Research group Membrane Materials and Processes

Towards Bottom-up Engineered Electrodes for Redox Flow Batteries

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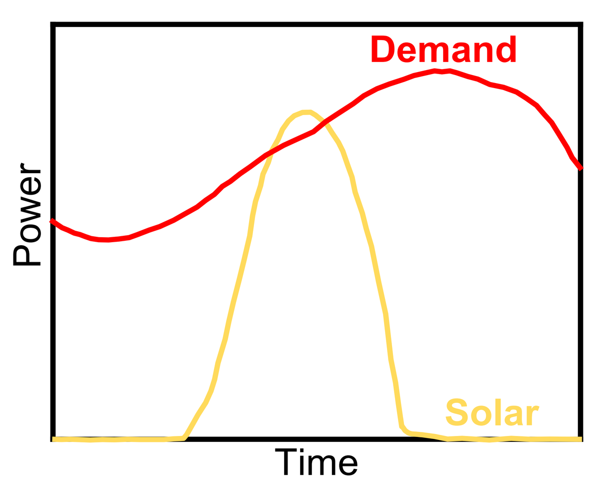
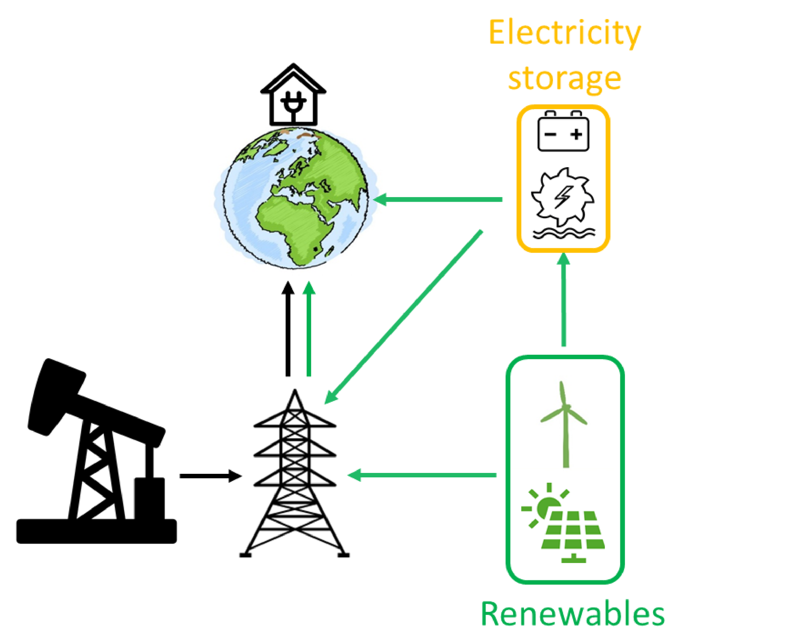
Need for large-scale energy storage

Renewable energy technologies are **intermittent** and unpredictable, and their integration motivates the need for **large-scale energy storage**.



