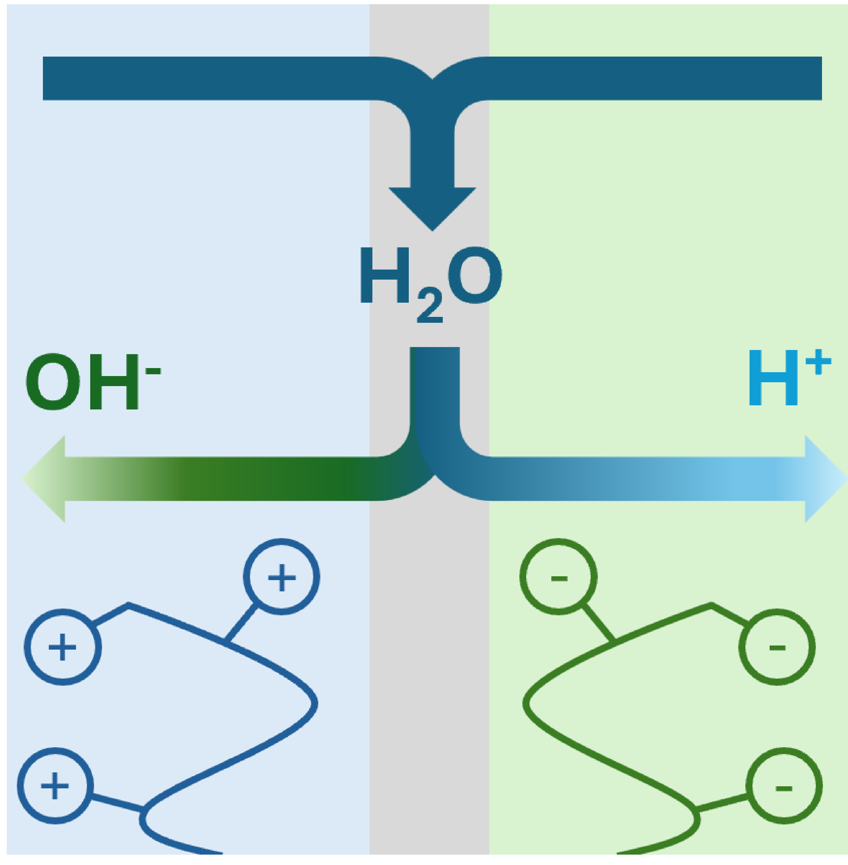
Development and application of bipolar membranes for next-generation sustainable electrochemical systems

Julian Black, Qilei Song
Department of Chemical Engineering, Imperial College London

Overview

Bipolar membranes (BPMs) are a class of ion-exchange membranes with the ability to dissociate water at the interfacial junction, generating protons and hydroxide ions. This enables BPMs to develop and maintain strong pH gradients across electrochemical devices. These unique properties have broad application potential and can improve energy efficiency and enable innovative electrochemical systems. Widespread adoption is limited by voltage losses and membrane instability. Combining recent advancements in BPM catalysis with new monopolar membrane designs will develop a new generation of BPMs that can be implemented and individually tailored for high performance in a variety of electrochemical systems. Here, we report BPMs fabricated using new polymers and tailored with optimised properties for application in high-performance electrochemical devices.

