FUMATECH BWT GmbH

IFBF 2026

The Role of Membranes in Flow Batteries

June 15th, 2026

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The Membrane Company

BWT GmbH (a member of FIBA group)

Turnover ~ 1.712 million

Employees ~ 6.400

12 R&D centres

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Membranes for Separation and Energy Storage

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MULTILAYER COATING :

LINE 1: 600 MM

LINE 2/3:1800 MM

LINE 4/5:1200 MM

Industrial Clean Room Membrane Production

Available annual production capacity for Energy applications 2026:

PEM electrolysis :	500.000 sqm
Redox Flow Batteries :	6.000.000 sqm
Humidifier membranes :	8.000.000 sqm
Fuel Cell membranes :	12.000.000 sqm

Markets and Products

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Energy Storage	Hydrogen	Carbon Dioxide	FUMEGA	The Mobility F.C. Membranes
Membranes for Energy Storage in Batteries	Membranes for the Production of Hydrogen	Electrodialysis with Bipolar Membranes	Electro-Membrane Separations and Ultrapure Water	Fuel Cell Membrane Technology
Vanadium and all other Redox Flow Batteries	PEM and Alkaline Water Electrolysis	CO2 Capture and Conversion	JV FUMATECH & MEGA	JV FUMATECH & Chemours

We strike for a total membrane production capacity for all our markets in water treatment and energy applications of 50 Mio.sqm by the year 2030

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Highlight

State-of-the Art:

Long-duration energy storage in all Vandadium flow batteries

Alternative batteries based on

- all organic electrolyte
- complex metal electrolytes and Iron-Chromium electrolytes
- alkaline metal electrolytes
- Hybrid batteries

Potentially huge volumes:

250.000 – 1,5 Mio m2 of membranes per GW

Market for LDES by 2030 could be about 30 GW

The membrane affect performance but more important controls the electrolyte management !

Long duration energy storage:

RFB because of Safety!

Long storage time > 4 h!

Direct competition with LiB, hydrogen and others

From EES towards LDES:

from 1990 : kWh range FB

towards 2030 : GWh range LDES

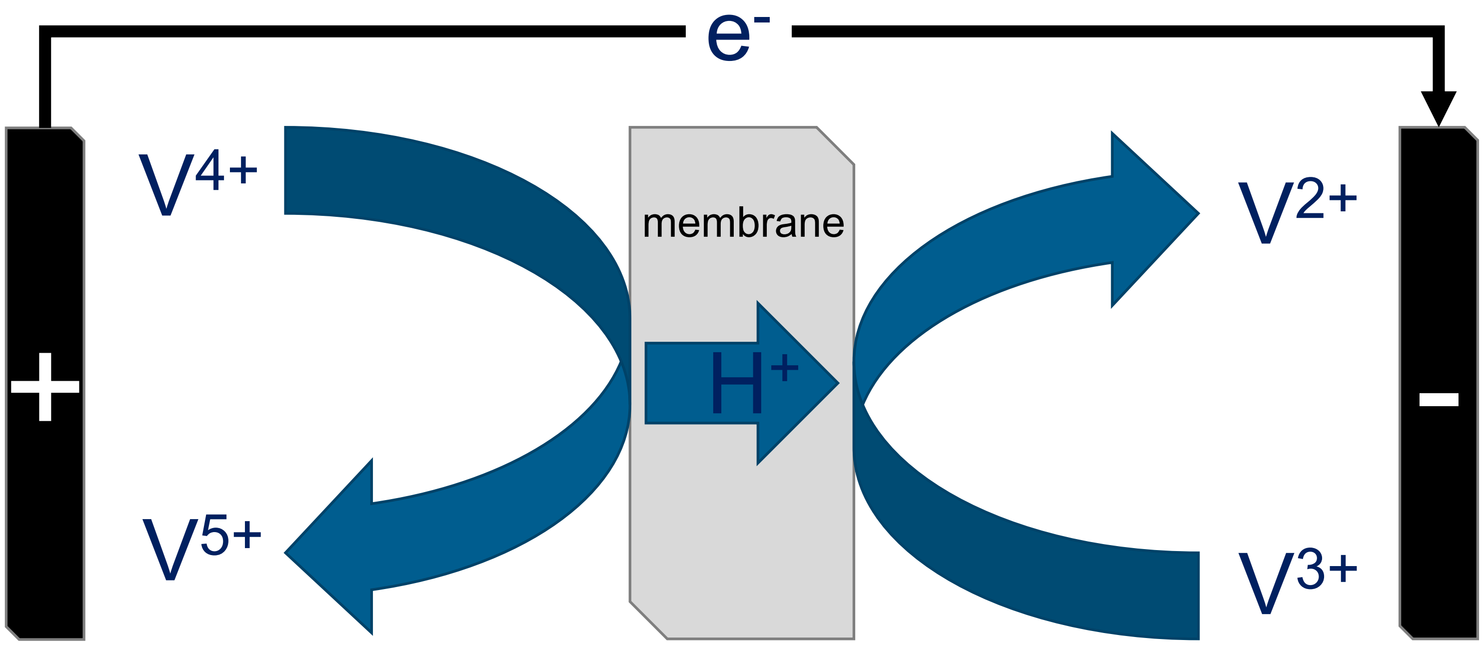
Capex is shifting from membrane and stack cost to electrolyte cost

