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# Upscaling of proton conducting ceramic cells

# Advantages and disadvantages of PCCC



## -Lower operating temperature (400-600 °C),

- + Use of inexpensive ferrite steel for interconnects
- + More reliable sealing
- + Lower thermal stresses resulting from thermal-expansion mismatch
- + negligible electrode sintering

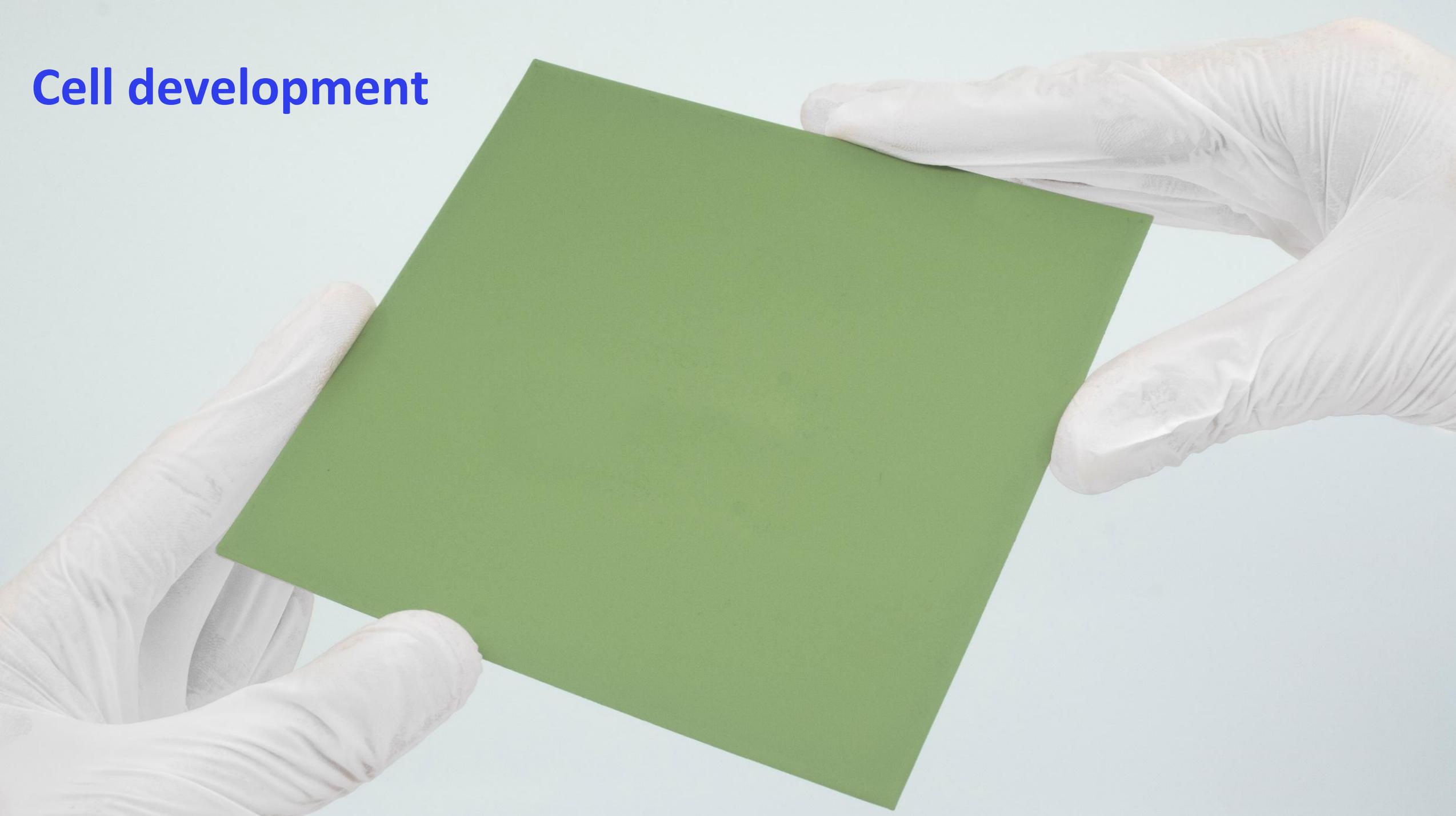
## -Water formed at the cathode/air side

