MM/P Membrane Materials & Processes
Department of Chemical Engineering and Chemistry
TU/e EINDHOVEN UNIVERSITY OF TECHNOLOGY

Future of energy storage: low-cost flow batteries that enable the green energy transition

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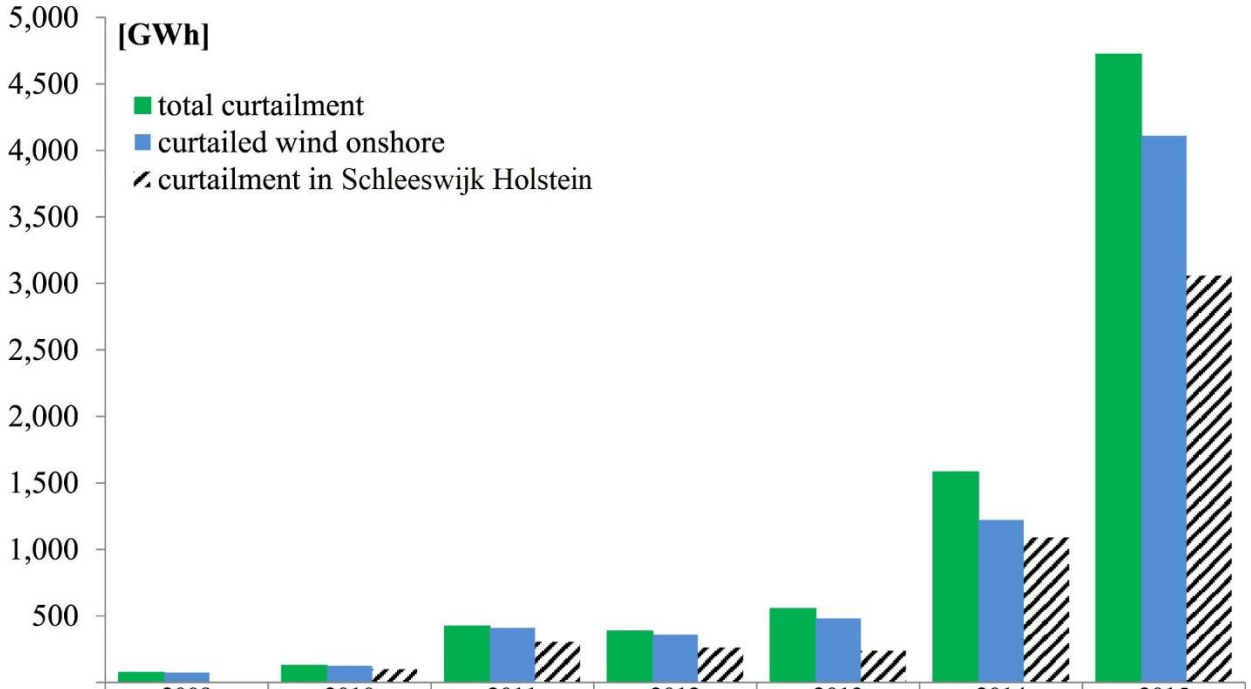
elestor

Green energy transition is not happening yet?!

Clean energy sources are abundantly available …
… and the technologies have been developed

The cost of surplus electricity in Northern Germany



[GWh]	2009	2010	2011	2012	2013	2014	2015
total curtailment	74	127	421	385	555	1,581	4,722
curtailed wind onshore	73	125	410	358	480	1,221	4,110
curtailment in SH		100	308	262	239	1,092	3,055

Curtail: action of destroying surplus electricity

Total curtailment: sum of curtailed solar and wind

Schleeswijk Holstein Netz AG: the biggest green grid operator

Source: Renewable energy curtailment: A case study on today's and tomorrow's congestion management, H. Schermeyer et al.

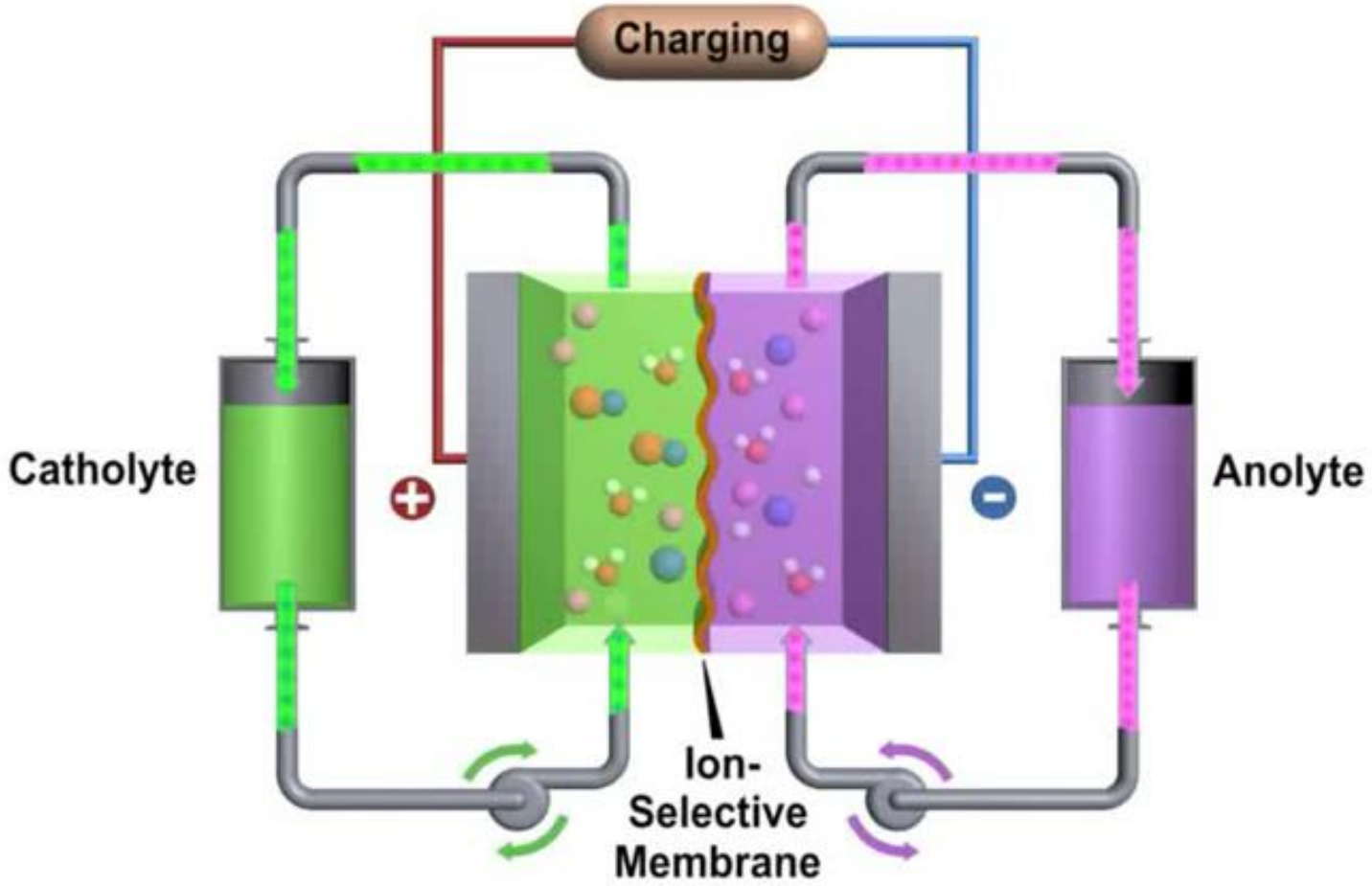
In 2015, about 3% of Germany green electricity was curtailed and it costs approx. 480 M€

