



# VFB Electrolyte: Performance & Durability

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IFBF 2025, Vienna, Austria 

*25<sup>th</sup> June 2025*



# Invinity ENDURIUM™ Battery Array



Example 3 MW / 12 MWh  
ENDURIUM™ Configuration

RATED POWER:  
CONTINUOUS

**3-250+**  
MW

ENERGY STORAGE:  
NOMINAL

**12-500+**  
MWh

ENERGY STORAGE:  
DURATION

**3-18**  
HOURS

LIFETIME:

**25**  
YEARS

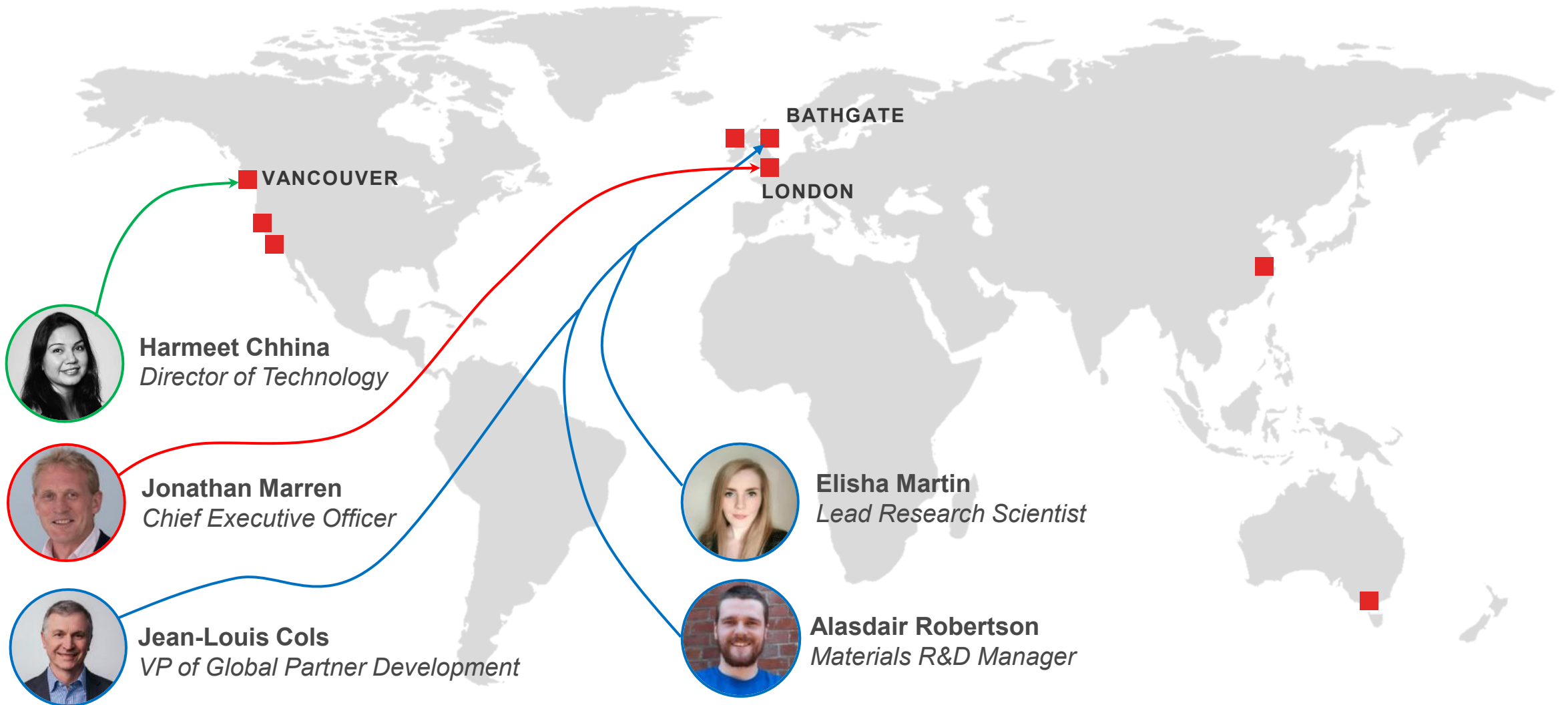
RECOMMENDED  
DEPTH OF  
DISCHARGE:

