Flow Batteries:
Design And Experience

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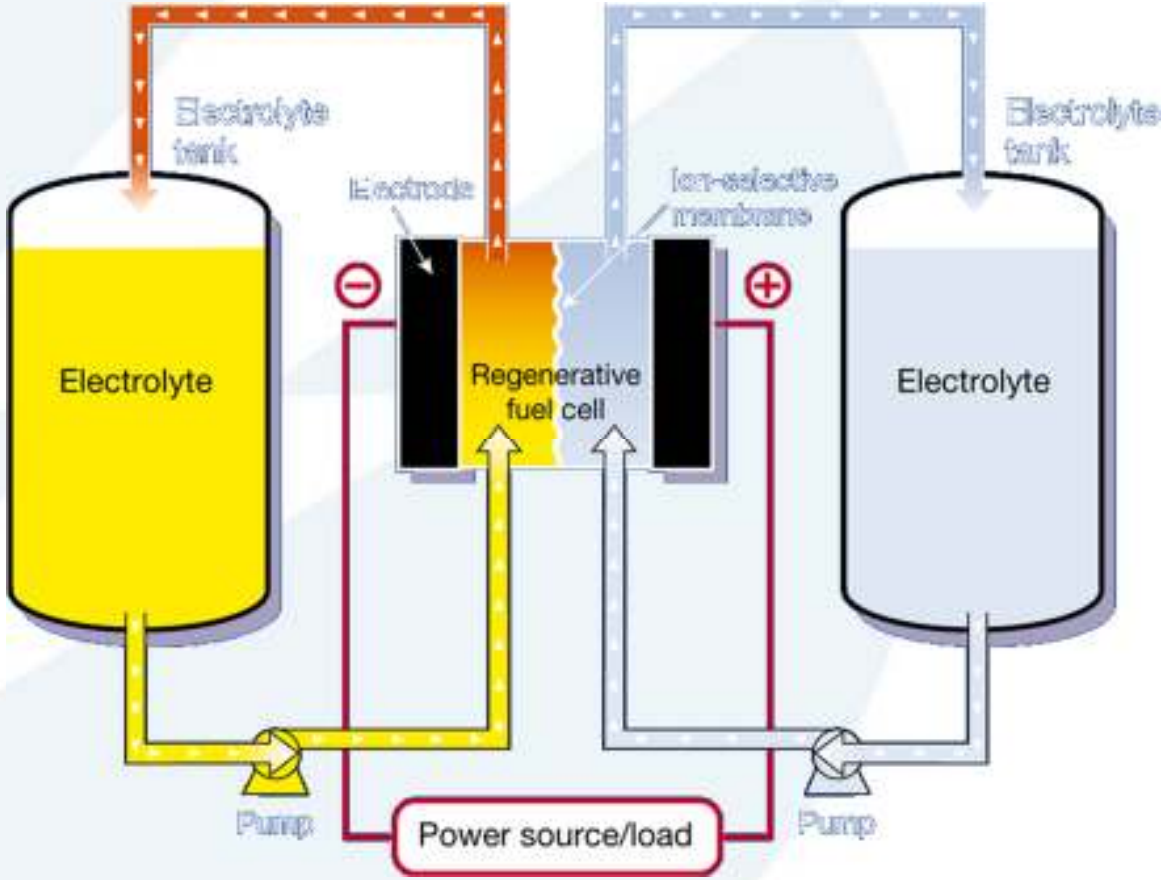
WhEST

RFB Energy Storage System

- **Power and energy are separable**
- **Modules capable of mass production**
- **Operates at ambient temperature and pressure**
- **Two moving parts**
- **Environmentally benign**

