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Advancing Safe Aqueous Pseudocapacitors based on Organic Molecules for Industrial and Grid Energy Storage

Pim Broersen || PE & ES Event 27-05-2026

Sustainable process and energy systems (SPES)

KIP Project: Process efficiency and Flexibility – Industrial Electricity storage

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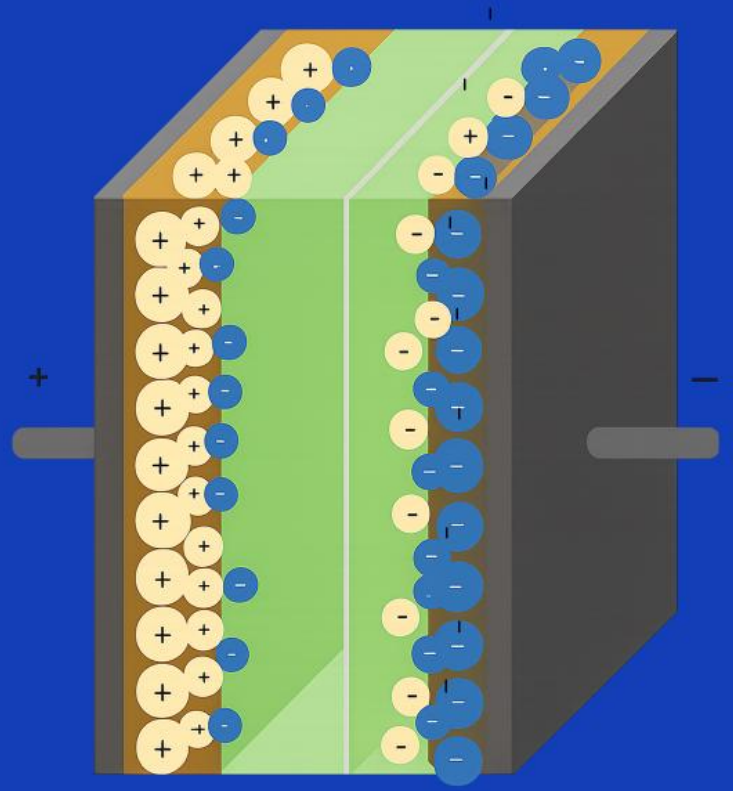

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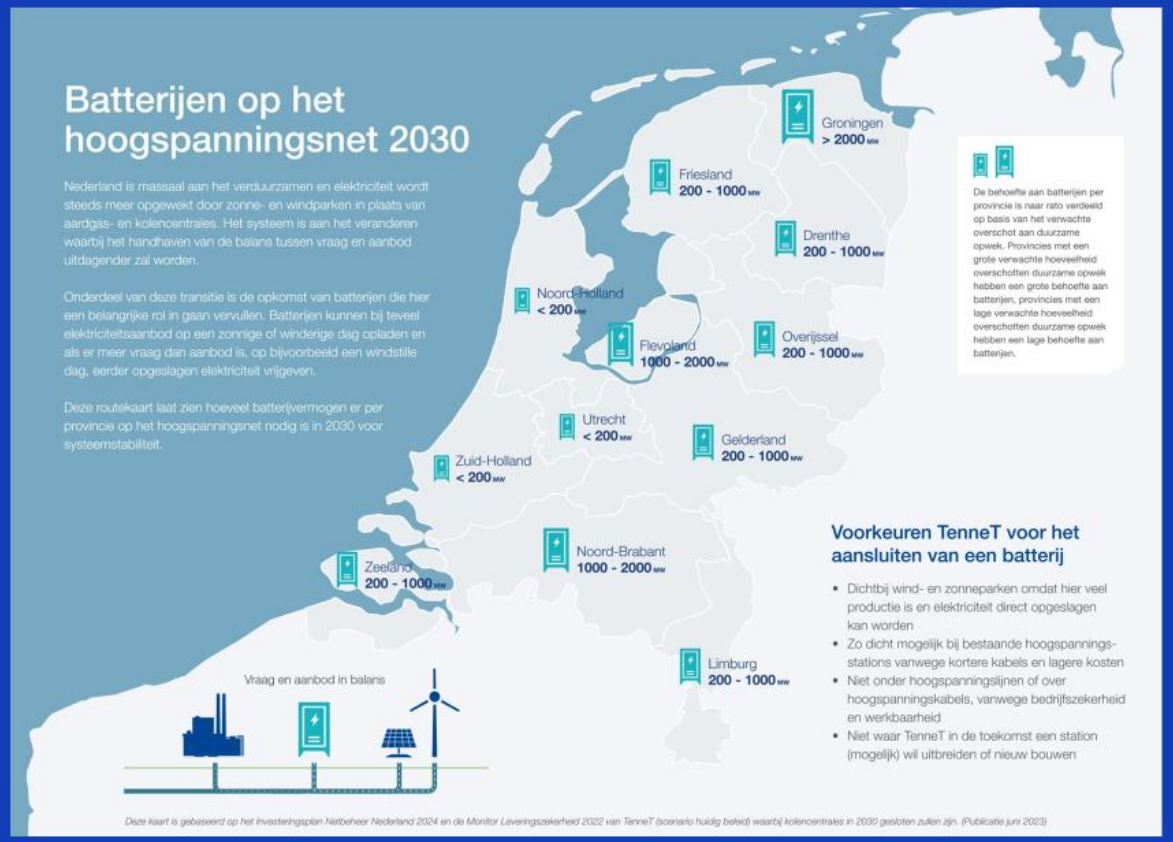
The energy storage challenge

