40 Year VFB Anniversary Symposium

Current Flow Battery Research at UNSW

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ARC Research Hub for Integrated Energy Storage Solutions

NORTH HARBOUR CLEAN ENERGY

RioTinto

ENELEST

Australia – New Zealand FLOW BATTERY NETWORK

Trailblazer Recycling & Clean Energy

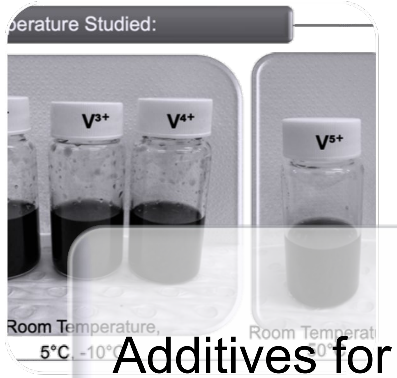
Overview

- Electrolyte studies
- Lab scale cells
- Scale up
- Dynamic Modelling
- Monitoring and Control

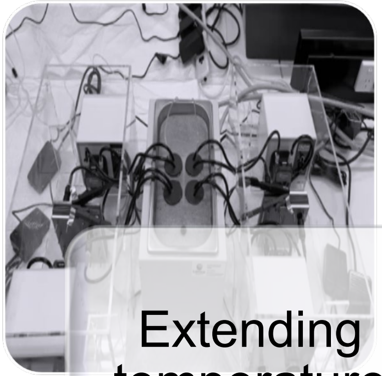
Electrolyte study focus areas

Methods for electrolyte production

Analysis of impurities and their effects



Additives for stability and enhancement

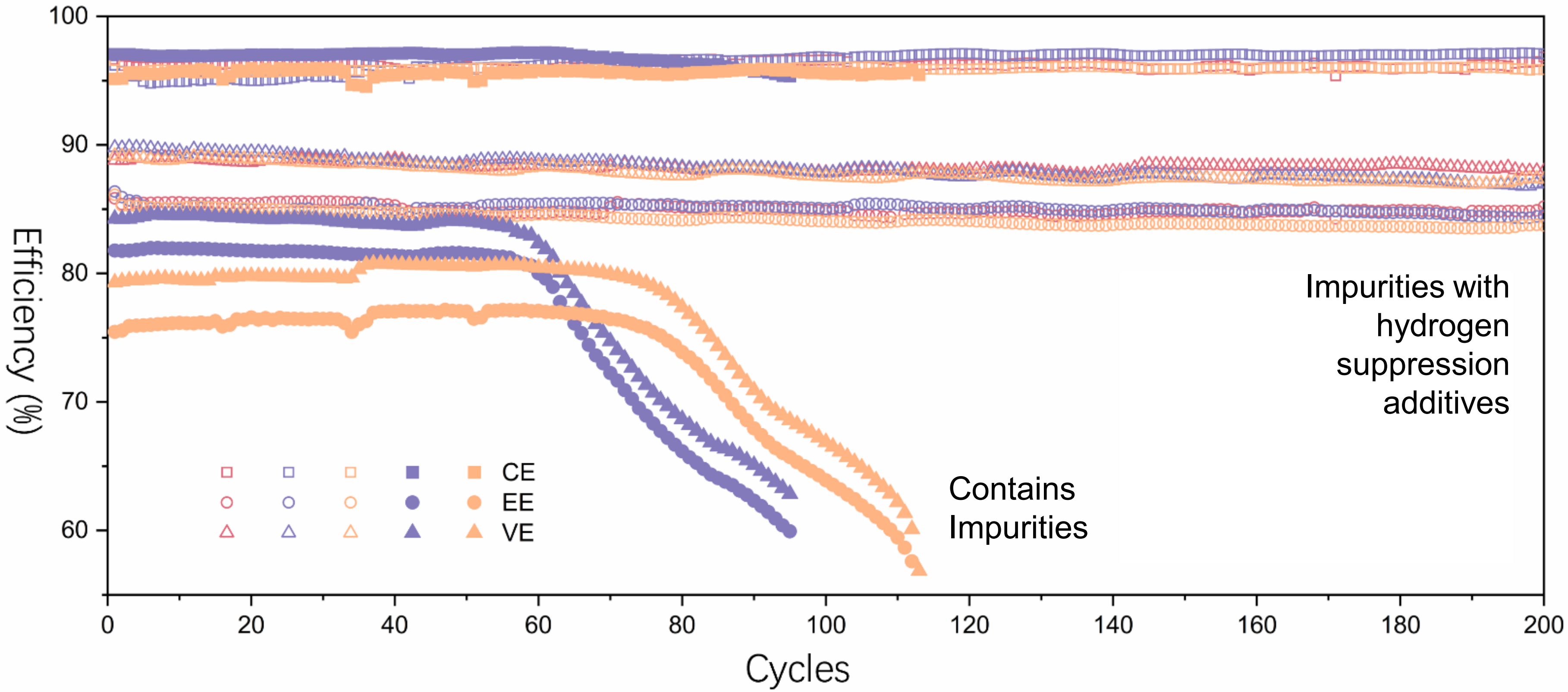


Extending temperature operating limits

Operational stability

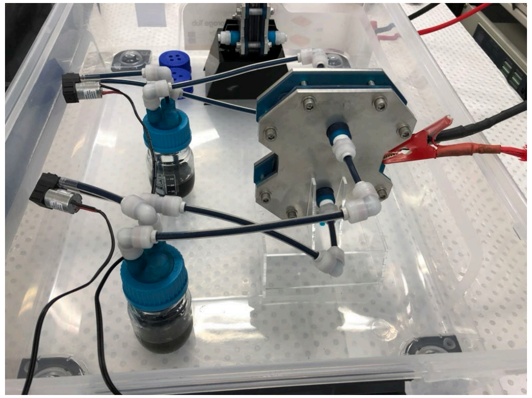
Long term stability

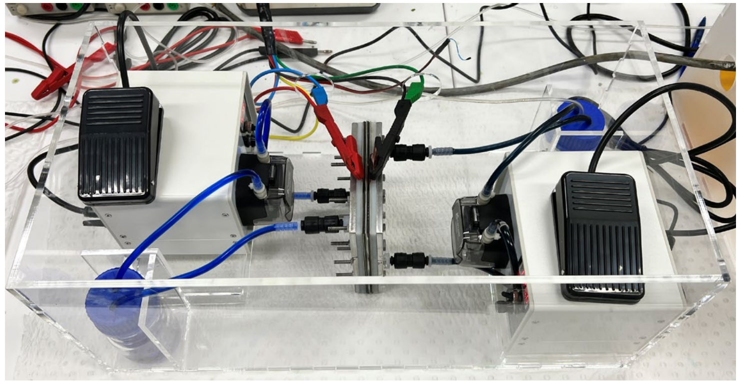
- Maintain capacity performance
- Effect of impurities
- Additives for improved performance
- Charging limits
- Hydrogen suppression
- Reduce capacity fade



