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Improving Performance of PEM Water Electrolysis Utilizing Nanofiber-Enhanced Porous Transport Electrodes with Low Iridium Content

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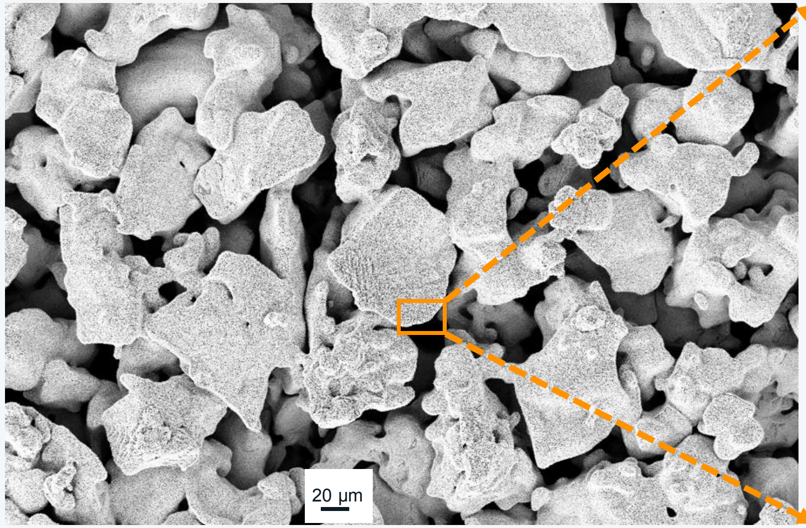
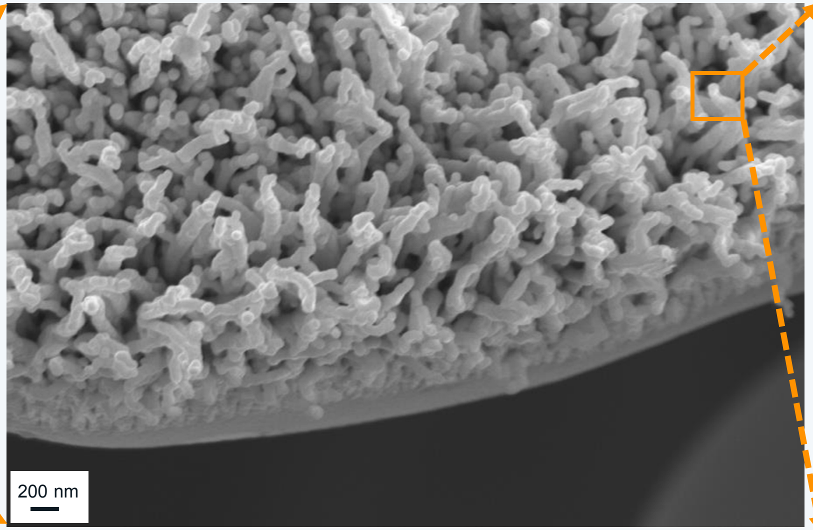
Smoltek Hydrogen – Our Purpose

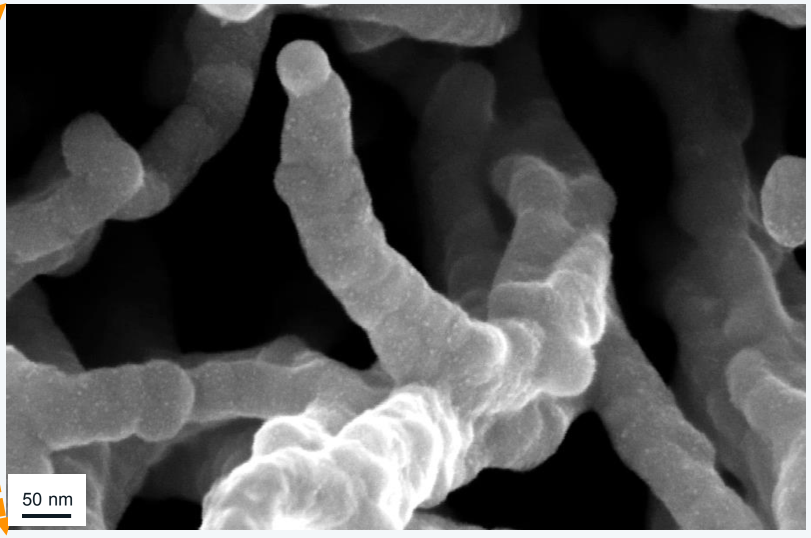
- Unlock GW scale green H_2 generation using PEM water electrolyzers
- Anode Porous transport electrode (PTE) with enhanced surface area created by CNFs
- Durable performance for PTE at low to ultra- low Ir loading
- Cost-efficient supply chain for all volume processing steps for PTE



