

Low-Energy Nuclear Reactions: An Electrochemical Engineering Perspective

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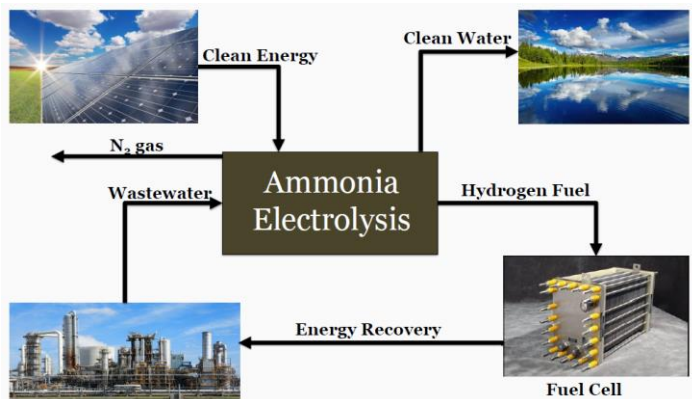
ARPA-E LENR Workshop

October 21, 2021

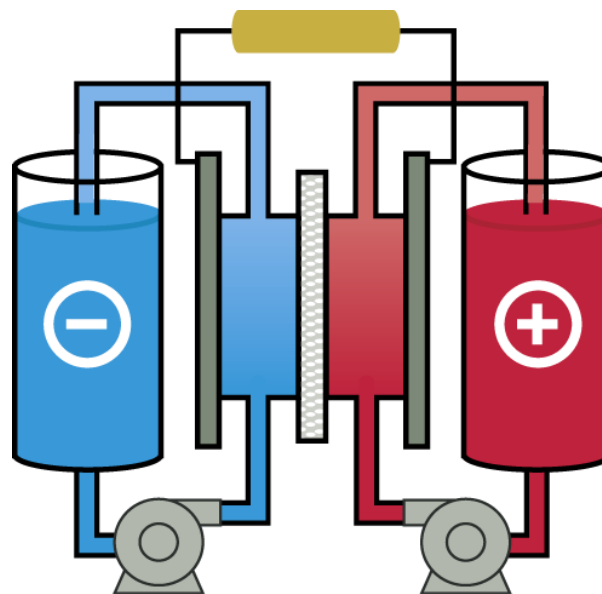
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Electrochemical processes span a range of technologies

Ammonia electrolysis



Energy storage

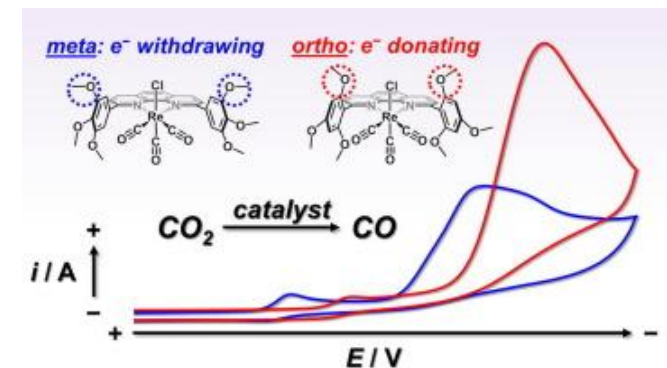


Neyhouse et al., *J. Electrochem. Soc.* 2021.

Neyhouse et al., *ACS Appl. Energy Mat.* 2021.

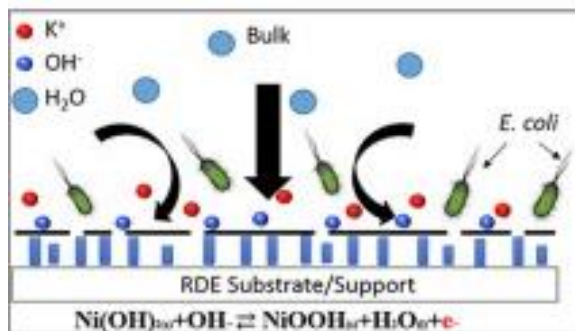
Neyhouse & Brushett, *Ency. of Energy Storage* 2022.