- **Industry needs**: reduce carbon footprint, electrification, flexibility, cost-effective and scalable energy storage solutions to overcome grid congestion and price fluctuations
- **Huge market ahead**. **Grid-scale electricity storage expected to reach 120 GW by 2030** (IEA). Netherlands lagging behind (compared to e.g. Germany) in terms of growth in energy storage (**~150MW installed today, 9GW needed by 2030** according to TenneT)
- **Li-ion batteries currently used as one-size-fits-all solution**, but has several drawbacks (use of CRM, environmental impact, flammability)
- **Vanadium flow batteries is a mature technology and good alternative for LDES**, but with severe supply chain bottlenecks (unreliable sourcing, price fluctuation, no vanadium source in Europe)
- **Organic flow batteries are a promising alternative**, but current performance are limited by poor solubility/stability of organic molecules, and high price of raw materials (due to synthesis costs)



https://www.tennet.eu/nl/battery-energy-storage-systems-bess
https://tennet-drupal.s3.eu-central-1.amazonaws.com/default/2023-06/TenneT_s_position_large_BESS_-_Public_Info_-_update.pdf

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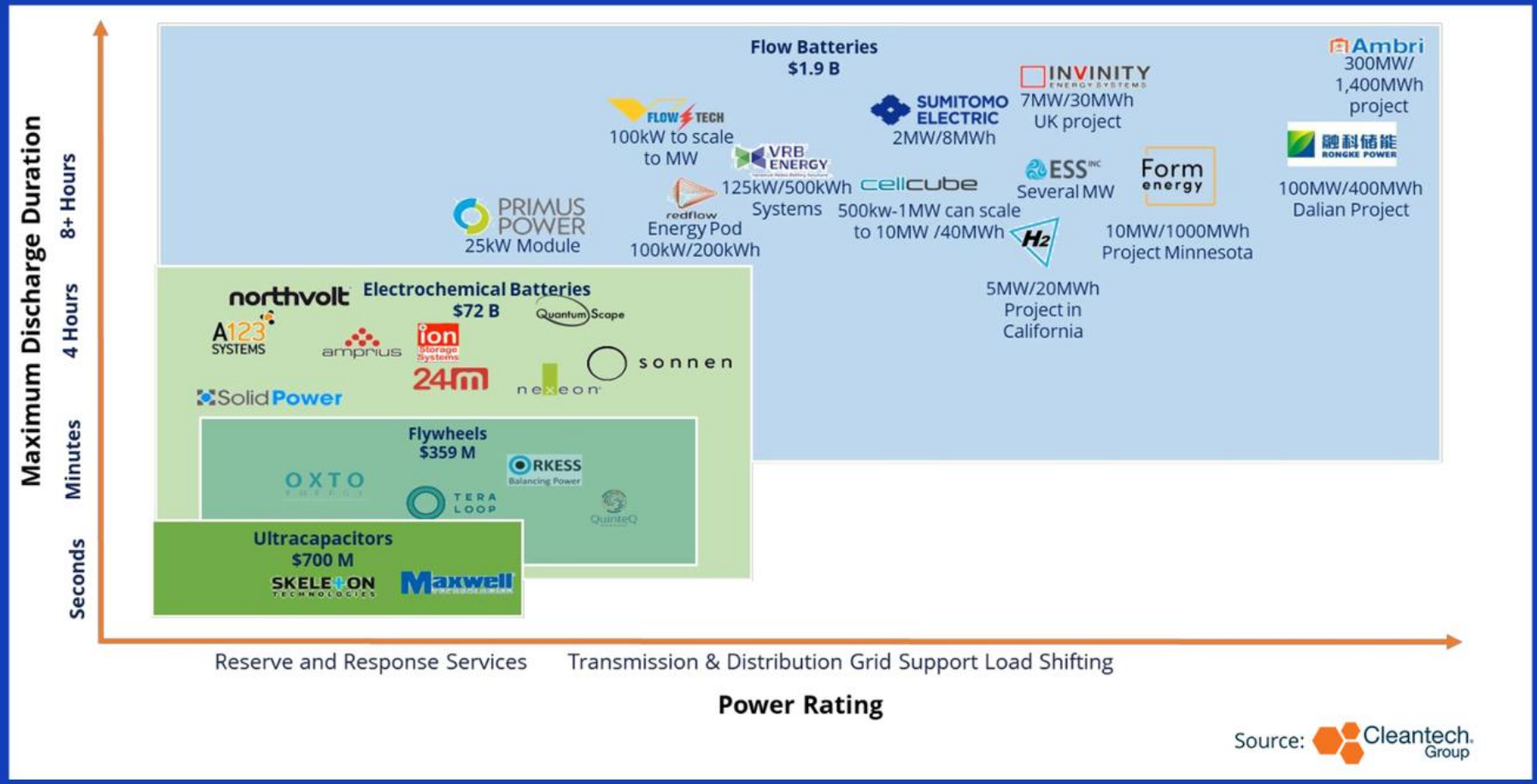
Electricity Storage is needed at all time scales



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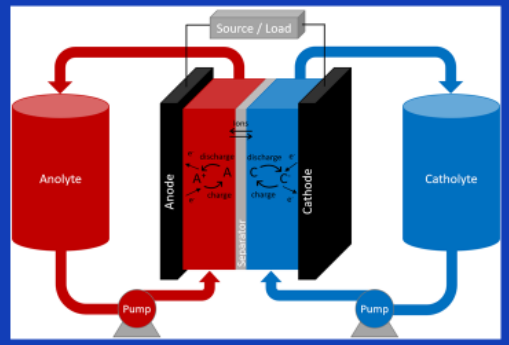
TNO's work in Organic Redox Flow Batteries

Organic molecules for redox flow batteries

+ Environmentally friendly
+ Industrially available
+ Lower price
- Low solubility
- Long term stability



TNO's STRATEGY for Redox Flow Batteries

- **Combining carbon materials with redox active organic molecules** to go beyond solubility limits and stability of molecules
- Develop of slurry or solid booster mediated redox flow battery

Activated carbon

- Using common industrial dyes as redox active organic molecules has the advantages of:
  - Low cost
  - Non-toxic
  - Safe
  - Sustainable
  - European sourced