Smoltek Hydrogen - Porous transport electrode

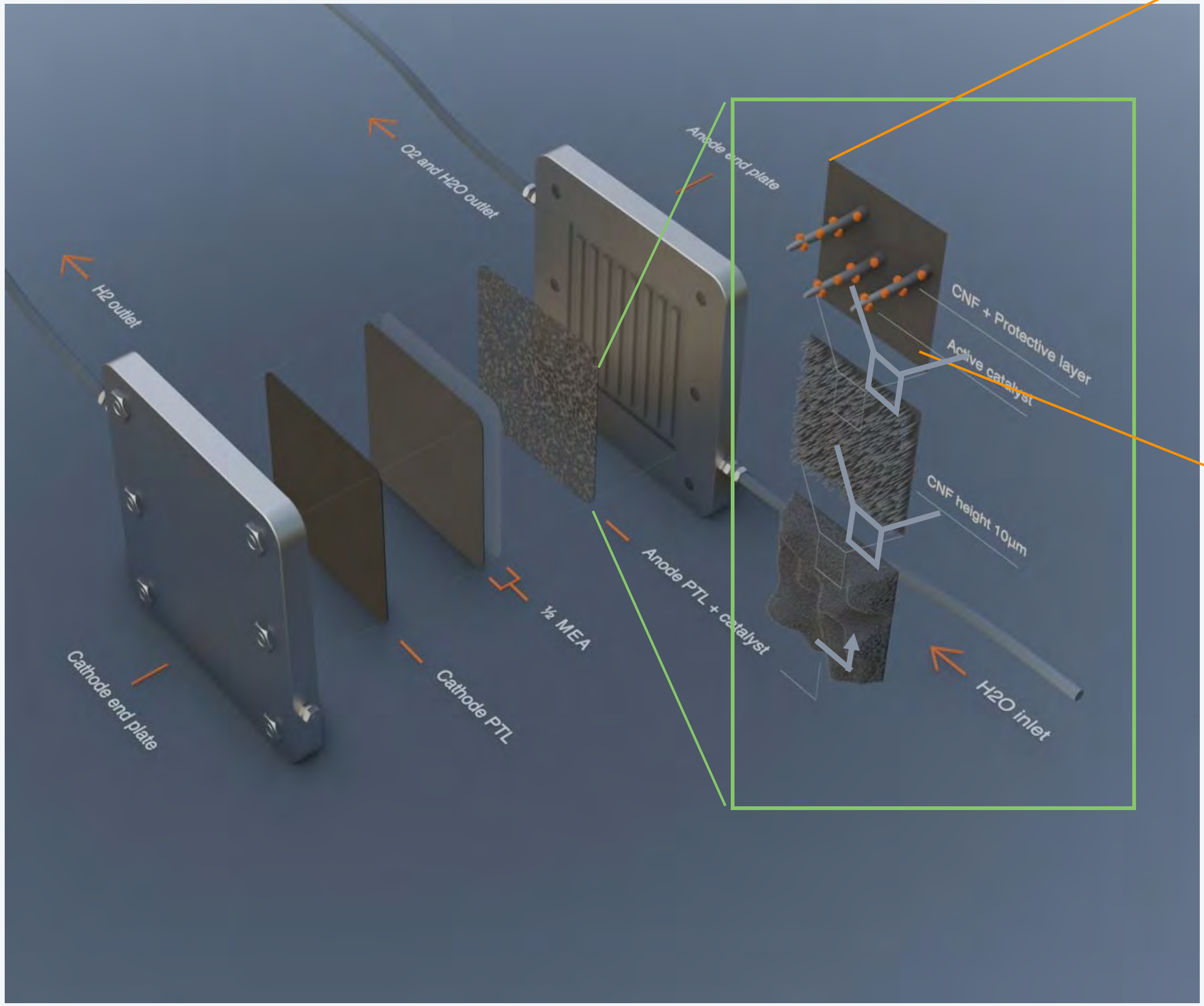


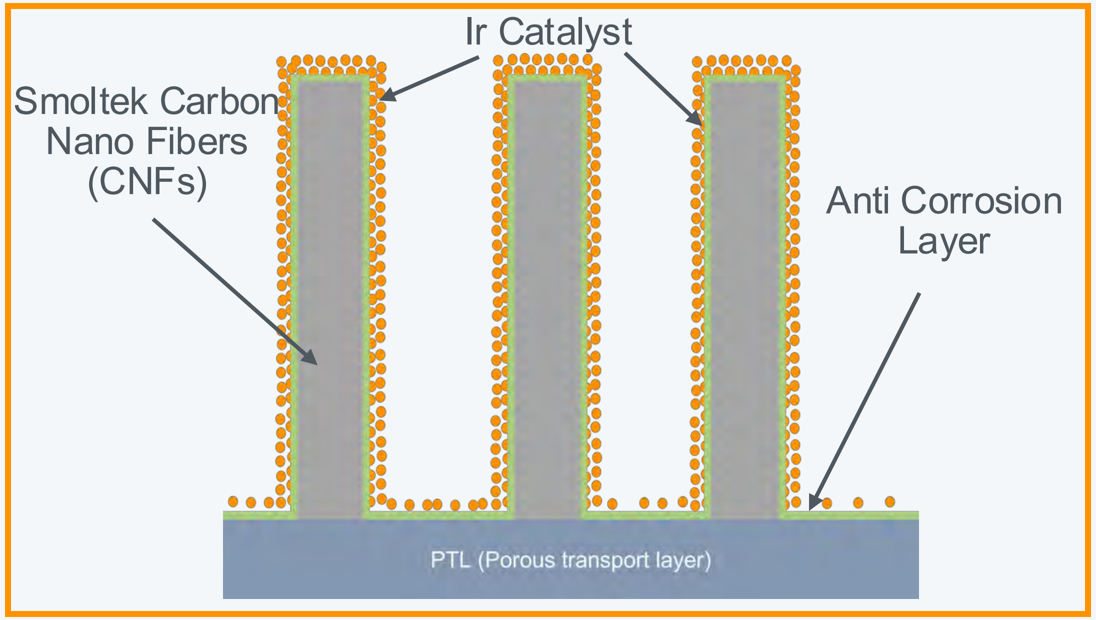
PTE with Enhanced surface area

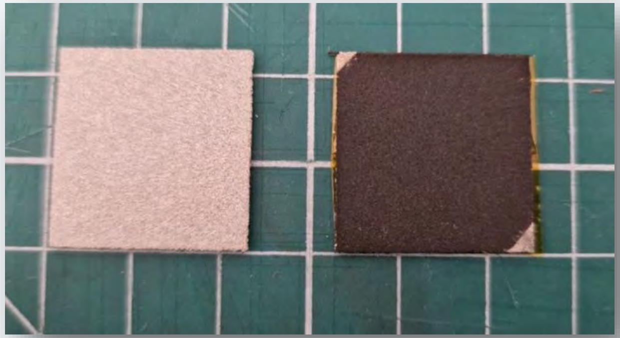


Nanostructure inside the PTE

Smoltek PTE in PEM Water Electrolyzers

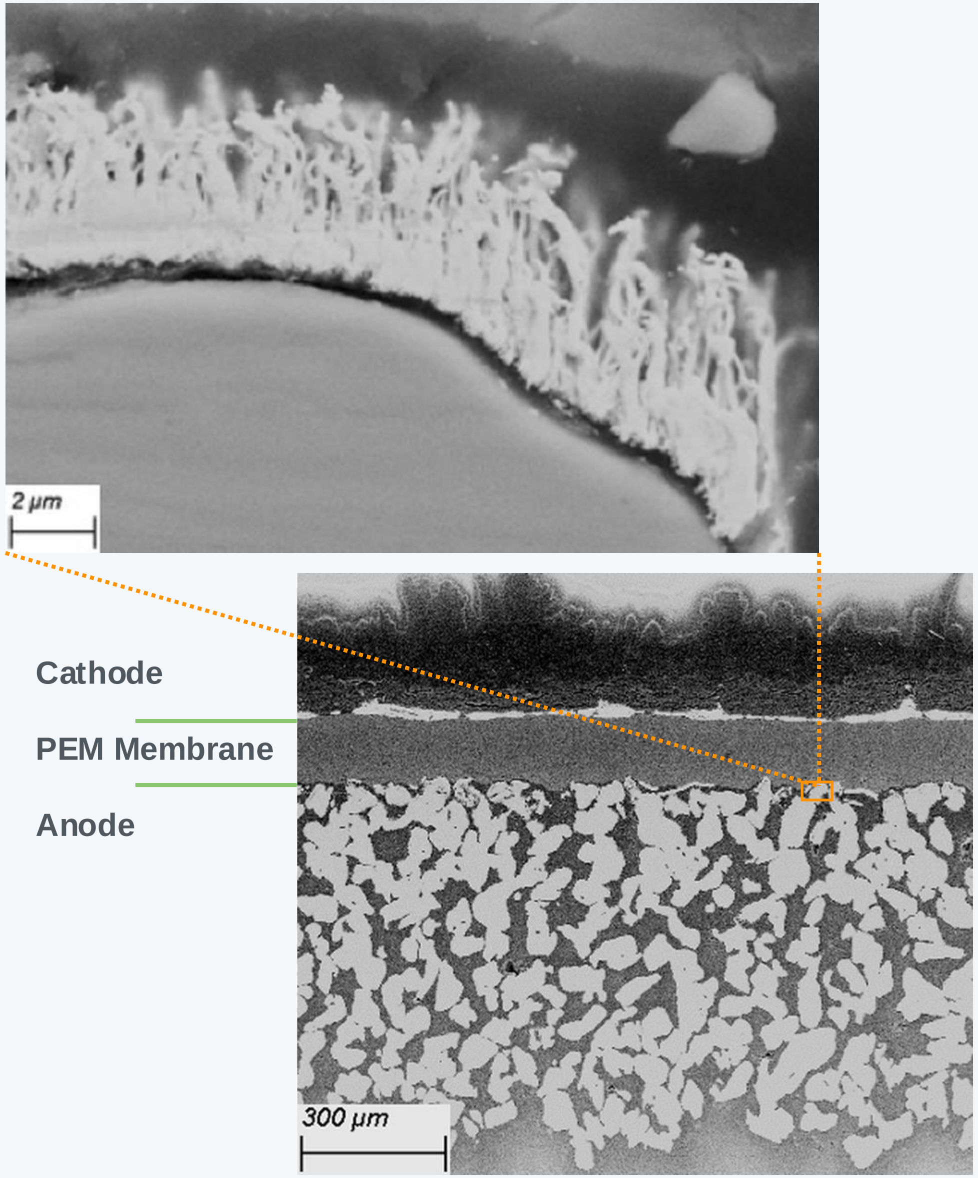






- **Increased surface area by Smoltek CNFs.**
- **Lower Ir loading amount to ≤0.1 mg Ir/cm².**
- **Electrodeposition of Ir over the Pt coated CNFs**

Nanostructured PTE for PEMWE – Nutshell

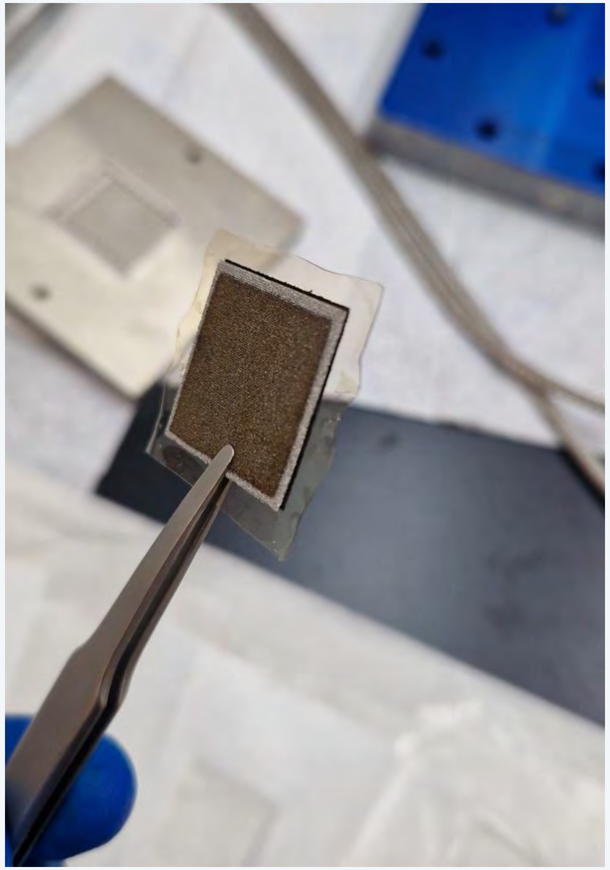


- **PTE Anode characteristics**:
  - **3**…10 µm vertical nanofiber, **100**…150 nm thick, 20…**50**% porosity
  - Graphitic core and high aspect ratio of fibres, **ALD (thermal) Pt coating** 12…**25**…50 nm without pin holes