The demand for storage in a changing world

- With more electricity generated by sun & wind – and less fossil:
  - We will need to bridge longer periods of time
  - We need more Capacity [MWh] rather than more Power [MW]
  - The market: >100 times more storage is needed (from 4.67 to 500 TWh)
- Flow batteries can be designed with any MW/MWh combination and in any location

Cost-effective storage system is the missing link in the energy transition

Flow battery working principle



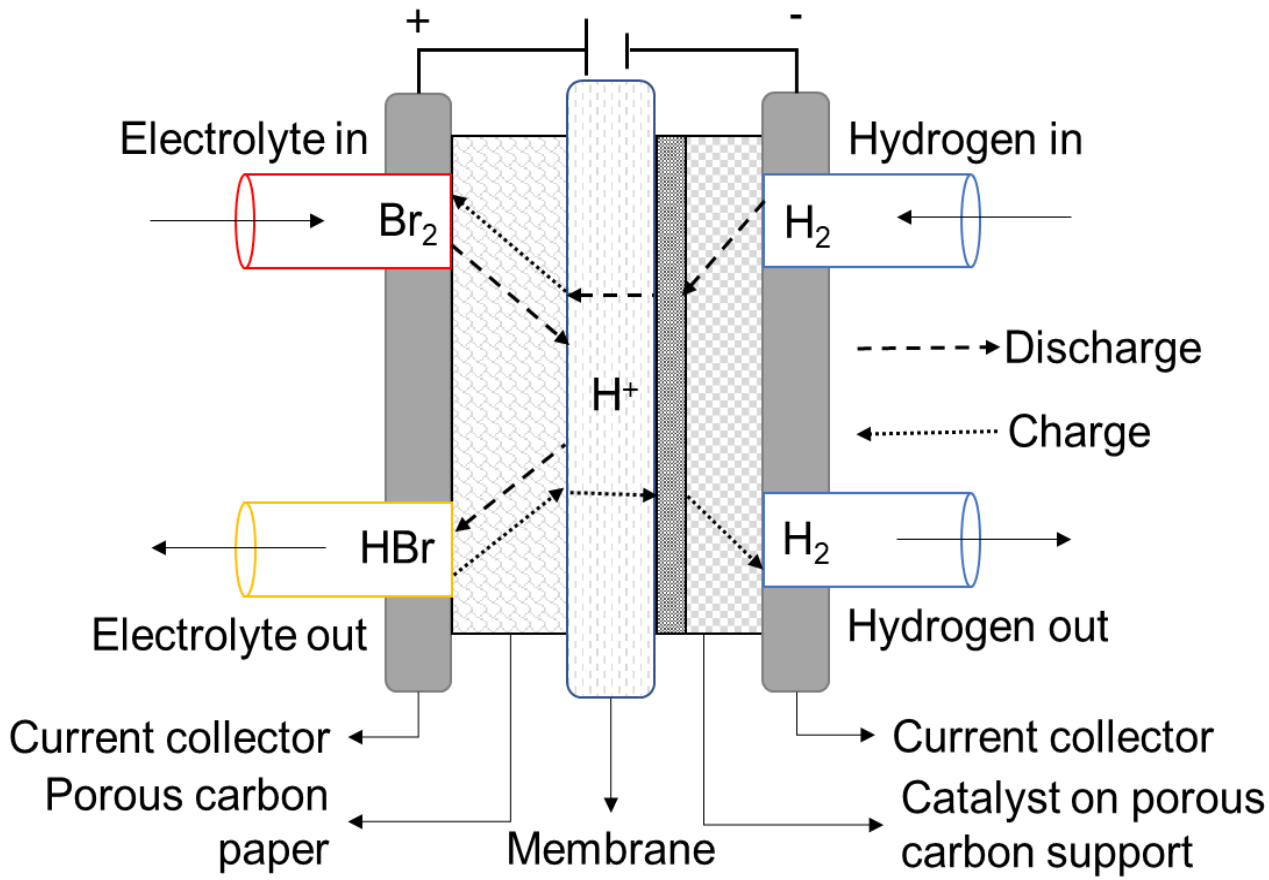
Source: Pacific Northwest National Laboratory (PNNL) S&T

Benefits of flow battery

- Power and Capacity are not coupled:
  - Membrane surface area → Power [kW]
  - Active material volumes → Capacity [kWh]
- As safe as conventional batteries, or even better
- Lifetime independent of ‘Depth of Discharge’
- Fundamentally, no capacity degradation and no self-discharge
- Upgradable and serviceable

Hydrogen-bromine flow battery (HBFB)

$$H_2 + Br_2 \underset{\text{Charge}}{\overset{\text{Discharge}}{\rightleftharpoons}} 2\,HBr + \text{electrical energy}$$



High power system:

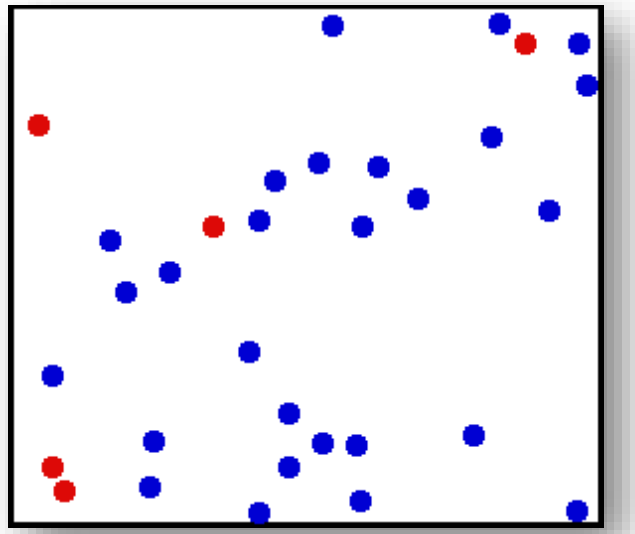
- High reaction rate

Low cost system:

- < €20/kWh reactive materials cost

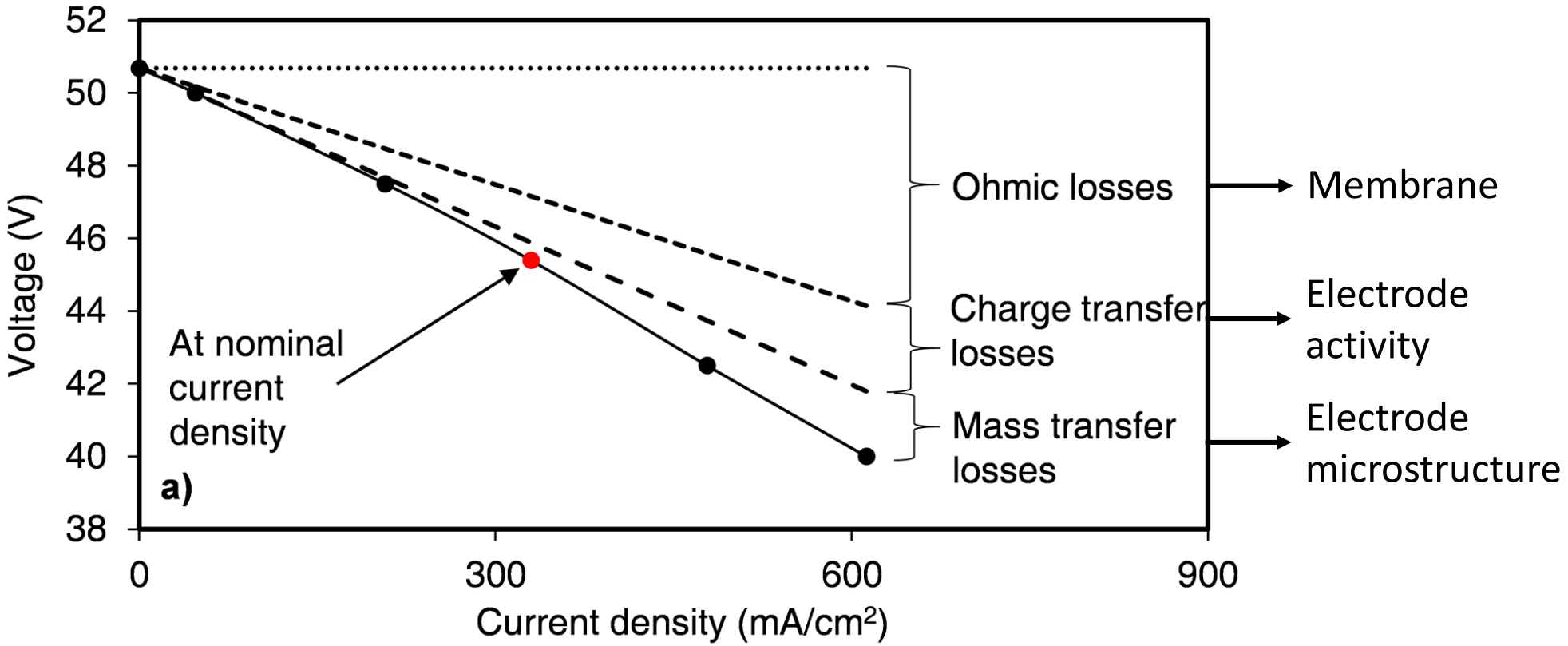
Benefits of HBFB

- Abundant supply (<0.002% of global HBr reserves are sufficient for 500 TWh storage capacity)
- Active materials can be fully recycled, in cooperation with the largest bromine producer in the world
- Highly reactive bromine species
- No hydrogen compressor required