Functionalized activated carbon with organic molecules

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One Material, 3 technologies, countless applications

1 material

Functionalized activated carbon with organic molecules

Supercapacitor

- Grid stability
- (AI) data centres
- e-bikes
- Winches
- Non-Flammable battery packs
- Drones
- Defence applications

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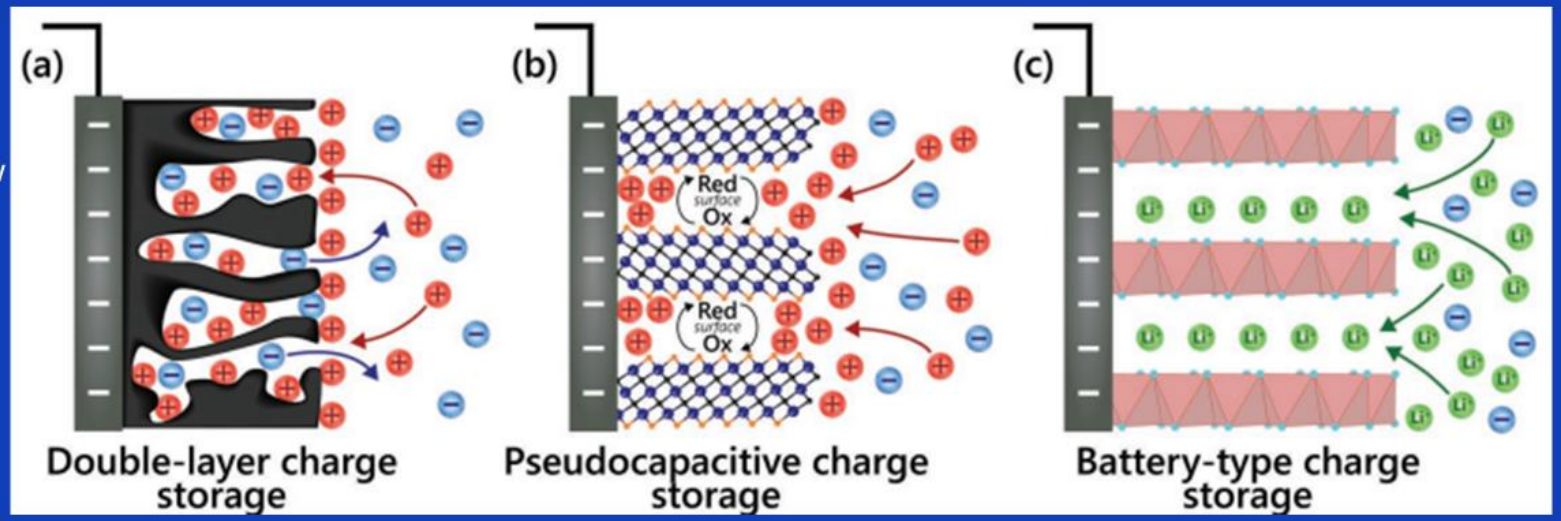
The influence of the charge storage mechanism on the device performance

- Different charge storage mechanisms lead to different electrochemical behaviour
- Battery: high energy density but low power density and short lifetime
- EDLC: high power density and long lifetime but low energy density
- Idea: Combine the best of both worlds in a PSEUDOCAPACITOR