Lab scale cells

- Active cell area 25cm^2
- Conducting plastic electrode advances
- Membrane evaluation
- Design improvements
- Lower resistance and pressure drop
- Higher overall improved performance and stability





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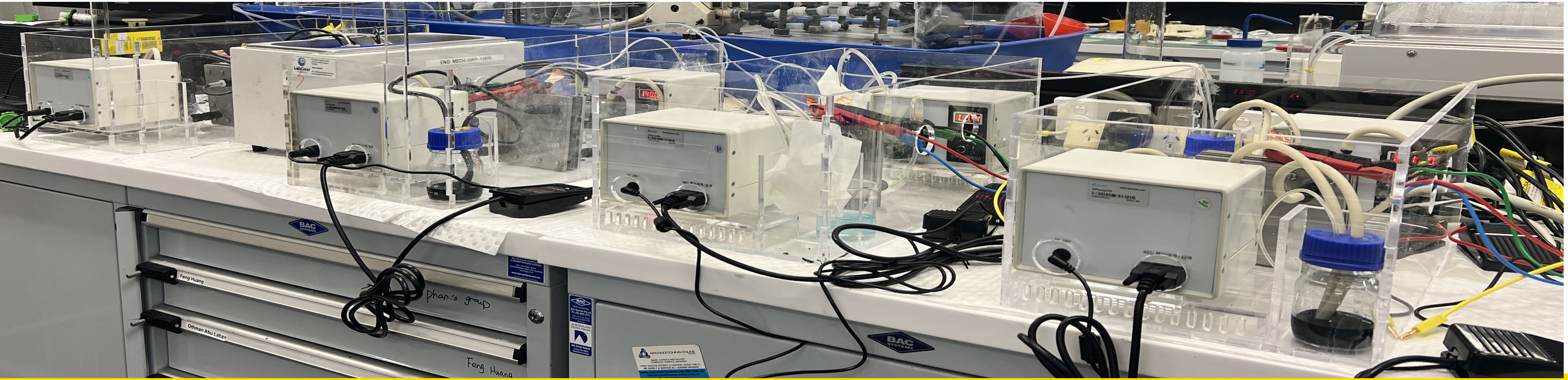

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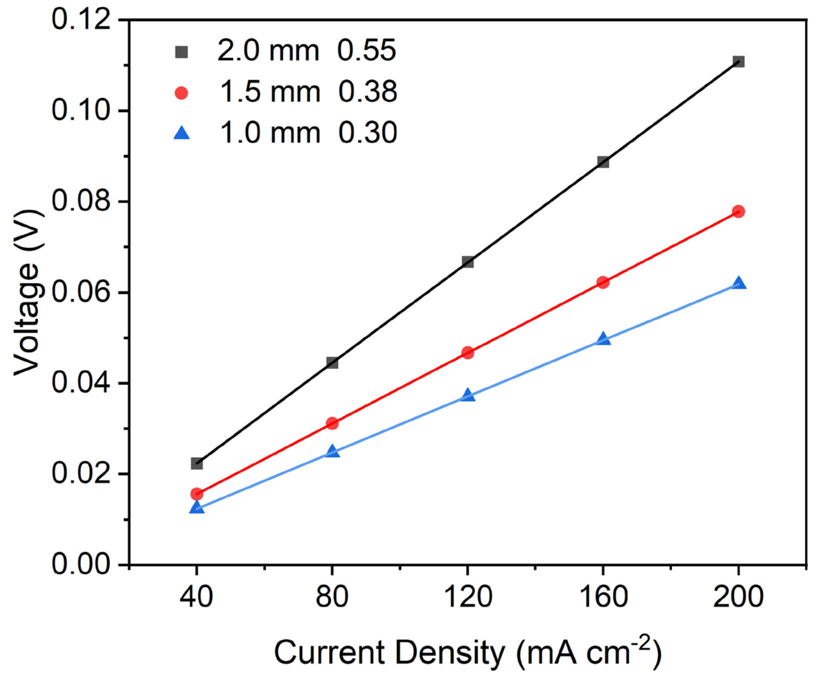
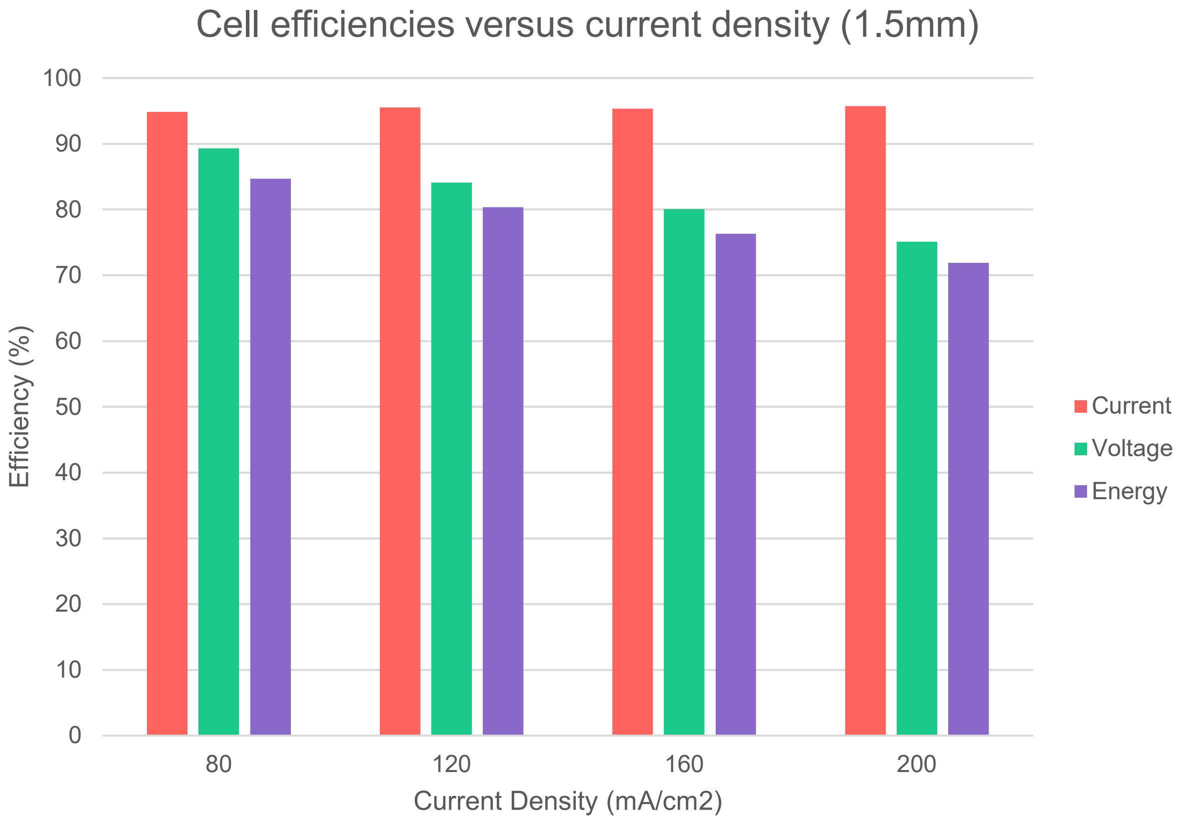
Lab scale cells