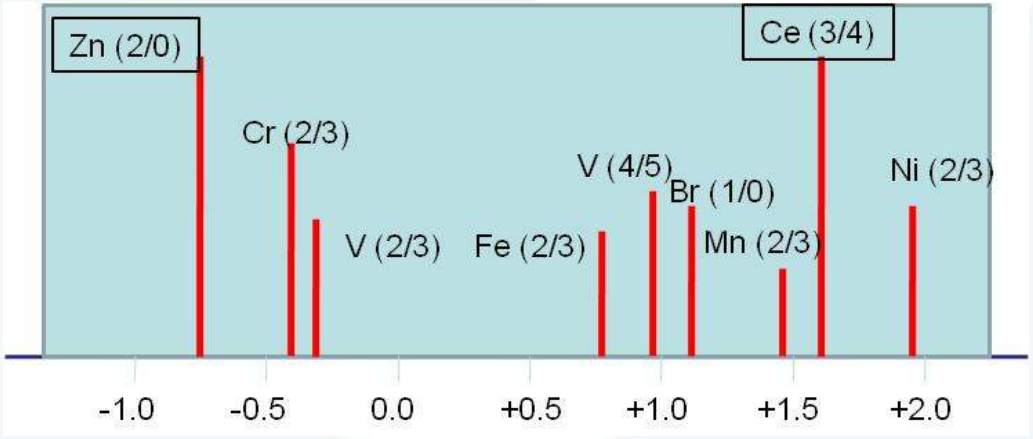


Flow Battery Benefits

- Energy storage capacities are independent of their power rating.
- The same electrolytes are used in all the cells of the module providing a common state of charge. Moreover, measurement of the state of charge of the electrolyte is equivalent to measuring the state of charge of the entire system.
- Overcharging and fully discharging does not usually cause permanent damage to the electrodes or electrolytes.
- The flowing electrolyte provides a convenient means to thermally manage flow batteries – in contrast to conventional battery systems.
- The flowing electrolyte provides a means to chemically manage the electrolyte(s) for the entire battery.

Redox Couple Selection

- Find a pair of redox couples with a high cell voltage
  - One couple can be highly oxidised
  - The other couple can be highly reduced



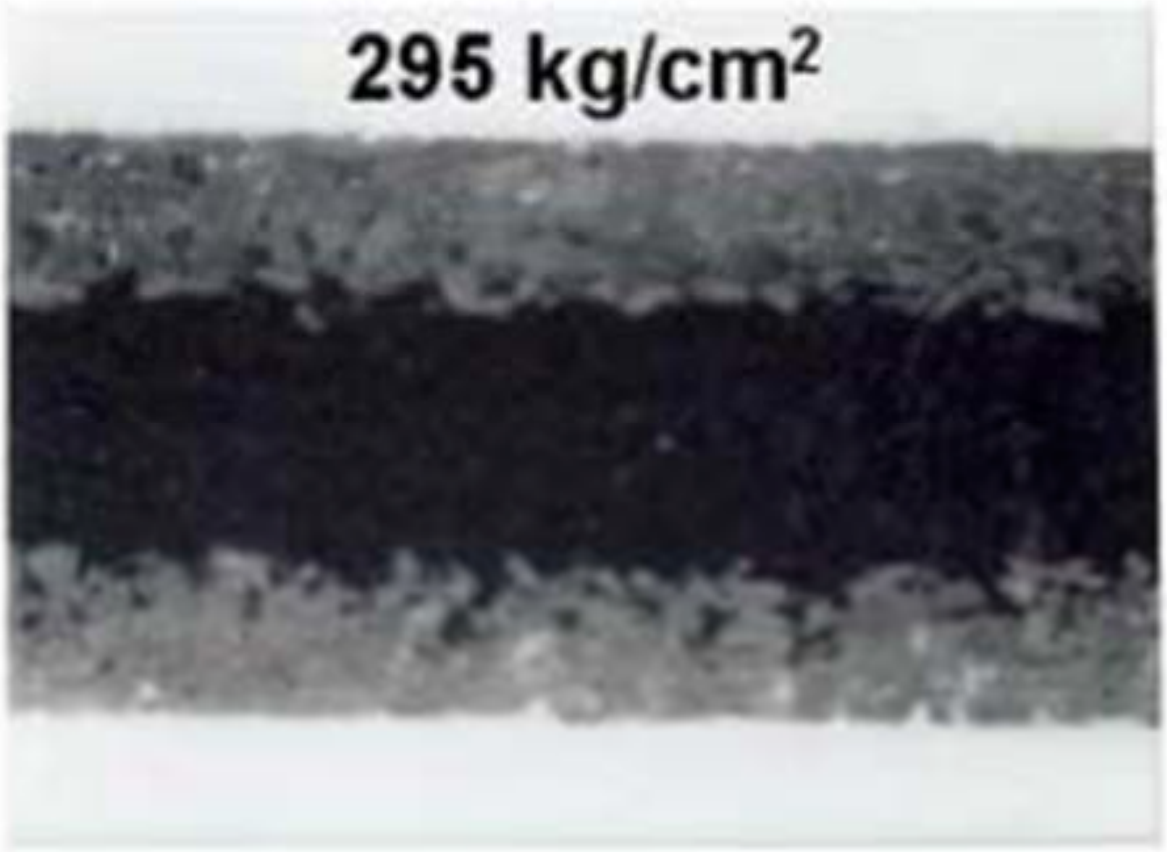
- **But** both redox couples must be:
  - stable themselves and, preferably, in combination
  - Effective at practical electrodes
  - reasonable in cost, easily sourced, transported, stored…