Carbon dioxide conversion



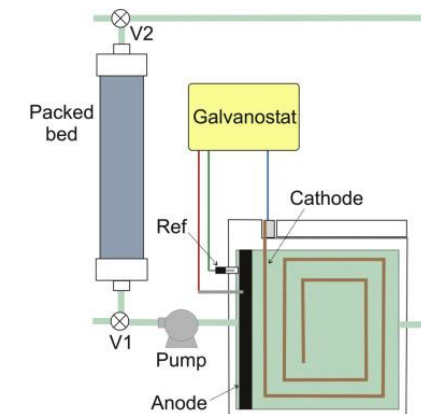
Neyhouse & White, *Inorg. Chim. Acta.* 2018.

Electrochemical sensors



Ramanujam, Neyhouse, et al., *J. Chem. Eng.* 2021.

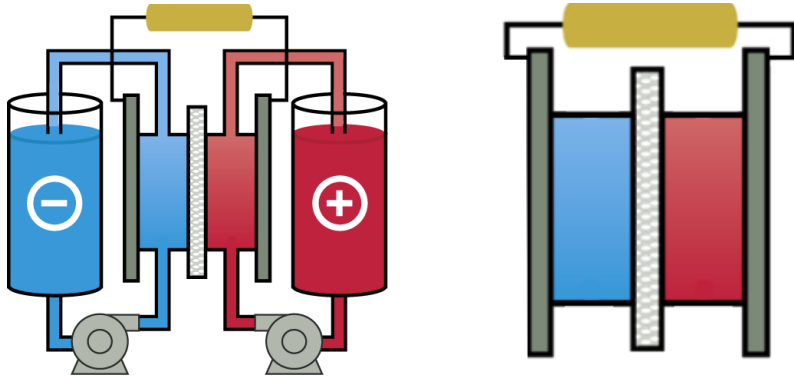
Materials recycling



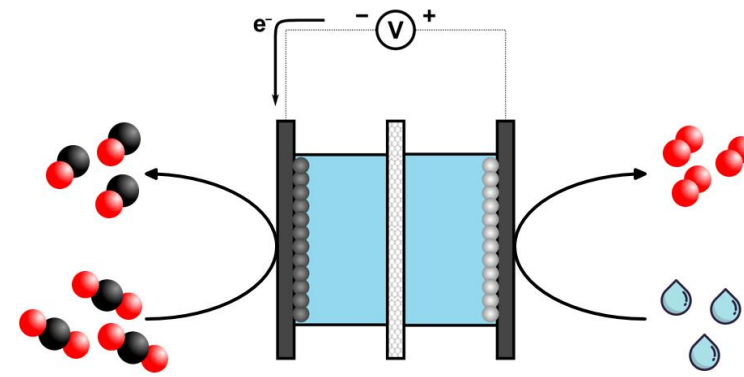
Diaz et al., *J. Clean. Prod.* 2016.

We can generally classify processes as *galvanic* or *electrolytic*

**Galvanic processes
convert chemical energy to
electrical energy**



**Electrolytic processes
convert electrical energy to
chemical energy**

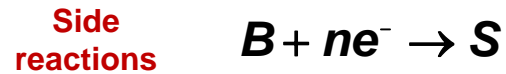
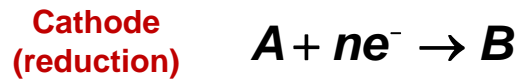


**Voltage measures the energy inputs or
outputs for electrochemical systems**

**Current measures the overall conversion in
electrochemical reactions**

Understanding the relationship between current and voltage requires a detailed description of (electro)chemical processes