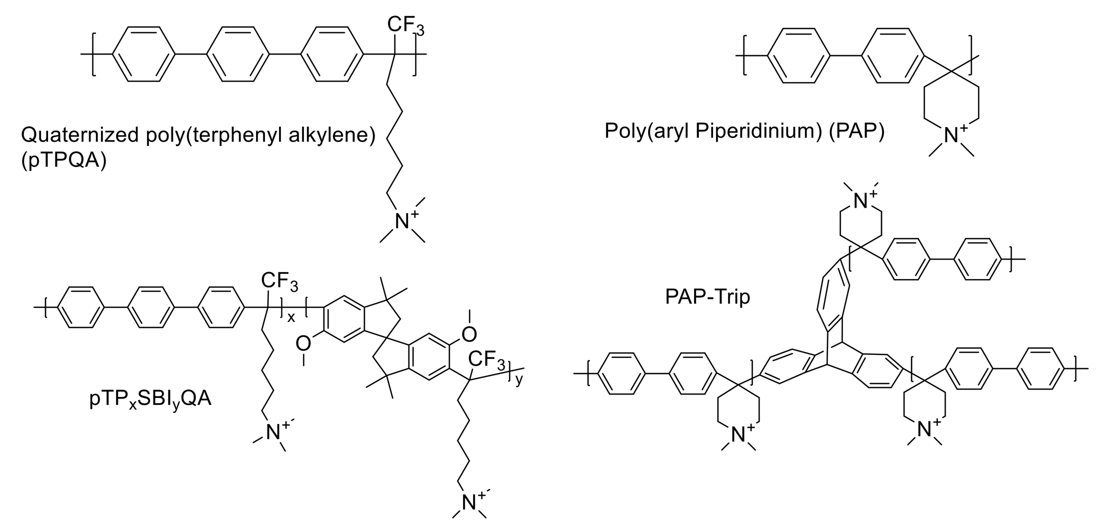


Applications

BPMs have a broad range of applications including:

- Energy storage in acid-base batteries
- CO_2 capture and conversion
- Hydrogen generation via water electrolysis
- Hydrogen fuel cells
- Desalination
- Lithium extraction
- Green cement production

AEM



- AEMs require high permselectivity, conductivity, stability
- There is a trade off between selectivity and conductivity
- Balance can be managed by enhancing free volume

WD CL

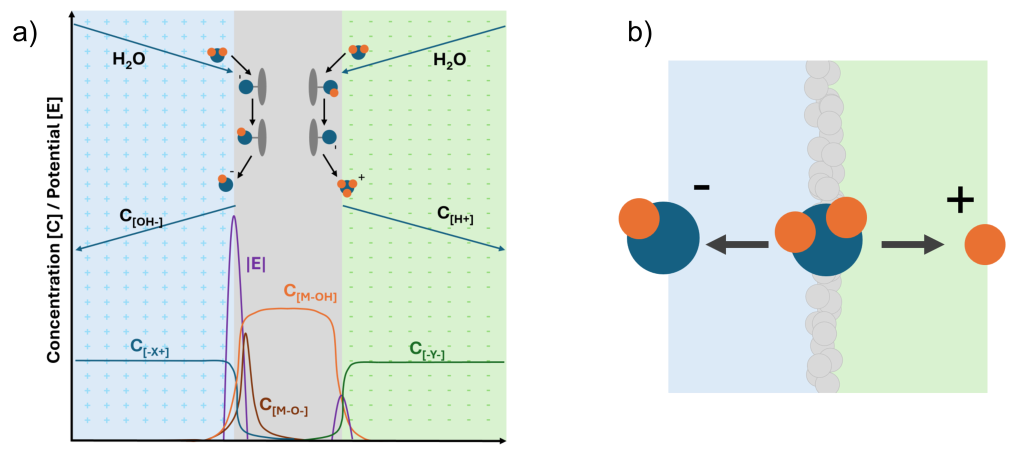
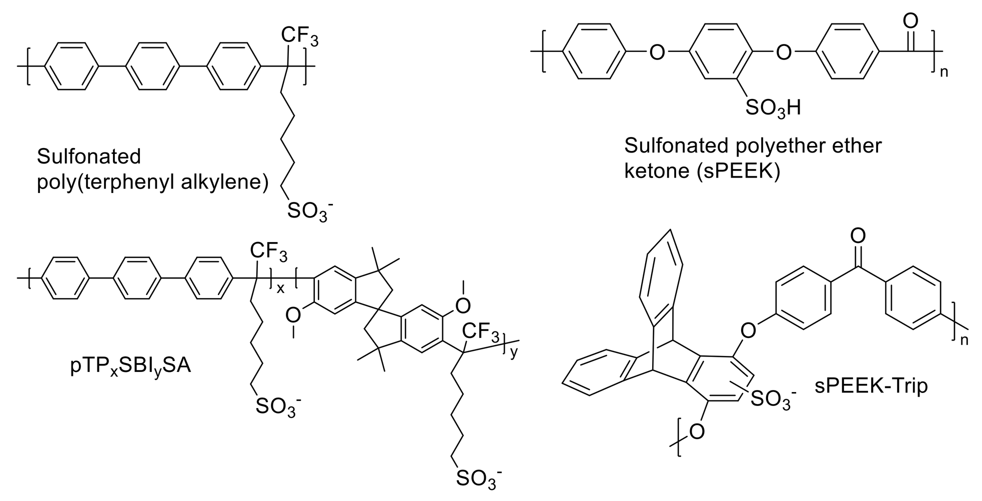


