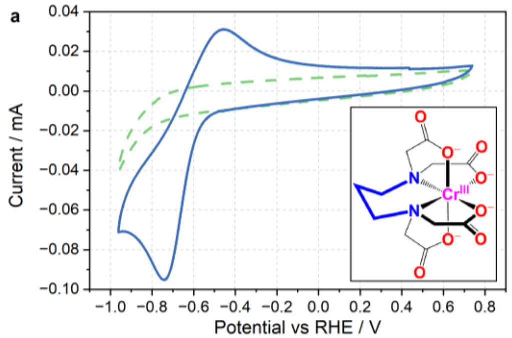
FLOW BATTERY MEDIATORS DRIVING CHEMICAL REDUCTION



ALKALINE pH HER







CrPDTA

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