Bench Scale

Electrodes

- Chemically/electrochemically stable
- Inert
- High electrochemical surface area
- Low over potentials
- High Mass transport
- Operate at low flow rates
- Low pressure drop
- Ease of cell Design

Composite Electrode



Membrane

- Separates electrolytes from chemically mixing
- Defines flow channel
- Selective to species ionic transfer
- Controls ionic current efficiency
- Some systems require more selectivity than others
- Can be an expensive component
- Need to understand system needs

Reactor Design Limits

- Mass Transport

  $C = I/nAFk$

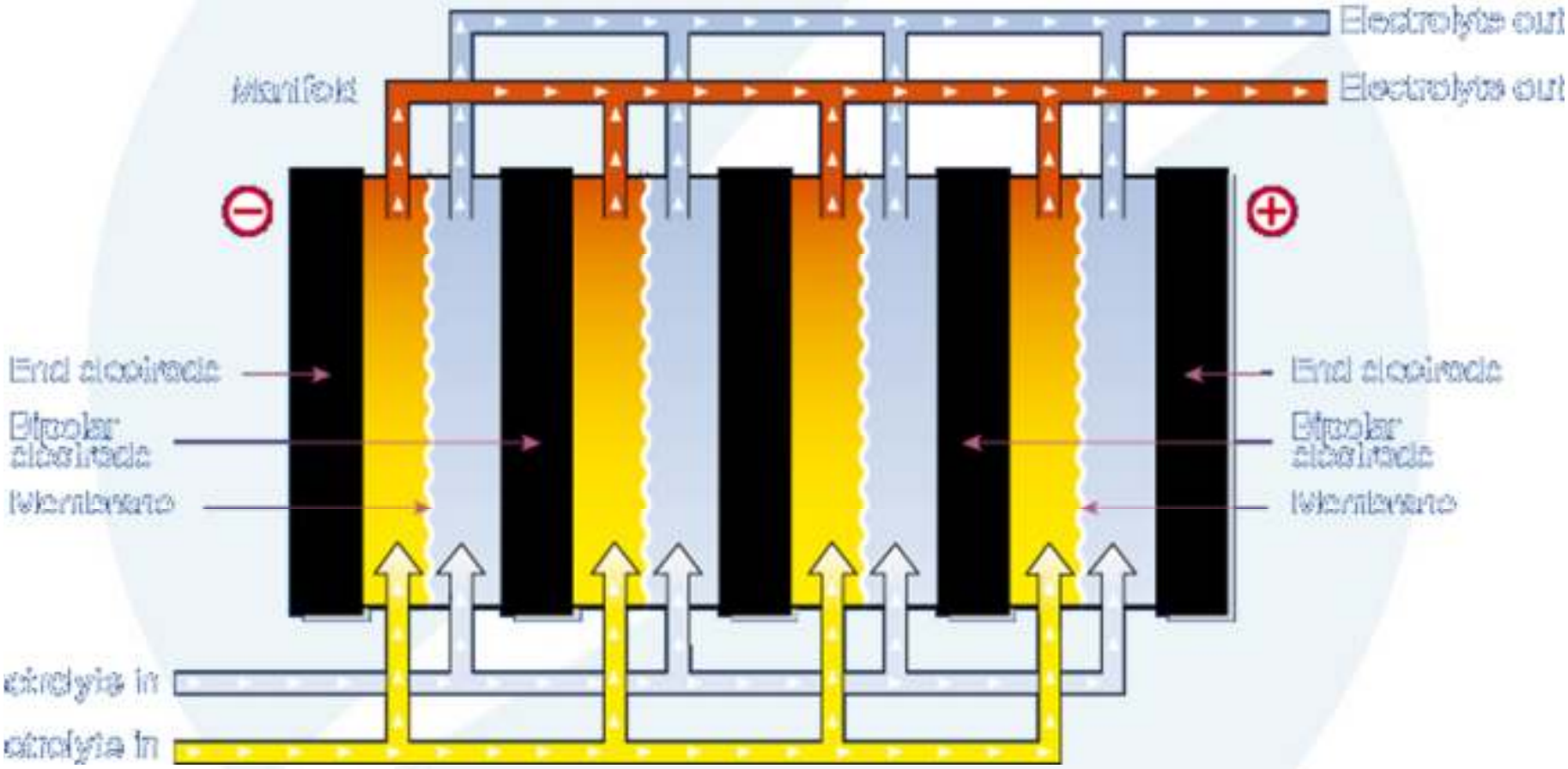
- Conversion per pass

  $Ci - Co = I/nFQ$

Pressure Drop

- Cost of pumping electrolyte approx. 3 % loss
  - Stack losses
  - System pipework
- Low pressure drop, low resistance to flow
- Differential pressure control across membrane
- At odds to high resistance shunt current requirements
- Balance between shunts and pumping losses in design
- Cannot ignore pumping power in system efficiency calculations

Bipolar Stack



Desirable Features: Flow Cells Stacks

- Controlled and uniform electrode potential
- Controlled and uniform current density
- Controlled mass transport
- Controlled and understood hydrodynamics
- Minimal shunt losses
- Low pressure drop
- Ease of control and automation

Desirable Features: Flow Cells Stacks

- High electrode area
- Stable reactor materials
- Good sealing/Leak proof
- Not prone to flow channel blockage
- Easy of maintenance
- Safe and convenient operation
- Reliable

Shunt Currents

- What are Shunt Currents ?
  - Discharge through process electrolytes
  - Occur within modules & plant pipework
- Why are they important
  - Represent a loss in the system
  - Target < 1% nominal current loss

Shunt Current Design Inputs

- Cell voltage
- Electrolyte resistance
- Manifold Resistance
- Port Resistance
- Over potentials
- Cell number
- Use resistor model to calculate current leakage