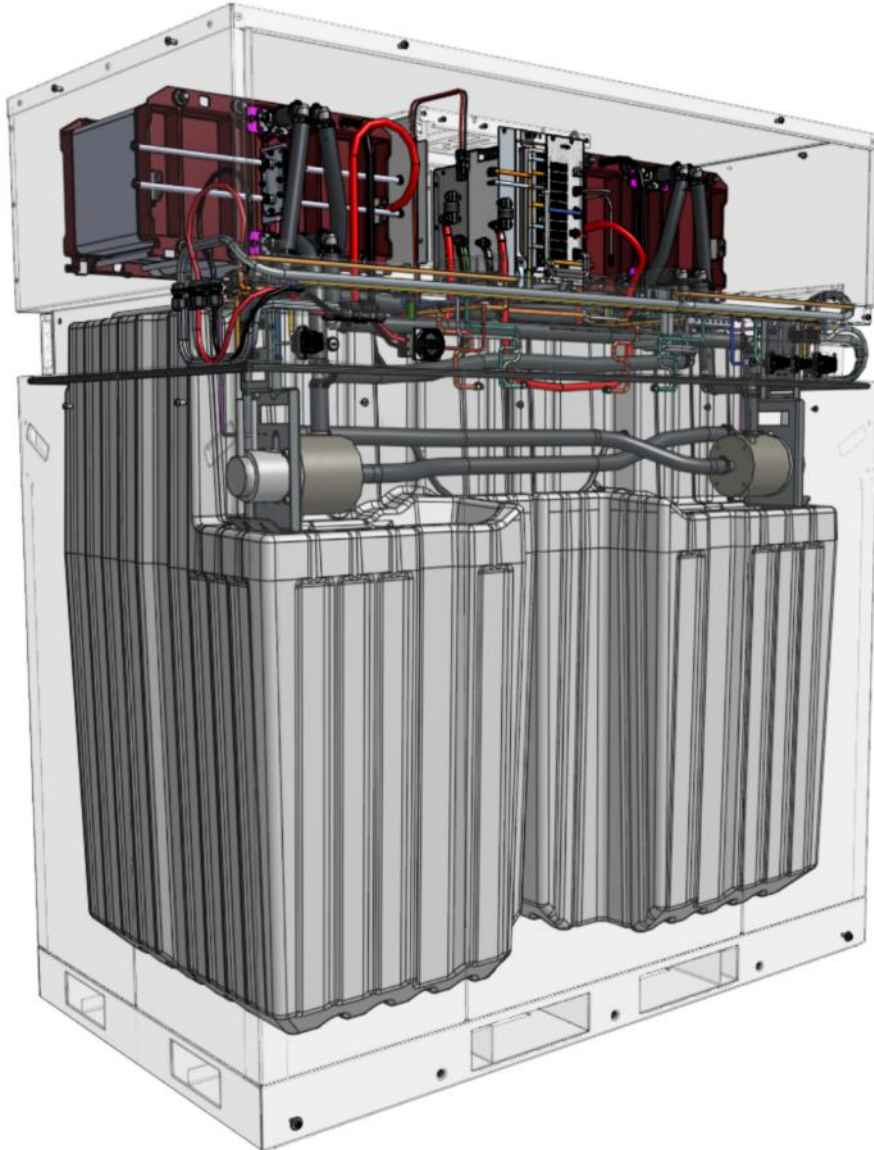
**100%**

CYCLE LIFE:

**UNLIMITED**

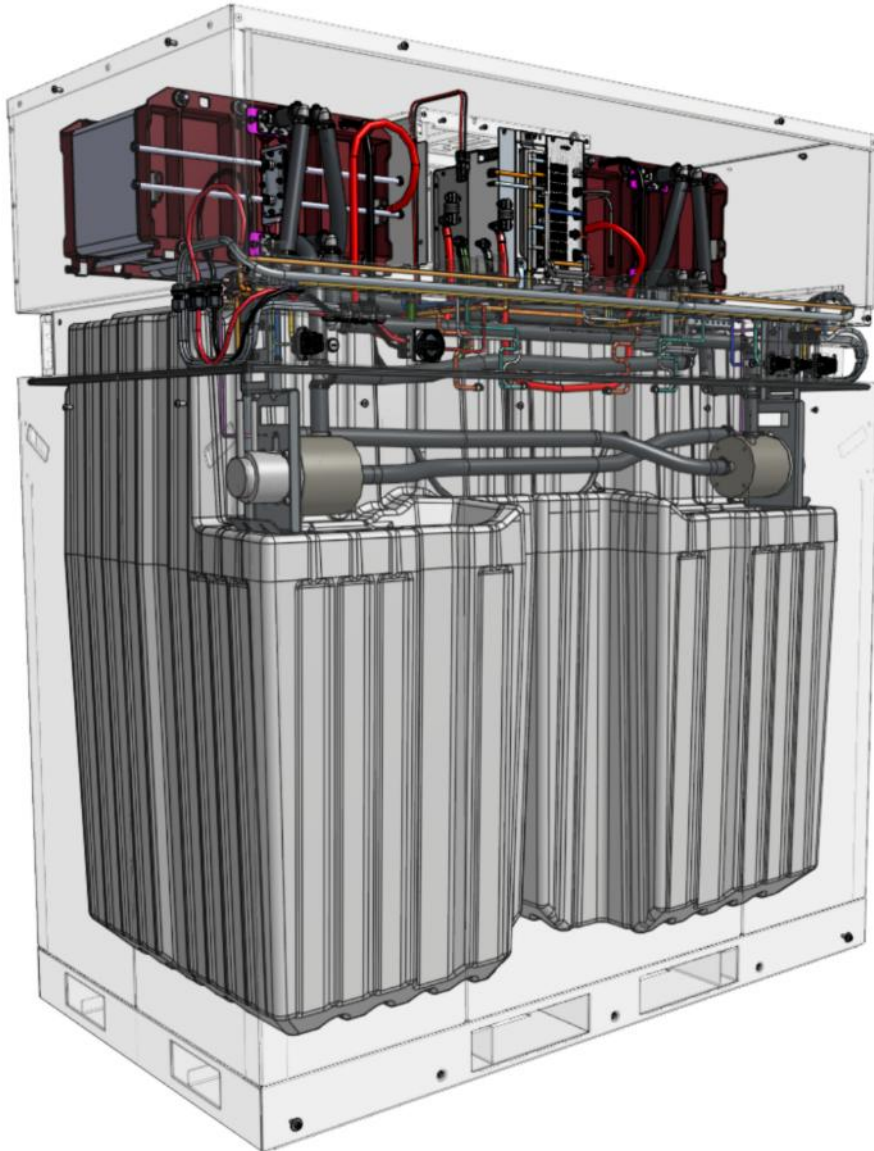
# Invinity's 2025 IFBF Attendees





## Electrolyte is a critical component of all flow batteries

- *Major component of total system volume, mass, & cost*
- *Molarity & total volume define energy-storage capacity*



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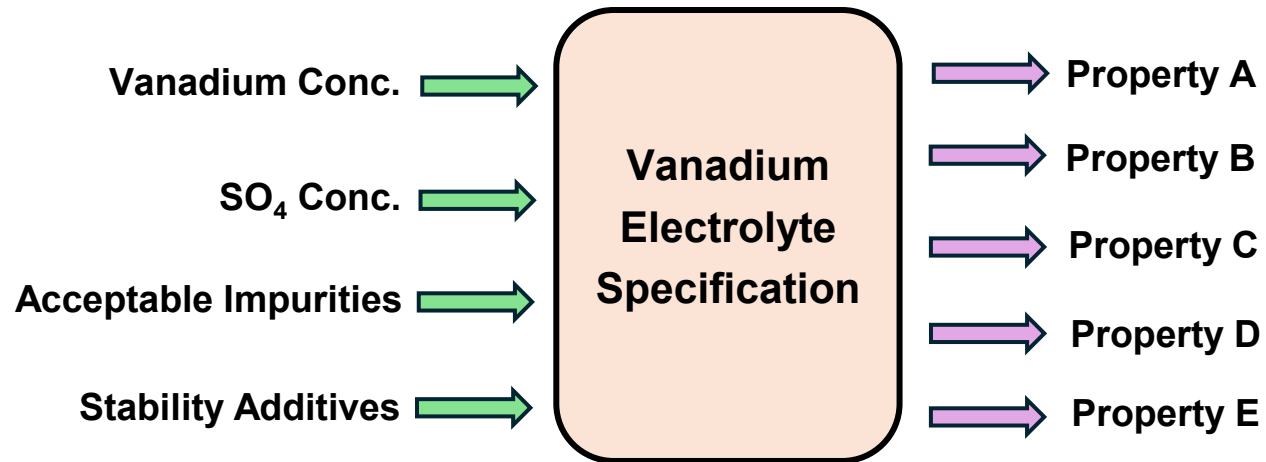
Vanadium electrolyte is typically an acidic aqueous solution containing:

- 1.5 - 2.0 mol/L vanadium sulfate salts
- 4 - 5 mol/L sulfate ( $\text{SO}_4$ )

*Pseudo*-standardised, but individual VFB manufacturers often have distinct electrolyte specifications

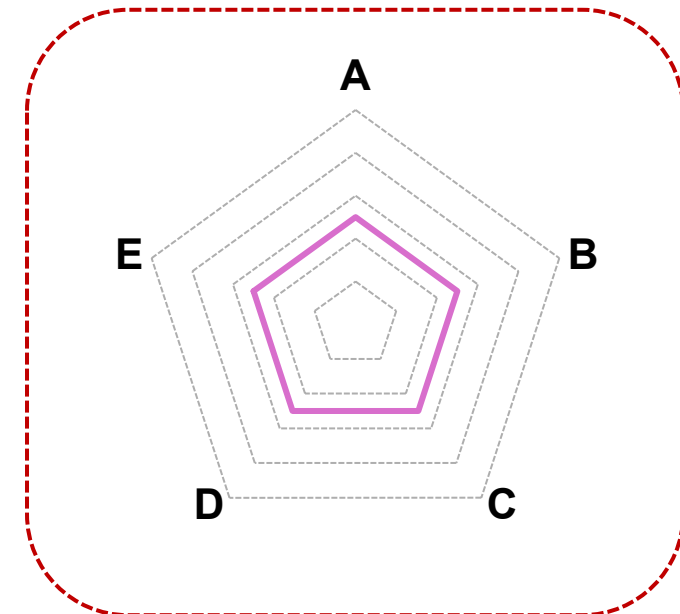
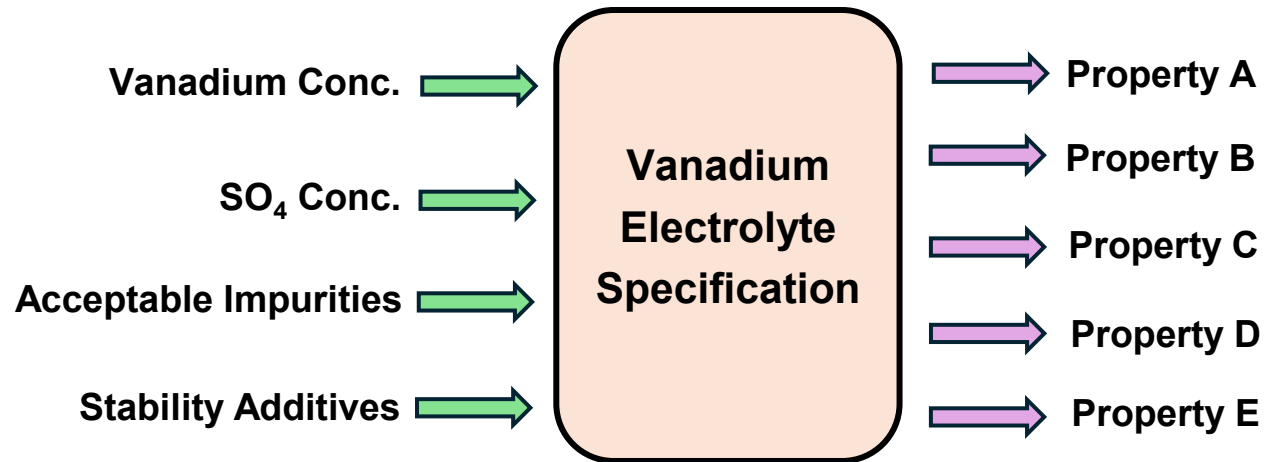
# Specification Development

- Small number of compositional levers which manufacturers can control for electrolyte
  - *Defines an array of electrolyte properties and key elements of its in-system behaviour*