High energy density

High power density

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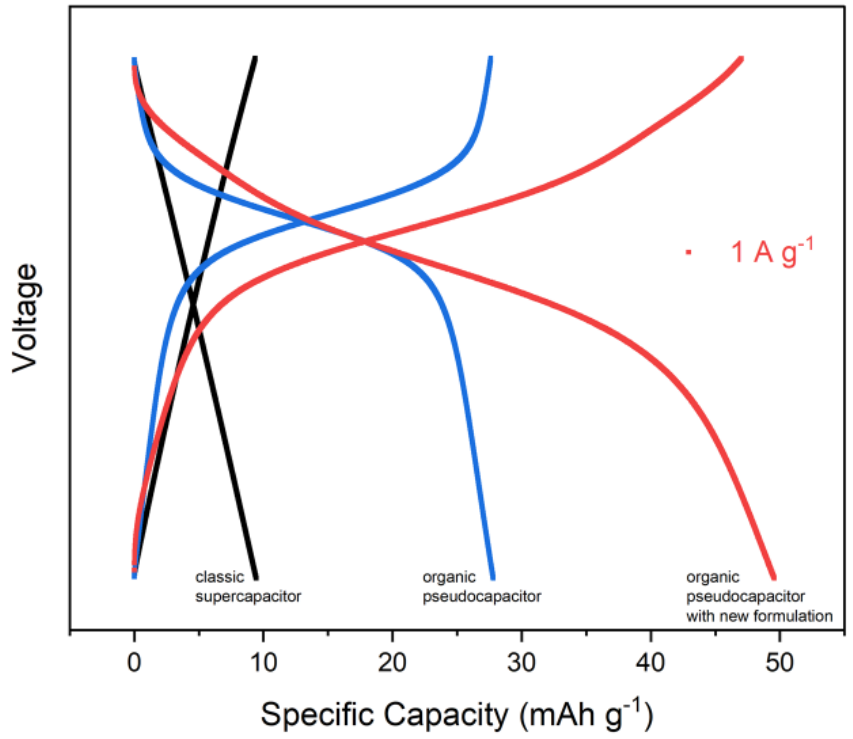
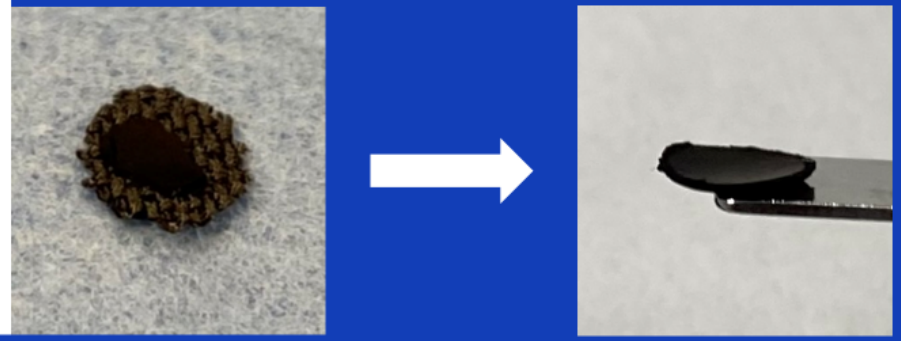
Bridging capacity gap between capacitors and batteries



- Classic charge/discharge behavior of carbon materials in commercial supercapacitors
- **3x increase in capacity** upon addition of the organic molecules
- **5x increase in capacity** by optimizing electrode formulation and carbon materials; moving towards free-standing electrodes