- + no fuel dilution such as in SOFCs
- + hydrogen can be compressed

## - High sintering temperature (> 1500 ° C required)

- Scaling up of planar cells is challenging due to high sintering T
- TEC mismatch
- Stacking of planar systems not fully realized
- Sealing needs to be improved
- Steam resistant electrodes required
- Electronic "leak" in electrolysis mode

# Cell development



# Materials – focus on implementing “proven” materials

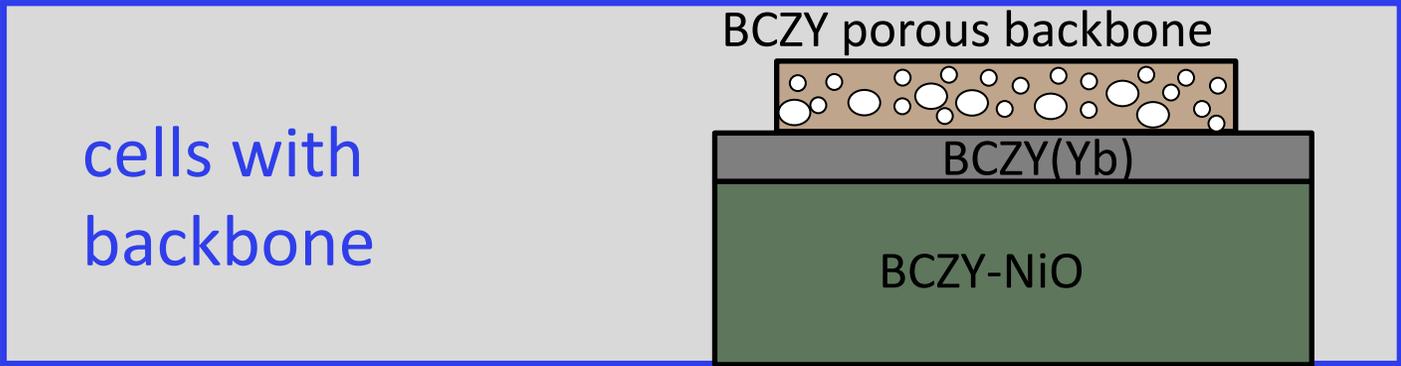
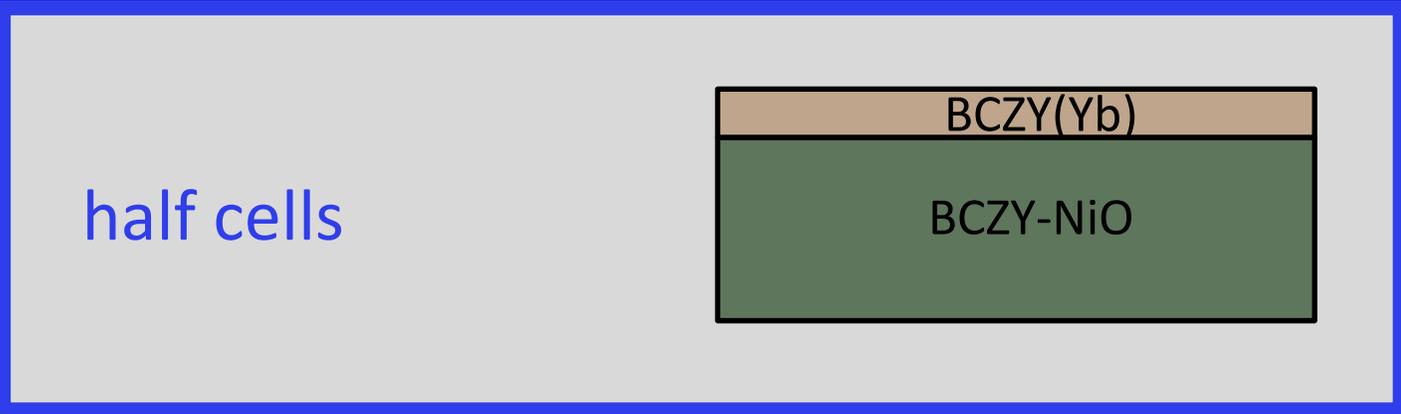
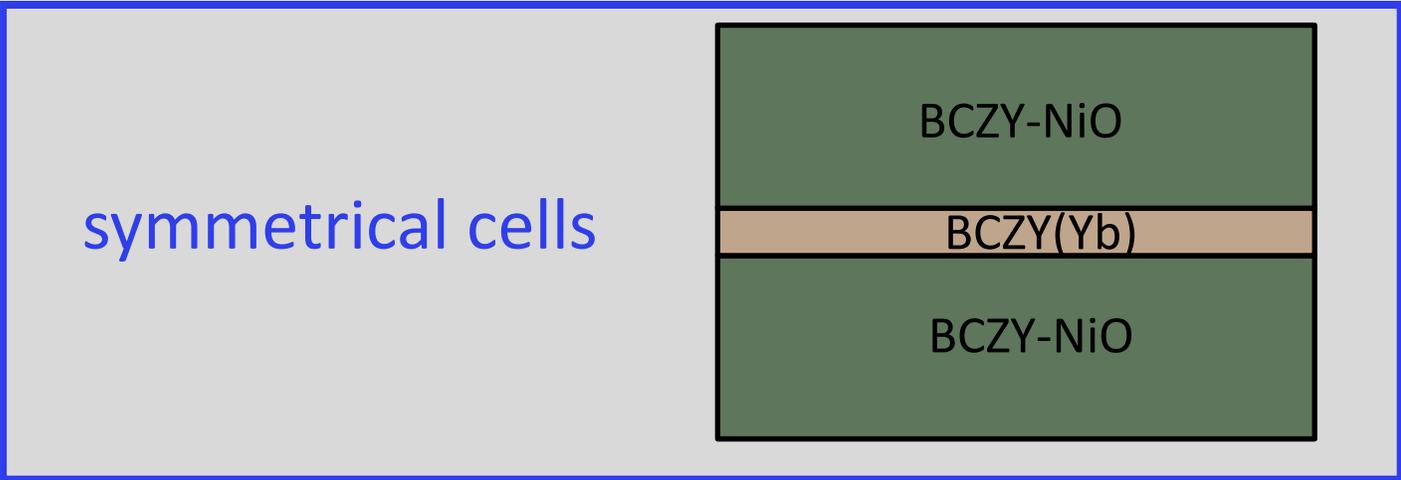
## Electrolyte and fuel electrode