Chemical / electrochemical reactions



Energy / power balance (voltage losses)

$$V_{cell} = OCV + \eta_k(I) + \eta_\Omega(I) + \eta_m(I)$$

Minimum energy

Kinetic losses

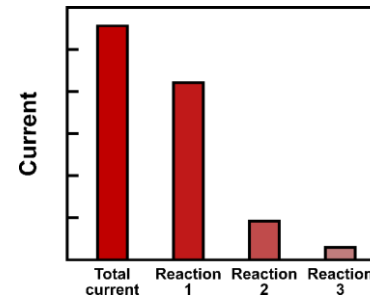
Ohmic losses

Transport losses

Electrochemical thermodynamics and kinetics

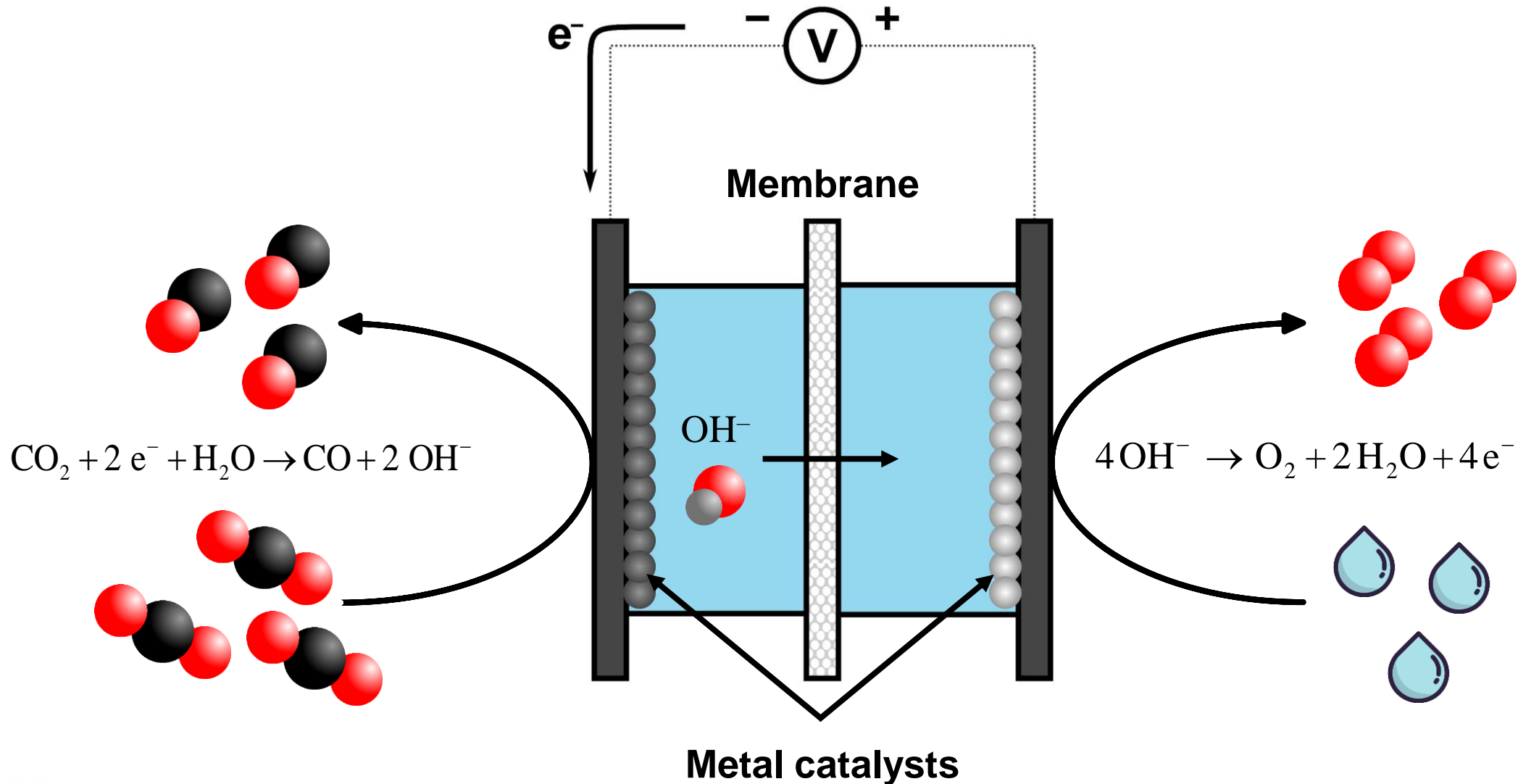


Closing the electron balance (product analysis)

