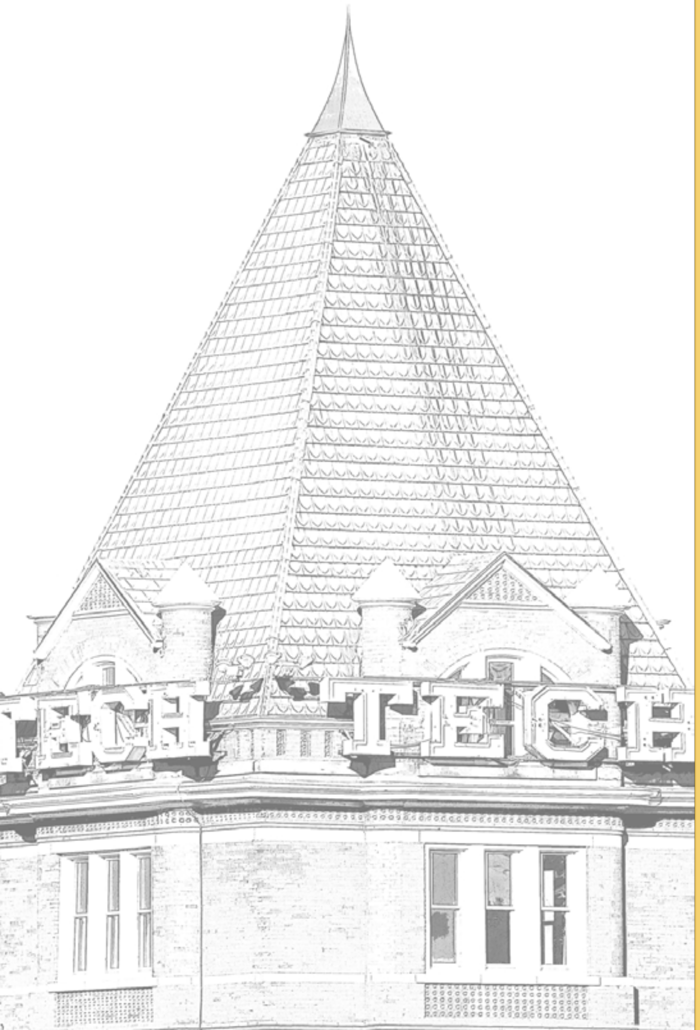

SALINITY GRADIENT ENERGY

Membrane synthesis and system optimization for reverse electrodialysis

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Jin Gi Hong; Haiping Gao;
Yongsheng Chen*
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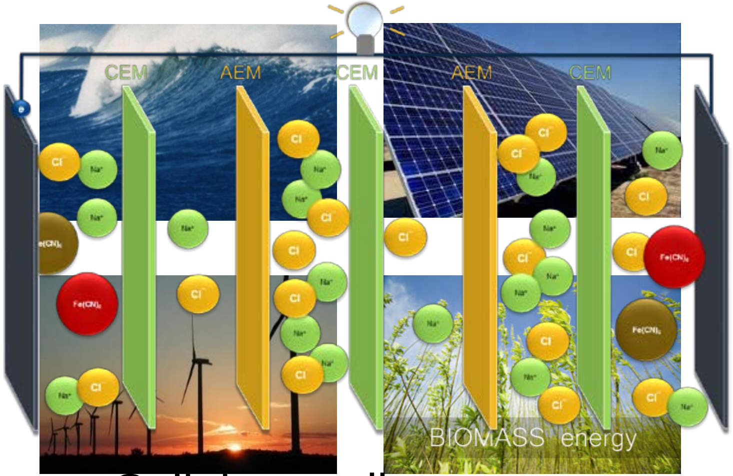
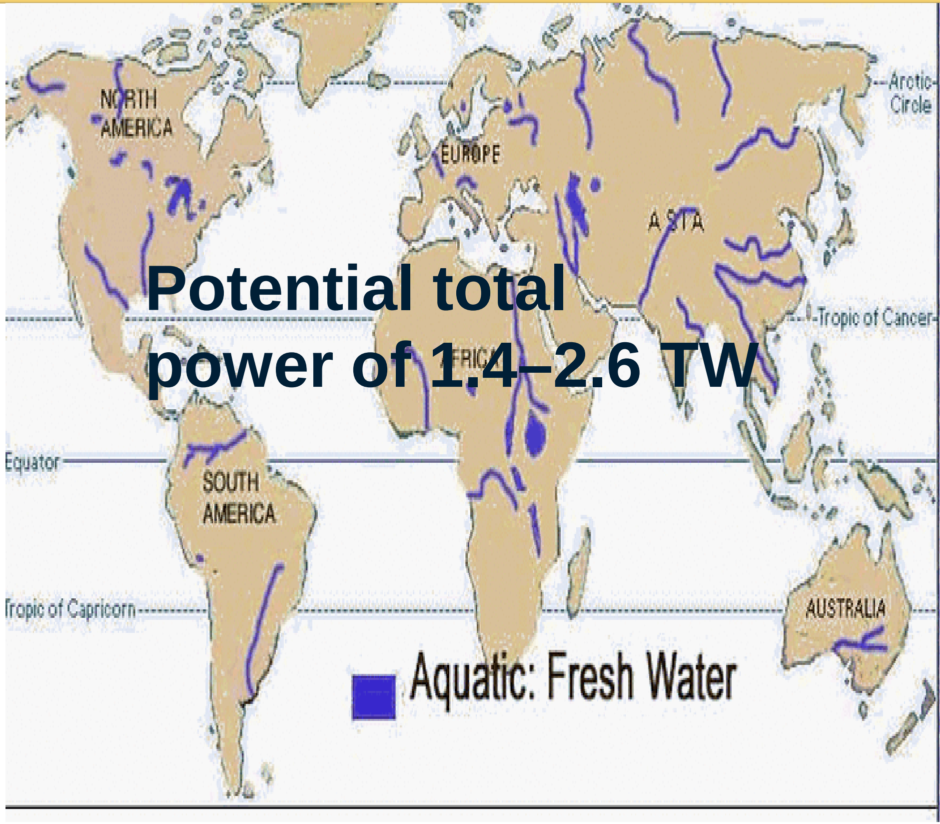
INTRODUCTION

Background

- Energy dependence on fossil fuels is a major contributor to **global warming** and **air pollution**
- Clean and sustainable energy sources are environmentally preferable



