Technology Intelligence Brief
Vanadium Redox Flow Batteries (V-RFBs)

Prepared for Client X by

Technoligence Office for Consulting & Research

Summary

Vanadium Redox Flow Batteries (V-RFBs) represent a mature and scalable energy storage solution. This report provides a concise overview of their technology landscape, key R&D levers, patent activity, and future opportunities for Client X. The focus is on improving operational temperature, automation of cell stack production, and electrolyte performance—areas where **Technoligence**'s technology intelligence framework can guide investment and industry collaboration.

1. Technical overview of V-RFB and its Value Chain

Vanadium redox flow batteries (V-RFBs) are currently the most mature representative of RFBs and are already commercially available (TRL 9). Due to the different setup and application scenario, the KPIs used for Lithium-Ion Batteries do not necessarily play a major role for RFBs.

Unlike other battery storage technologies, it must be emphasized that energy density and power density are not the most relevant for RFBs and can be scaled separately. In other words, energy density is not critical in RFBs due to its stationary applications.

<u>The most important technology domains to pursue (R&D tracks)</u>

1-Electrolyte: widen the safe temperature window & raise solubility
2-Electrodes: cut overpotentials & tame H_2 evolution
3- Membrane/Separator: lower ASR without inviting crossover

4-Flow field & cell hydraulics: mass transfer up, pumping loss down
5-Stack-level automation: shunt currents, pressure & SoC control
6-Thermal management and control: Battery management system designed for extreme local climates.

2. Technical bottlenecks for VRFB identified from various industry reports and R&D roadmaps

- One bottleneck of RFBs can be the limited operating temperature range of typically 5–40°C for vanadium-based RFBs.
- Another bottleneck is the lower round trip efficiency compared to Lithium-Ion Batteries. Further developments in the battery cell (electrode materials, flow field designs, etc.) could improve efficiency.
- Another limiting factor for RFB production is the cell stack production, which is currently mostly performed manually. Automated production processes and scale-ups are necessary to reduce costs.

Based on our client's R&D capabilities, we suggested that they should focus on projects that improve the operational temperature in VRFBs.

Suggested R&D Projects for our Client

Suggested R&D projects for Vanadium Redox flow battery to improve operational temperature window (below ~10 °C and above ~40–50 °C) should focus on:

a) Electrolyte chemistry (highest leverage)

- ***Mixed-acid electrolytes (H_2SO_4 + HCl):*** *Push vanadium solubility, suppress V(V) precipitation at high T, and reduce low-T crystallization—enabling ~−5 °C to 50 °C operation when well-optimized. Watch chloride-corrosion compatibility for hardware.*
- ***Methanesulfonic acid (MSA) as co-acid/additive:*** *Improves low-T stability of V(II/III) and delays V(V) precipitation at high T; recent simulation and experimental work reinforces mechanisms.*

- ***Additive packages (phosphate, organics, ligands):*** *Tailor speciation to widen the 10–40 °C "sweet spot" noted in reviews; aim for >2.0 M V stable across ≥0–50 °C without viscosity spikes.*

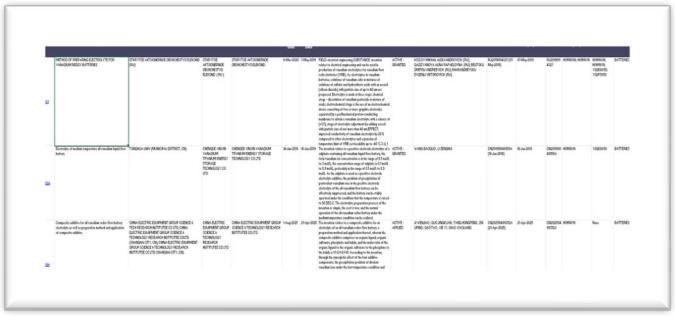
b) System controls & BOP

- ***Electrolyte conditioning & SOC management:*** *Avoid V(V)-rich states at high T; avoid deep V(II) at low T; incorporate temp-aware charge limits.*
- ***Thermal management:*** *Low-mass heat exchangers + predictive control tuned to electrolyte phase diagrams from your chosen chemistry. (Pairs naturally with the mixed-acid/MSA route above.)*

c) Priority experiment set

- *Head-to-head: 2.0–2.5 M V in* ***H_2SO_4-only vs H_2SO_4+HCl vs H_2SO_4+MSA****, map stability from −5 → 55 °C (visual precipitation + operando impedance).*
- *Long-hold tests at 45–50 °C near 80–90% SOC (positive electrolyte) to quantify V(V) gel/solid onset times across chemistries.*