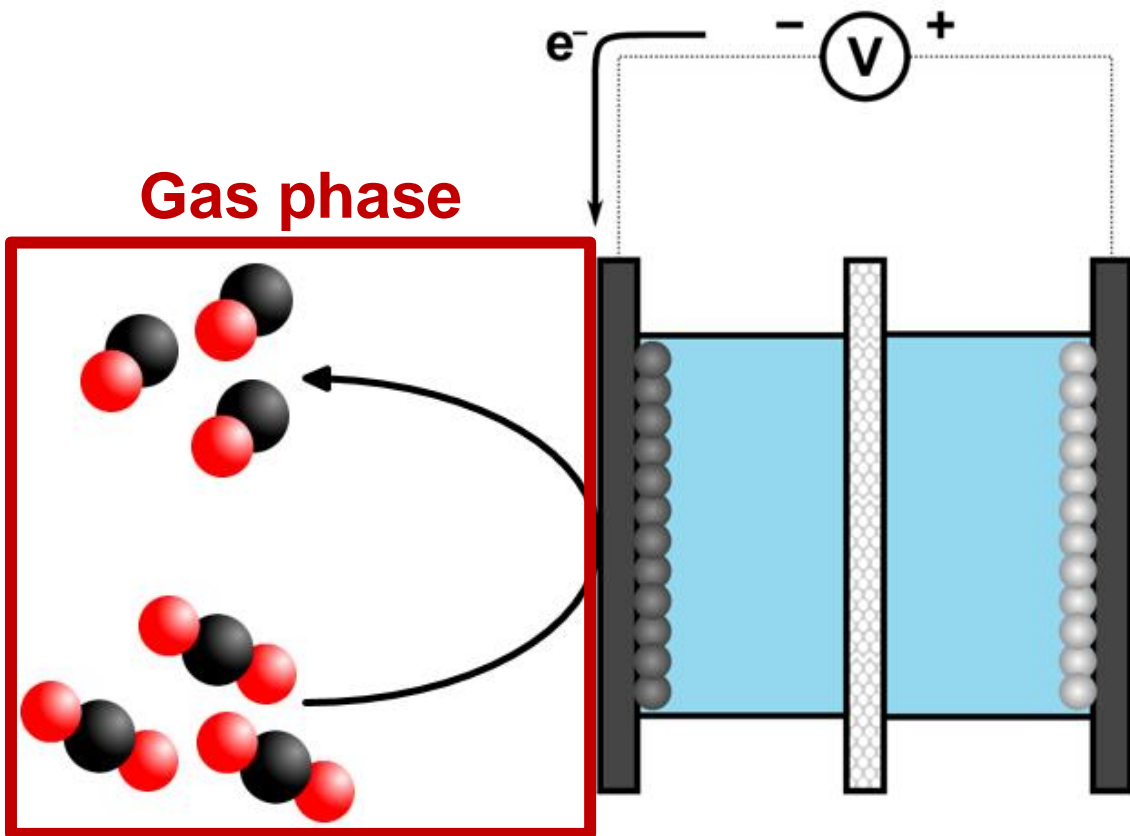


$$I = I_1 + I_2 + \dots$$

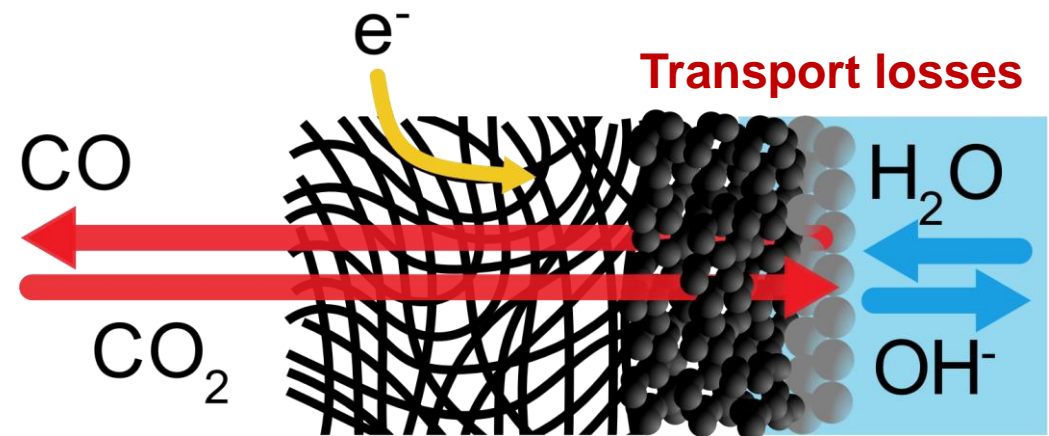
A case study in CO₂ electrolysis



Characterizing 3-phase electrochemical systems

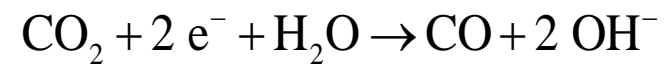


Energy / power balance

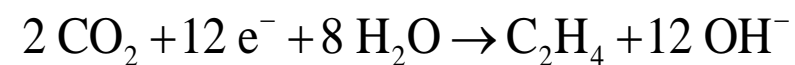
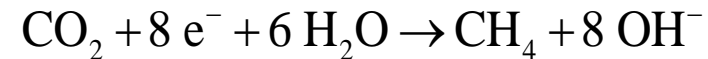


Chemical / electrochemical processes

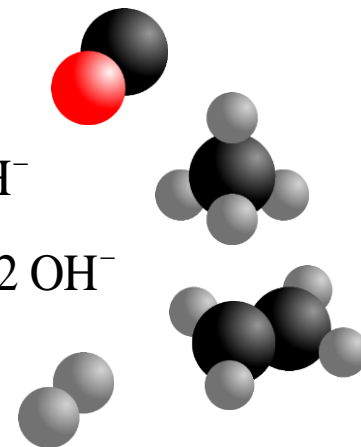
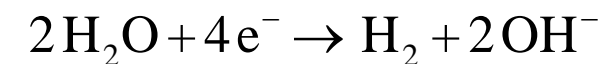
Target reaction