Performance

Dry cell resistivity (Ω cm^2)
(excludes membrane)





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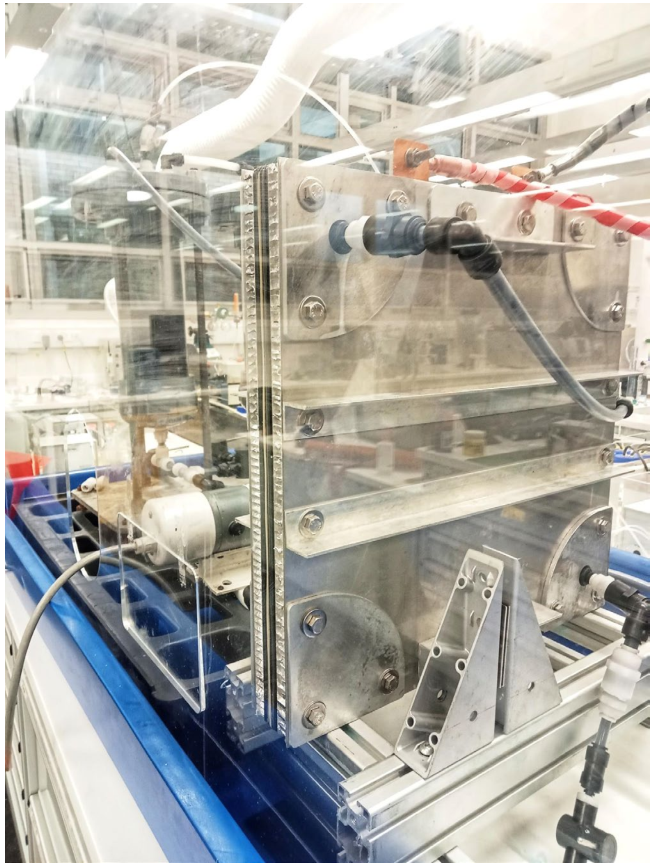
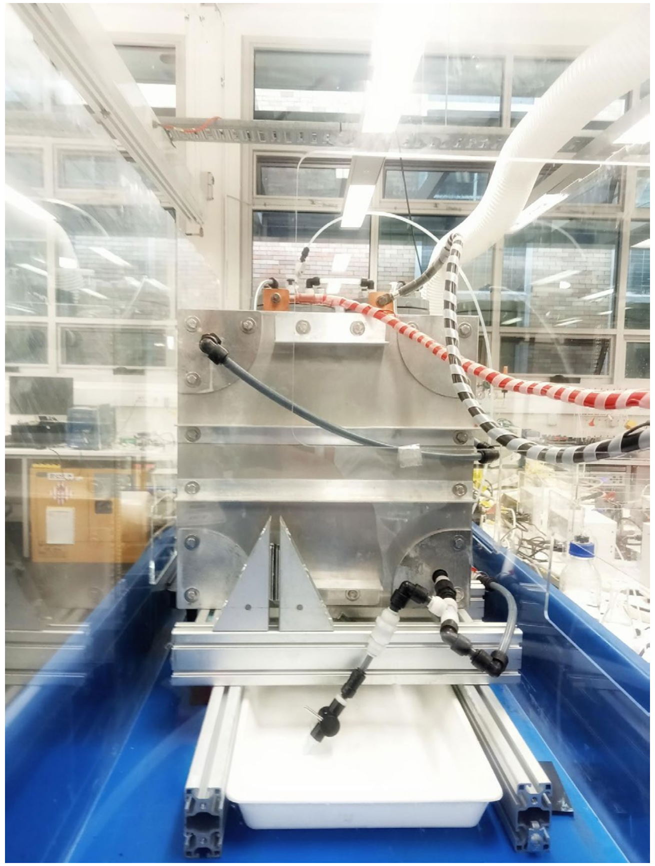
Scale up - 1000cm^2 active area