Temporal mismatch between solar power generation and consumer demand

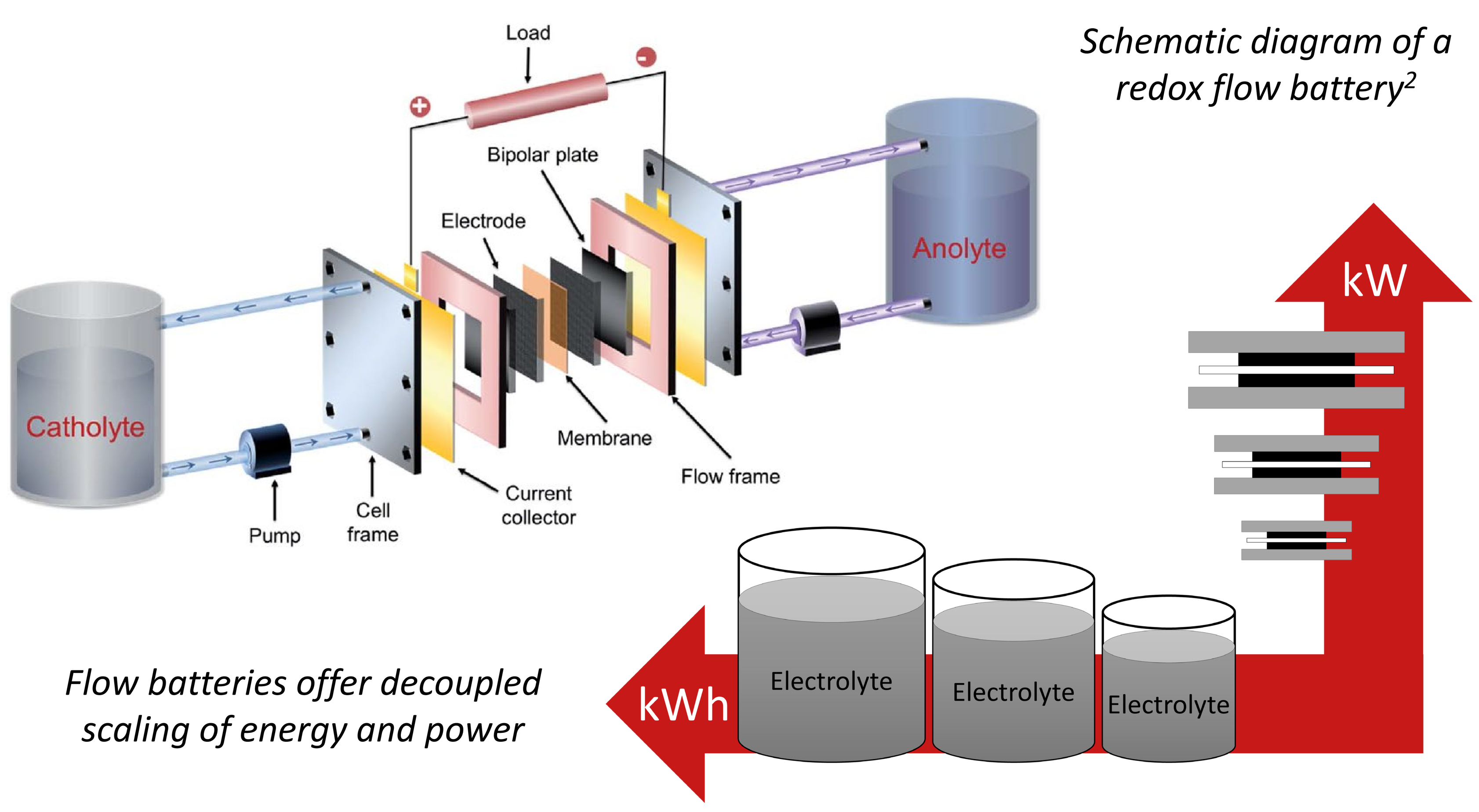


Implementation of intermittent energy sources requires new large scale energy storage systems

Redox flow batteries (RFBs)

RFBs are **rechargeable** electrochemical reactors that are promising for **grid storage** due to decoupling of energy (tank size) and power (reactor size), creating **upscaling** possibilities[1].

Schematic diagram of a redox flow battery[2]

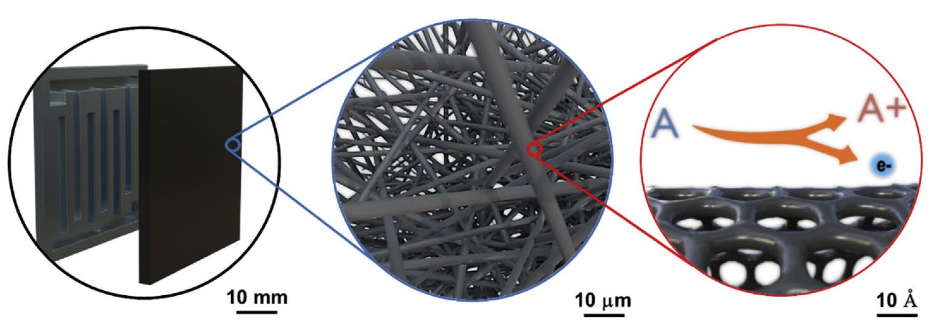


Flow batteries offer decoupled scaling of energy and power

Current **elevated cost** (i.e. >$500/kWh)[3] hinders widespread implementation. Increasing power density would result in cost reduction.

Electrodes play a central role

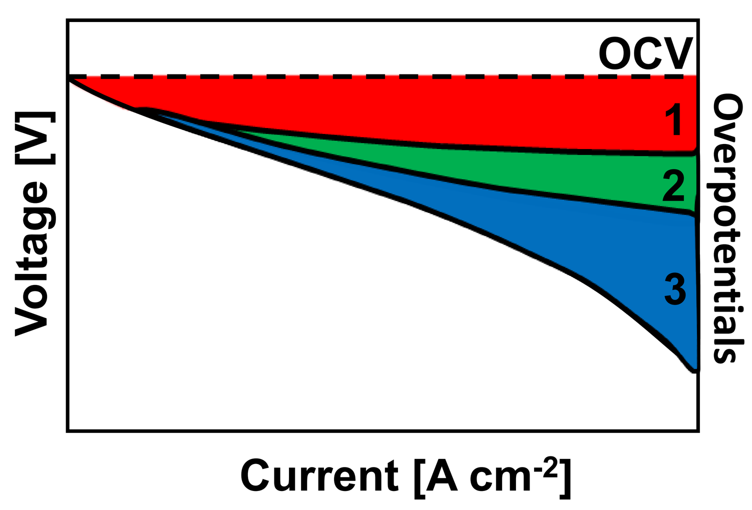
Porous electrodes need to fulfil several performance-relevant functions, e.g. provide surface area for electrochemical reactions, distribute liquid electrolytes, conduct electrons, and cushion mechanical stresses.