Salinity gradient energy



Potential total power of 1.4–2.6 TW

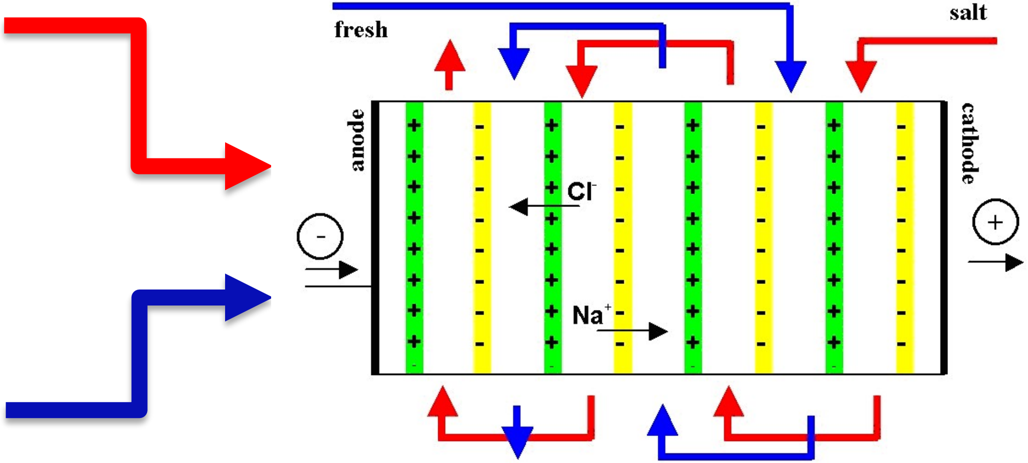
Source: www.arabiangazette.com; apollo.lsc.vsc.edu; freshwaterinfo.weebly.com; www.dovelion.org; www.solarpowernotes.com; Wick and Schmitt, Marine Technology Society Journal, 11 (1977) 16-21

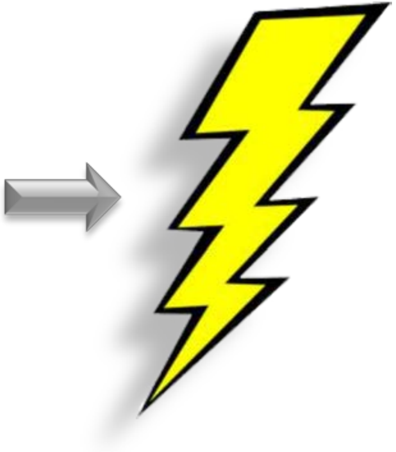
INTRODUCTION

Salinity Gradient Power by Reverse Electrodialysis (RED)