3. Patent search to identify current state-of-art and gaps

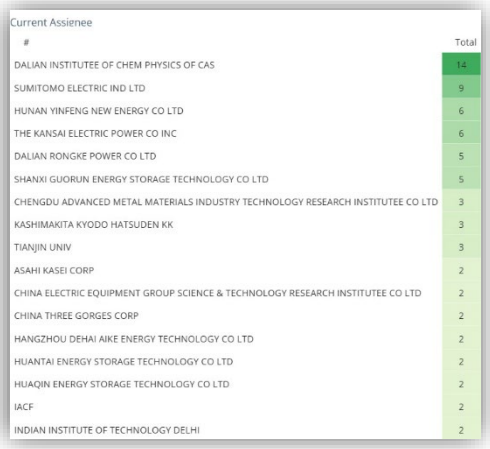


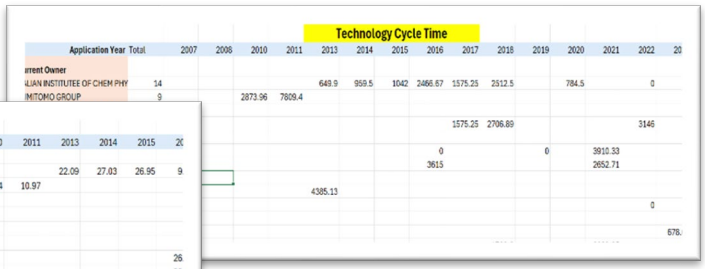
After identifying the technical domain that our client is interested in, we conducted a Boolean patent search that combined relevant CPC classes and text to identify the prior art in all international patent jurisdictions. After searching, checking, and refining, 143 patents were grouped for further analysis. This list is considered as the most relevant **patents that define the technical domain** that we are interested in.

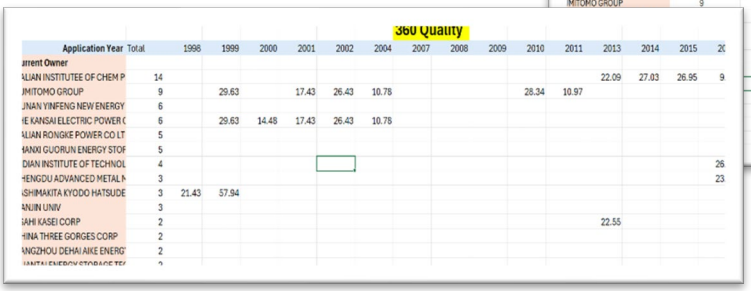
4. Patent analyses and landscaping

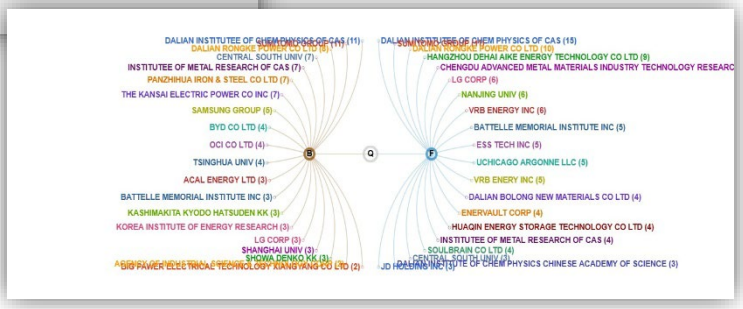
Various analyses were conducted:

- Top owners.
- Top inventors.
- 360 Quality patents.
- Technology Cycle Time.
- Patents having the most forward citations (cited by future patents).
- Most important patents (using various criteria).
- Licensed patents.
- Patents that have recently changed ownership (assignee name).



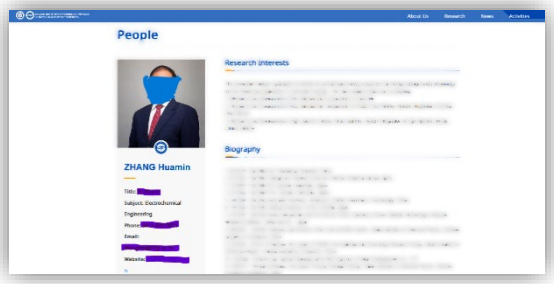






From our patent analysis we provided various conclusions to our client. An example of our conclusions is discussed below.

- We found that some companies and inventors have recently developed solutions that solved some of the current technological needs of our client. The key ones to consider were “DALIAN INSTITUTE OF CHEMECAL PHYSICS”, “SUMITOMO”, and recently “FRAUNHOFER”.
- The top inventor in this specific domain which relates to VRFB electrolytes is Zhang Huamin from Dalian Institute. He, along with his colleagues, and PhD students have made considerable developments in the electrolyte advancement in VRFB.



- Furthermore, a very recent, but strong patent in terms of claims belonged to the Fraunhofer Institute. Their US patent application (still pending) presented very strong claims in terms of improving the electrolyte operating temperature.
- To understand the commercialization aspects, we tracked licensed patents, and patents that have recently changed ownership/assignee. Some of the patents from Dalian Institute were reassigned to **Dalian Rongke Power Company**. This company has successfully deployed over 3 gigawatt-hours (GWh) of utility-scale Vanadium flow battery (VRFB) systems to date (2025). Recently, they also licensed its technology to Saudi Aramco for a VRFB installation in Saudi Arabia.

5. Technical gaps & risk areas

By analyzing the actual **claims** in the strongest patents in the data set, we identified the gaps between in the patents in this technology domain. This provided our client with good indications regarding future R&D projects they could pursue in the near future.