Similar high performance as small-scale cell achieved during scale up

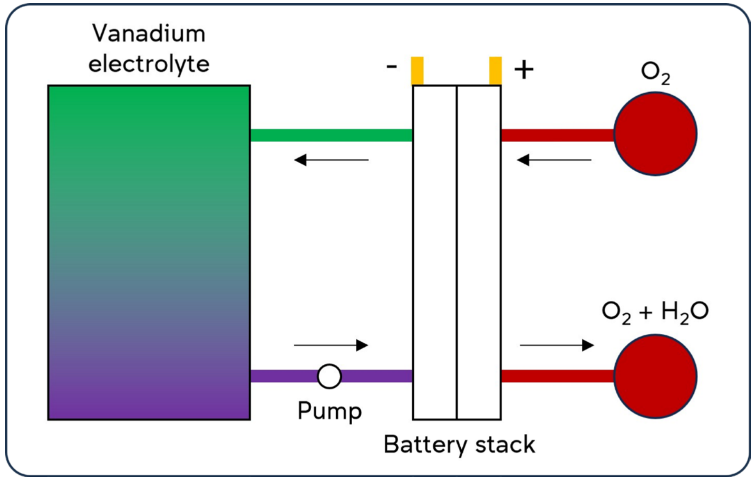


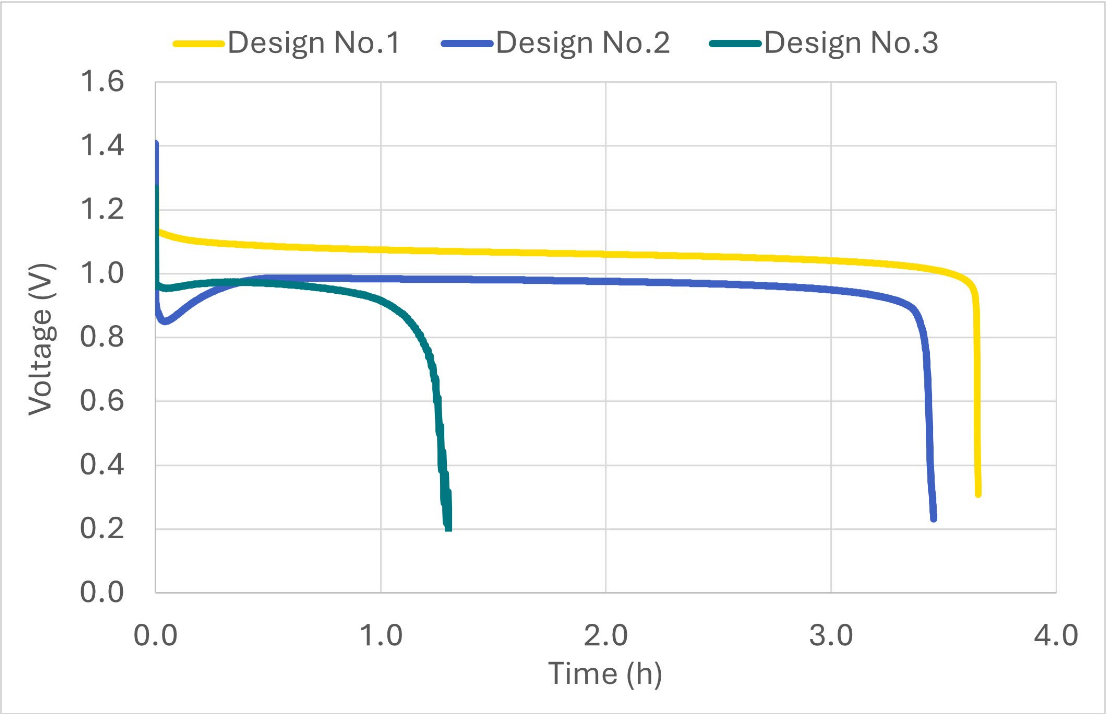


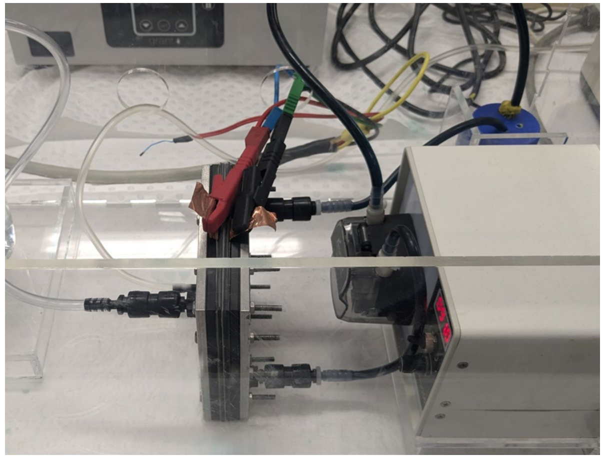
Vanadium Oxygen Fuel Cell

- VOFCs demonstrated at UNSW in mid 90s single and 5 cell stacks.
- Positive VFB half cell replaced by the oxygen reduction reaction
- Up to 4 times the energy density of the conventional VFB

- Currently 85% capacity utilization has been achieved
- Current work focusing on:
  - Cell design and gas distribution
  - Membranes
  - Catalysts
  - Recharging







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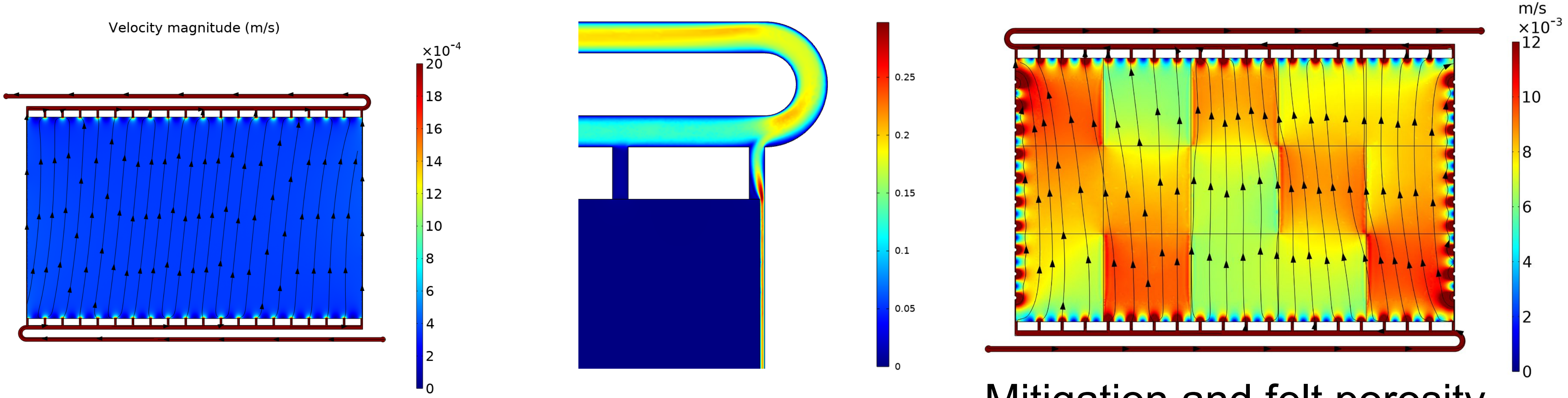
Numerical Modelling for VFB and other chemistries
(eg organics and Iron flow)