Membrane selectivity and durability are getting more relevant

Membranes and Separators for RFB

A flow battery electrolyte is complex and both anions (OH^-, Cl^-, …) and cations (H^+, Na^+, K^+, …) could possibly permeate the membrane by diffusion and electro-migration.

Membrane selection : microporous Separator versus. Cation- or Anion exchange membranes

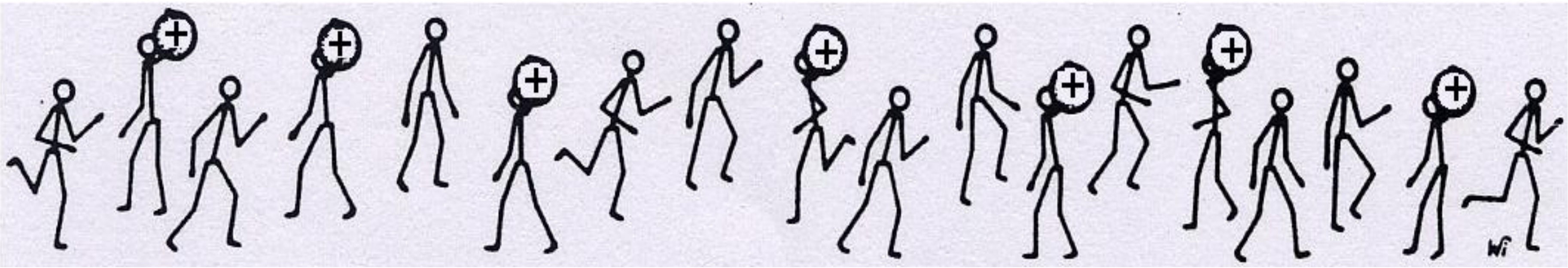


The ideal membrane is not cation selective but proton selective

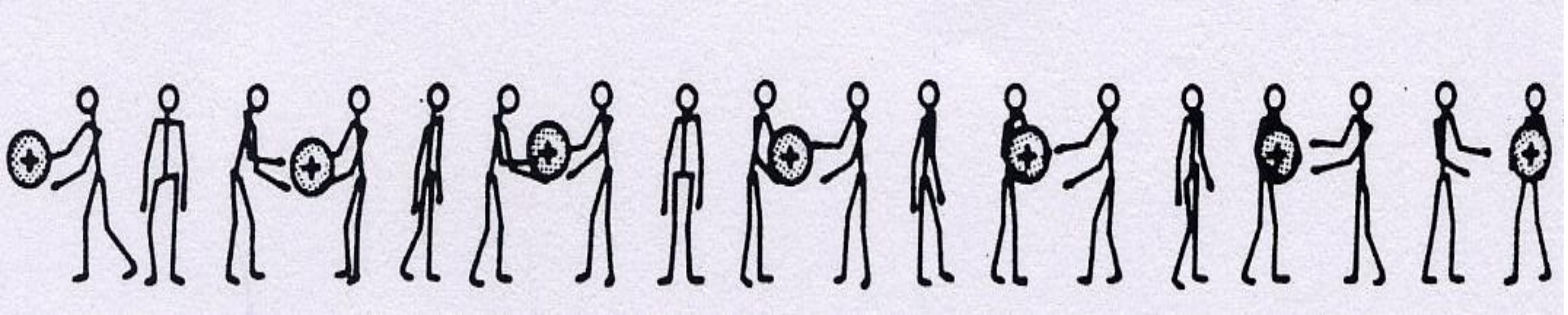
- ►In symmetric electrolytes such as VRFB, lower membrane selectivity could be controlled by Remixing of the electrolyte.
- ► In asymmetric systems such as Organic flow batteries, the electrolyte will have to be disposed at EOL.
- ► In Fe/Cr systems, low selectivity has to be compensated by equimolar mixtures of Fe/Cr in both anolyte and catholyte.