Development Stack Design

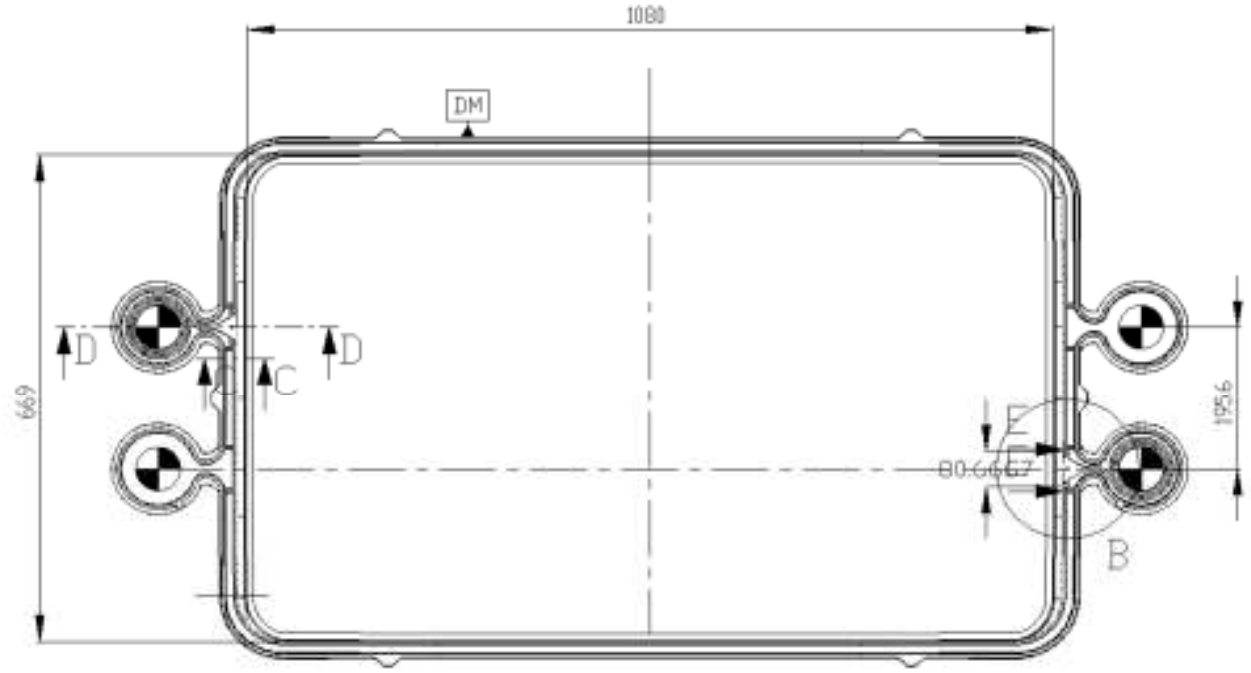
- Frames machined to allow design development
- O-ring seals for assembly/disassembly and post mortem analysis
- Compression moulded carbon/HDPE composite electrodes
- Compression secondary bonded active surface activated carbon/PVDF “tile”
- Voltage probes per cell for bipole stack voltage monitoring and shunt current measurement
- Flexible flow distributor sections
- Flexible design of manifold/shunt current management
- Polymer electrodes for welding