Ocean Water

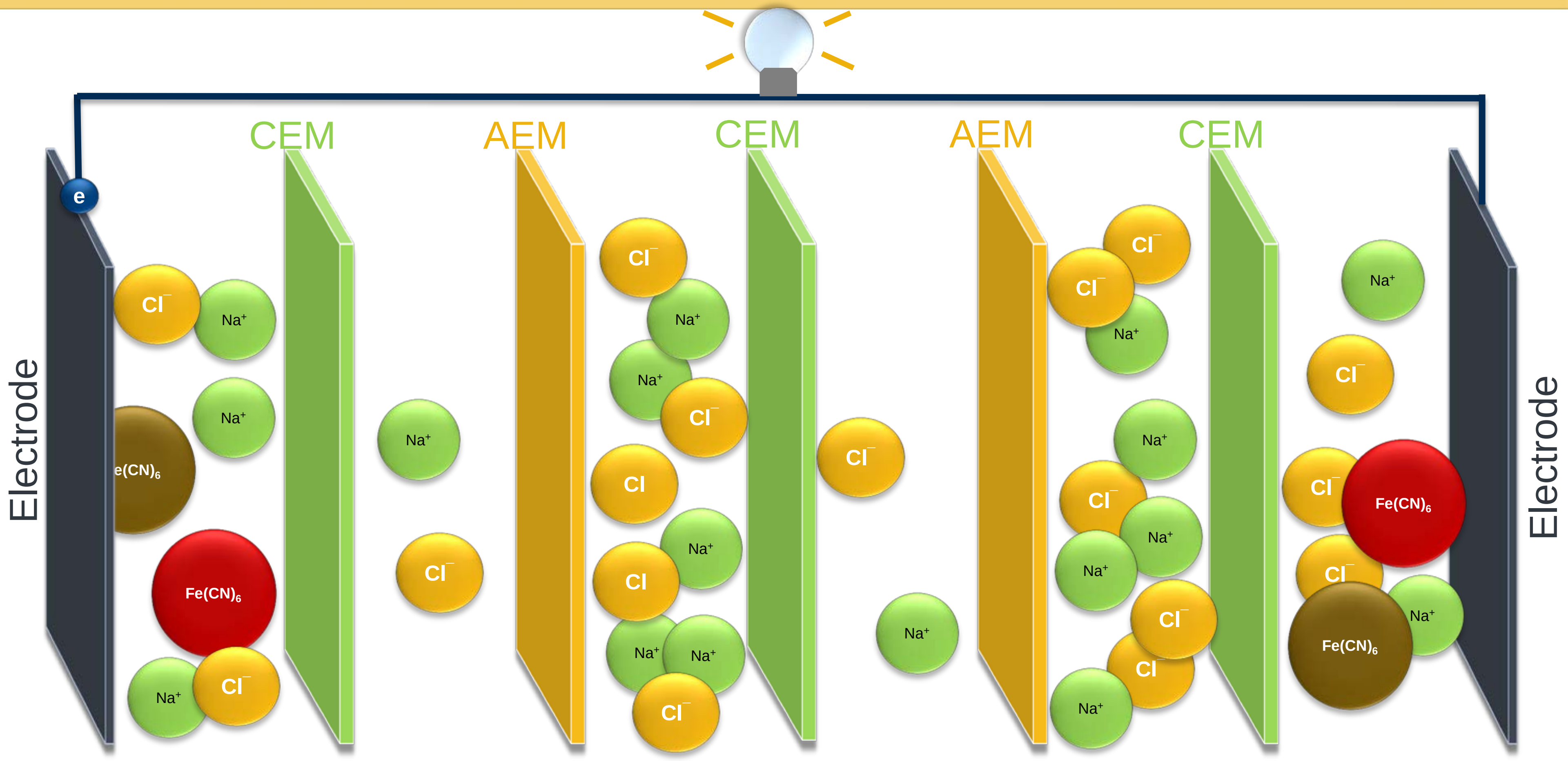
River water





Source:www.climatetechwiki.org

PRINCIPLE

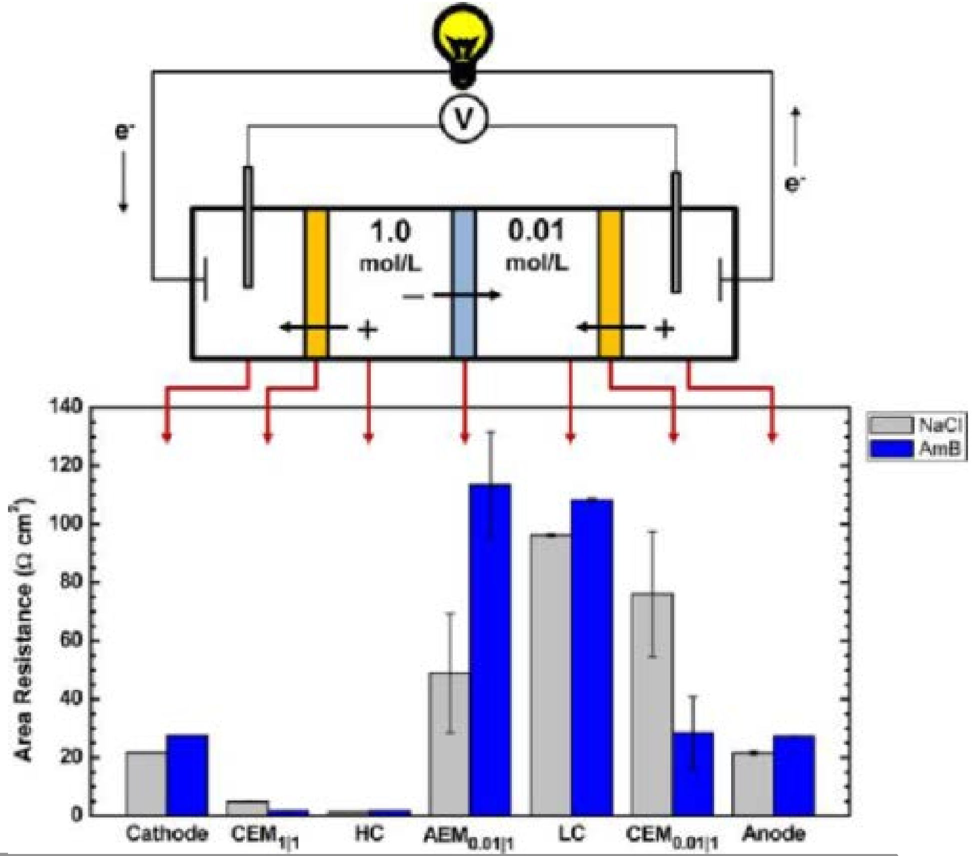


PRINCIPLE

$$P = \frac{E_{stack}^2}{4R_{stack}}$$

$$E_{stack} = \alpha \frac{RT}{nF} \ln \frac{a_c}{a_d}$$

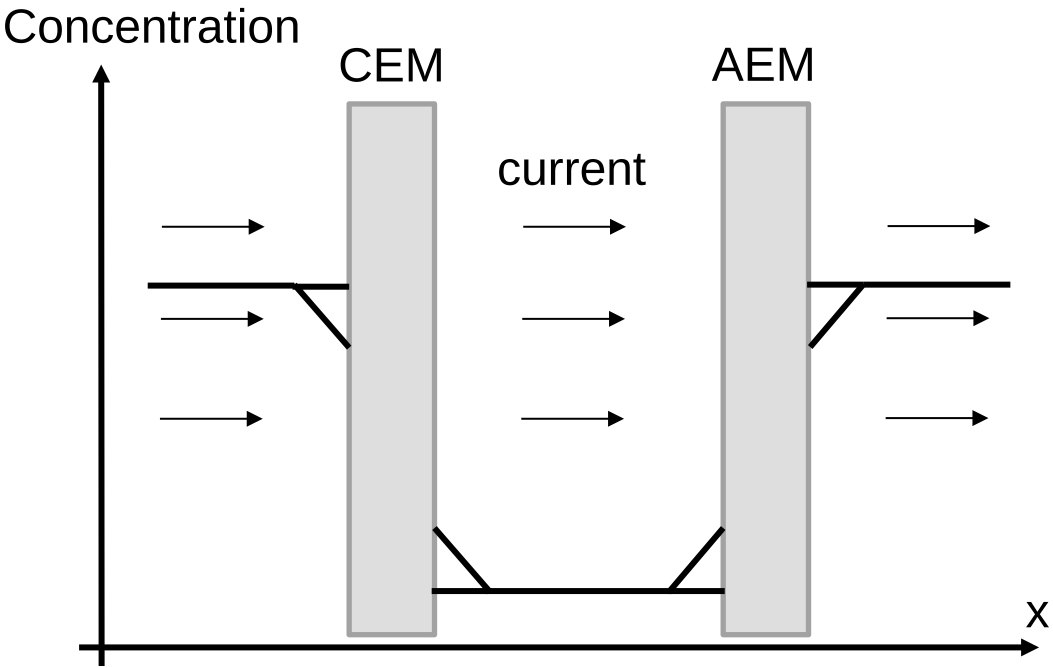
$$R_{stack} = R_{mem} + R_{solution} + R_{DBL} + R_{electrode}$$



Hong, J. G. B. Zhang, S. Glabman, N. Uzal, X. Dou, H. Zhang, X. Wei, and Y. S. Chen. J Membrane Sci, 486 (2015) 71-88; *Geise, G. M., A.J. Curtis, M.C. Hatzell, M.A. Hickner, B.E. Logan,, Environmental Science & Technology Letters, 1 (2013) 36-39.*