    Platinum loading **0.6**…**1.1**…1.3 mg/cm^2
  - 6…20 nm porous Iridium nanoparticle layer

    Iridium loading 0.1…**0.2**…0.7 mg/cm^2,
- **Tolerates up to 2.6 V @ 2A/cm^2 for 1000 hours (successfully demonstrated…. ECS 245)**
- **Lab and A4 size prototypes**

PEM Water Electrolysis using PTEs – Testing details



- **Anode** : Smoltek PTE (0.2 - 0.7 mg/cm^2_{Ir} *)*
- **Cathode** : Carbon GDE with Pt (0.5 mg/cm^2_{Pt})
- **Membrane** : Nafion 115 (127 μm)
- **Cell Temp.** : 80 °C for polarization curves
  60 °C for durability testing
- **Water flow** : 100 ml/min (80 °C) at anode
- **Polarization** : 0.025 A/cm^2 per min (JRC protocol)
- **EIS** : 0.1, 1 , 2 A/cm^2
- **Durability tests** : constant current , 2 A/cm^2

- **Electrode Area** : 5 cm^2
- **Cell Assembly** : 8 bolts , 3.5 Nm torque

I-V Curves with PTEs having varying Ir loading

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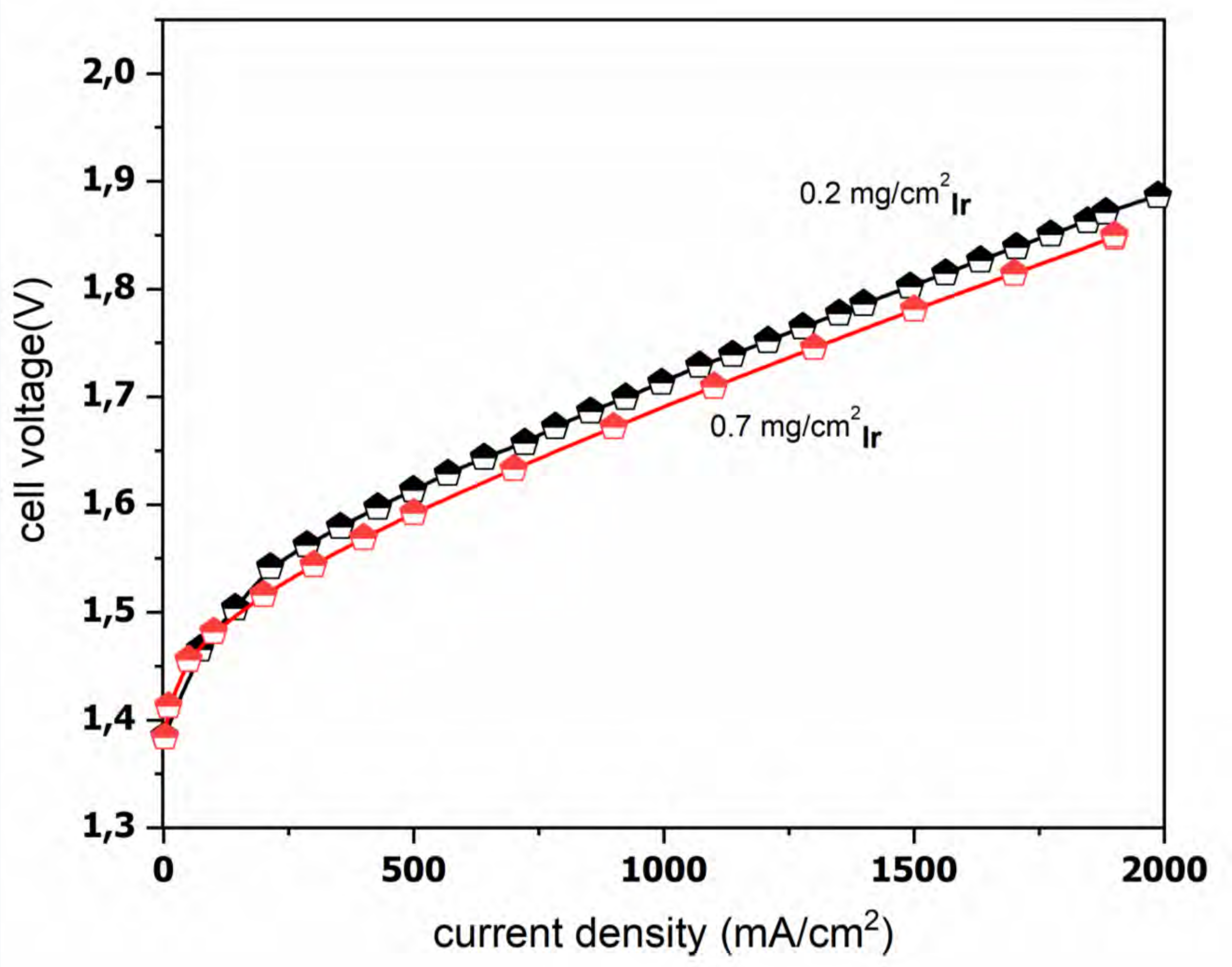
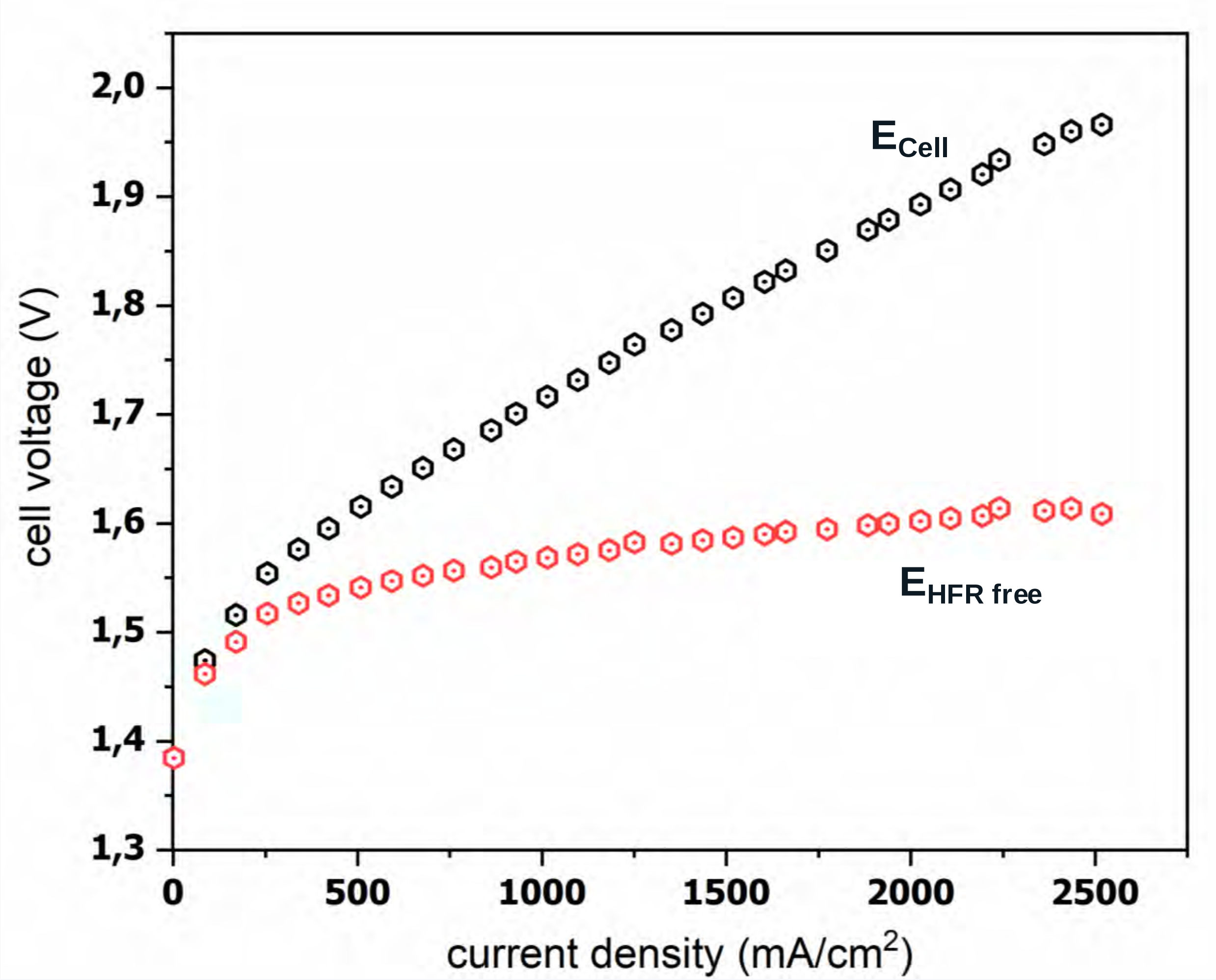