- $\text{BaCe}_{0.2}\text{Zr}_{0.7}\text{Y}_{0.1}\text{O}_{3-\delta}$  (BCZY27)
- ~~$\text{BaCe}_{0.4}\text{Zr}_{0.4}\text{Y}_{0.2}\text{O}_{3-\delta}$   
(BCZY442)~~
- $\text{BaCe}_{0.7}\text{Zr}_{0.1}\text{Y}_{0.1}\text{Yb}_{0.1}\text{O}_{3-\delta}$  (BCZYYb711)
- And more...

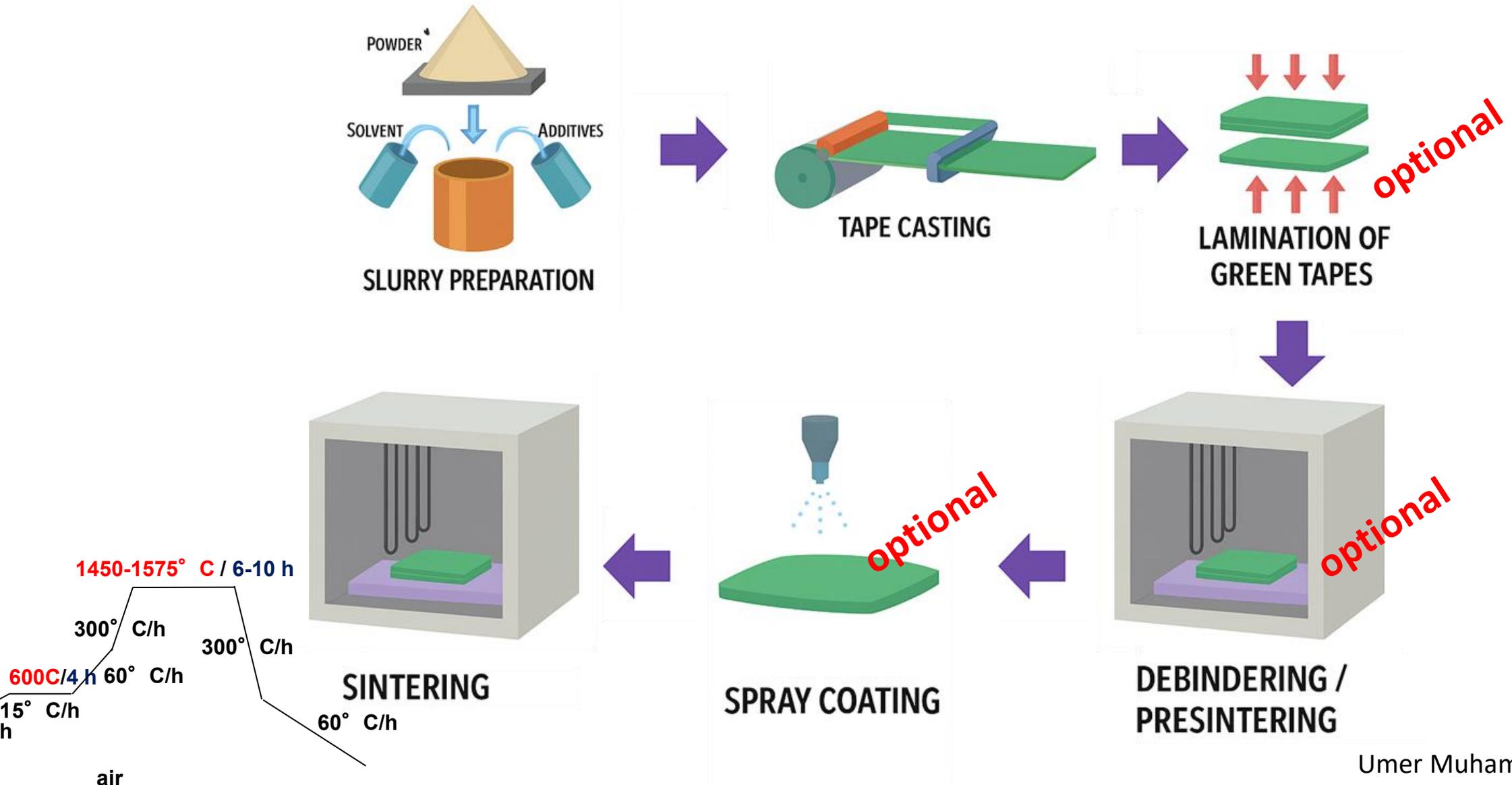
## Steam/oxygen electrode

- $\text{PrBa}_{0.5}\text{Sr}_{0.5}\text{Co}_{1.5}\text{Fe}_{0.5}\text{O}_{5+\delta}$  (PBSCF)
- $\text{La}_{0.35}\text{Pr}_{0.15}\text{Sr}_{0.5}\text{FeO}_{3-\delta}$  (LPSF)
- $\text{Ba}_{0.5}\text{Gd}_{0.8}\text{La}_{0.7}\text{Co}_2\text{O}_{5+\delta}$  (BGLC)