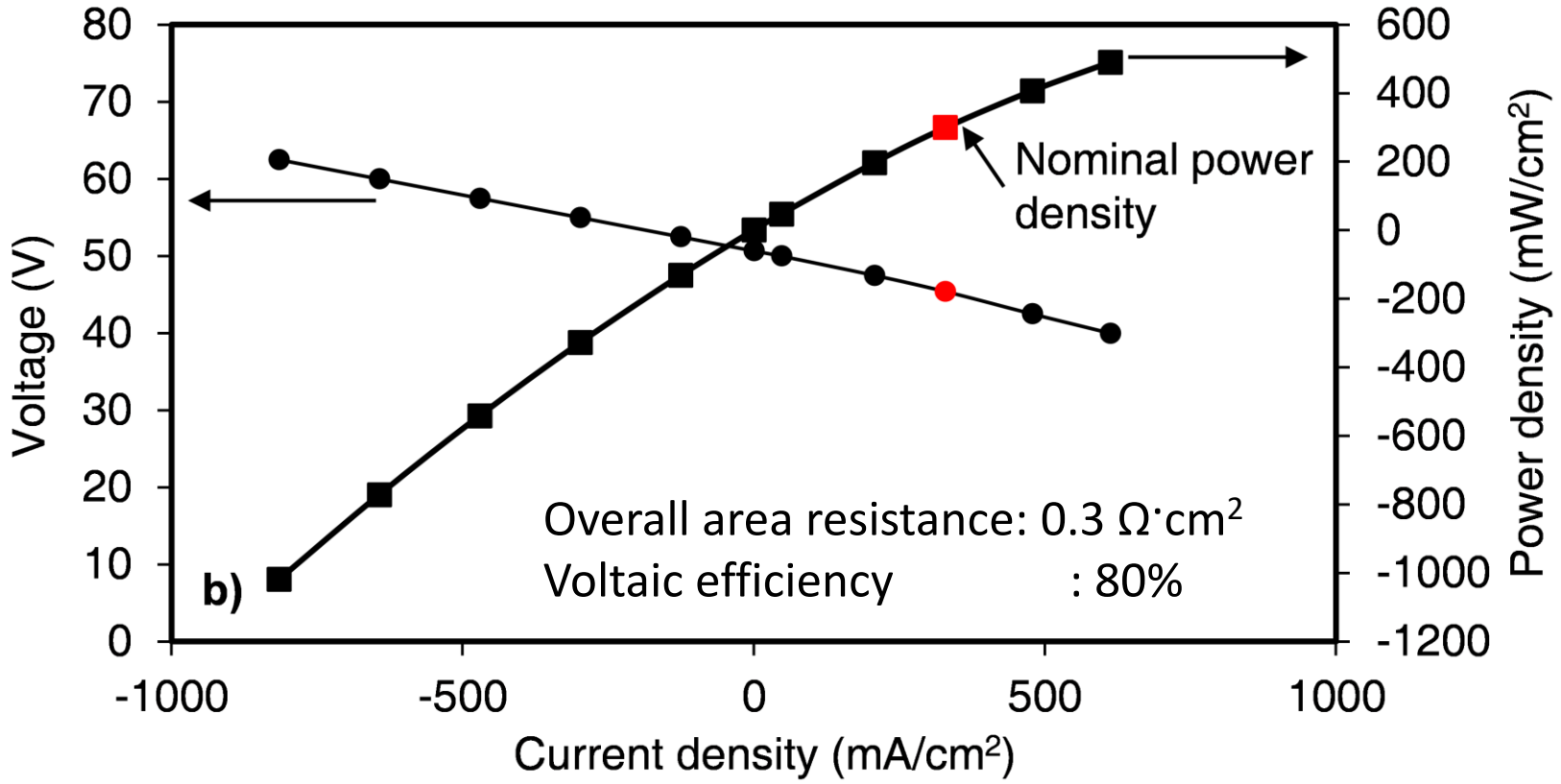
Performance of HBFB

- I-V curve and losses contribution



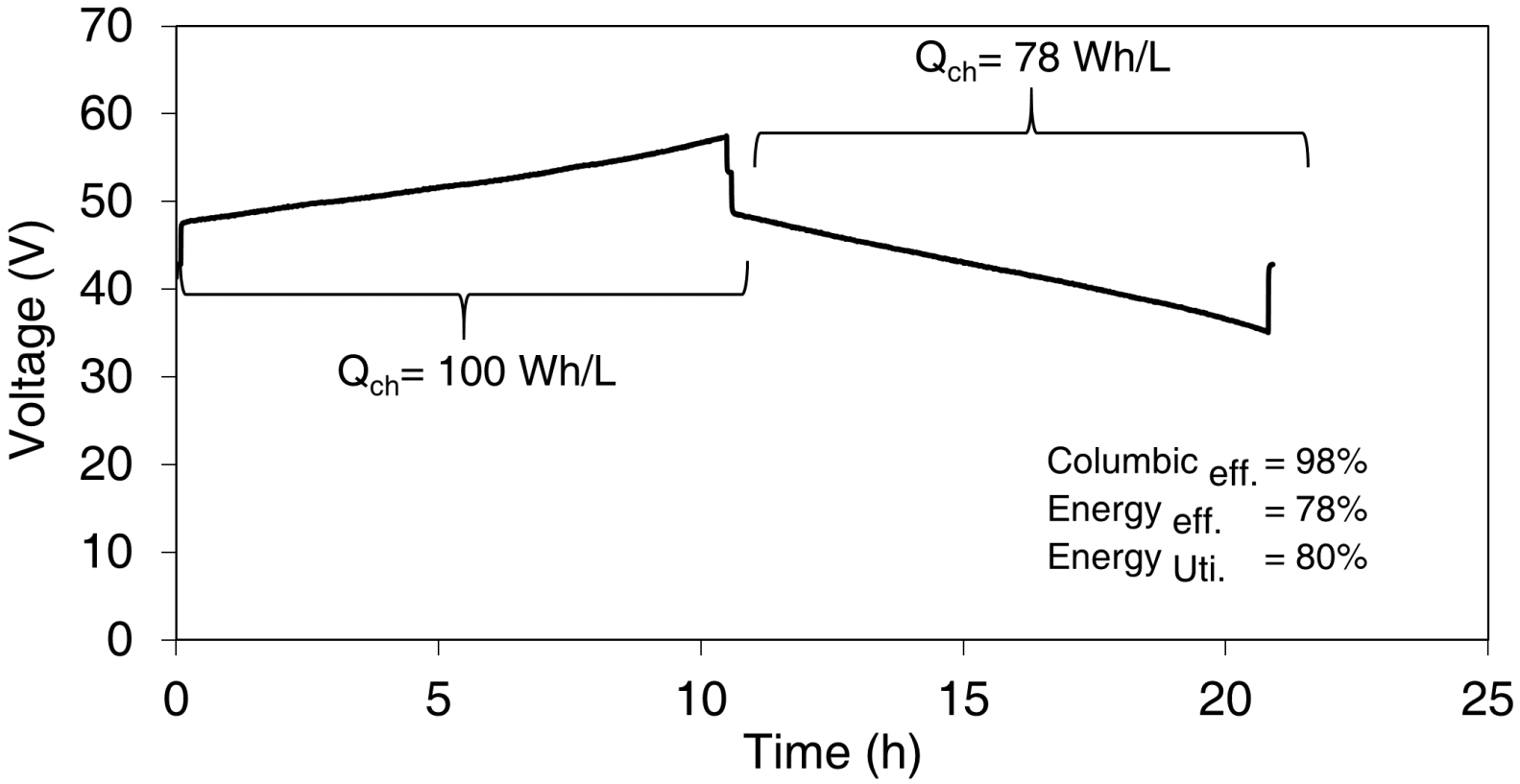
Performance of HBFB

- Polarization curve



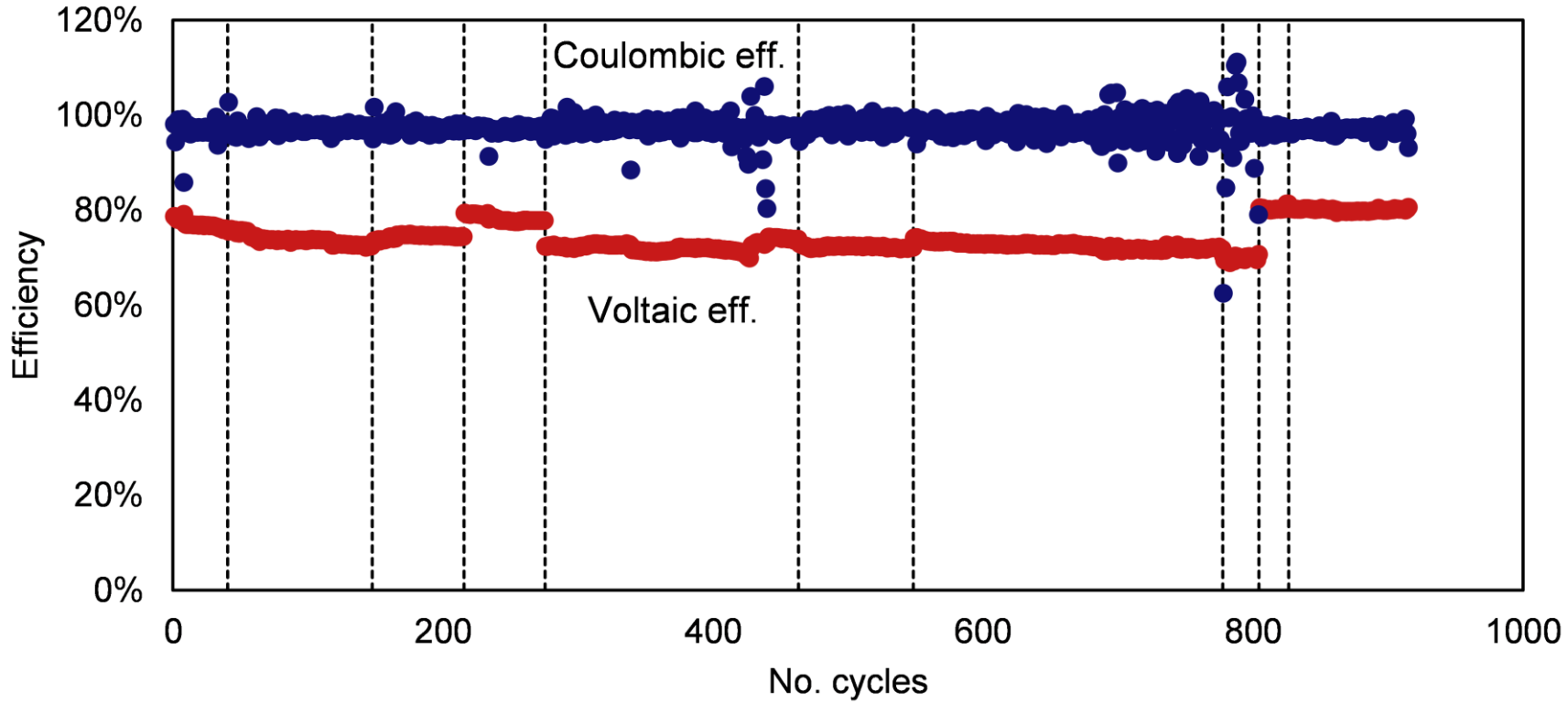
Performance of HBFB

- Cycling profile



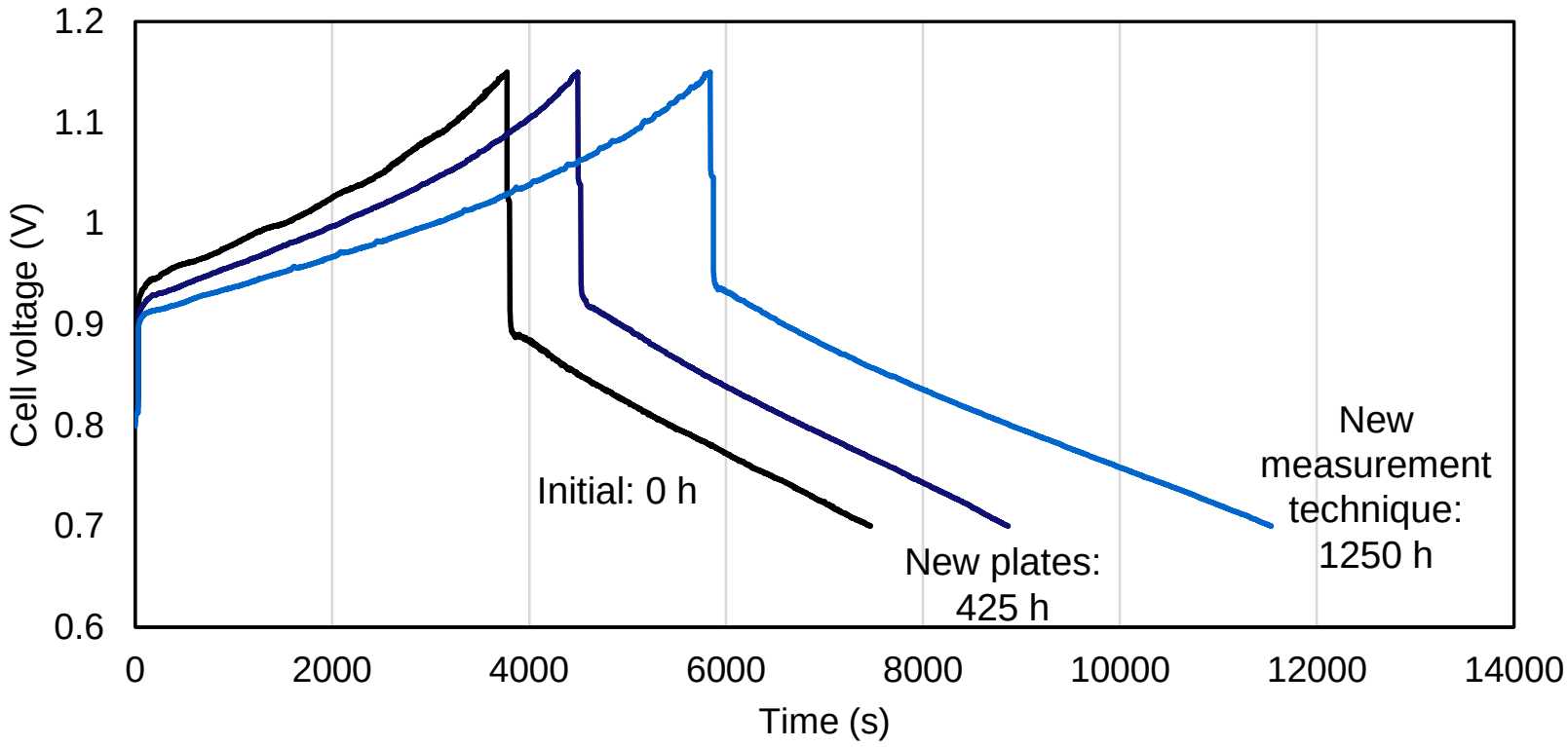
Performance of HBFB

- Long term testing – efficiency profile



Performance of HBFB

- Long term testing – cycling profile



Elestor HBFB storage system model

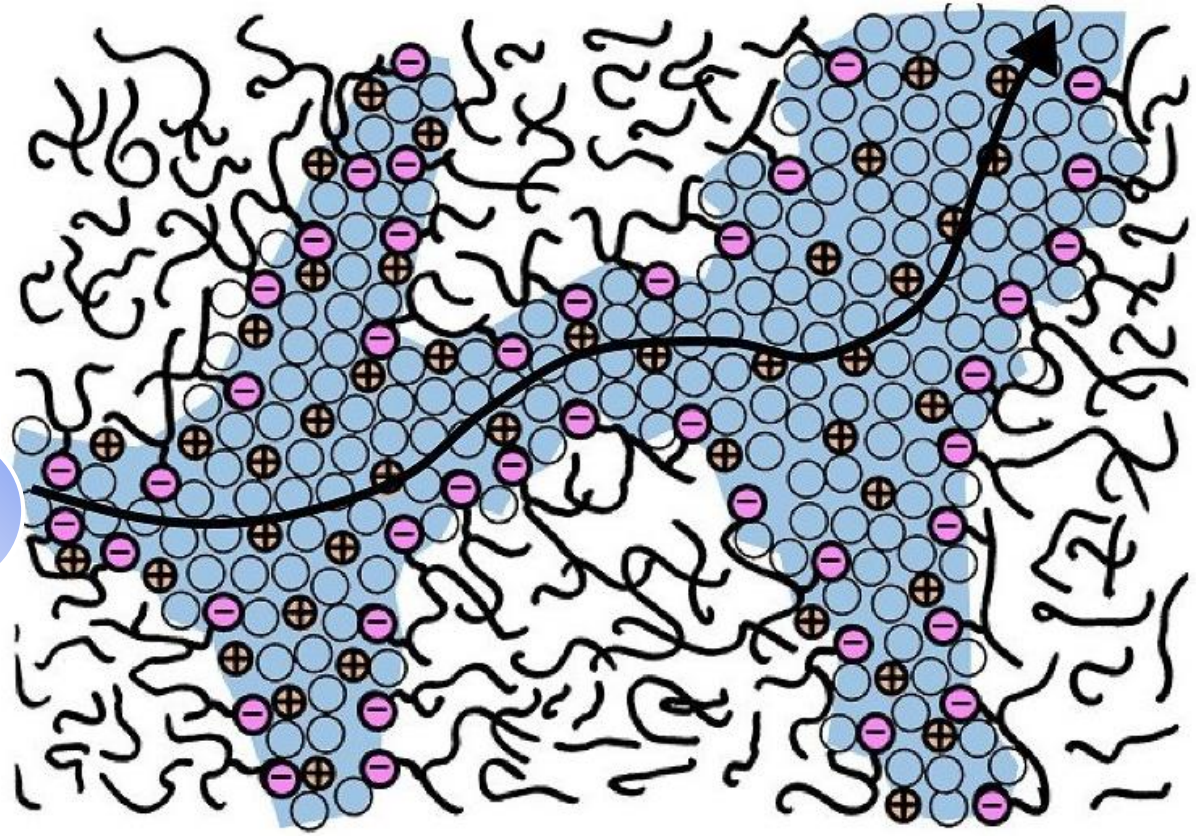