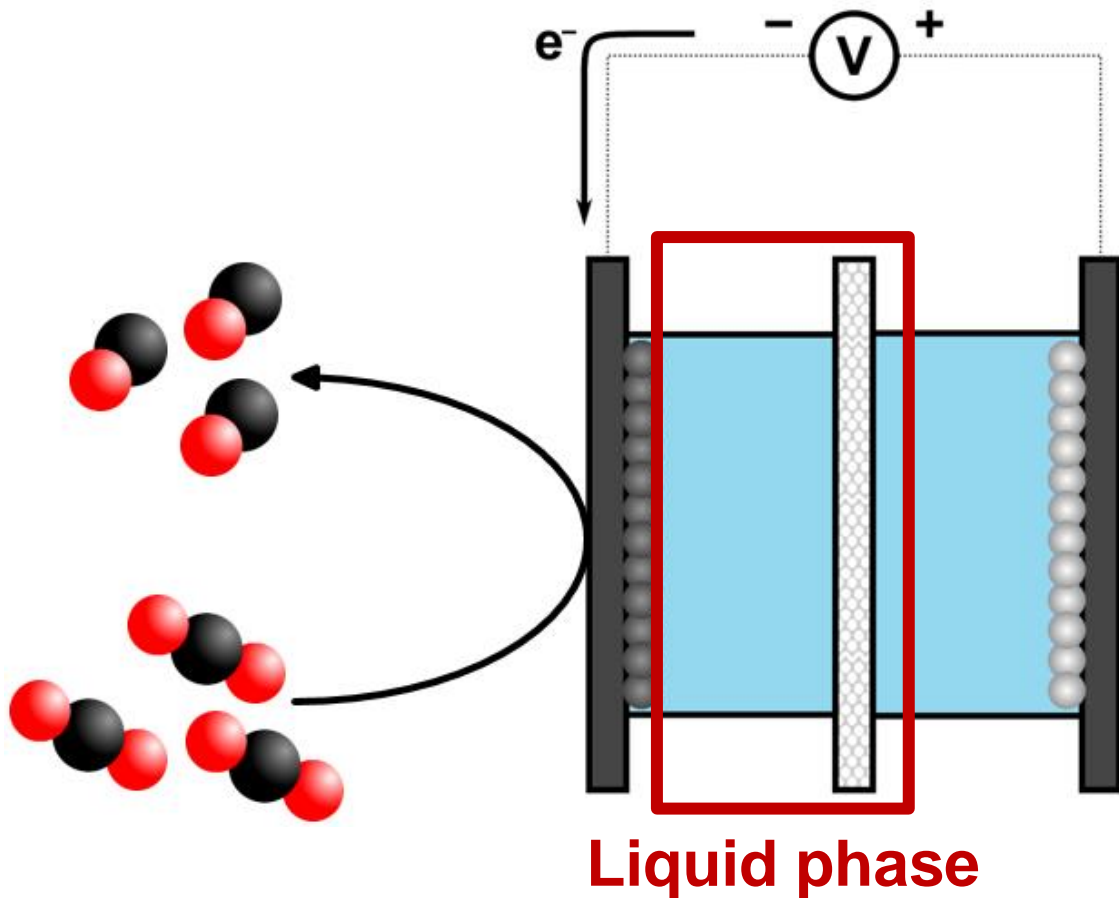
Side reactions



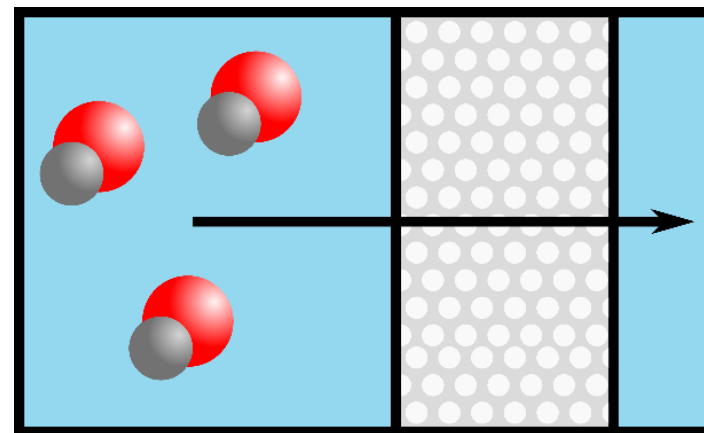
Undesired reactions



Characterizing 3-phase electrochemical systems



Energy / power balance



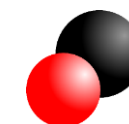
Ohmic losses

$$\eta_{\Omega} = IR$$

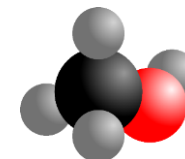
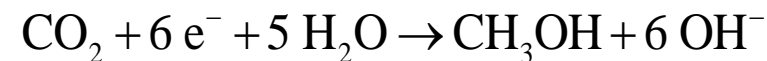
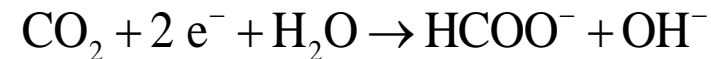
$$R = R_{elec} + R_{mem}$$

Chemical / electrochemical processes

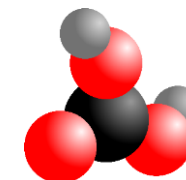
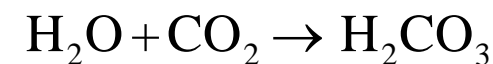
Target reaction