PRINCIPLE

Concentration Polarization

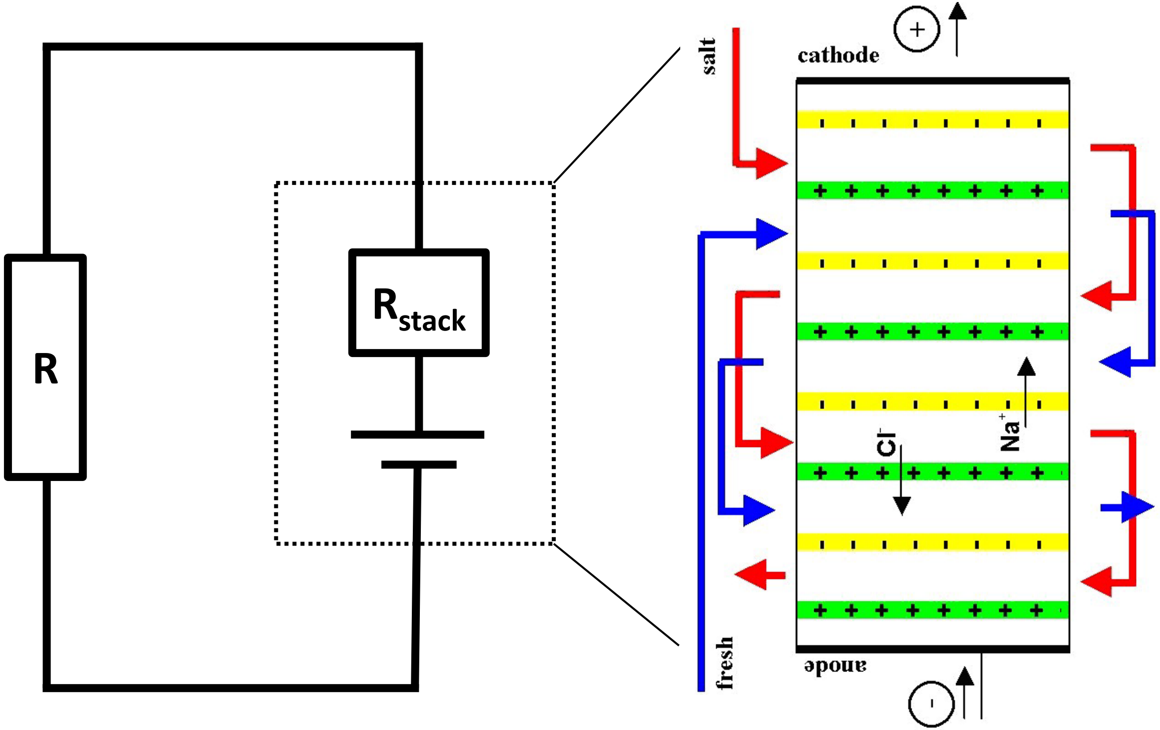


$$E_{stack} = \alpha \frac{RT}{nF} \ln \frac{a_c}{a_d}$$

$$R_{solution} = \int \frac{dx}{\kappa(c)}$$

PRINCIPLE

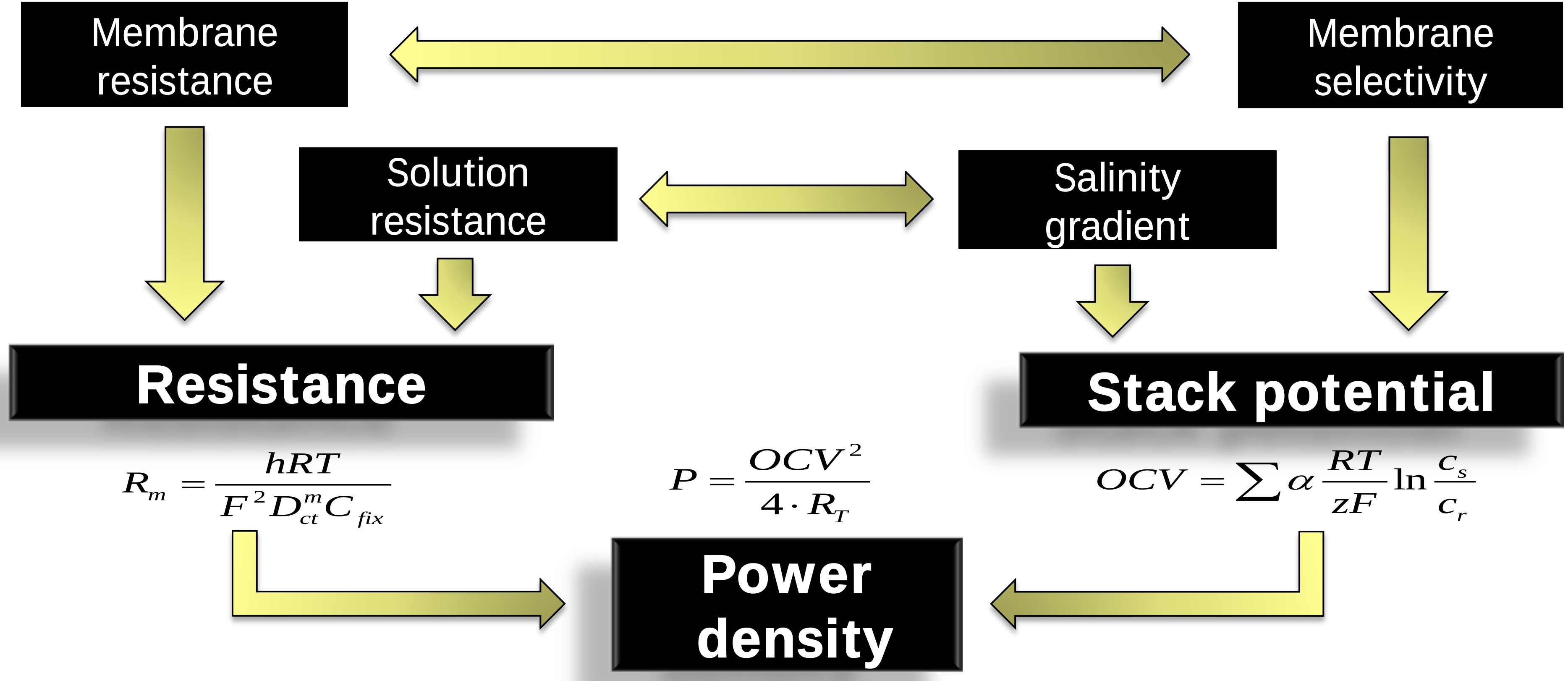
RED as a battery



$$E_{stack} = \alpha \frac{RT}{nF} \ln \frac{a_c}{a_d}$$

PRINCIPLE

Key factors



$$R_m = \frac{hRT}{F^2 D_{ct}^m C_{fix}}$$

$$P = \frac{OCV^2}{4 \cdot R_T}$$

$$OCV = \sum \alpha \frac{RT}{zF} \ln \frac{c_s}{c_r}$$

APPROACHES

Limitations

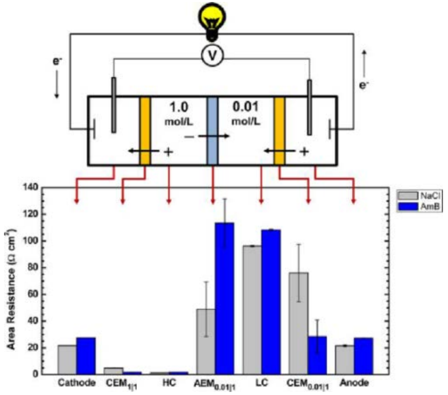
- Membrane performance
- Dilute compartment
- Concentration polarization

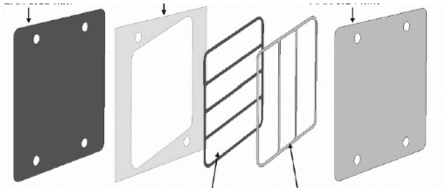
Solutions

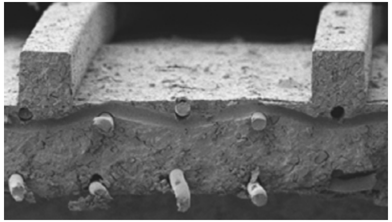
- Corrugated membrane
- Thinner compartment
- Stack without spacers

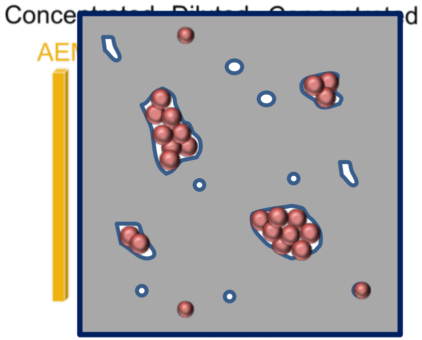
Other ideas?