- Designed storage system summary for minimum viable product

Parameter	Value	Unit
Nominal (dis.) power	500	kW
Storage time	10	h
Energy efficiency	78	%
System efficiency	70	%
System lifetime	10+10	year

High performance – low cost HBFB is a promising technology to store surplus electricity

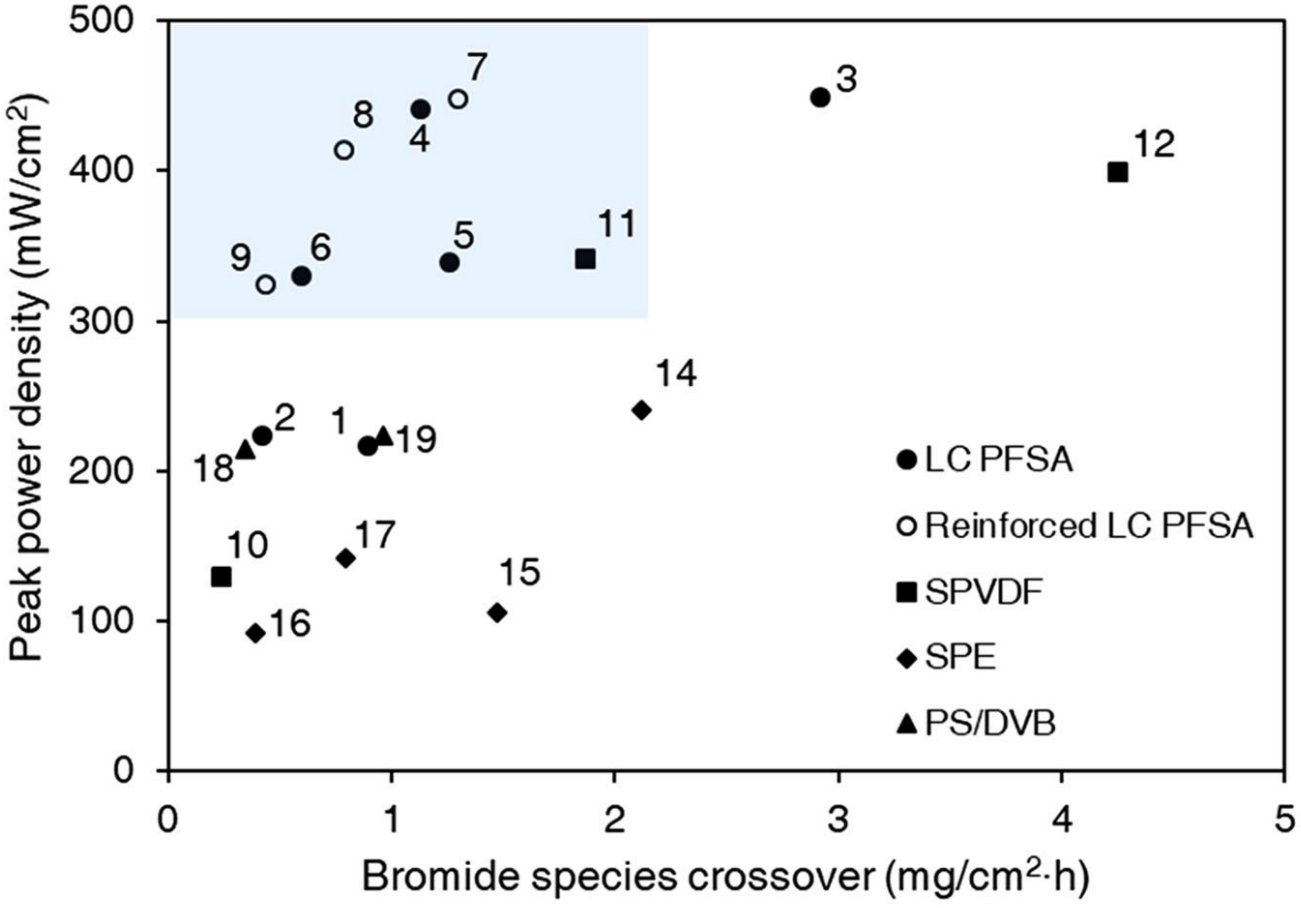
Membranes for HBFB technology

- Nafion® type membranes:
  - Polymer backbone
  - Functional groups (hydrophilic & proton conductive)
- Performances:
  - Proton conductivity
  - Selectivity
  - Cost