Cation versus Anion Exchange Membrane

Cation exchange membrane: strong correlation between proton transport and electrolyte transport. The protogenic group is a sulphonic acid group bound to the membrane ionomer.



Anion exchange membrane: proton transport dominated by structure diffusion (Grotthuss Mechanism). Strong acid base interaction with an amphoteric protogenic group of the membrane.



Cation versus Anion Exchange Membrane

Vanadium flow batteries	proton selective AEM	fumasep® FAP-series (FAP-450)
	cation selective CEM	fumasep® F-series (F-950, FS-830)
Organic flow batteries	cation-exchange membrane	fumasep® E- and S-series (E-620-PE(K)
	anion-exchange membrane	fumasep® FAA-series (FAA-30-PE)
Iron-Chromium batteries	bilayer mixed membranes	fumasep® FBM

Cation exchange membranes	Anion exchange membranes
Low selectivity	High selectivity
High conductivity	Medium conductivity
High electrolyte transfer	Low electrolyte transfer
High oxidation stability	Medium to good oxidation stability
High cost for PFSA	Medium to low cost

General Membrane Properties

Ideally, the membrane should meet following condition:

- Low resistance (= high conductivity, high VE)
- High selectivity (= high efficiency, high CE)
- Ex-situ durability under V(5+)
- Oxidation stable
- Reductive stability
- In VRFB, stable in the presence of chlorine (chlorine formation at high SOC)
- Stable in the presence of impure electrolytes
- Mechanically robust and low-cost (optionally reinforced with microporous films
- Low cross-over of liquids
- Operation range for high current densities over the entire State-of-Charge (5 – 95% SOC)