- Nanocomposite membrane
- Resin in dilute compartments
- Ultra-thin membrane
- Integrated unit



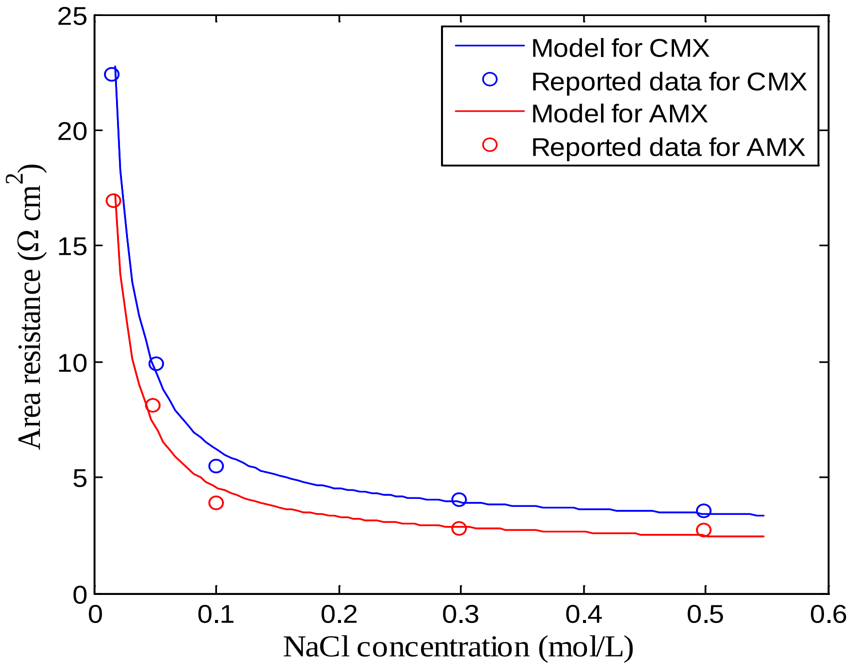






Nagase, K., J. Kobayashi, T. Okano. 2009. J. R. Soc. Interface, 6(suppl. 3) ; *Geise, G. M., A.J. Curtis, M.C. Hatzell, M.A. Hickner, B.E. Logan,, Environmental Science & Technology Letters, 1 (2013) 36-39; Dlugolecki, P., J. Dabrowska, K. Nijmeijer, M. Wessling, J Membrane Sci, 347 (2010) 101-107.*

Measurement of membrane resistance (DC current)



Data from Dlugolecki et al. (2008)

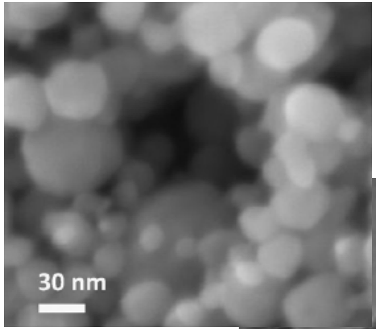
$$R_E = \left(\frac{\delta}{r \cdot \Lambda} \ln \frac{1+r}{1-r} \right) \cdot \frac{1}{C_0} + \frac{hRT}{F^2 D_{ct}^m C_{fix}}$$

$$r = \frac{i}{i_{\lim}}$$

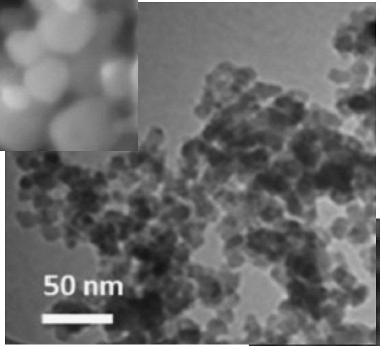
MEMBRANE SYNTHESIS

Nano-composite ion exchange membranes

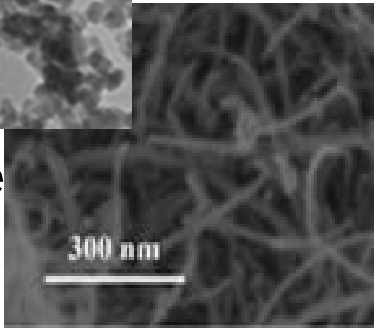
- Addition of inorganic filler particles with extra functionalized groups can tune the membrane structure and morphology, improve thermal, chemical, and mechanical properties of polymer matrix and retain stability
- Investigation of the effect of nanoparticle size and loading on membrane properties