Figure 1 – (a) Species concentration and electric field profiles in BPM, (b) second Wien effect on water dissociation

- Water dissociation is driven by second Wien effect and catalyst
- Catalysts must balance electric field and catalytic effect

CEM



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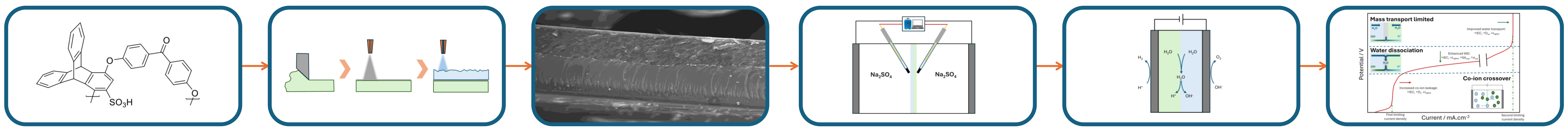
Workflow



Polymer synthesis → BPM fabrication → Fabrication characterization → Membrane characterization → BPM device application → Performance analysis

Fabrication

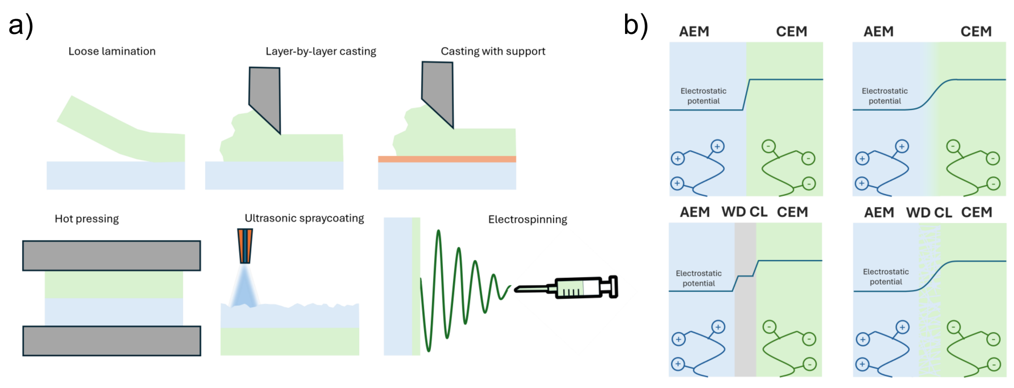


Figure 2 – (a) BPM fabrication methods, (b) BPM structures and electric fields for an abrupt junction, smooth junction, BPM with catalyst layer, 3D junction.

- Fabrication plays an important role in overall BPM performance
- Strong physiochemical interactions improve stability
- Balanced polymer properties required
- Junction can be tailored to improve stability and enhance kinetics