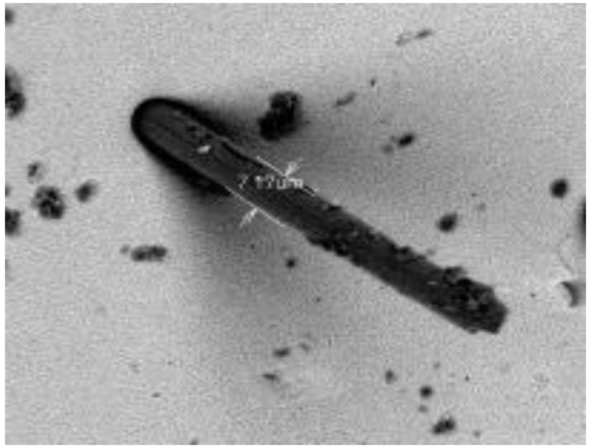
Mechanical Properties

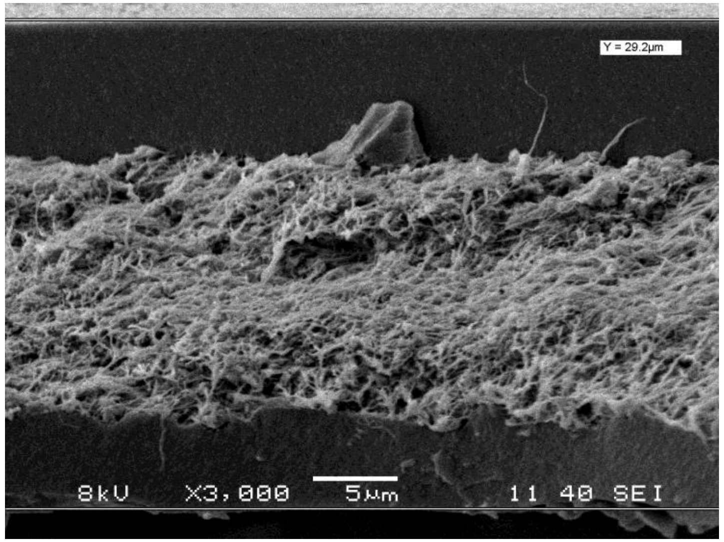
Mechanical properties of flow battery membranes are very relevant as for the stack design :

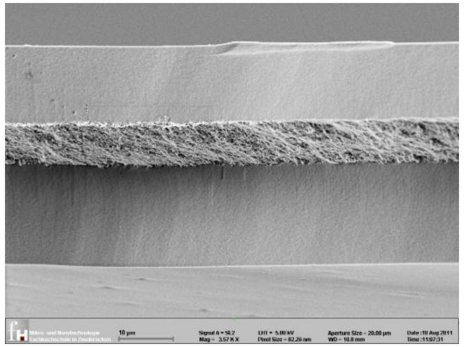
- Control of swelling and dimensional change
- Durability under the seal (creep resistance)
- Penetration of carbon fibres into the membrane

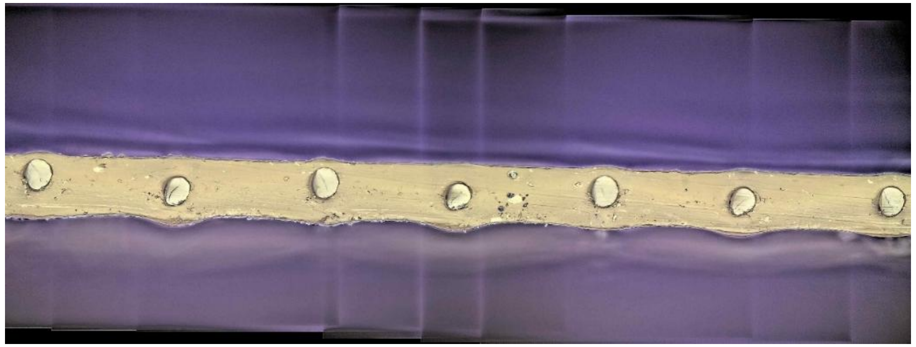
- Swelling from dry to wet
- Installation in the dry-state should be possible (no pre-swelling needed)

- Reinforced with woven PEEK, ePTFE, ePE, ePP, …









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Optical Inspection of Membranes

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In-Line quality control during production :

1. high-frequency thickness control (weight of the wet film, dry film and film after annealing in g/cm^2)