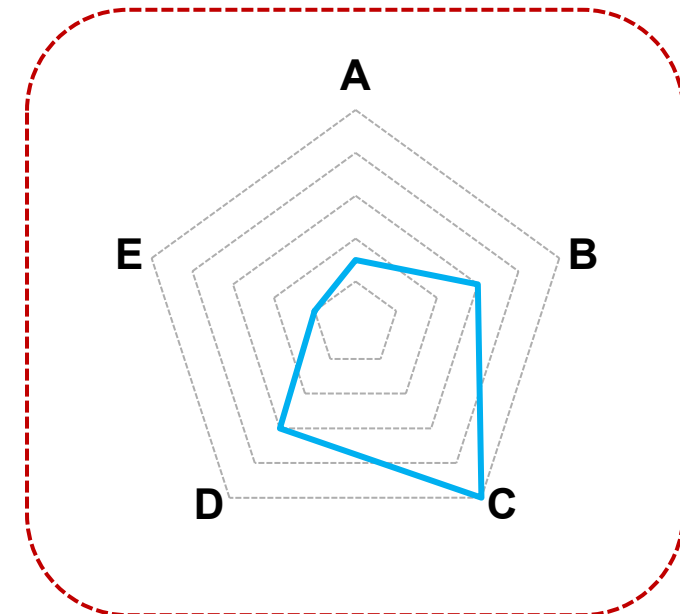
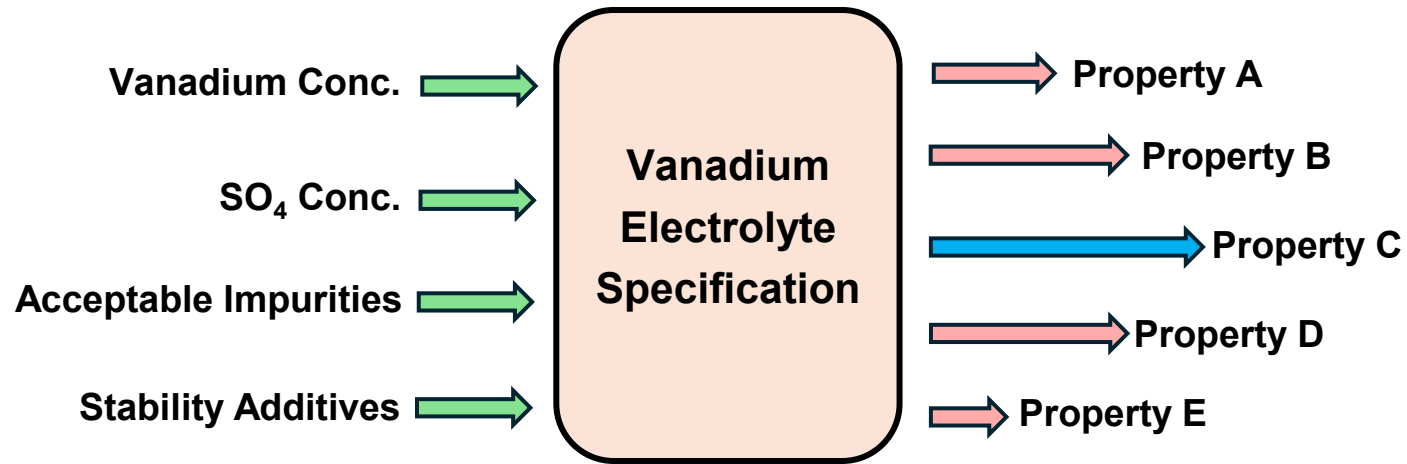
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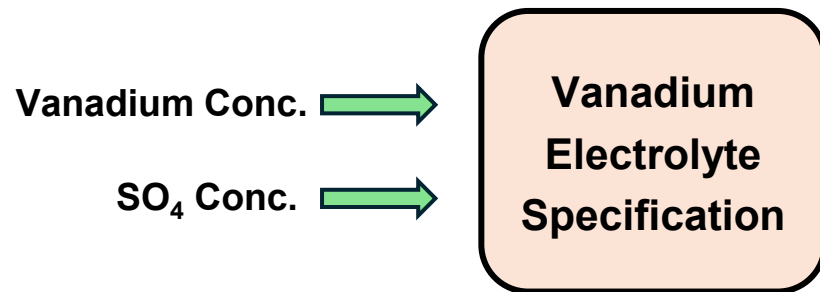
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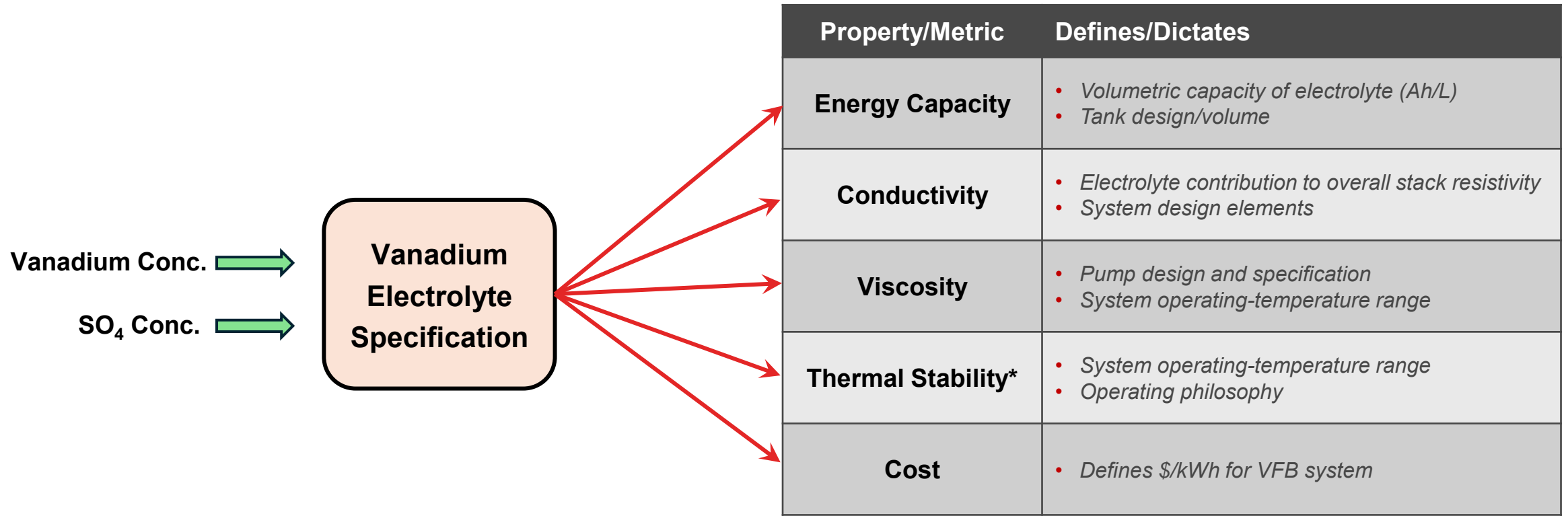
# Bulk Composition

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  - *Define various key properties of both electrolyte and systems*