Optimization of electrode microstructure necessitates understanding at multiple length-scales[4]

<u>Key properties:</u>

- Surface area ↑
- Pressure drop ↓
- Mass transport ↑
- Mechanical properties ↑

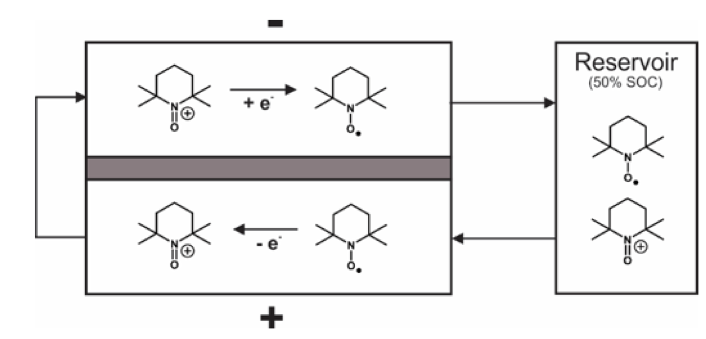


Discharge polarization curve

1. Activation losses
2. Ohmic losses
3. Mass transport losses

Microstructure-performance relationship

Electrode microstructure impacts mass transfer resistance and electrochemical performance. Hierarchically-organized electrodes provide low pressure drop and improved power density.



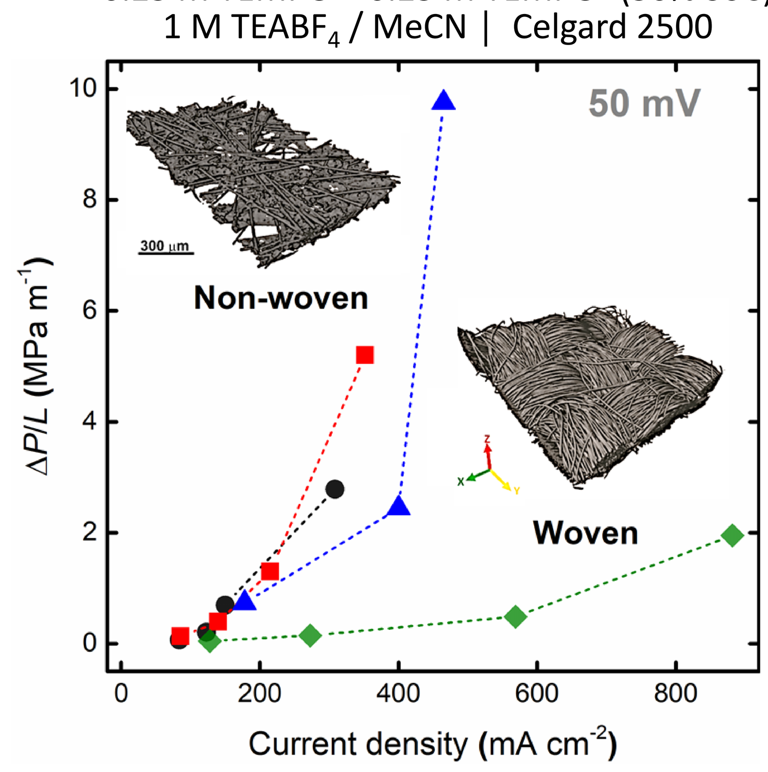
Electrochemical characterization of electrodes using single cell electrolyte[4]