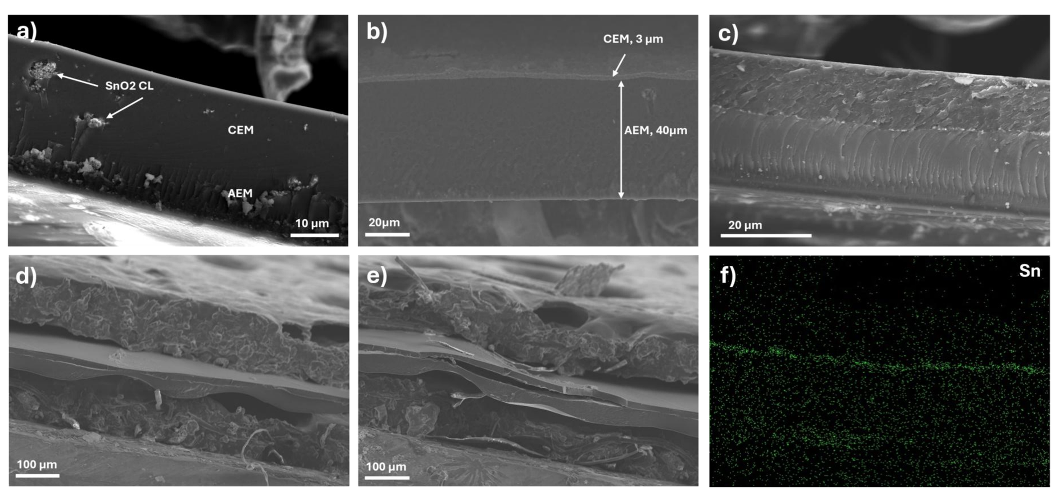
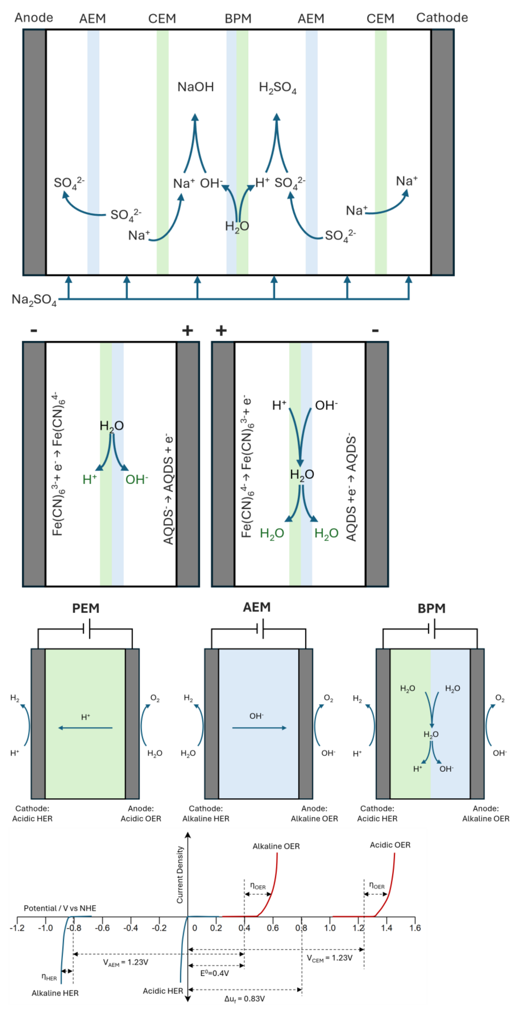


Figure 3 – (a) SEM image of layer-by-layer casted BPM, (b) SEM image of handheld spraycoated BPM, (c) SEM image of ultrasonic spraycoater BPM, (d) uneven surface with bumps that can form from ultrasonic spraycoating, (e) Blistering where the AEM and CEM separate due to poor interfacial compatibility, (f) SEM elemental analysis spectrum of Sn illustrating SnO2 catalyst layer from c.

- Ultrasonic spraycoating produces good BPMs but can create inconsistent layers
- Continued work optimising fabrication protocol will be required
- Fabrication is important but polymer properties determine performance and stability

Application



Electrodialysis is used to assess BPM acid-base generation and can be applied to desalination, lithium extraction, and carbon capture.

Redox flow batteries are used for large scale energy storage. High voltages can be achieved by combining redox couples with acid-base generation.

BPM electrolysers can reduce overpotential and PGM catalyst requirement by operating anode and cathode in optimal pH.