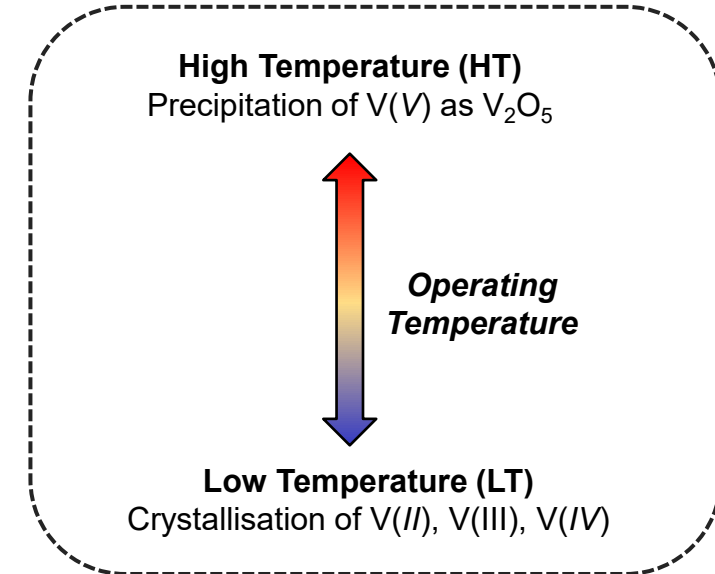
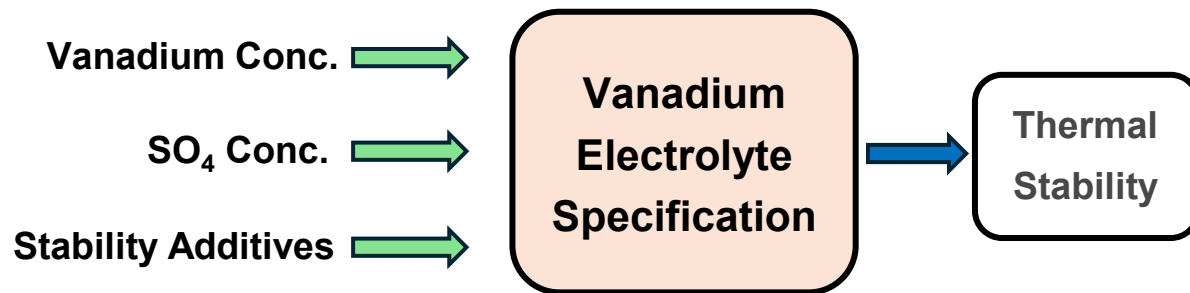
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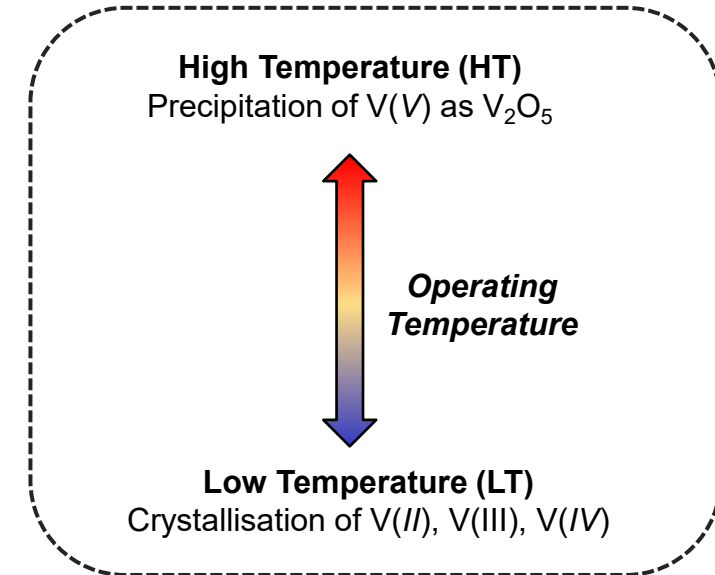
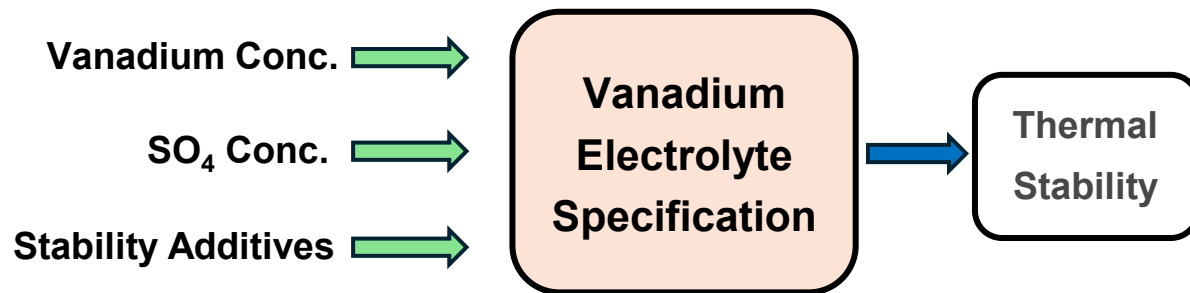
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  - *Critical that electrolyte remains homogeneous at all times*
  - *Stable region can be enhanced via inclusion of stabilizers*

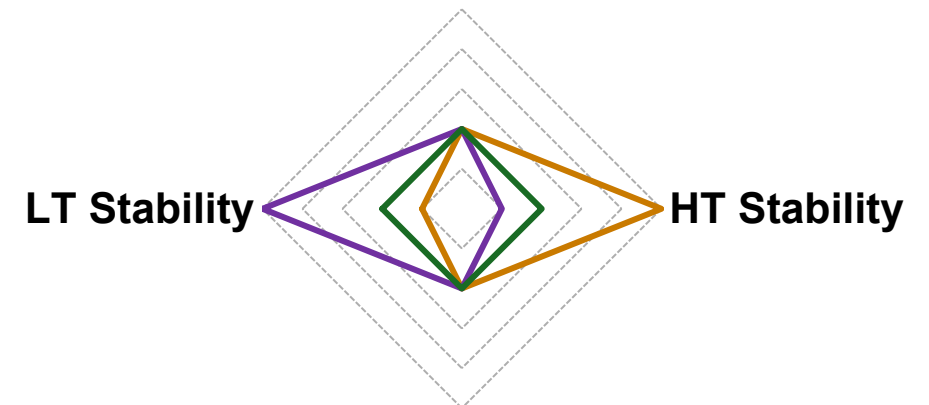


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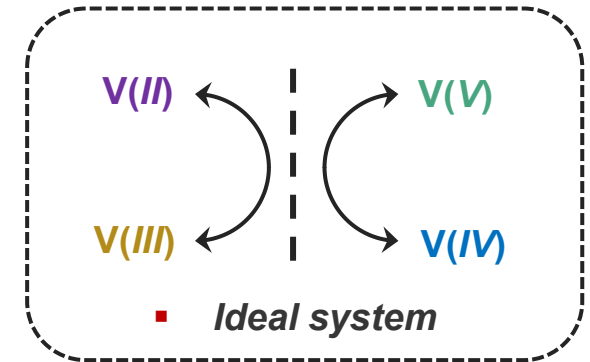


- Thermal stability varies inversely with [V<sub>TOTAL</sub>]
- Increasing [SO<sub>4</sub>] has opposite effects on HT vs. LT stability
  - *High SO<sub>4</sub> improves HT stability, but reduces LT*



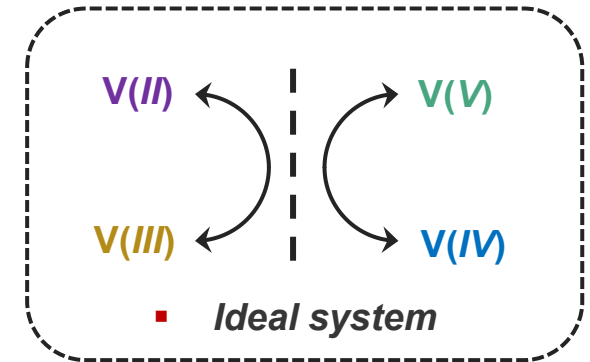
# Control of Electrolyte Oxidation State

- Key to long-term VFB durability that average oxidation state of electrolyte is maintained at ~3.5
  - *i.e. that SoC is the same in both negolyte & posolyte*
- Significant deviations from ideal balance can limit discharge capacity
- VFB developers typically specify a 1:1 ratio of V(III):V(IV) in as-supplied electrolyte