Cell level modelling



Modelling issues of felt tolerance

Mitigation and felt porosity variation modelling

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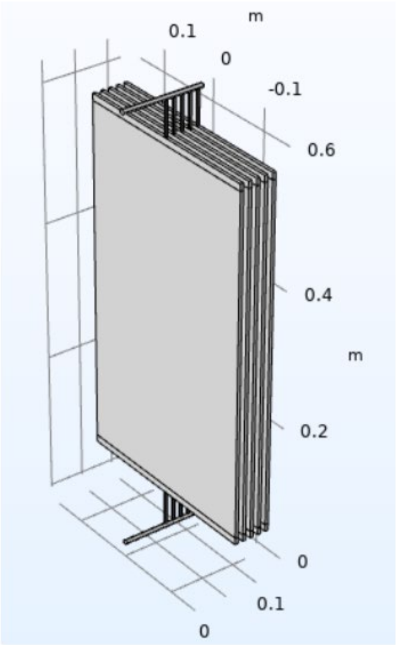
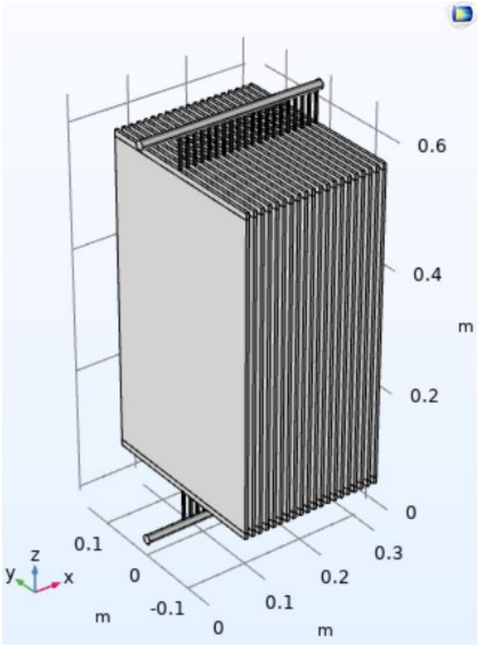
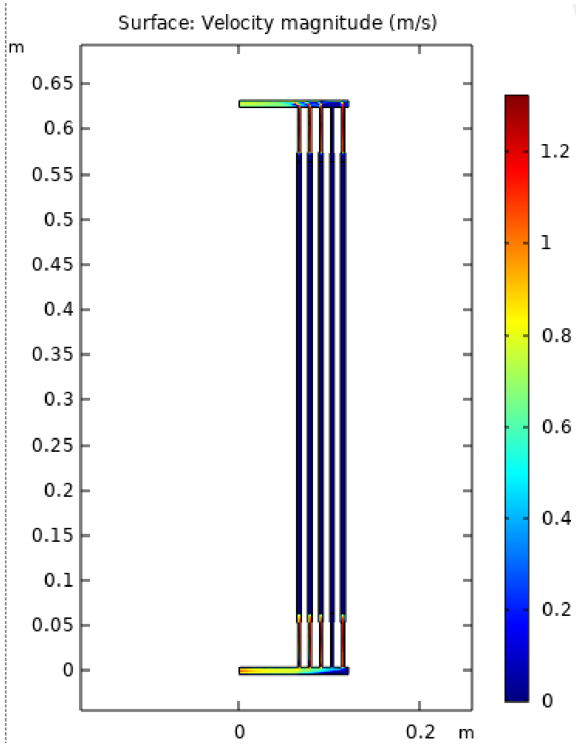
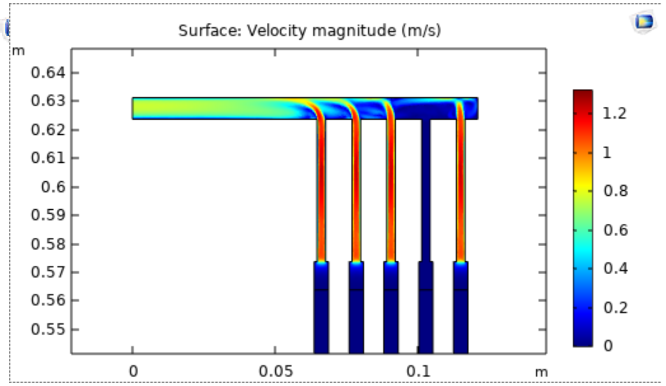
Numerical Modelling of cell designs and for VFB and other chemistries
(eg organics and Iron flow)