Iron oxide



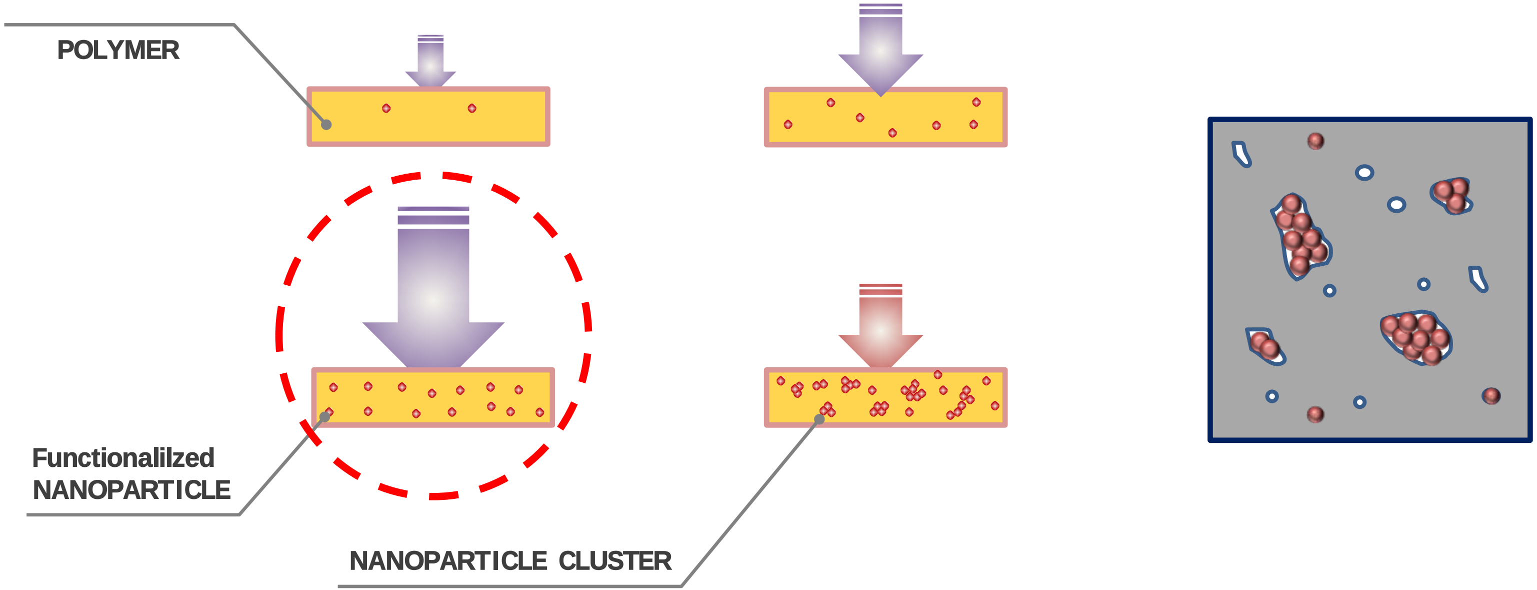
Silicon dioxide



Carbon nanotubes

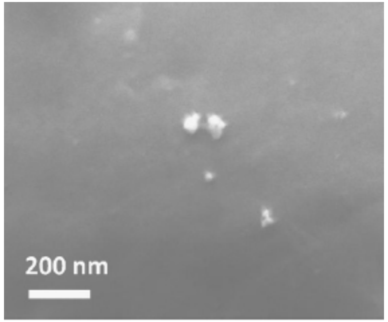
MEMBRANE SYNTHESIS

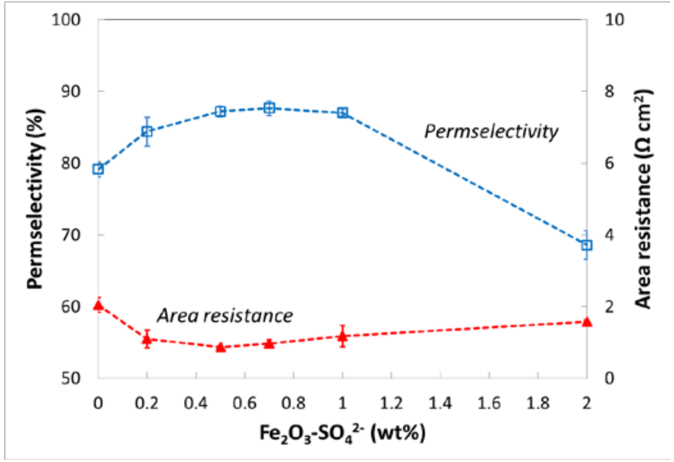
Nano-composite ion exchange membranes

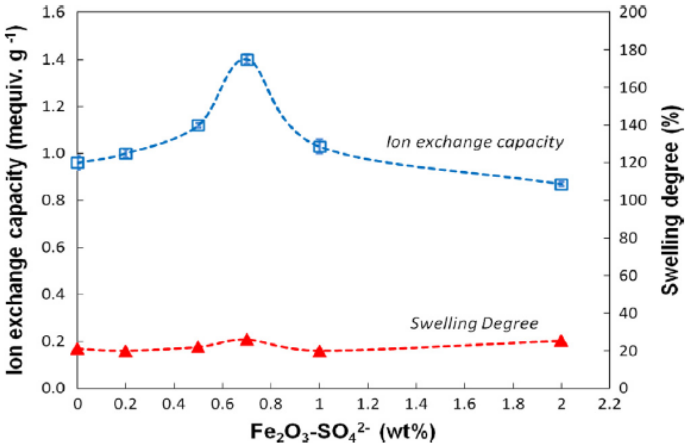


MEMBRANE SYNTHESIS

Sulfonated iron oxide





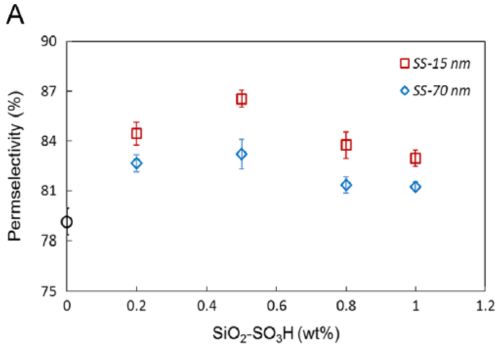


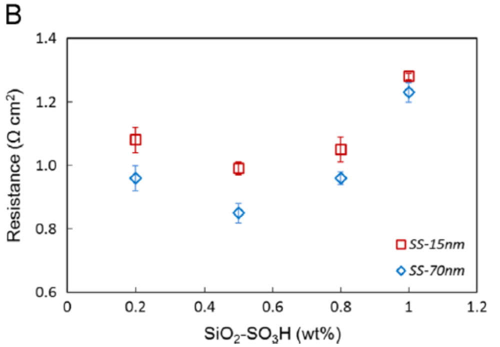
✓ Best performed key electrochemical properties at 0.5–0.7 wt% Fe_2O_3-SO_4^{2-}

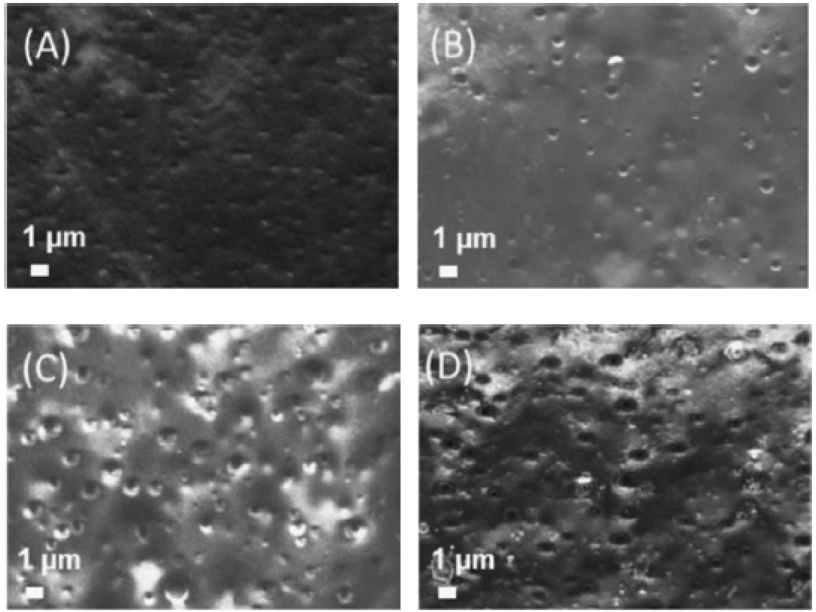
Hong, J. G. and Y. S. Chen. 2014. J Membrane Sci, 460 (2014) 139-147.