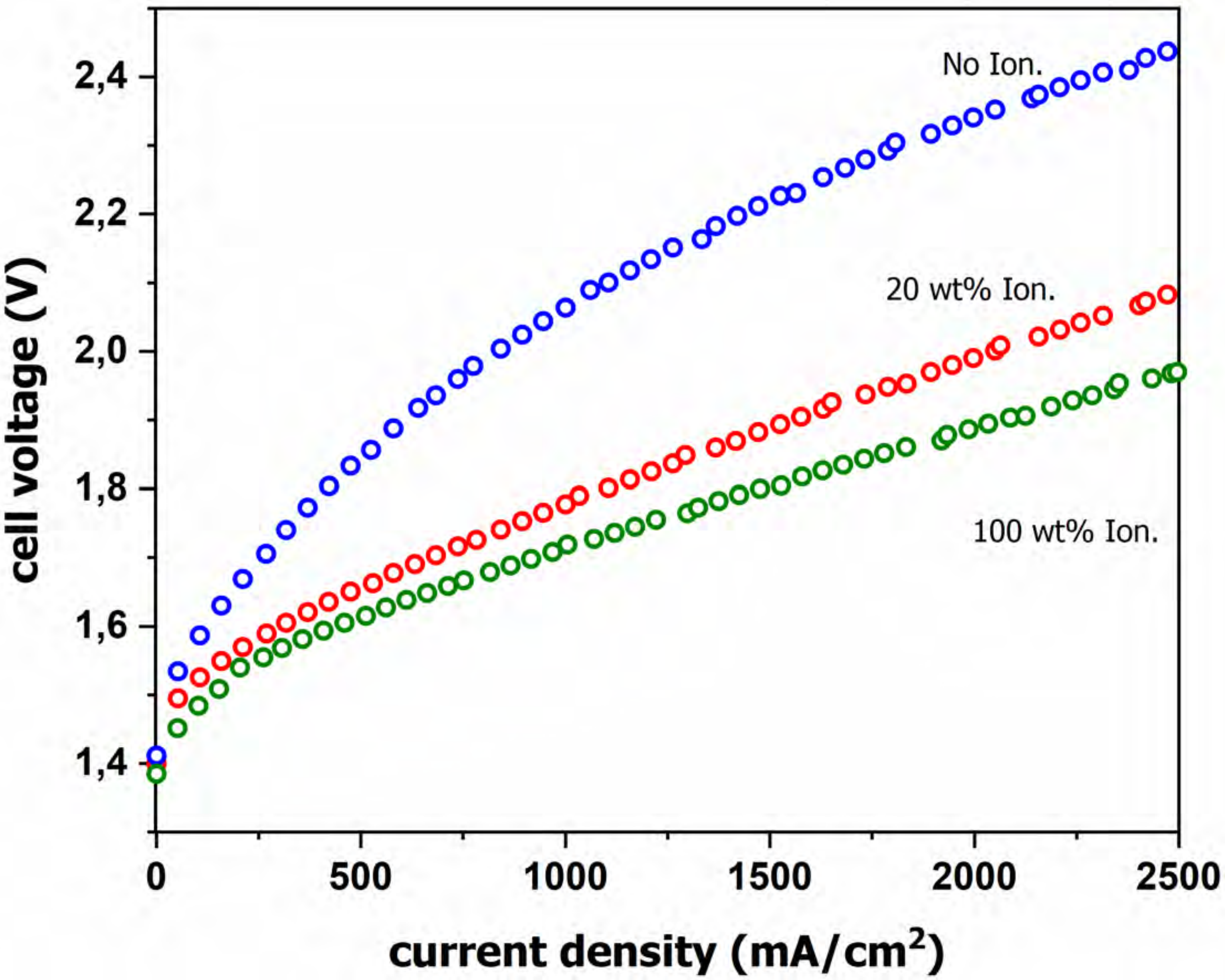


1.85 V for 2 A/cm^2 - 0.2 mg/cm$^2_{Ir}$ (~ 80 % cell efficiency)

Pol. curve with 0.2 mg/cm^2$_{Ir}$ PTE

I-V Curves for the PTEs with varying Ionomer loading

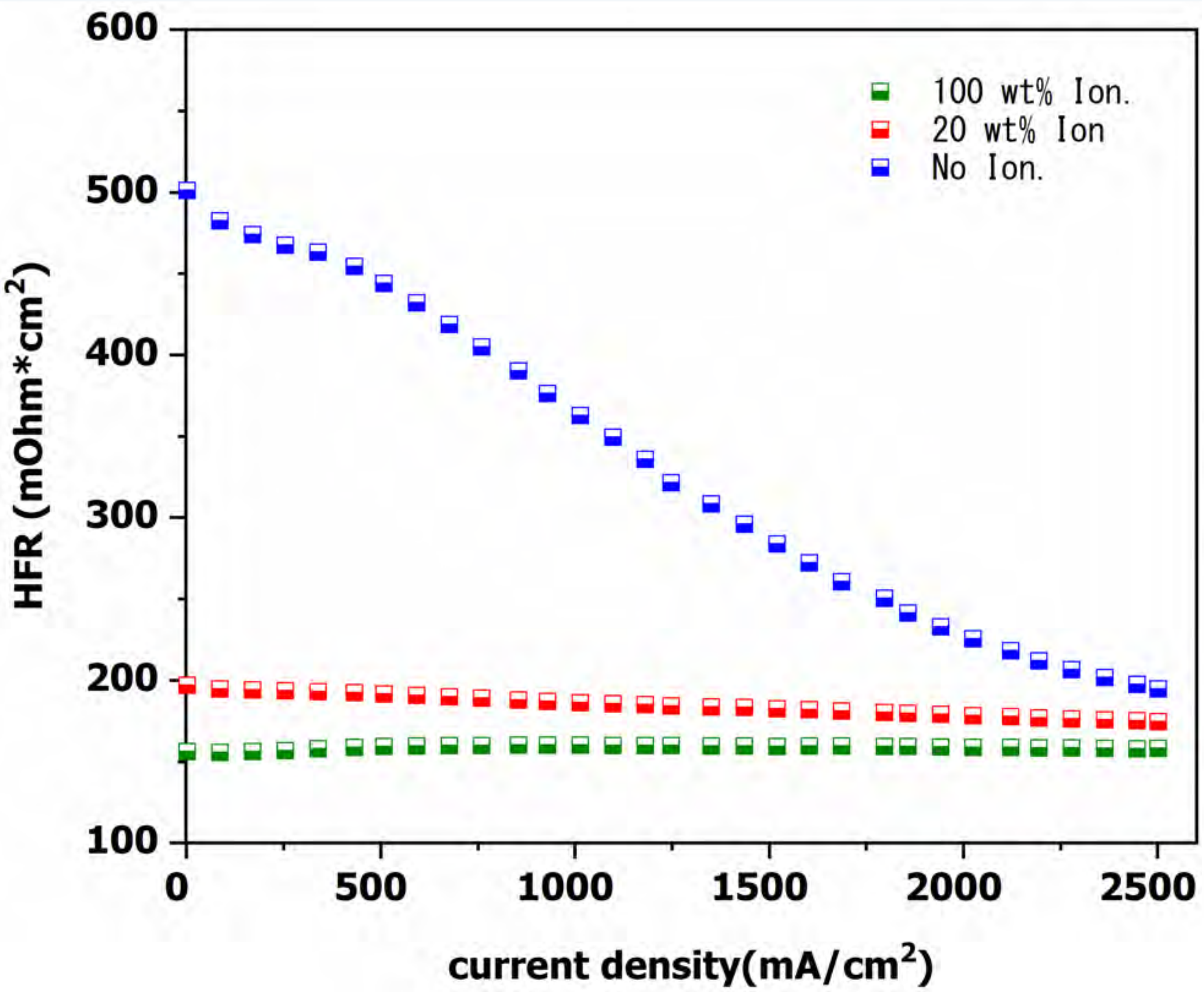
- **Anode** : Smoltek PTEs with 0.2 mg/cm^2_{Ir}
- **Cathode***:* Carbon Paper GDE (0.5 mg/cm^2_{Pt})
- **Membrane** : Nafion 115
- **Temperature** : 80 °C
- **Ionomer** : Nafion D521 (wt.% w.r.t. Ir loading)