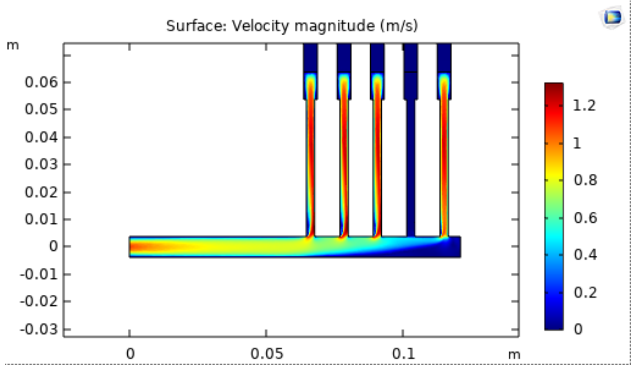
Stack level modelling





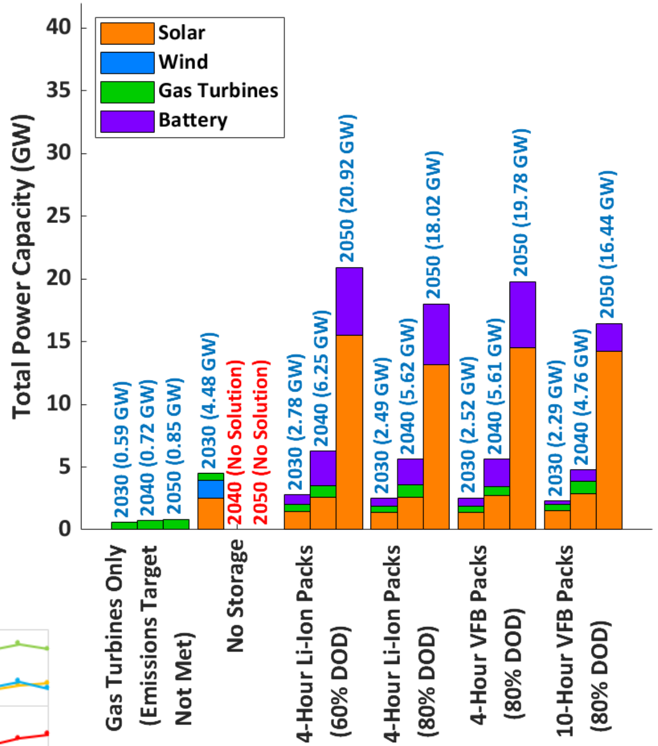






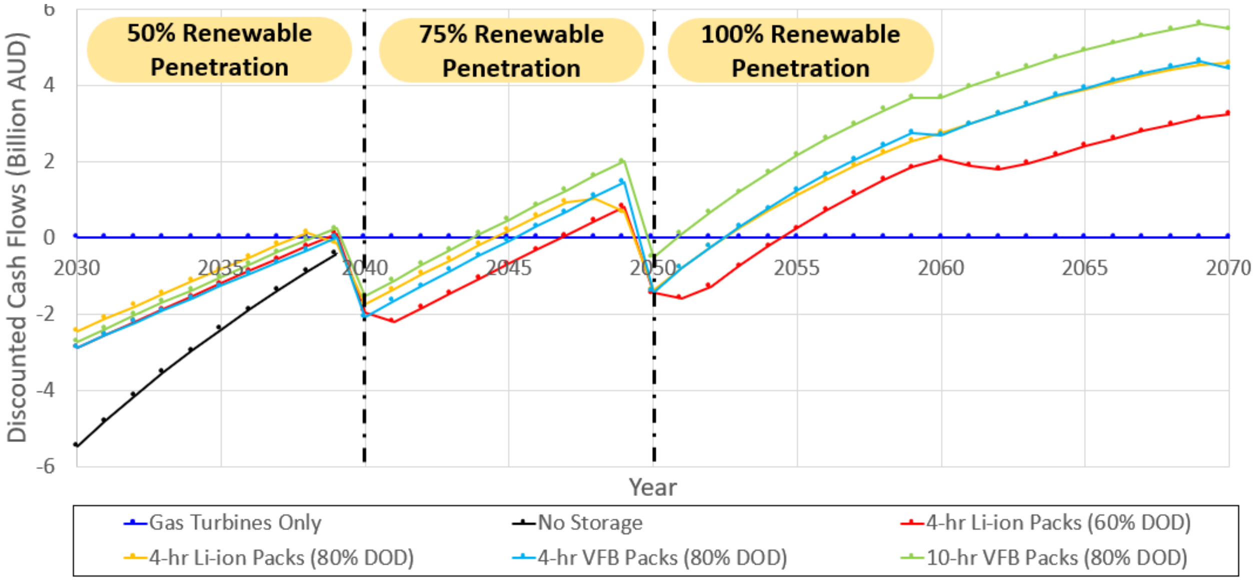
Technoeconomic modelling

Powering remote installations



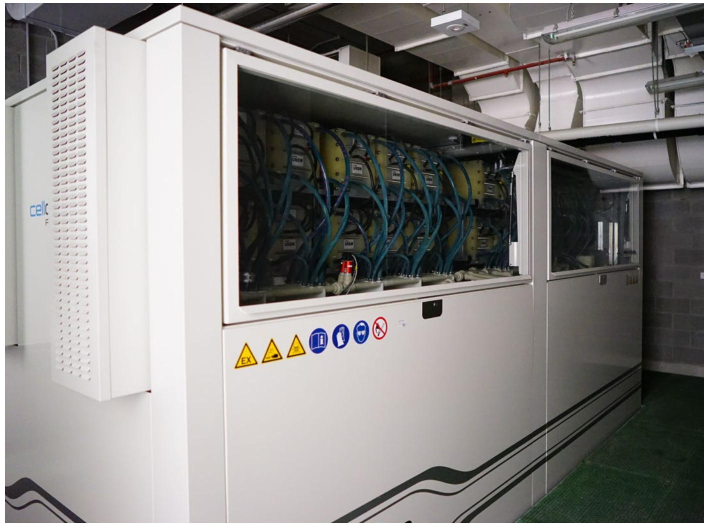
Costs considered inc:

- Capital and maintenance
- Carbon emissions prices
- Value of generated energy



Current Research @ UNSW

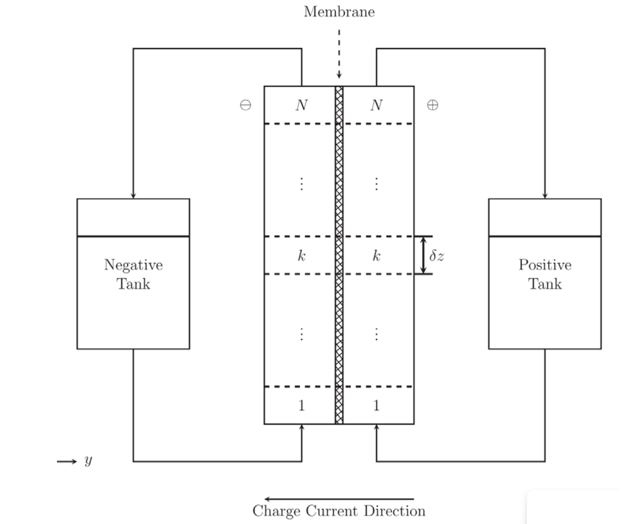
Modelling and Control of Vanadium Flow Batteries

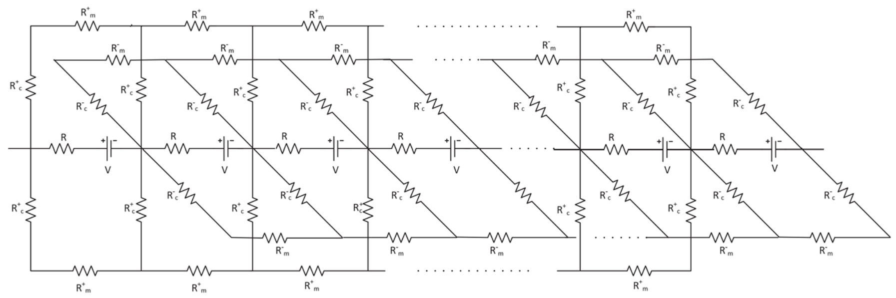


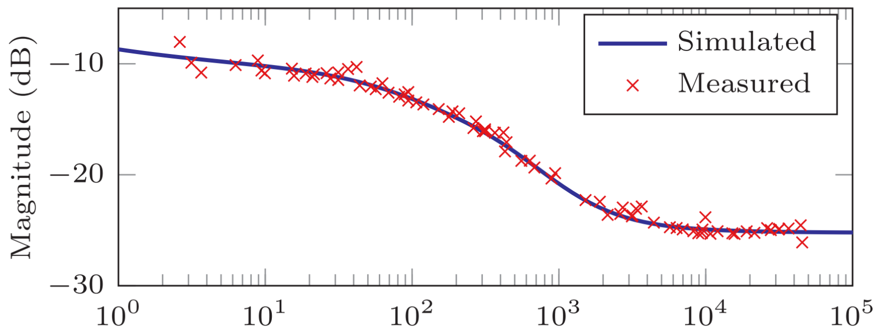
Dynamic Modelling of VFBs

For online monitoring and control purposes

- Captures key dynamics of flow batteries
- Dynamic plug flow models (Li et al 2015)
- Modelling the reaction/side reactions and ion diffusion during charging/discharging and standby (self-discharge) (Tang et al 2011, 2012)
- Online SOC imbalance monitoring (Li et al 2021)
    - A procedure for membrane permeability estimation
- Shunt current (Tang et al 2013, Skyllas-Kazacos et al 2016)
- Battery impedance during charging / discharging operations (Li et al 2018) – Frequency Control Ancillary Services
- Electrical safety analysis (Shu et al 2024)