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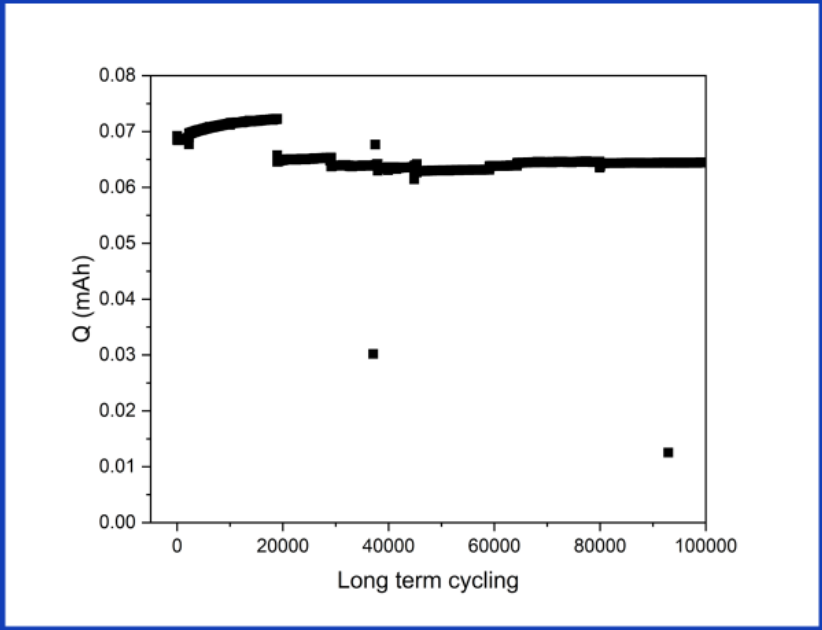
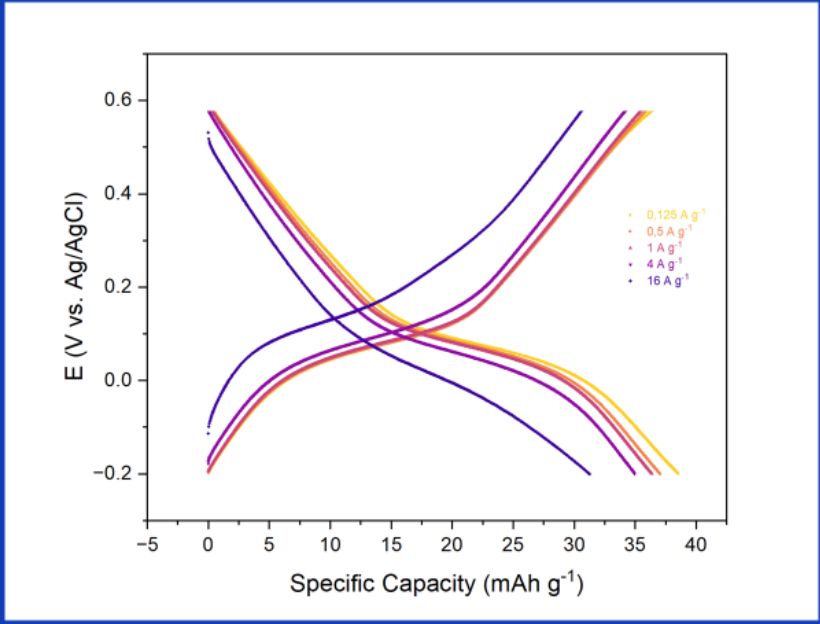
Capacity Retention and Power Density

No measurable capacity fade over 100K cycles indicating **excellent stability of the organic molecules**



The nearly overlapping discharge curves from 0.125 to 4 A/g demonstrate **excellent rate capability** and **low internal resistance**, indicating near-ideal capacitive behavior



Where does TNO Organic Pseudocapacitor stand?

KPI	Benchmark Supercapacitors (EDLC) (e.g. Skeleton)	TNO-proven	TNO targets 2026-2028
Energy density (Wh/kg)	6-10	9-10	>20
Cycle life	1 000k cycles with < 20% capacity fade	100k cycles without measurable capacity fade	•1 000k cycles with <20% capacity fade •Calendar aging •Testing at different T
Power density (W/g)	15-30	12.5	15-30
Pricing ($/kWh)	25 000	12 000	400

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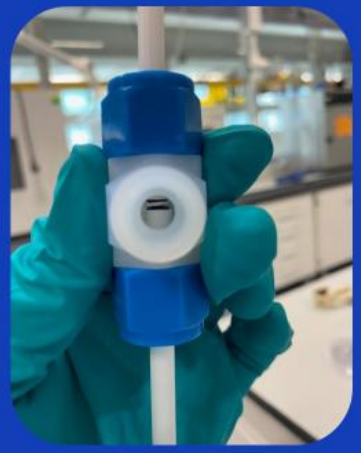
What's next?

2024



2025

2026

2026-2028

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Heynen and TNO

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- Joined forces to profit from combined knowledge
- Material development, industry experience and customer need
- Accelerate implementation of this new technology


Thank you for your attention!
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