Initial results

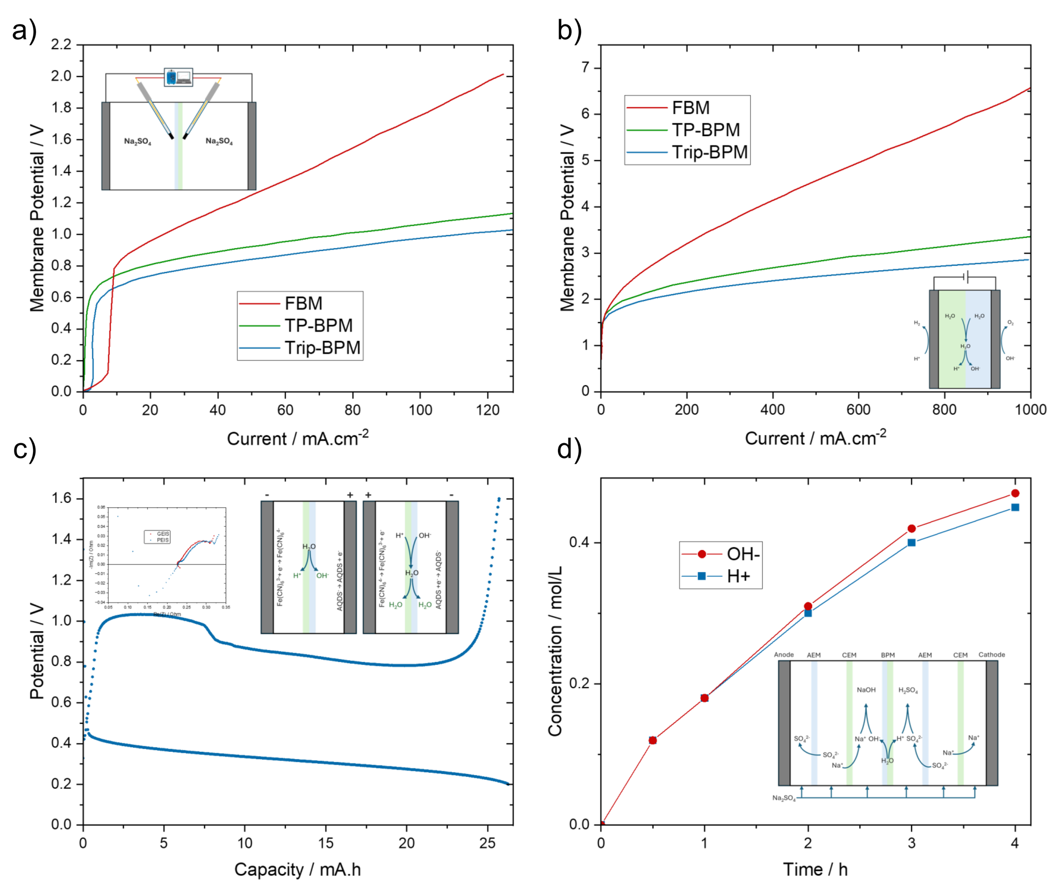


Figure 4 – (a) H-cell IV-curves and (b) BPMWE IV-curves for commercial FBM, pTPSA/pTPQA BPM (TP-BPM), and sPEEK-Trip/PAP-Trip BPM (Trip-BPM). (c) BPM-RFB charge/discharge for TP-BPM, (d) acid-base generation for TP-BPM.

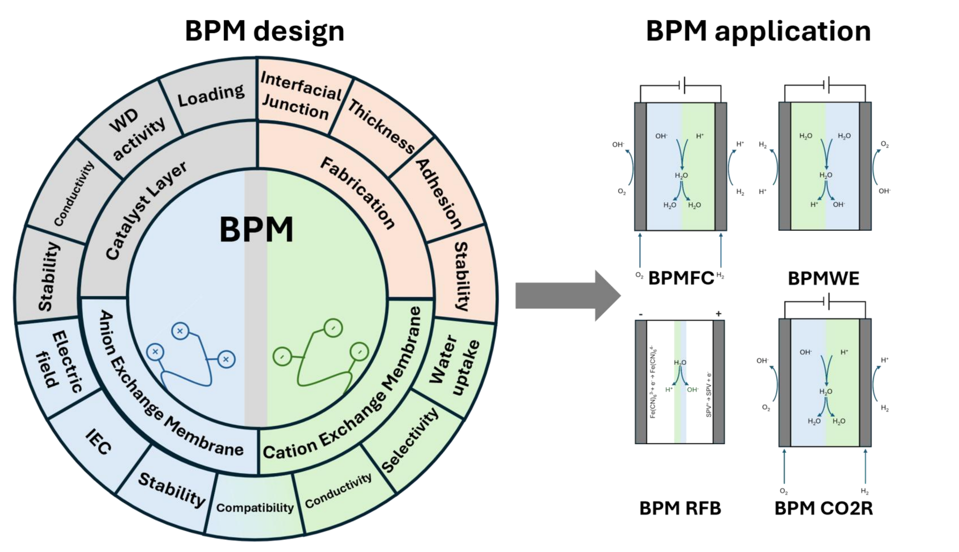
Outlook

Challenges:

- Mechanical instability
- WD overpotentials and ohmic losses
- High manufacturing costs
- Limited scalability
- Application specific operational demands

Future work:

- Fabrication techniques
- Advanced materials development
- Interfacial layer investigation
- Electrochemical device application and optimisation



A fabrication protocol will be developed and optimised. New promising materials will be identified, developed, and characterised. These materials will be used to fabricate BPMs which will be characterised and applied in electrochemical devices. The devices will be optimised and BPMs will be tailored for device-specific target properties.

Acknowledgements

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