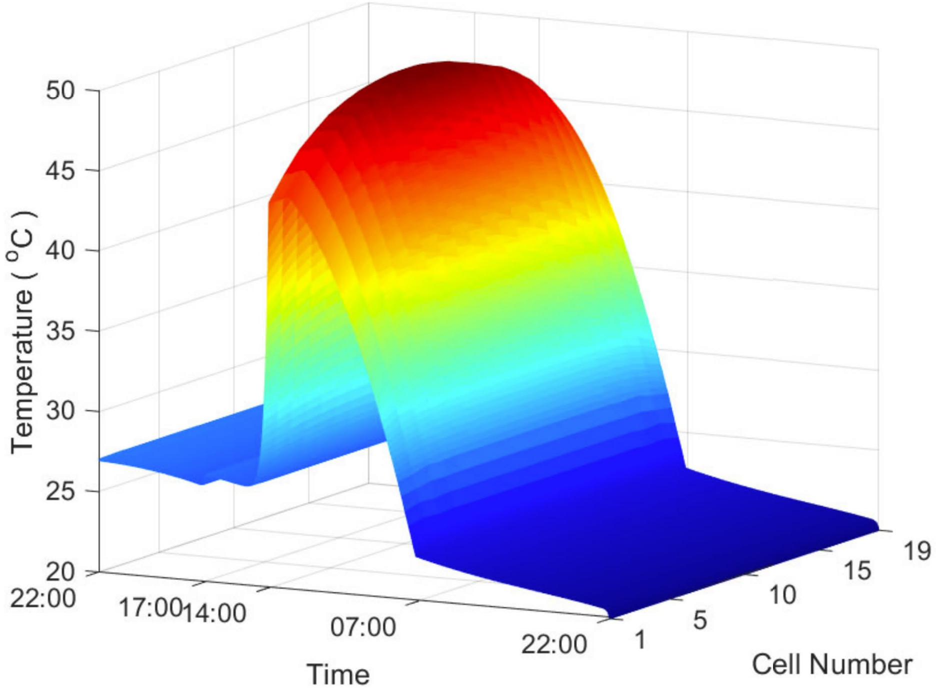






Dynamic Thermal Modelling of VFBs

- During charging/discharging and standby (Tang et al 2012)
- Multi-cell stacks (Yan et al 2016a, 2016b)
- Containerized VFBs (Shu et al 2023a, 2023b)
  - Design options for different operating environments
    - Passive / active cooling & heating / insulation



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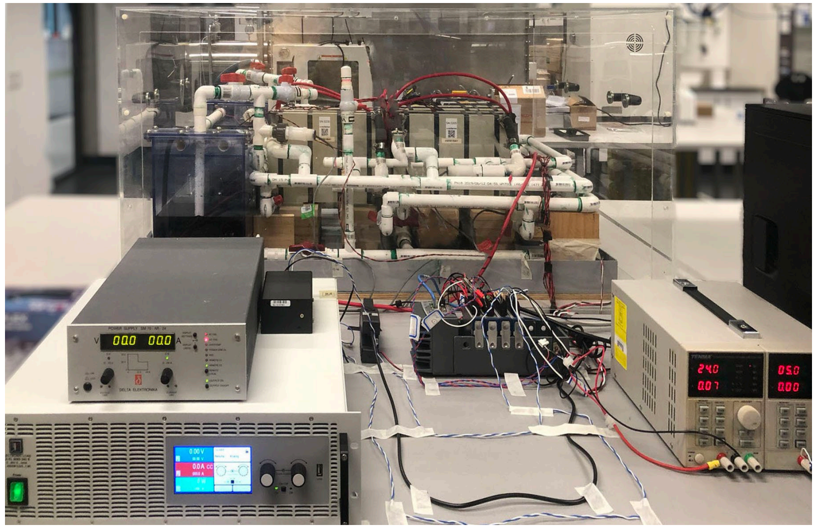
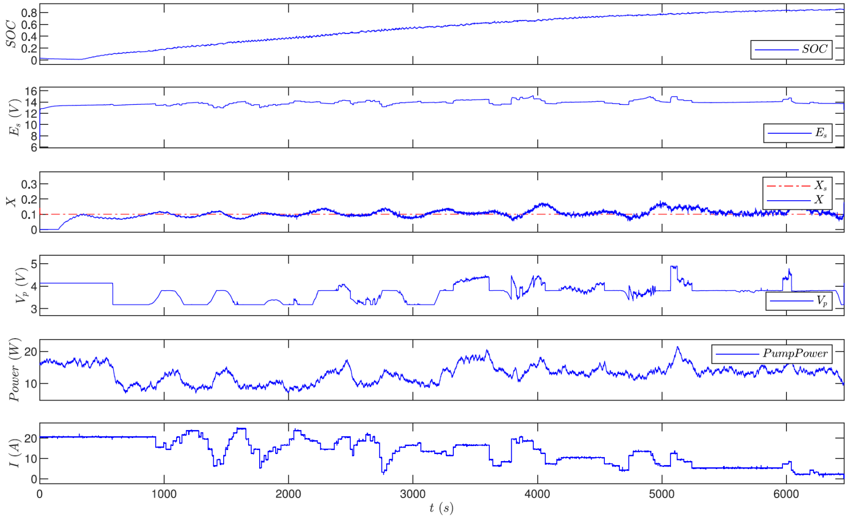
Real-time Control of VFB

Optimal Control of Flow Batteries

Intermittency of renewable energy sources - variable battery input and output power