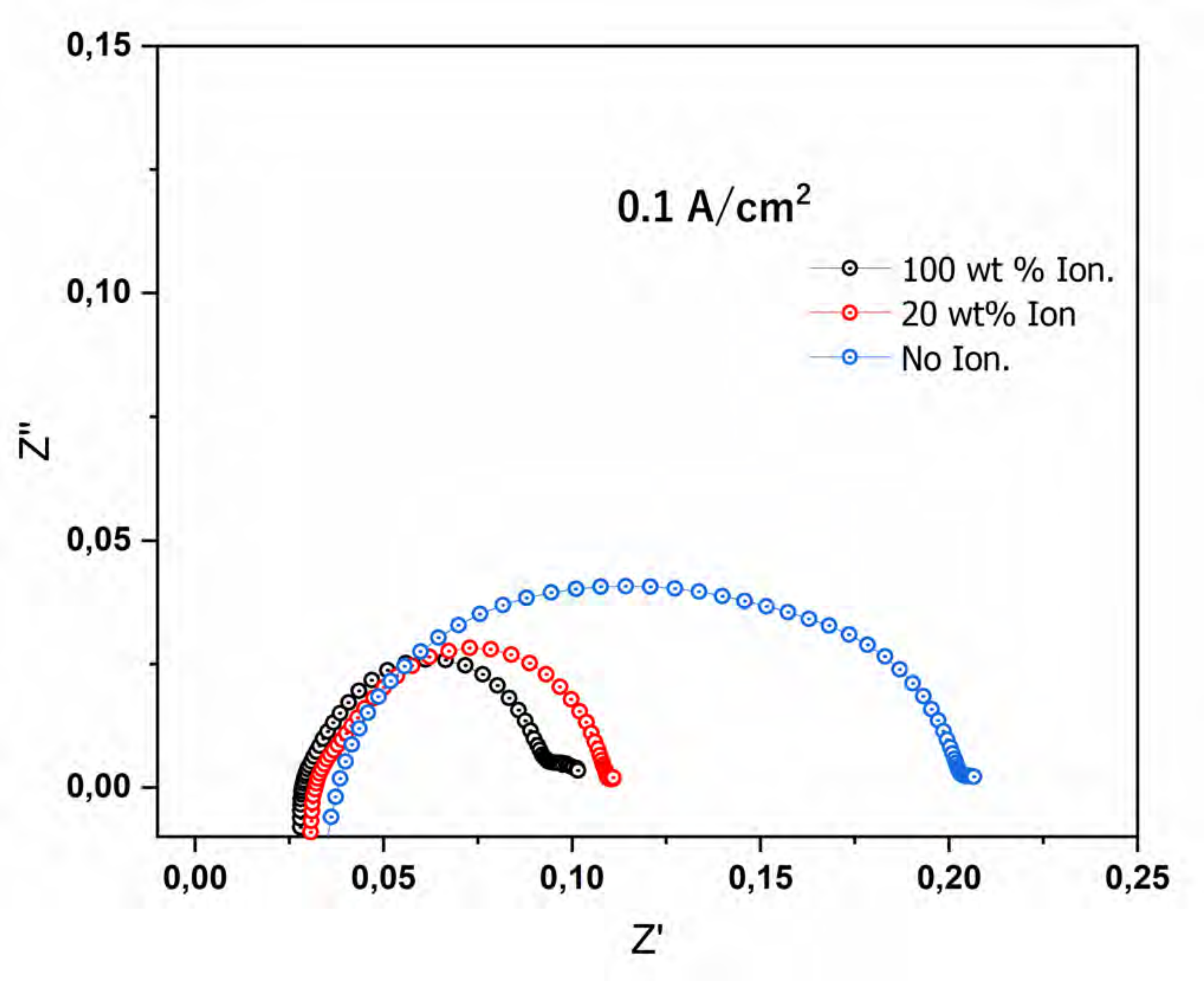


Tafel Slopes

82.5 mV/dec – No Ion.
65.1 mV/dec – 20 wt.% Ion.
69.1 mV/dec – 100 wt.% Ion

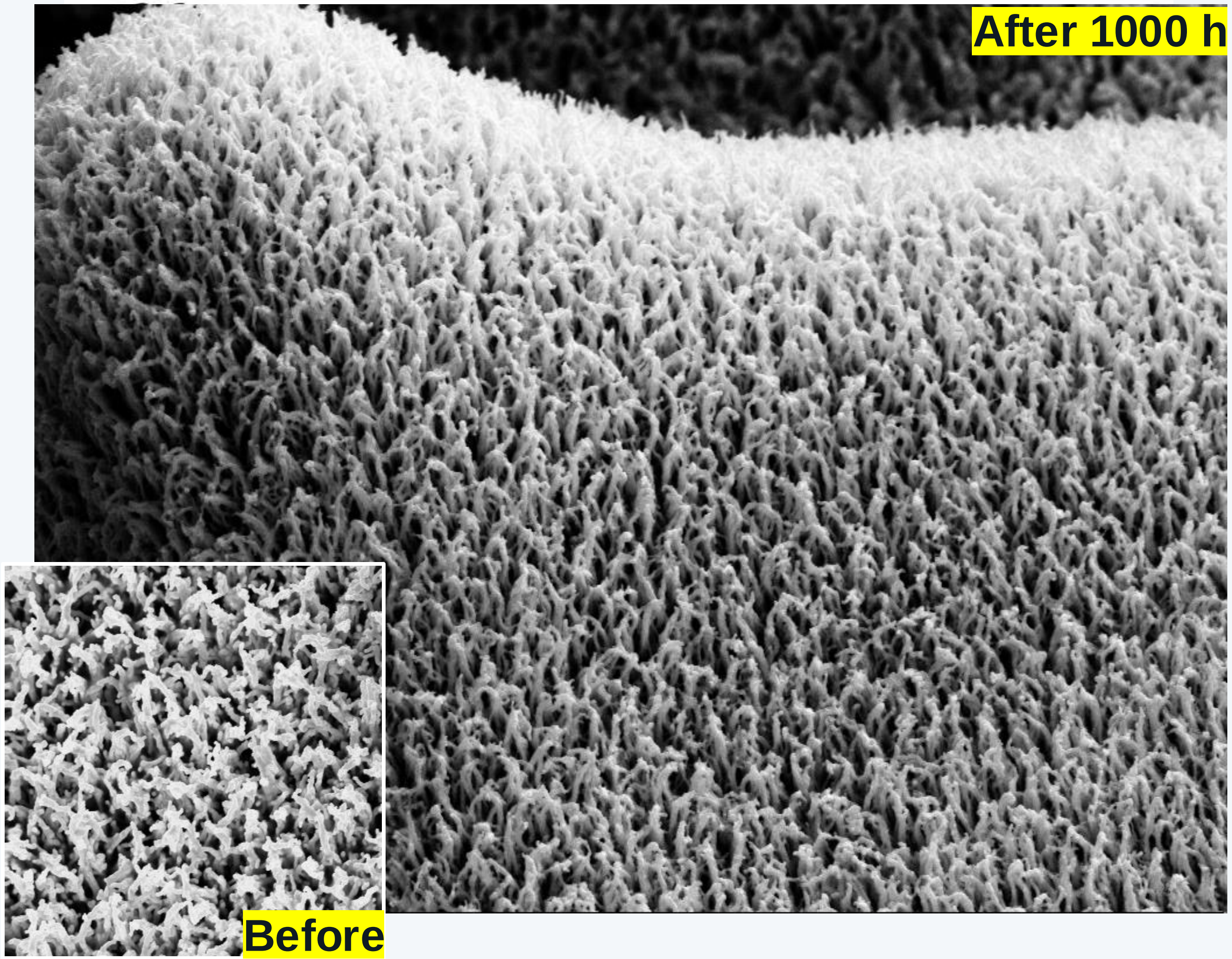
- Tafel Values are influenced by Ion. loading
- Suspecting additional voltage losses even with Ion.