MEMBRANE SYNTHESIS

Sulfonated silicon dioxide





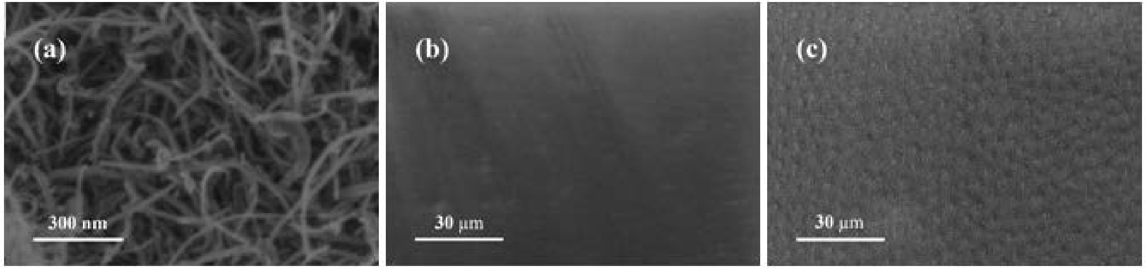


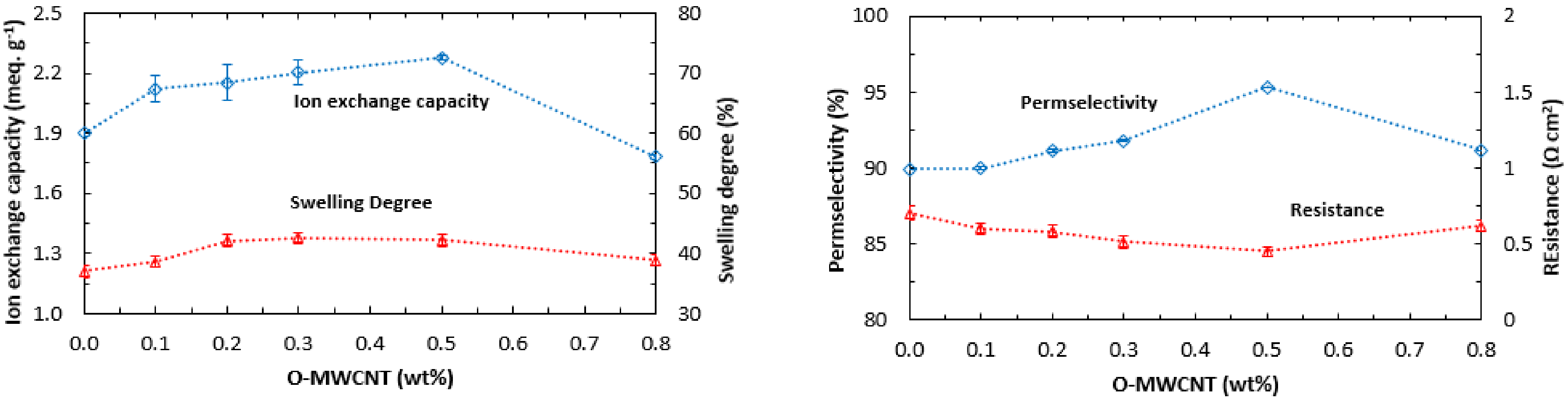
✓ Best performed key electrochemical properties at 0.5wt% SiO_2-SO_4^{2-}