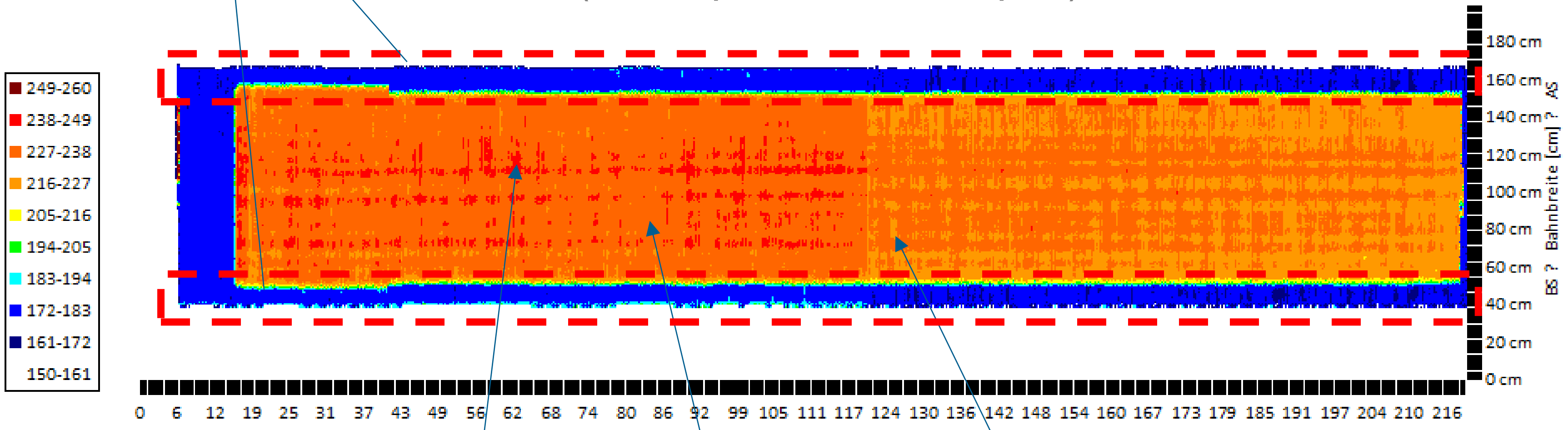
2. Optical inspection

Video analysis for

- thickness
- defects,
- pinholes,
- particles
- or other deviations

Cut-off edges

FAP-450
(entire production in-spec)



+2 to + 3 µm

+1 to + 2 µm

0 to + 1 µm

Electrochemical Characterisation

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- Determination of membrane‘s resistance via electro-impedance spectroscopy and comparison with polarisation curve

- Determination of coulombic, voltage and energy efficiencies, osmotic and electro-osmotic permeabilities

- Determination of cells resistance and IR drop

- Determination of self-discharging behavior

- Carrying out of extended cycle tests (at least 100 cycles) at 160 mA/cm^2 with selected samples: determination of changes of coulombic efficiency, cell‘s and membrane‘s resistance and electrolyte‘s capacity

Electrochemical Characterisation

- Determination of coulombic, voltage and energy efficiencies, osmotic and electro-osmotic permeabilities

Membrane	Thickness / µm	Reinforcement	CE / %	VE / %	EE / %
FAP-450	45 +/- 3	no	97,5	92,8	90,5
FAP-420-PE	20 +/- 2	yes	99,0	91,6	90,7
F-950	45 +/- 2	no	93,0	86,5	80,5
VPX-20	20 +/- 1	no	98,8	94,5	93,3

C.E. = coulomb efficiency
V.E. = voltage efficiency
E.E. = energy efficiency

CE = Q(discharge) / Q(charge)
VE = U(1/2-time disch.) / U (1/2-time charge)
EE = CE * VE

Electrochemical Characterisation

- Determination of coulombic, voltage and energy efficiencies, osmotic and electro-osmotic permeabilities

Membrane	EOP @ 40 mA/cm^2 [µl/(cm^2.hr)]	OP @ 40 mA/cm^2 [µl/(cm^2.hr)]	EOP @ 60 mA/cm^2 [µl/(cm^2.hr)]	OP @ 60 mA/cm^2 [µl/(cm^2.hr)]
FAP-450	10,1	6,3	11,0	5,9
FAP-420-PE	9,6	4,1	11,5	4,8
F-950	30,3	2,0	45,7	3,1
VPX-20	1,4	0,6	7,9	5,8

EOP (Electro-osmotic permeability) = volume changes of electrolyte during charging. Average from changes cathode and anode is taken.
OP (Osmotic permeability) = volume changes of electrolyte during complete charging-discharging cycle

EOP depends partly on c.d., while OP not.