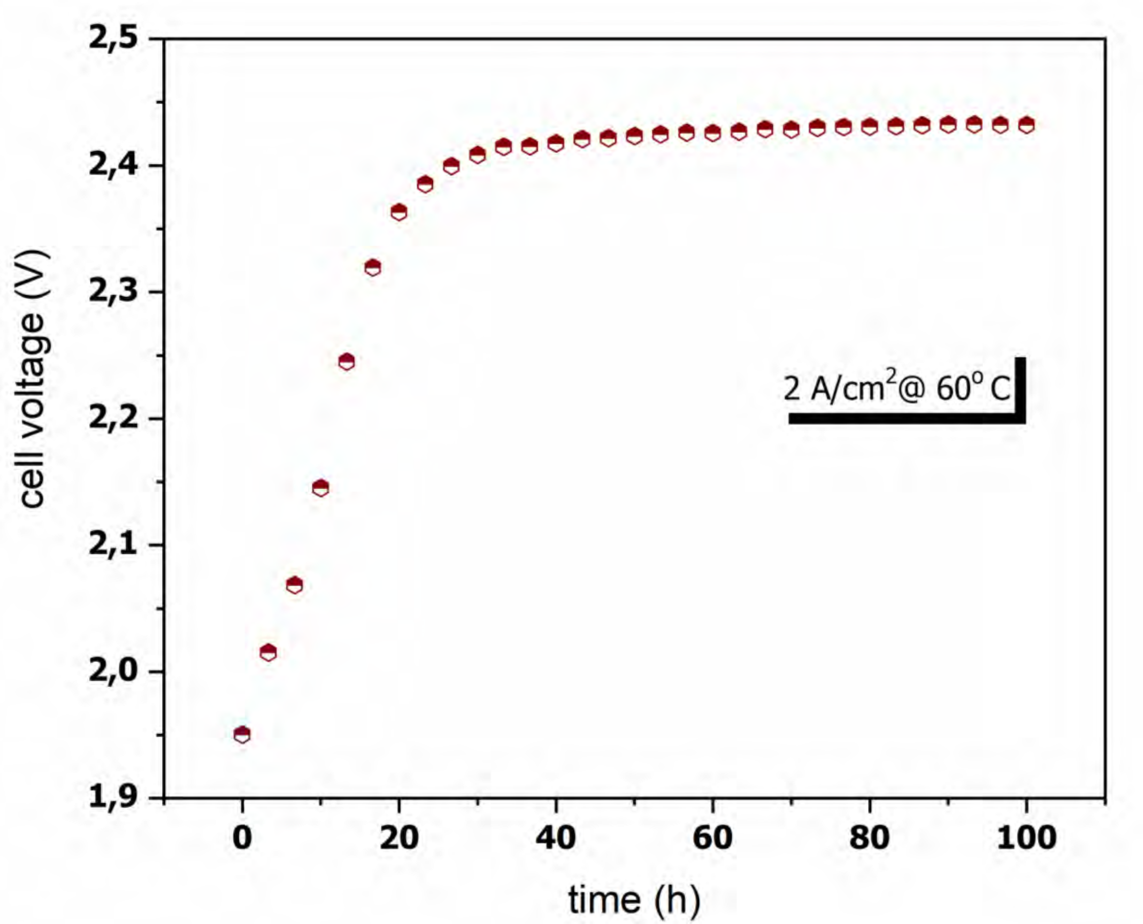




- Worse HFR with No Ionomer , Needs Ionomer for better PTE- PEM interface for better Ion transport
- Increase in Anodic R_{ct}

Durability of the PTEs – Constant current operation (1000 h)