Development Stacks 0.1 - 0.2m^2 – 60 Cells

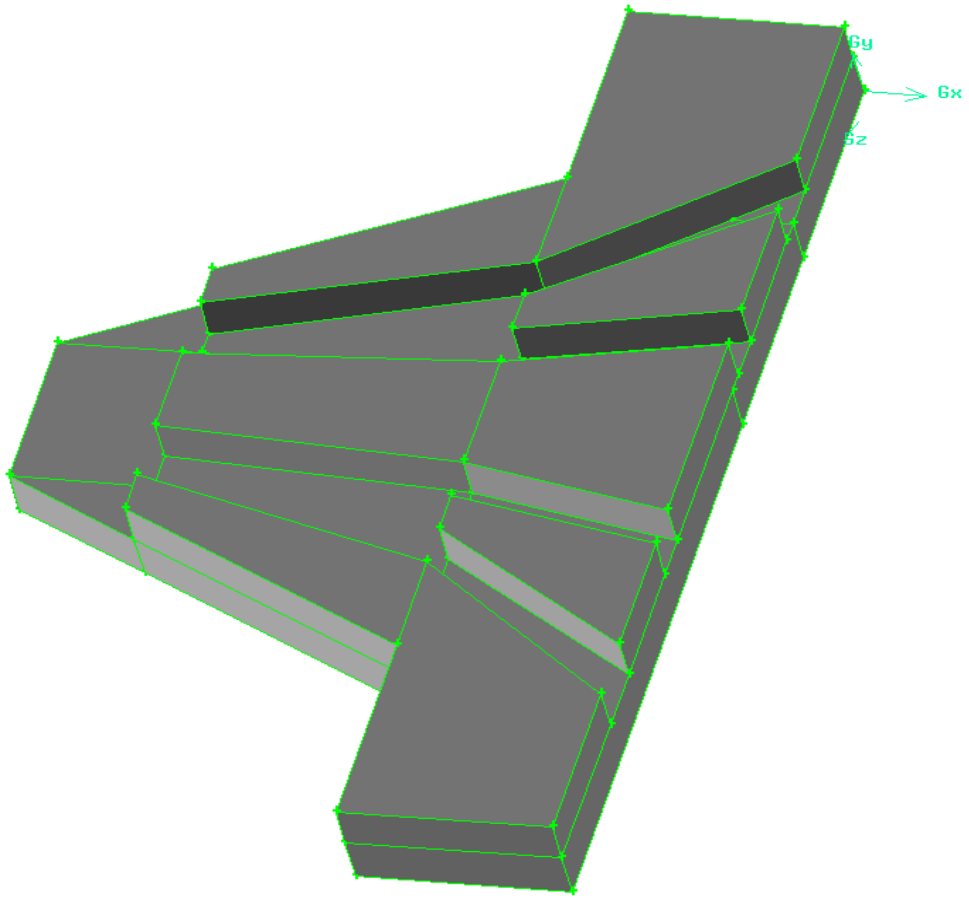
Production Stacks

- Injection moulded HDPE frame design – one piece with “clip-fit” seal and membrane pinch
- Flexible “pop-in” flow distributor
- Conducting extruded base electrode core pressure/temp bonded to secondary porous carbon/polymer tile
- Automated laser welded electrode/frame
- Fully stack assembly
- Minimal components
- Minimize cost

Frame Design



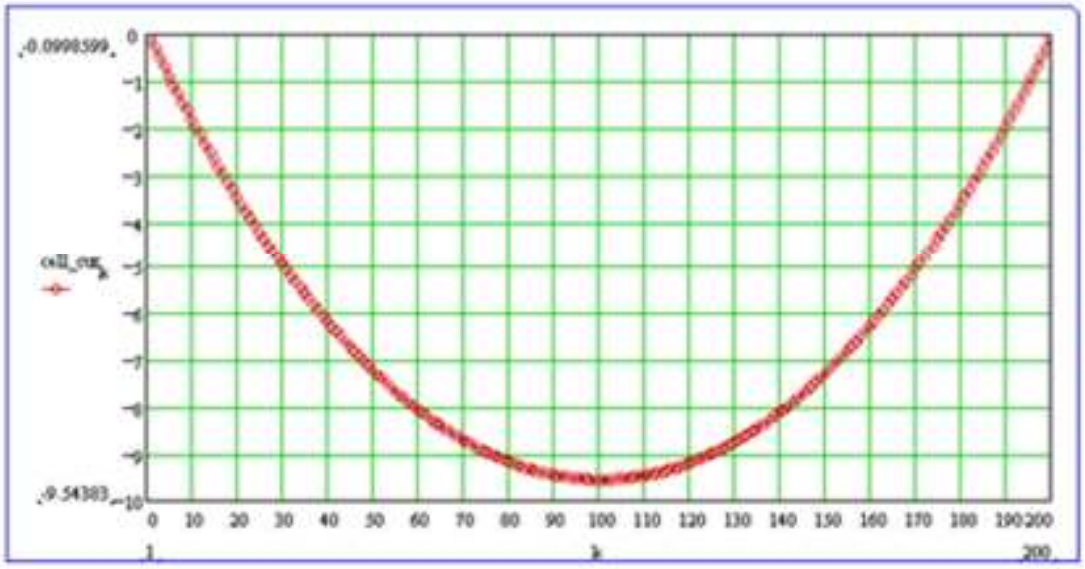
Flow Distribution



Shunt Currents

- Primary Control in module spiral
- length 500mm
- Provides 2200Ω shunt resistance

Shunt Current Losses



200 Cell Bipole Stack

200 bipole module

Nominal power 100 kW

No load voltage 300 V

Voltage range 150 -360 V

Operating temperature 20 - 40C

2m x 1.5m x 1m

Manufacturing

Wh Energy Storage Technologies (WhEST)

New UK Battery energy storage business

Flow battery design, development and delivery

Cell, stack and system design, build and supply

Battery electrode/electrochemistry R&D

Independent battery testing

Flow battery electrolyte supply and development

Provider of energy storage solutions

WhEST

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