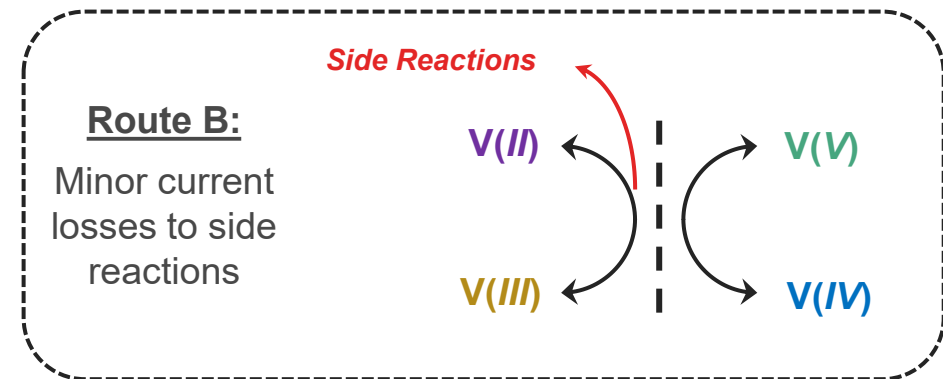
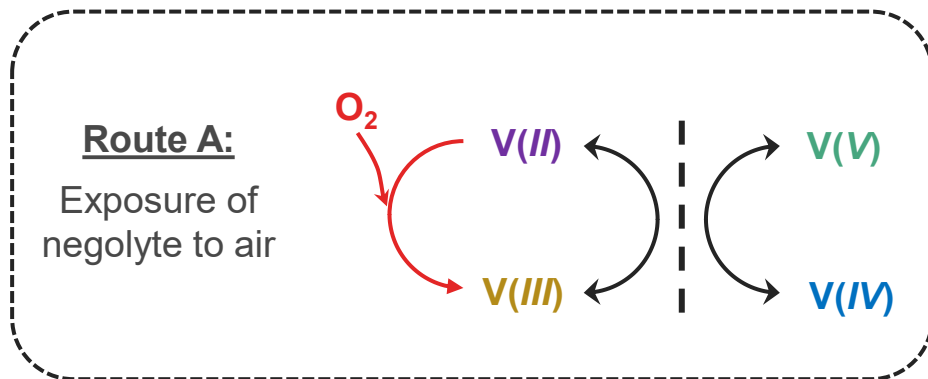


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- In practice, average oxidation state of electrolyte very slowly increases with time, *via* two primary routes:



# Control of Electrolyte Oxidation State

- Rate of electrolyte oxidation in VFBs is generally very slow, but must be managed to maintain long-term system durability
  - *If left unchecked oxidation can gradually erode the system's available capacity*
- Oxidation process is entirely reversible, and can be controlled by various methods
  - *Maximum permissible oxidation rate depends on developer's hardware and mitigation strategy*
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- **Route A:** Reaction with ingressive air
  - *Controlled by system design & maintenance protocols i.e. minimizing air exposure*
- **Route B:** Minor side reactions within electrolyte
  - *Controlled/minimised by electrolyte specification i.e. maximum allowable concentrations of specific impurities*

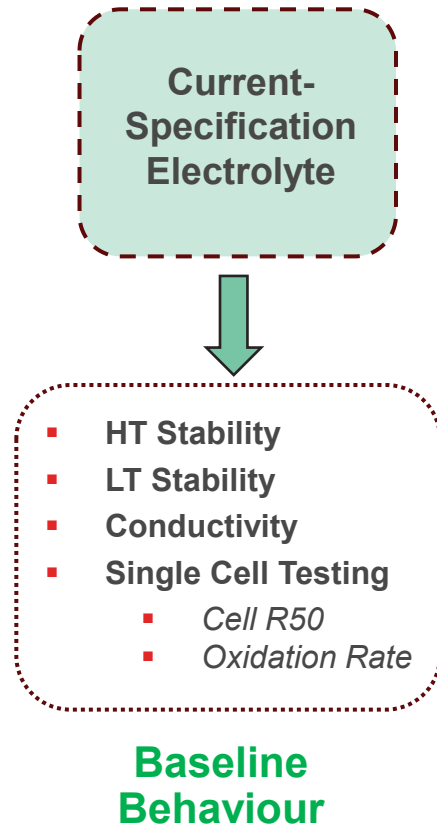


- IES' electrolyte specification is a living document
  - *Regularly honed, as ongoing R&D programmes expands understanding*
- Recent work explored the effects an array of metallic impurities of electrolyte performance
  - *Systematically probed the effects of growing elemental concentrations in isolation and combination*

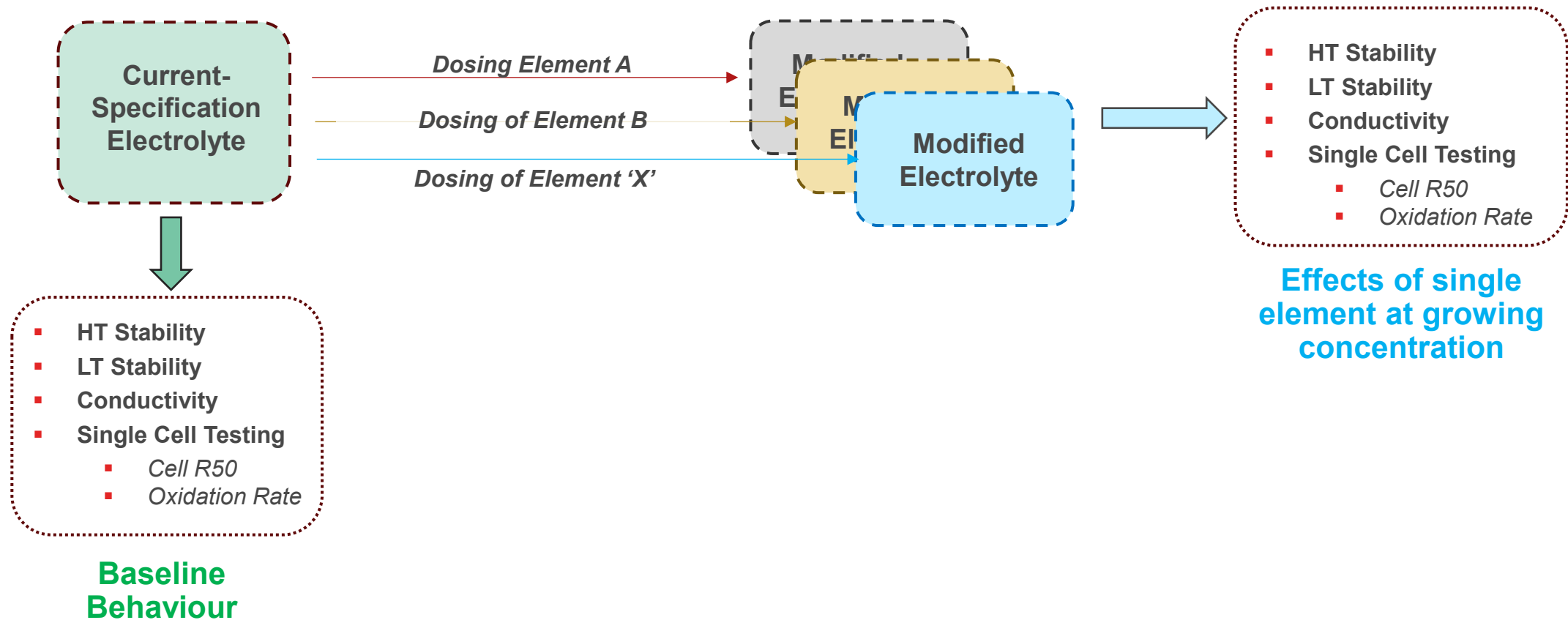
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## Questions:

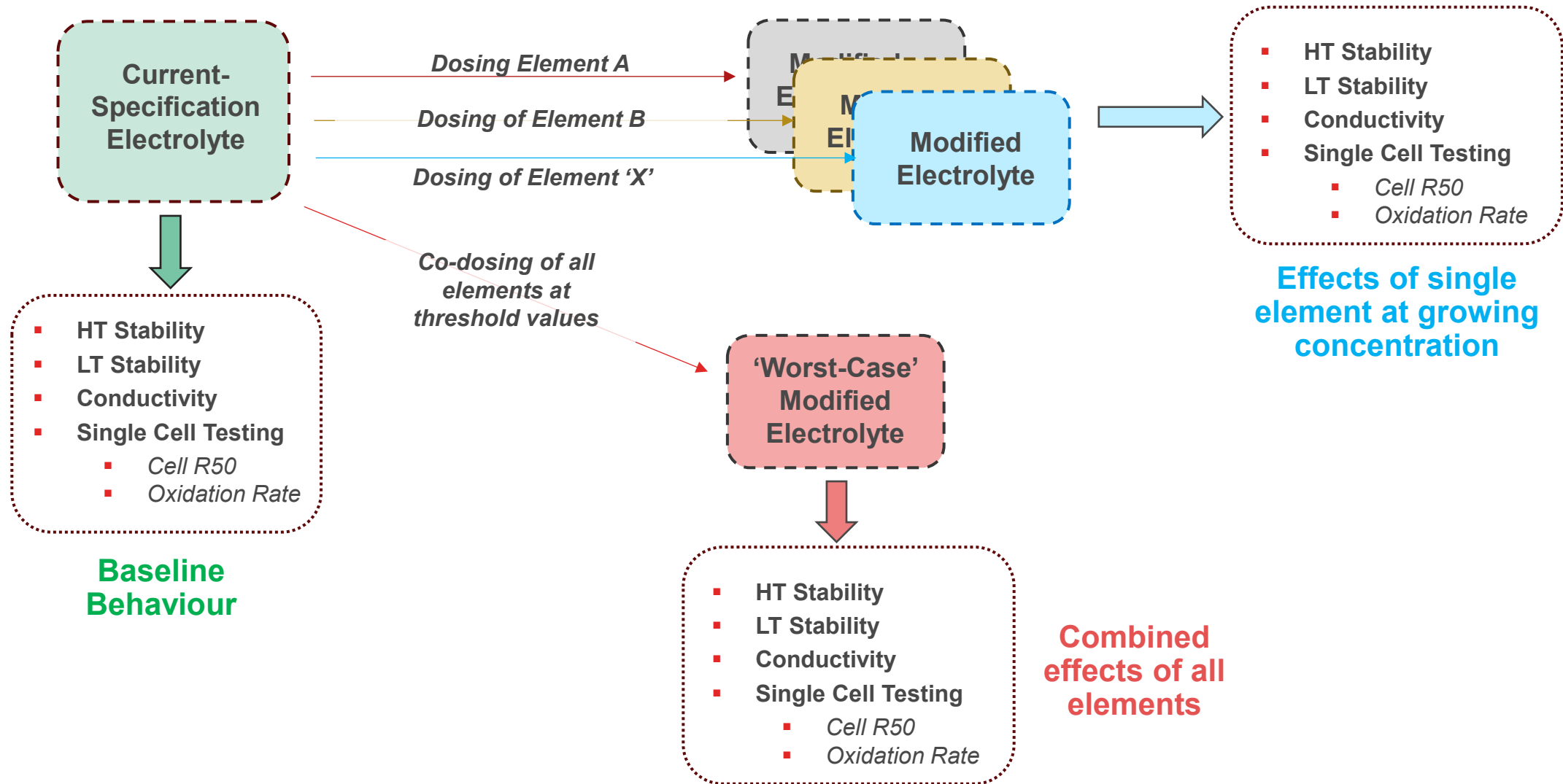
- How do electrolyte properties vary as metallic-impurity concentrations grow?
- Are there opportunities to further hone & optimise IES' electrolyte specification to enable reduced costs?