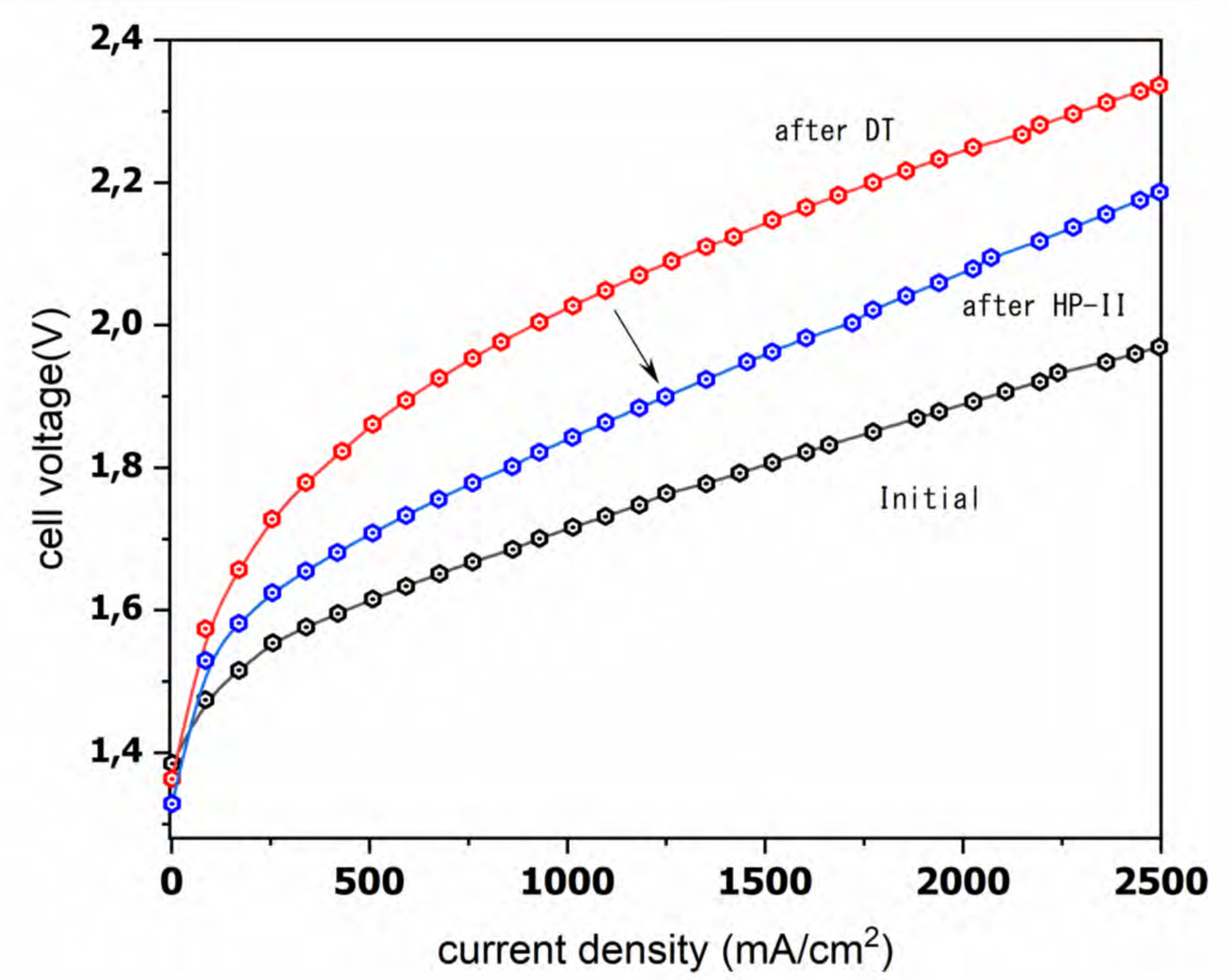


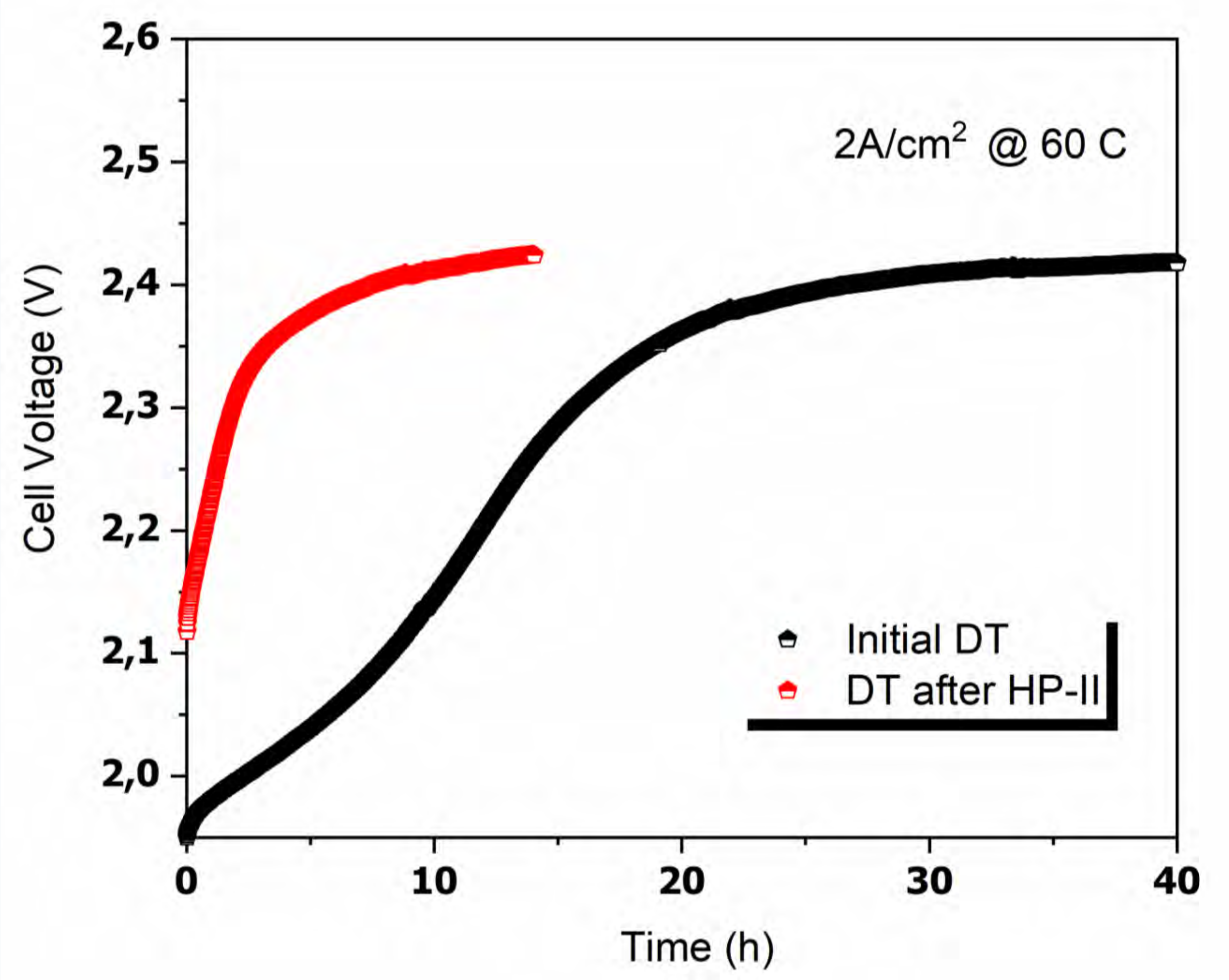


- Increase of voltage in the initial hours by ~ 400 mV, then stable
- After cell disassembly the PTE anode shows activity of IrO_x - half cell

➢ Initial Increase of voltage

Hot Pressing of MEA after durability test

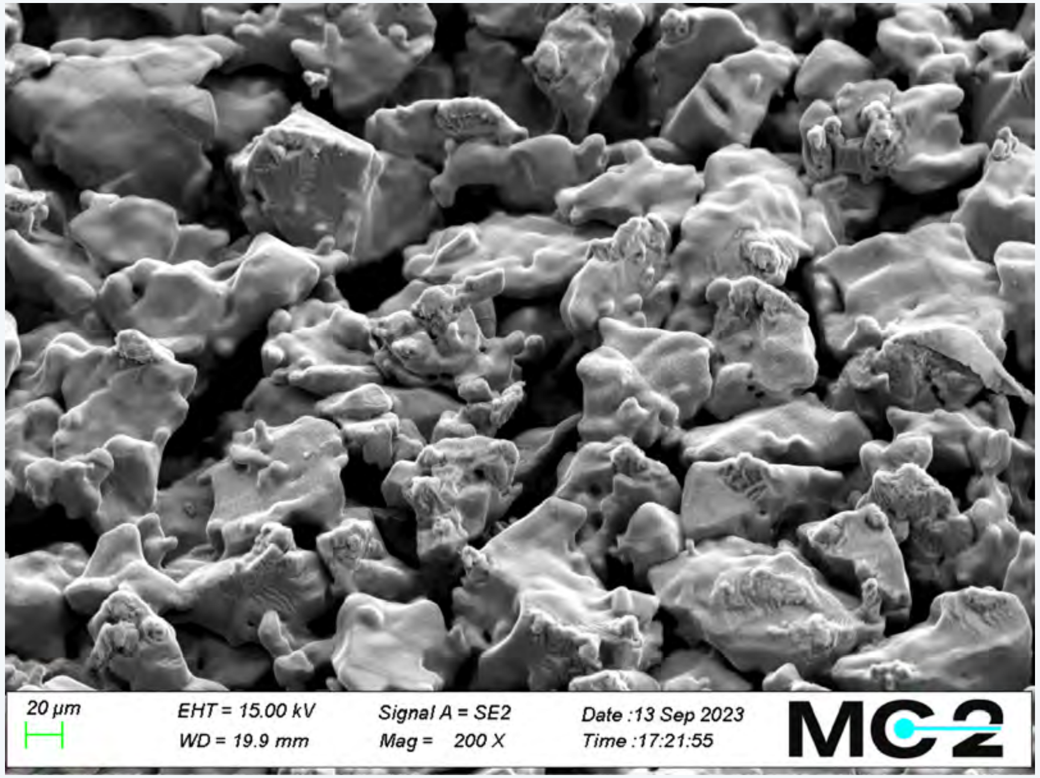




- ✓ Performance recovery (~ 50 %) – PTE not degraded
- ❑ The slope of increasing voltage, still exists

Hypothesis and Solutions on Voltage increase

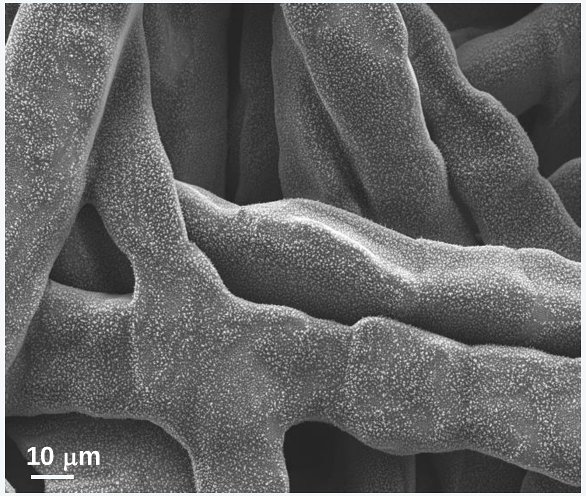
- ❑ Better contact between membrane and catalyst layer needed – *current PTL has corrugated structure*
- ❑ *Possible local delamination – from pressure developed at running 2A/cm^2 + Mass transport limitations*

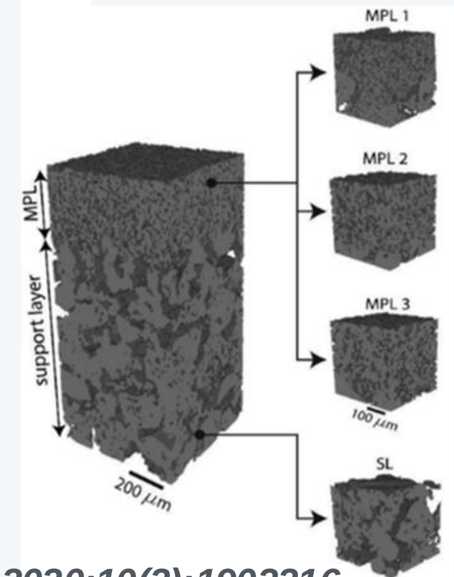


- ✓ PTEs with flatter domain (fiber PTLs) for better membrane catalyst contact

  Enables thinner membrane (Nafion 212 for instance) usage

- ✓ *Smaller grained PTLs with MPLs for better O_2 movement*





Adv Energy Mater. 2020;10(2):1903216

Upscaling of PTEs with CNF technology

SMOLTEK

- ❑ Already upgraded our R&D tool to support coating of A4 size PTL with CNF coating
- ❑ Core technology solutions to develop a recipe for CNF that can be scaled in both dimensions
- ❑ Compatible with different form factor PTL substrates
- ❑ Suppliers for volume production aligned – collaboration with *AGC Glass Europe*