D. K. Kreuer, J. Membr. Sci. 185 (2001) 29–39.

Performance mapping of HBFB membranes

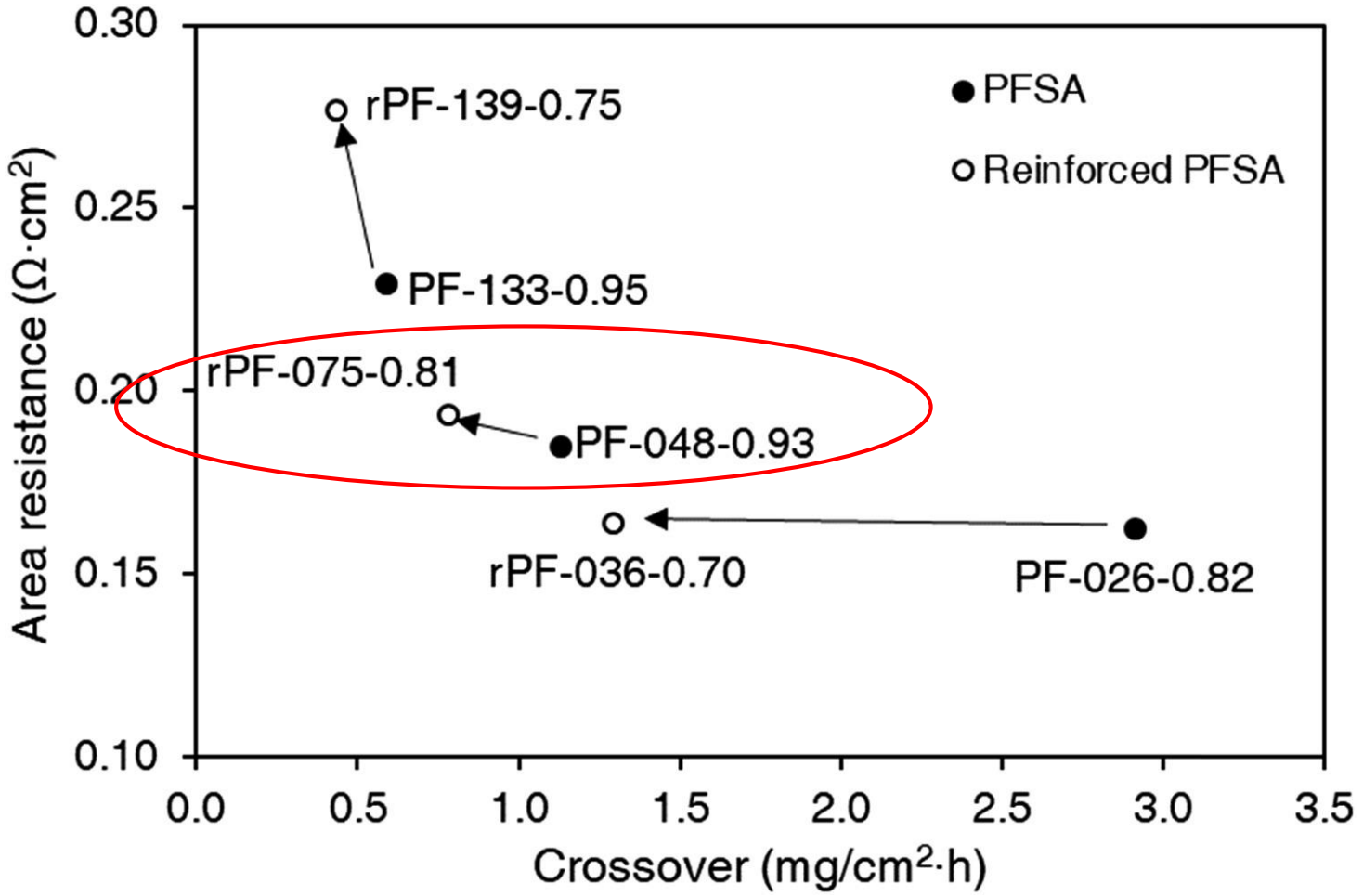


1 PF-052-0.47
2 PF-110-0.49
3 PF-026-0.82
4 PF-048-0.93
5 PF-103-1.00
6 PF-133-0.95
7 rPF-036-0.70
8 rPF-075-0.81
9 rPF-139-0.75
10 PV-054-0.41
11 PV-055-0.73
12 PV-056-0.86
14 PE-058-0.85
15 PE-103-0.87
16 PE-038-1.04
17 PE-046-1.58
18 rPS-106-2.10
19 rPS-179-2.71

Nafion® membranes:

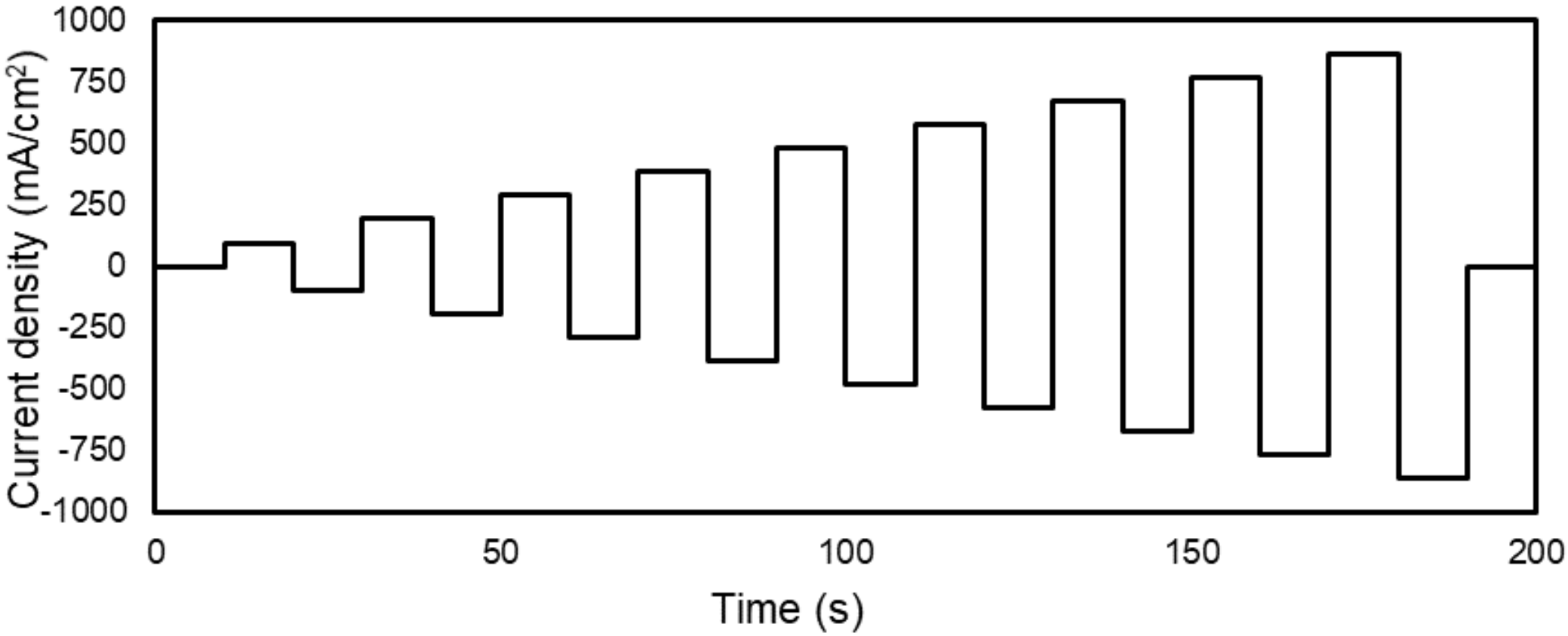
- Good inter-connectivity ionic pathways
  → High power
- Super acid functional groups
  → Low crossover
- Smaller hydrophilic region
  → Low crossover