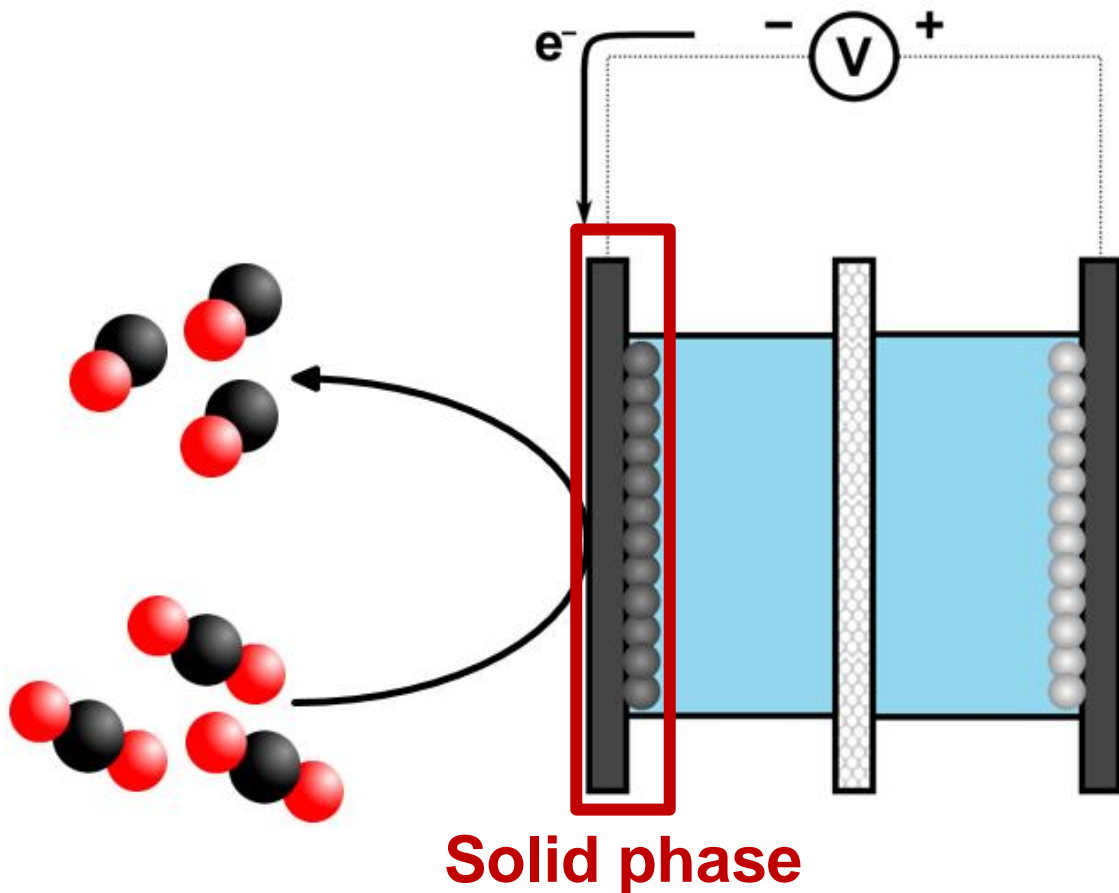
Side reactions



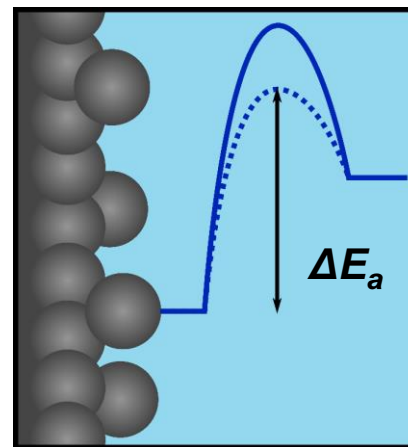
Undesired reactions



Characterizing 3-phase electrochemical systems



Energy / power balance



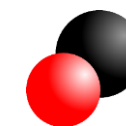
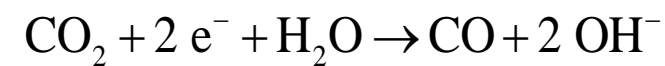
Kinetic losses