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Reduction of Platinum amount on PTL and CNFs

Spatial Atomic Layer Deposition (SALD)

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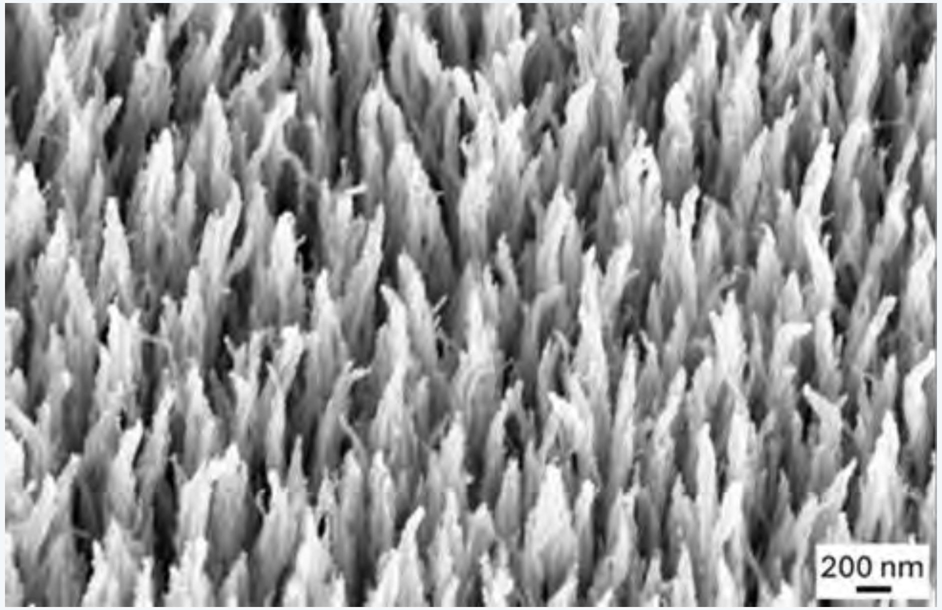
SPARKNANO

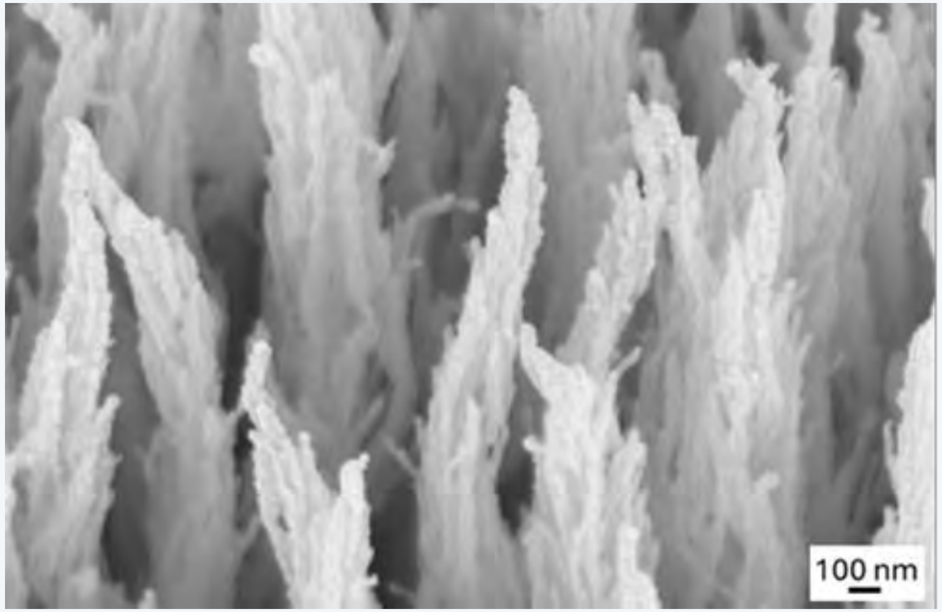
BUSINESS DEVELOPMENT

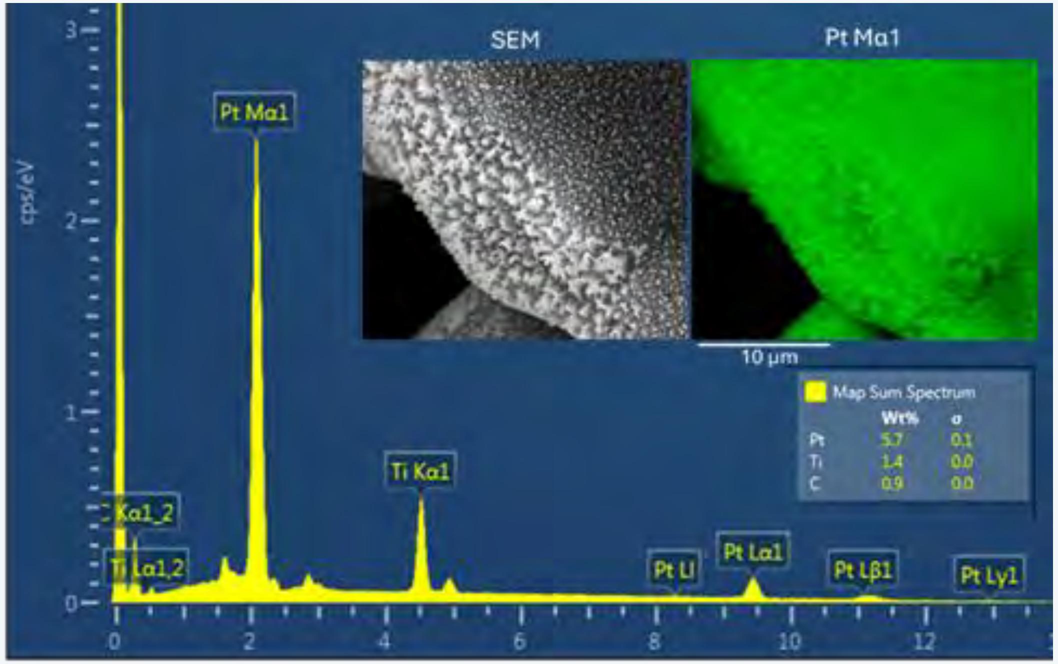
Smoltek Hydrogen and SparkNano present a joint whitepaper and hold a webinar about the collaboration

September 25, 2024 4 min read

Thinner Pt layers with SALD







- ✓ Pt ~ 0.6 mg/cm^2

  **Commercial PTLs are having 0.1-0.2 µm Pt thickness*

- ✓ Uniformly coated CNFs with Pt
- ✓ Fiber integrity and porous nature maintained

Conclusions and Outlook

- ✓ The CNF technology by Smoltek enables enhanced surface area to using of low loading of Ir & Pt in PEMWE
- ✓ The PTEs with 0.2 mg/cm^2_{Ir} shows promising WE performance
- ✓ Performance loss during first few hours of constant hour durability tests - Major issues recognized
- ✓ Scaling up potential for Smoltek PTEs cracked with recent achievement of A4 size CNF growth
- ✓ Collaboration with SparkNano's SALD - Thinner Pt coating/loading over the PTLs and CNFs (*could be extended to catalyst layers*) - boost to our upscaling plans

- ❑ PTEs for PEMWE with **0.1 mg/cm^2_{Ir}**
- ❑ Electrolyzer durability at **2 A/cm^2 ≤ 2V for 2000 hours** and beyond with ultra low Ir loading
- ❑ Electrolyzer testing at **pressurized cell conditions**
- ❑ ***Scale Up- Seeking Partners (****#fundraising)* ***and collaborators*** *to ensure GW scale green H_2 production*

Acknowledging Collaborators

SMOLTEK

CHALMERS UNIVERSITY OF TECHNOLOGY

DLR

SPARKNANO

Swedish Electricity Storage and Balancing Centre

Wallenberg Initiative Materials Science for Sustainability

Partner With Us @ Gothenburg, World's Best Sustainable City

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thank you!

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