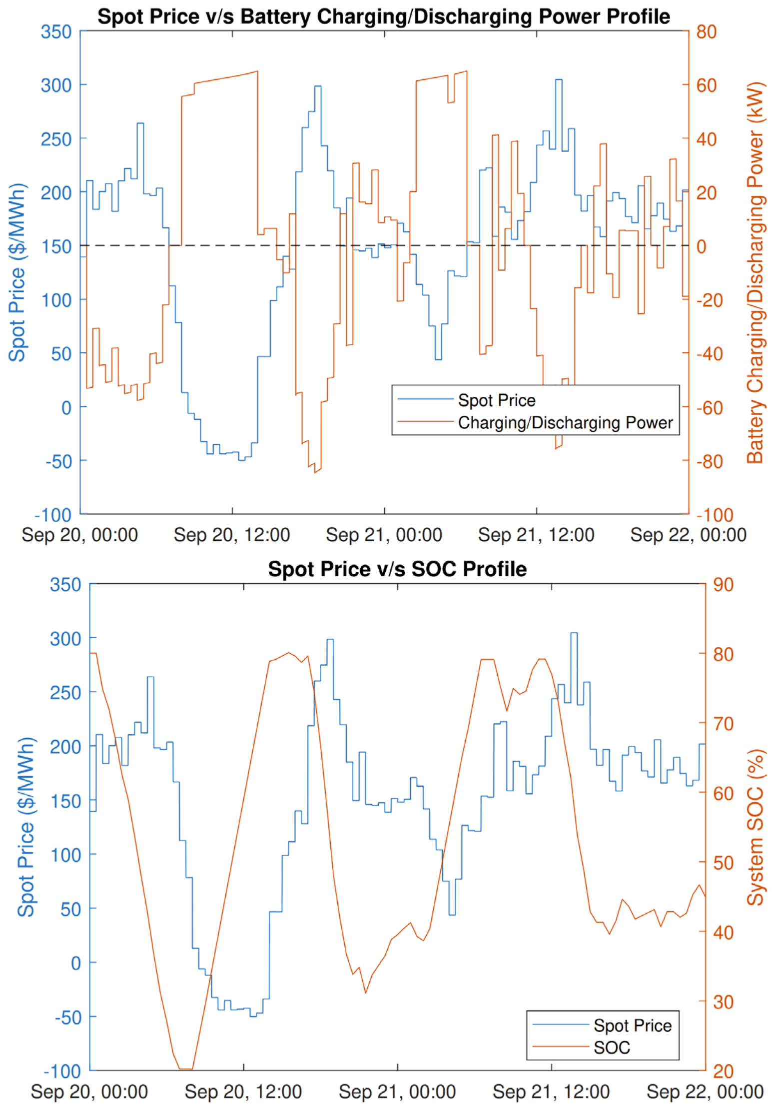
- Applications of modern control theory
- Model uncertainties, uncertain disturbances → model-based feedback control
- Dynamic VFB model: concentration overpotential; capacity loss; electrolyte imbalance; avoid gassing etc.
- Real-time control of battery operations for improved efficiency (Tang 2014; Li et al 2016);
  - Gain Scheduling (Li et al 2016, 2017);
  - Linear Parameter Varying framework (McCloy et al 2022)



Real-time Control of VFB

Real-time Optimal Control to Optimize Economic Benefit of Battery Operations

- Based on SOC, predicted future energy generation/ consumption /electricity price, etc.
- Power arbitrage
  - Real-time optimal control (e.g., charging /discharging current; flow rate) to maximize economic objectives
  - Economic model predictive control - real-time optimization over receding horizons to deal with errors of price prediction (Shail et al 2024)



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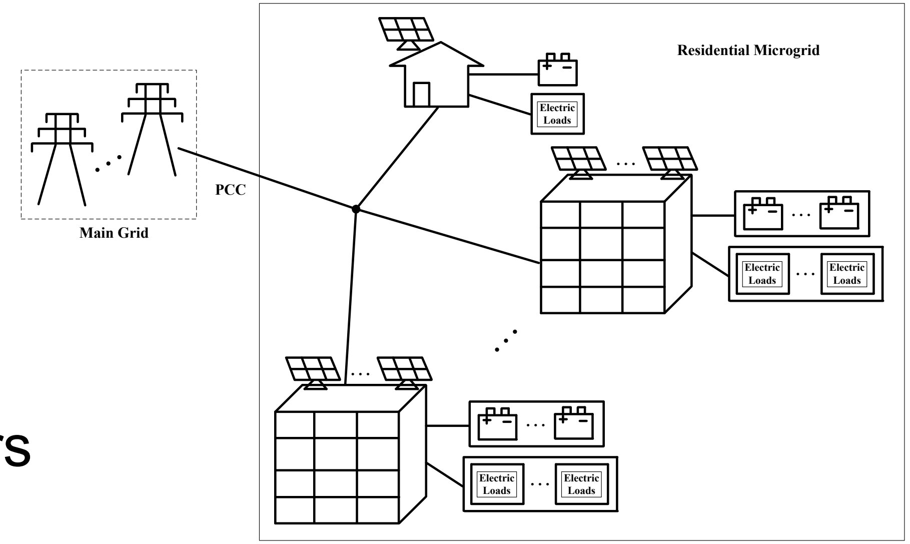
Battery Systems Integration and Coordination

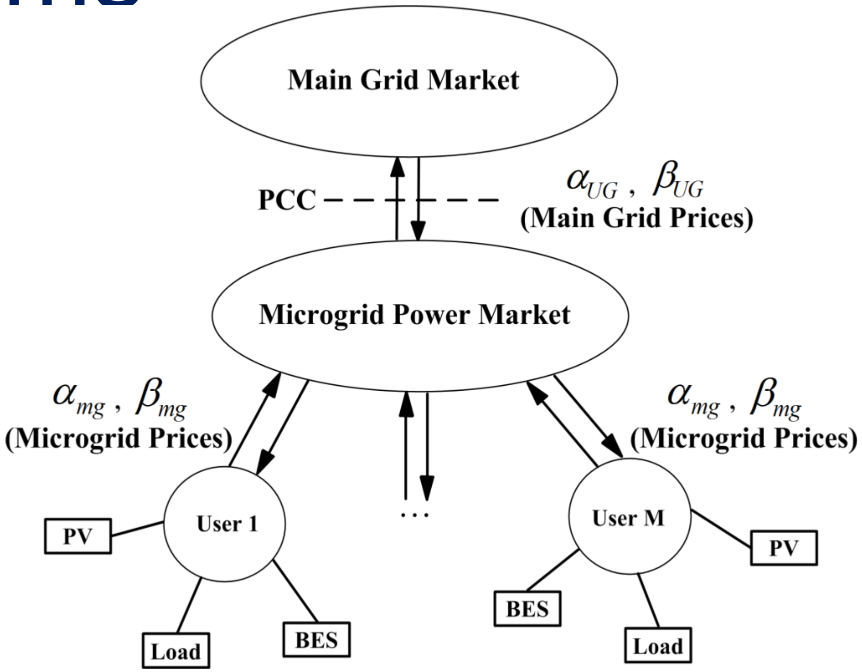
Coordination and control of geographically distributed battery energy storage systems

- Distributed control (using autonomous controllers with communications) to allow large scale implementation
- Optimizes the economic benefit of each user (owners of battery systems)
- Controllers are coordinated to reduce the dynamics (fluctuations) of the power flows in a microgrid – improving grid stability
- Taking into account predicted energy consumption, renewable energy generation and state of charge etc.



Distributed Energy Storage Systems

- Distributed economic model predictive control
- Power flow control for grid operations
- Dissipativity theory-based control algorithms for grid stability) (Zhang et al 2016, 2017a, 2017b, Wang et al 2017, 2018)
- Based on the dynamic VFB model
- Integrated with industrial scale demand-side power management (Wong et al 2023)
- Dealing with different energy storage systems and loads in the network



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Australian Government
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