Darcy-Forchheimer equation -

$$-\frac{dP}{dX} = \frac{\mu}{k} v + \beta \rho v^2$$

k = permeability
β = Forchheimer coefficient

0.25 M TEMPO + 0.25 M $TEMPO^+$ (50% SoC)
1 M $TEABF_4$ / MeCN | Celgard 2500

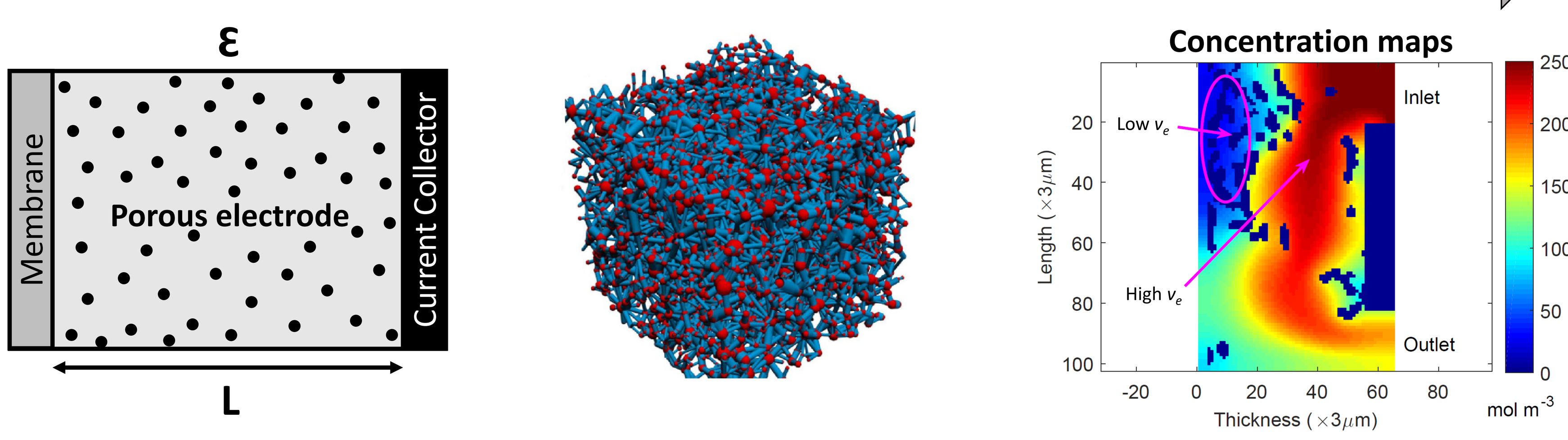


Normalized pressure drop versus current density for different electrode microstructures[5]

Computer-aided design

Multiphysics simulations are used to understand the influence of the electrode architecture. We use this knowledge to design new materials with reduced overpotentials.

Level of complexity and detail

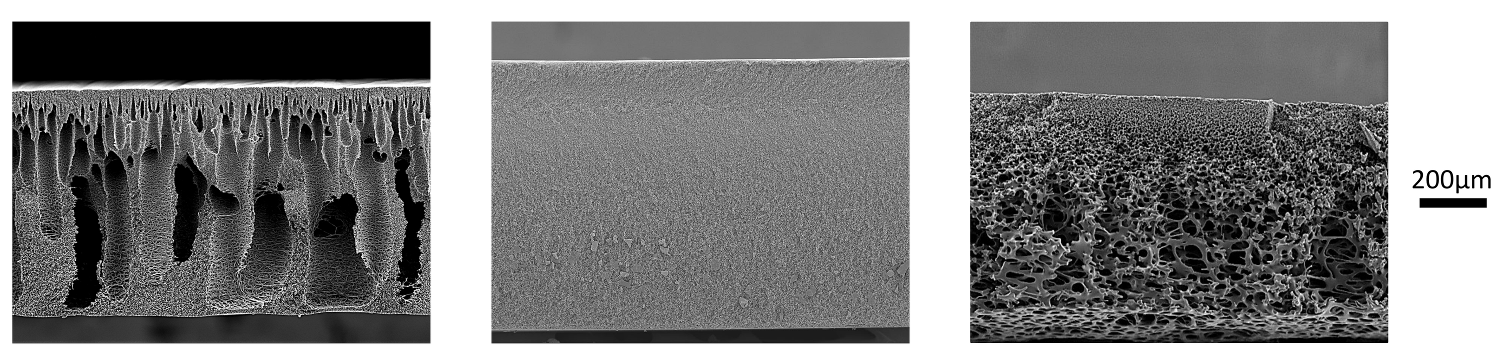


1D - Macroporous | 3D - Pore Network Model[6] | 3D - Lattice Boltzmann[7]

Novel synthetic methods

We develop **scalable methods** to synthesize highly-controlled electrode microstructures (e.g. porosity gradients).

Level of morphological control



Scanning electron micrographs for different in-house prepared porous electrodes.

References

[1] S. Shin *et al.*, *RSC Adv.* 3, 9095 (2013)
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[3] K. Mongird et al,. *PNNL report*, nº 28866 (2019)
[4] A. Forner-Cuenca *et al.*, *Curr. Opin. Electrochem.* 10.1016/j.coelec.2019.11.002 (2019)
[5] A. Forner-Cuenca *et al.*, *J. Electrochem. Soc.* 166 (10), A2230 (2019)
[6] J.T. Gostick, *Phys. Rev.* 96, 023307 (2017)
[7] D. Zhang *et al.*, *J. Power Sources* 447, 227249 (2020)

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