Electrolyte Cross-over

-Cation exchange (abbr. CEM), PFSA-based ones

-electrolyte cross-over direction $V^{(5+)}$: transfer of active species

-Net volumetric transfer towards the positive half-cell

-Anion exchange (abbr. AEM), proprietary proton conducting AEM

-electrolyte cross-over direction $V^{(2+)}$

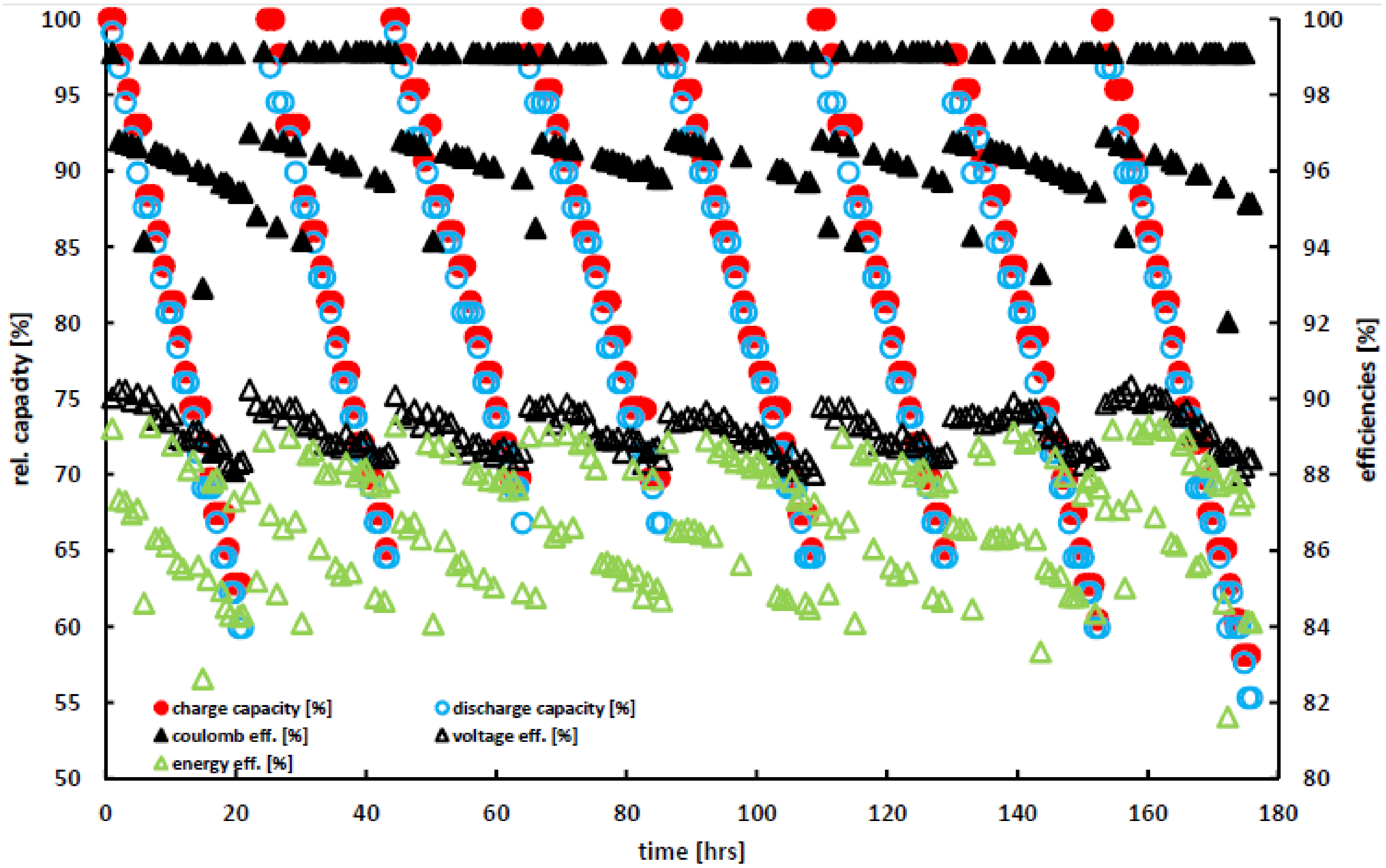
-Net volumetric transfer towards the negative half-cell

-Cross-over Management

-CEM: Remixing of catholyte and anolyte

-AEM: Rebalancing / Releveling either with a capillary between both electrolyte storage tanks or by an overflow from the negative into the positive half-cell

Electrolyte Cross-over and Releveling



Vanadium Diffusion in FAP Membranes

Vanadium Species (valency)	Vanadium Species	Diffusion Coefficient x 10^{-07} cm^2 / min
2	V^{2+}	2,09
3	V^{3+}	1,31
4	VO^{2+}	2,05
5	VO_2^+	2,85