Hong, J. G., S. Glabman, Y.S. Chen. J. Membrane Science. 2015, 482: 33-41

MEMBRANE SYNTHESIS

Sulfonated multi-wall carbon nano tubes

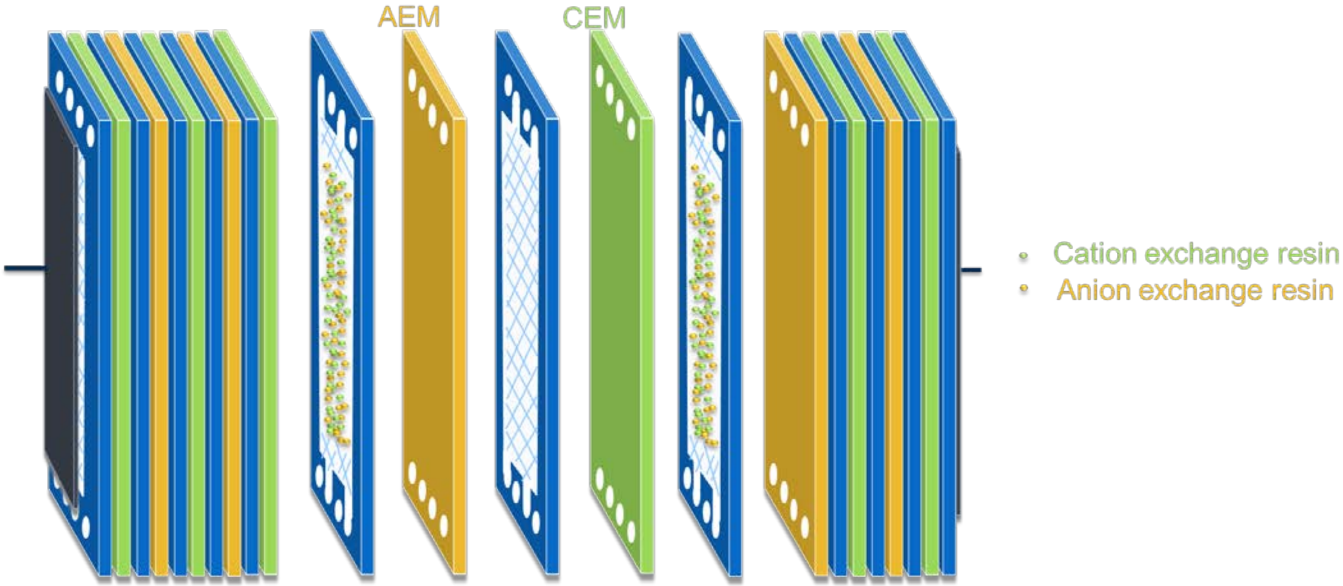




To be submitted to Journal of Membrane Science

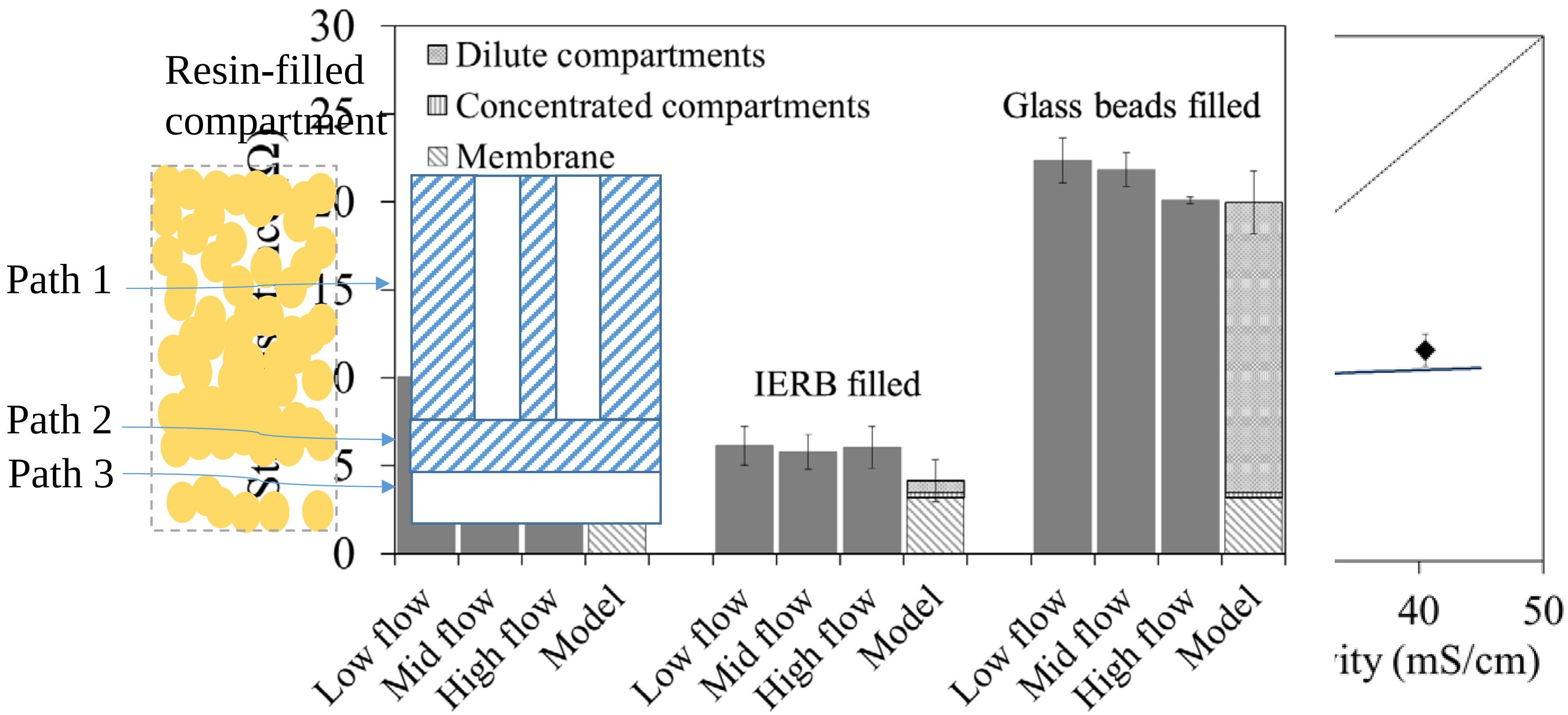
SYSTEM OPTIMIZATION

Ion exchange resin beads in an RED stack



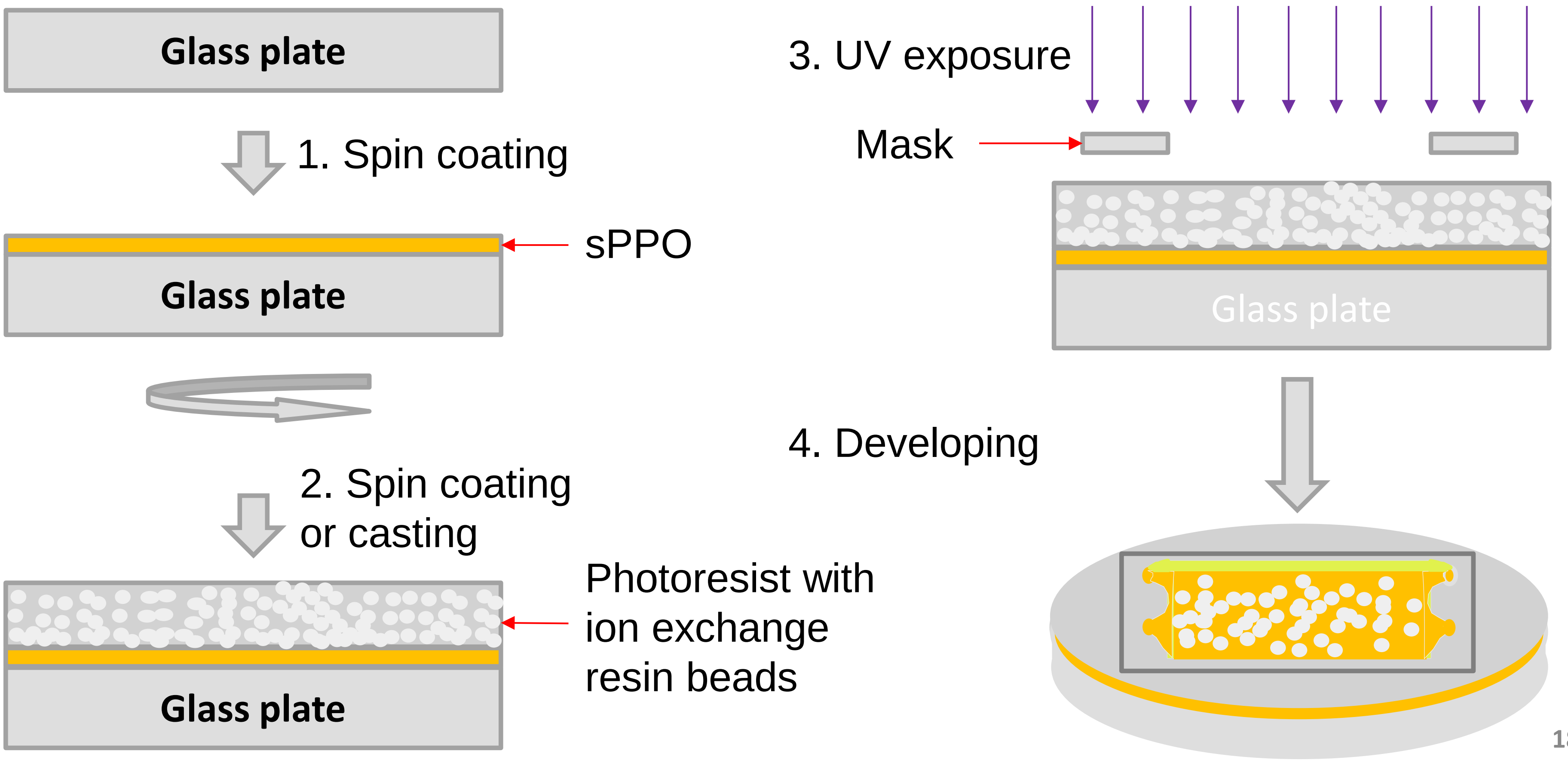
Submitted to Environmental Science and Technology Letters (under review); Patent disclosure submitted

SYSTEM OPTIMIZATION



Alvarado, L., A. Chen. Electrochimica Acta, 2014, 132: 583-597

SYSTEM OPTIMIZATION



SUMMARY

- Nanoparticle fillers can enhance cation exchange membrane performance;
- Addition of resin beads into the dilute compartments can improve the stack conductivity, therefore, enhance the stack power performance;
- Thinner membranes could be a potential solutions to RED applications based on model simulation

ACKNOWLEDGEMENTS

National Science Foundation
WHERE DISCOVERIES BEGIN

Litree Company

Questions & Answers