Short term impact of reinforcement

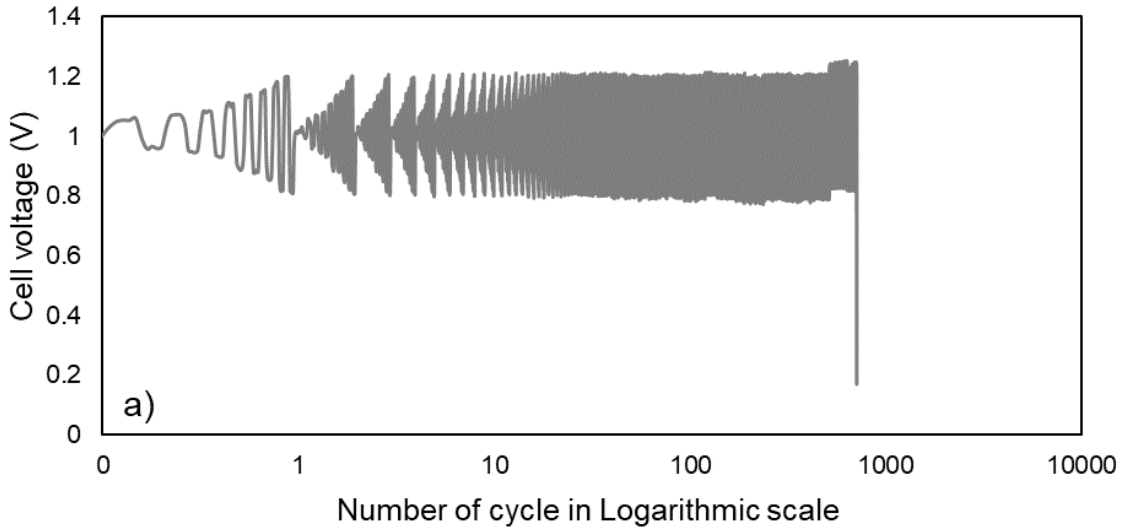


Long term impact of reinforcement – Method

- High-frequency cycling accelerated lifetime test (ALT)

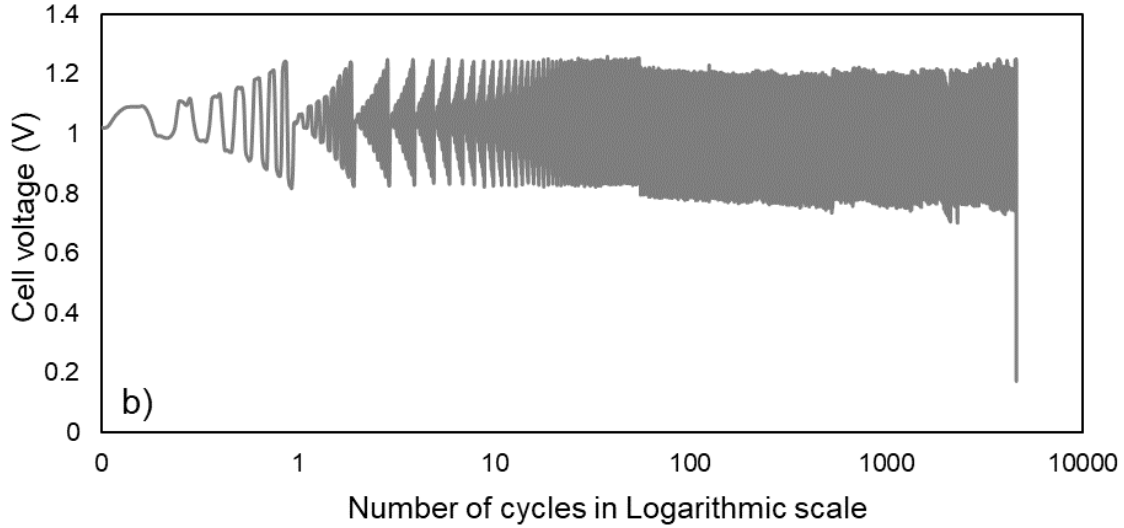


Long term impact of reinforcement – Results



a) Nafion®:

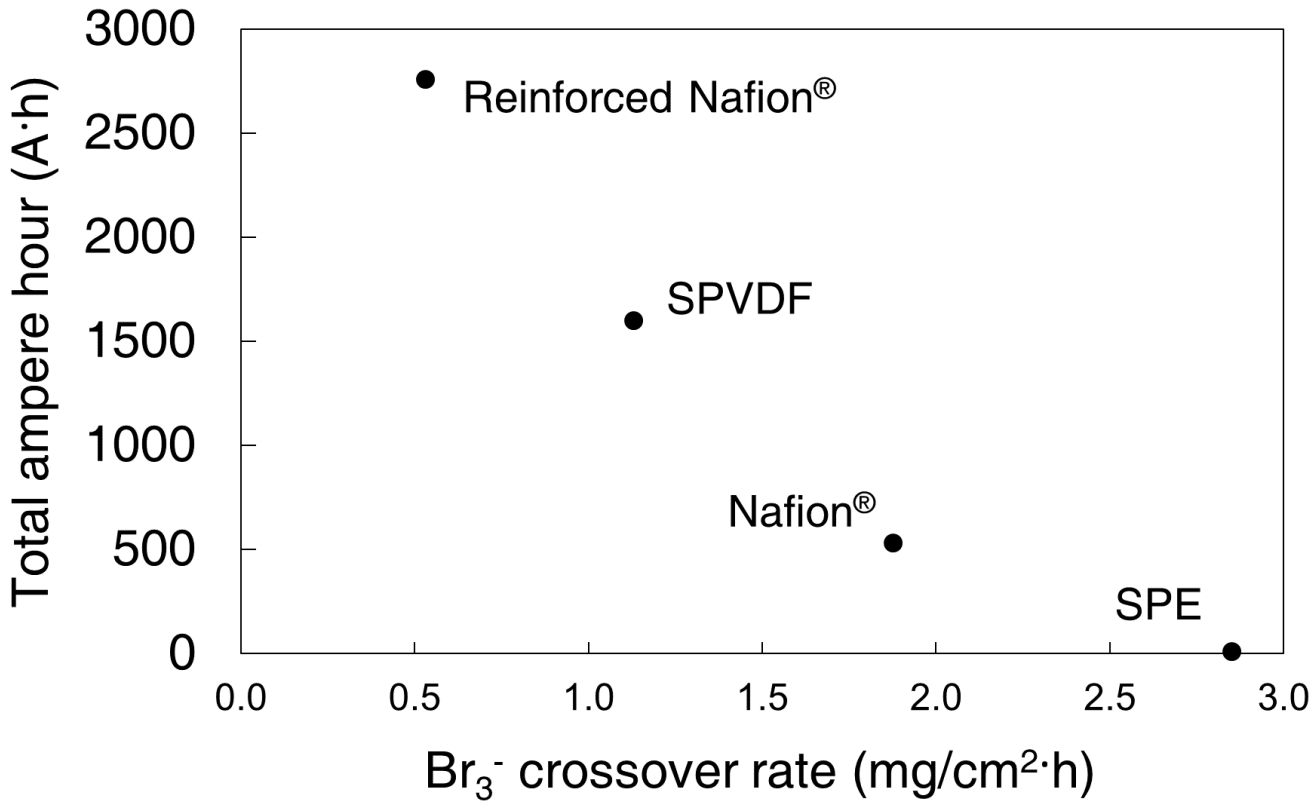
- Limiting current density: 850 mA/cm^2
- Number of cycles: ±710