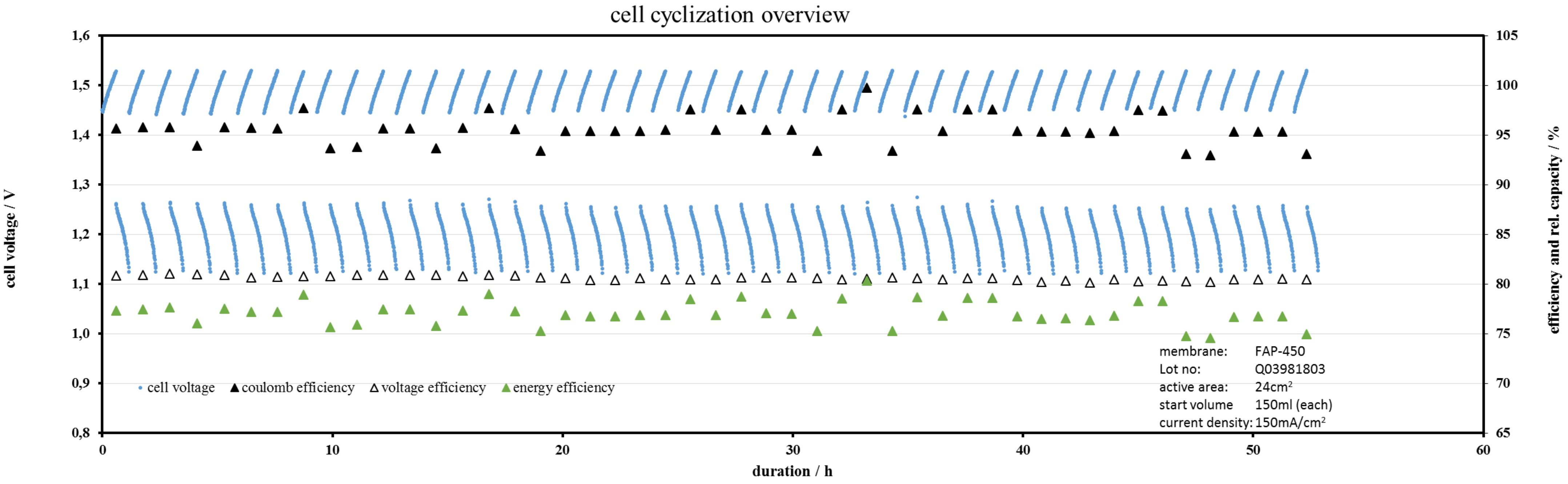
Re-balancing of electrolyte to the positive side needed. The concentration of Vanadium in the RFB electrolyte will change with less 0.01M relative to the total Vanadium concentration per 100 cycles !

Self - Discharging

-Self-discharging characteristics is measured from charge state 98%. The pumps circulate the electrolyte. Current cables are disconnected so no parasitic current is drawn. After 6 hrs the left-over capacity is determined.

Membrane	Thickness / µm	Reinf.	Self-discharge / (% of Q).hr^{-1}	Self-discharge / C.$(cm^2.hr)^{-1}$
FAP-450	45 +/- 3	no	4,4	3,8
FAP-420-PE	20 +/- 2	yes	4,0	3,1
F-950	45 +/- 2	No	0,47	0,77
VPX-20	20 +/- 1	no	3,2	3,4

Load Cycling at 150 mA/cm-2 with Rebalancing (FAP-450)



Current density 150 mA/cm2

Aver. Voltage efficiency 97 %

Aver. Coulomb. Efficiency 93%

Summary

Based on 25 years of development and production, we recommend the following types for VRFB:

FAP-450 :	most approved membrane of highest proven durability (15 years)
FAPQ-330 :	highest performance, high current densities of up to 400 mA/cm2 doable … no power drop effect at high SOC
FAP-420-PE :	sealing by ultrasonic or thermal welding possible
F-950 or FS-830 :	operation at current densities higher than 400 mA/cm2

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Thank‘s for your attention!