Product selectivity

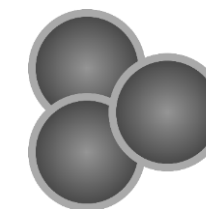
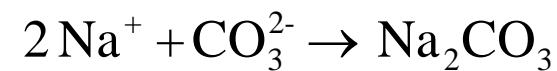
Ohmic losses

Chemical / electrochemical processes

Target reaction



Undesired reactions



Controlling reaction conditions is critical to isolating phenomena and mitigating undesired processes

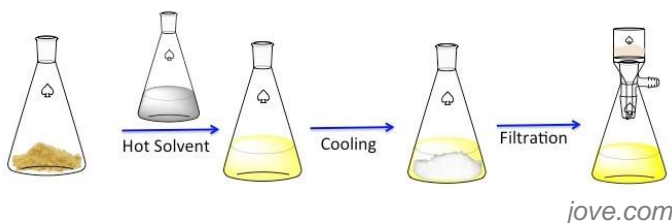
Solvent / electrolyte purity

Always use high purity reagents

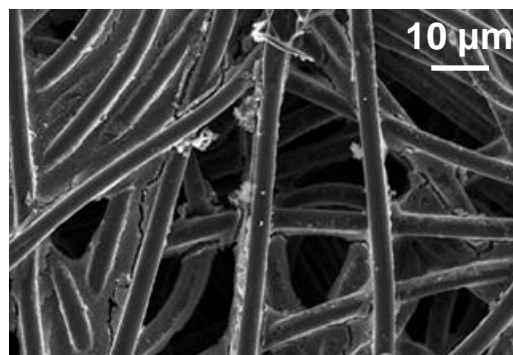
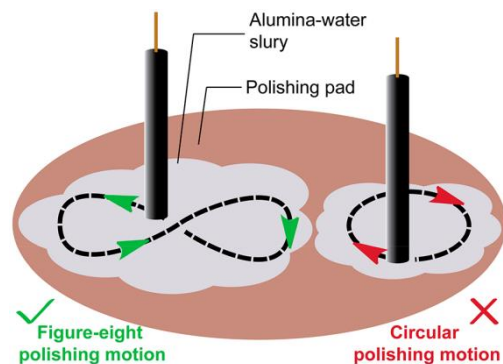


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Sometimes, this requires additional purification



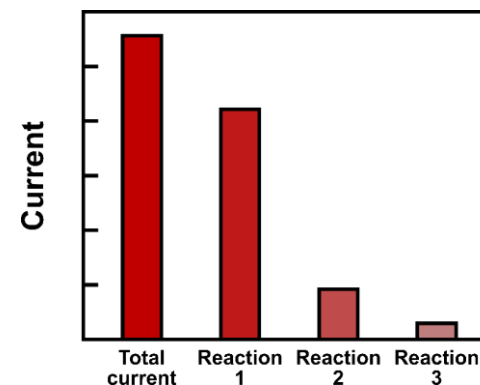
Electrode treatment and characterization



Precision product analysis (chemical characterization)

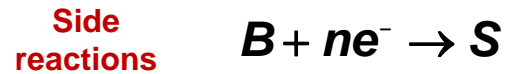
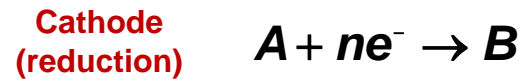
LC-MS

GC-MS



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Kinetic losses

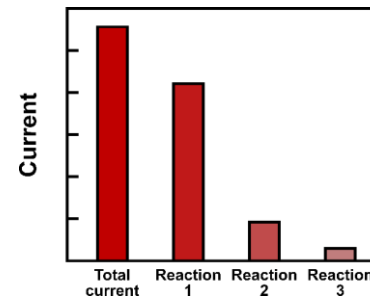
Ohmic losses

Transport losses

Electrochemical thermodynamics and kinetics



Closing the electron balance (product analysis)



$$I = I_1 + I_2 + \dots$$

Questions?

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