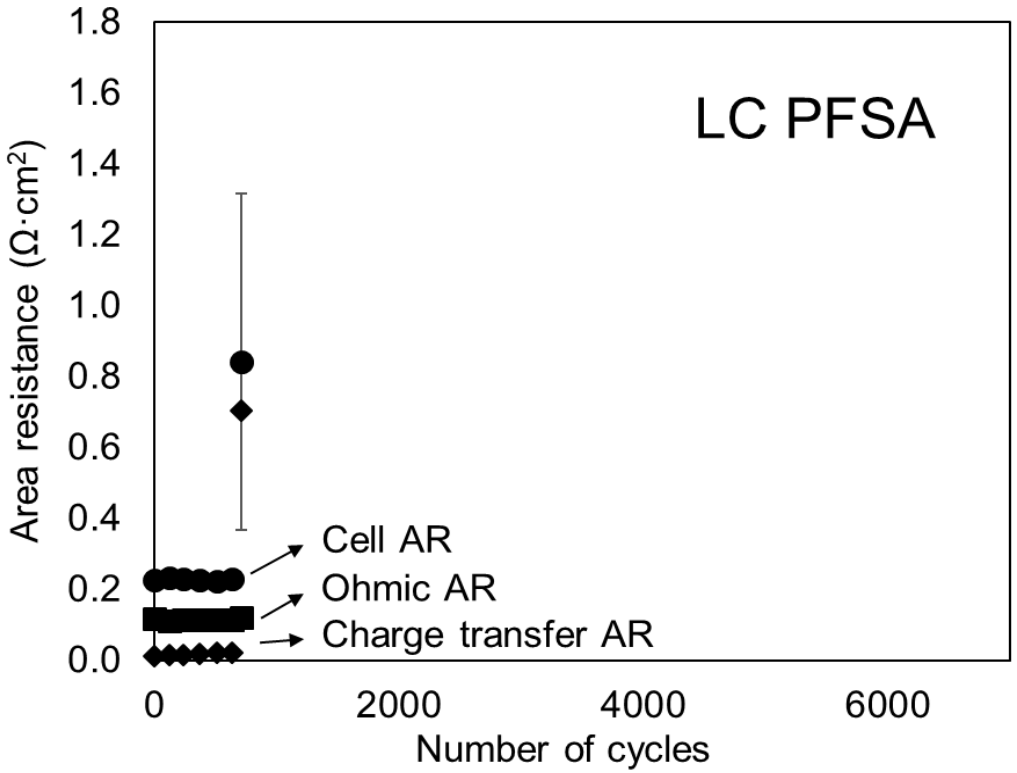
b) Reinforced Nafion®:

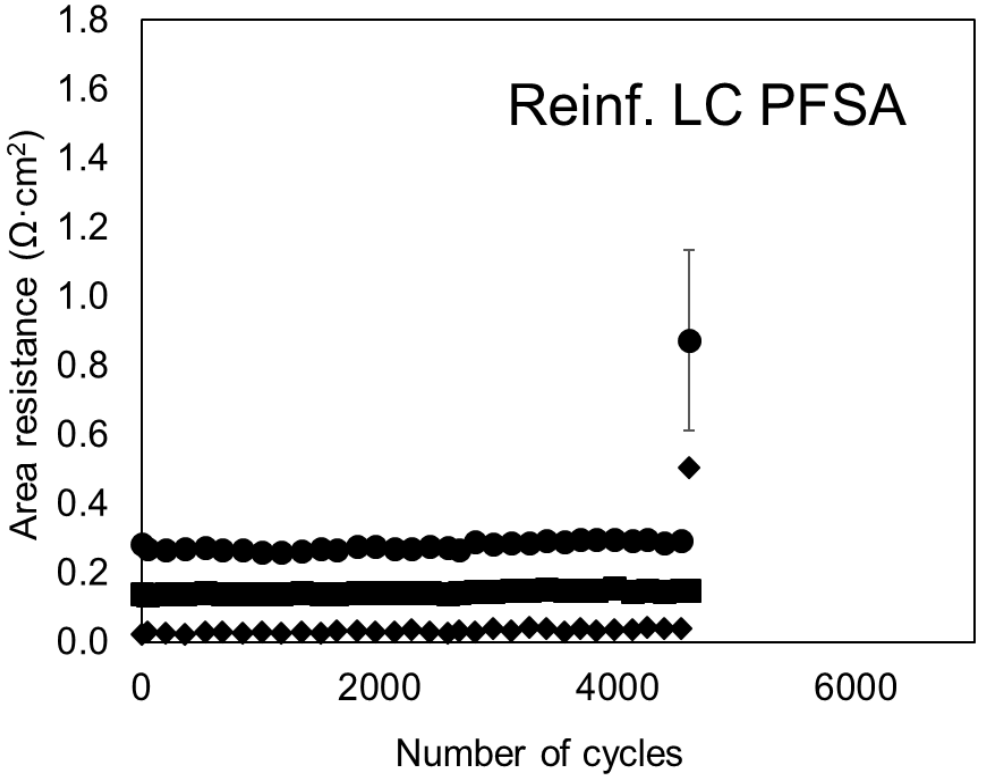
- Limiting current density: 750 mA/cm^2
- Number of cycles: ± 4600

Long term impact of reinforcement – Results



Failure mode analysis





Failure mode analysis

Element	Mass ratio with C		
	Native catalyst layer	Nafion®	Reinforced Nafion®
F	0.48	0.58	0.42
S	0.03	0.02	0.01
Pt	0.94	0.03	0.05

- Bromide species react with Pt particle → soluble bromoplatinic acid (H_2PtBr_6)
- Bromoplatinic acid is dissolved and exits the catalyst layer

Proton exchange membrane determines system efficiency, durability and cost

Take home messages

- Storage is the missing link in the energy transition
- HBFB technology is promising
- Membranes determine the system efficiency, durability and cost

Company profile

- Founded in 2014 by Wiebrand Kout (CTO) - MBI Guido Dalessi (CEO) in 2015
- International team of 20 FTEs (PhD/MSc/BSc/MLO)
- 2 PhD at the research group of Prof. Dr. Kitty Nijmeijer, TUe
- Member of ‘FlowCamp’ consortium (under Fraunhofer Institute)
- 1st financing: Dec 2015 (Dalessi, InnoEnergy, Enfuro)
- 2nd financing: Jul 2019 (Koolen Industries, InnoEnergy)

Recognition:

- 2016: Recognized with several national awards
- 2017: European IDTechEx Award, Berlin, for:

"Best Technical Development within Energy Storage"

(Juried by Fraunhofer, Universität Berlin, Toyota Motors Europe)

- 2019: Perl of the Region (received from The Economic Board)

Elestor expertise

- Deep tech know-how on:
  - Catalysts
  - Electrodes
  - Membranes
  - Electrolytes
  - Cell-stacks
  - Control & power electronics
  - System architecture
  - Compliancy

- Only Elestor does field tests
- >90,000 R&D hours since June 2014

Thank you for your attention

Elestor BV

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