# Effects of Metallic Impurities



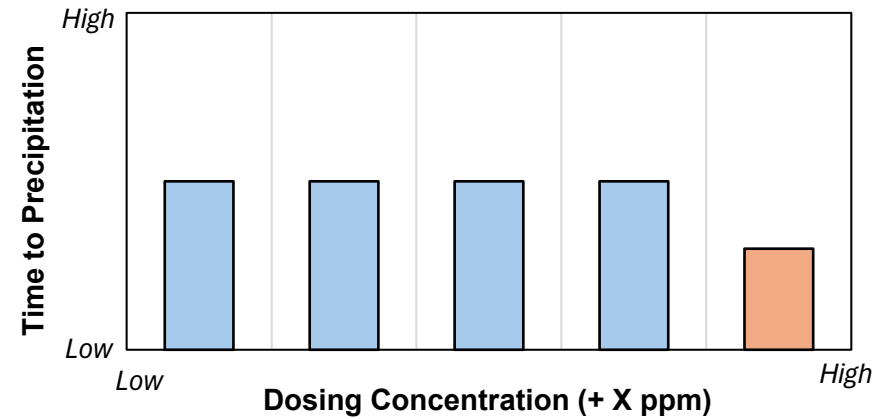
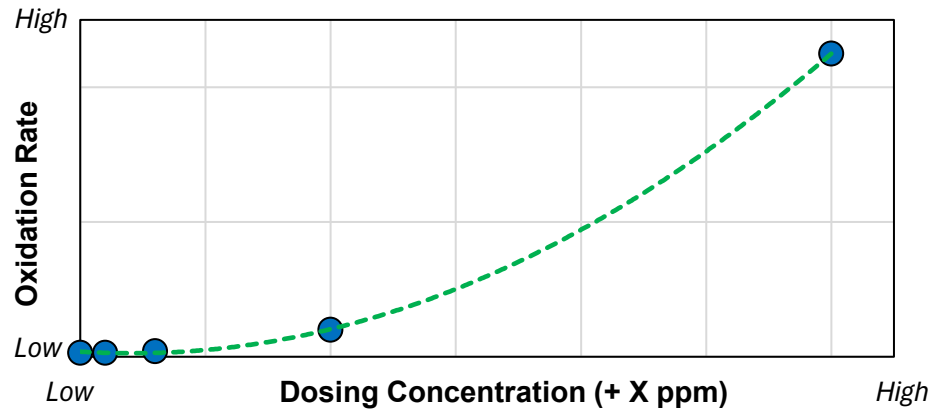
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## Key Findings:

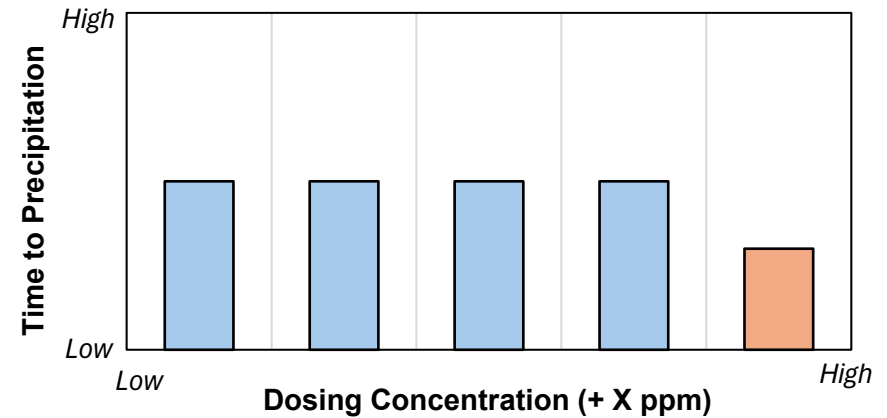
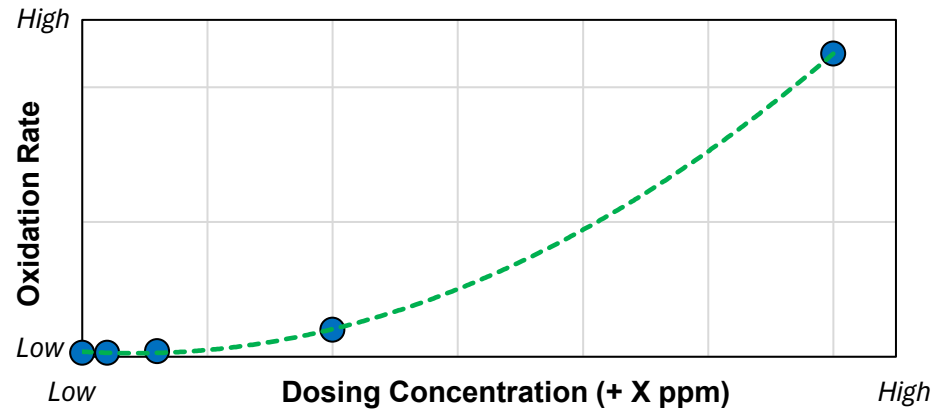
- Identified the concentrations at which various elements yield one or more negative impacts
- Able to accommodate higher concentrations of various elements than previously understood/specified



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## Key Findings:

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## Enabling:

- Further optimisation of IES' electrolyte specification
- Honing of IES' system operating protocols and safeguards
- Reduced capital & O&M costs, and reduced LCOS for VFB systems

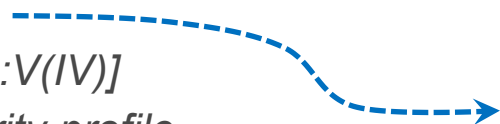
- Key facet of any specification is the ability to verify conformance
  - *Require accurate and robust analytical methods to measure key properties*
  
- For electrolyte, key metrics of interest include:
  - $[V_{TOTAL}]$
  - $[SO_4]$
  - $[V(III):V(IV)]$
  - *Impurity profile*

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Accuracy:  
Equipment Costs:  
Time per Sample:

	Gravimetric	Ion Chromatography (IC)	ICP-OES/MS	Acid-base Titration
Accuracy:	1	2	3	4
Equipment Costs:	2	3	4	1
Time per Sample:	4	3	2	1

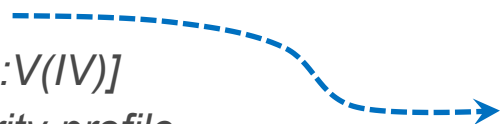
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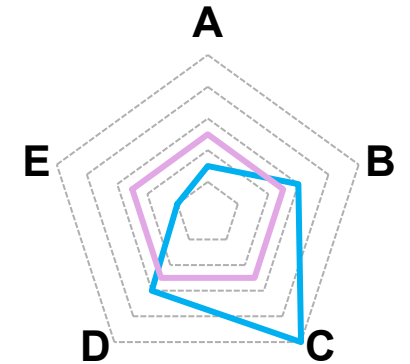
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- Sector-wide there is a low degree of standardisation in both preferred characterisation techniques and specific methods
  - Represents a barrier to growth and wide-spread application of VFBs

- Electrolyte specification is critical to VFB performance
  - *Defines critical elements of system performance, durability & cost*
- Manufacturers develop specification to align with system hardware, operating strategy and target markets
- IES specification is guided by extensive in-house R&D, and enables enhanced energy capacity
  - *See IES Poster: Advancing Vanadium Flow Battery Technology for Grid-Scale Markets*
- Recommend that current efforts to develop and maintain a unified VFB electrolyte specification should:
  - *Ensure latitude for manufacturer's optimisation of cost, performance, and durability*
  - *Standardise methods for characterising VFB electrolyte with high accuracy and precision*



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