# Cell Architectures

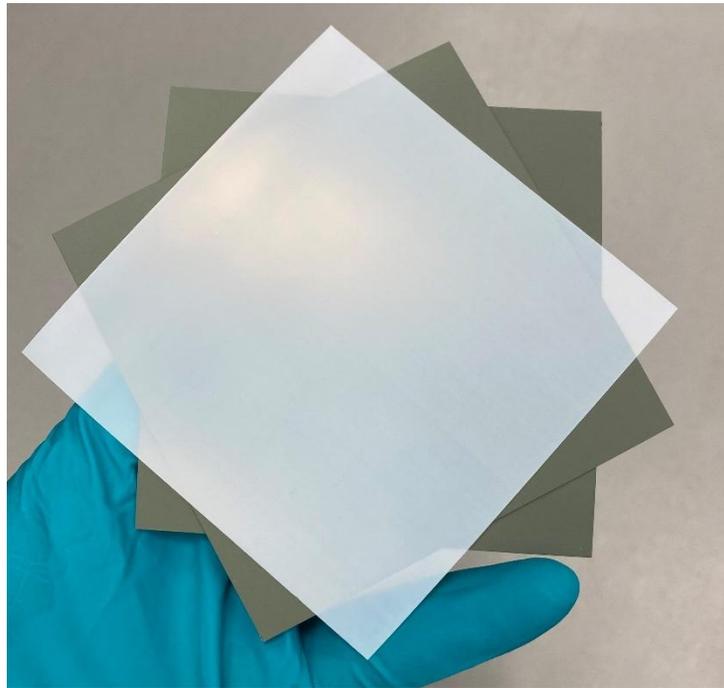


# Process flow – SoA tape casting and sintering

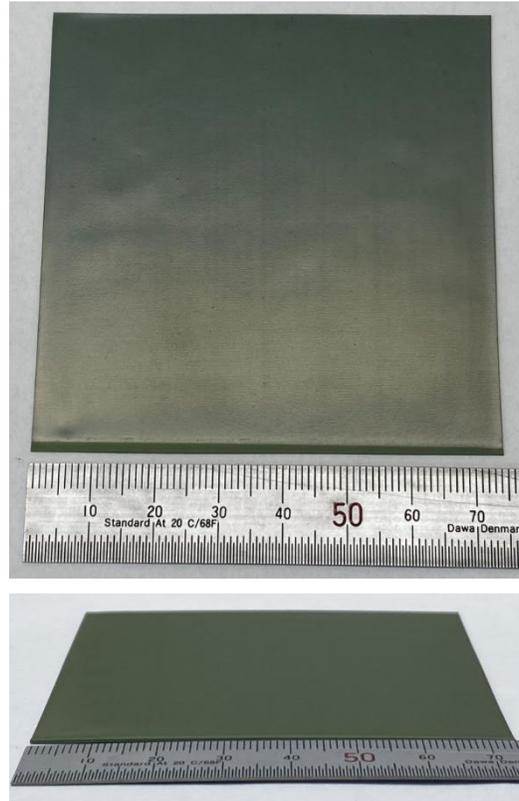


Umer Muhammad Abdullah

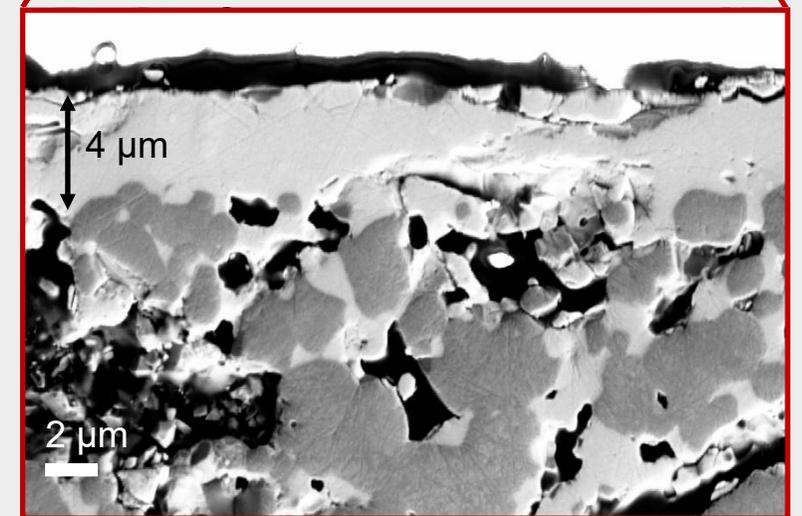
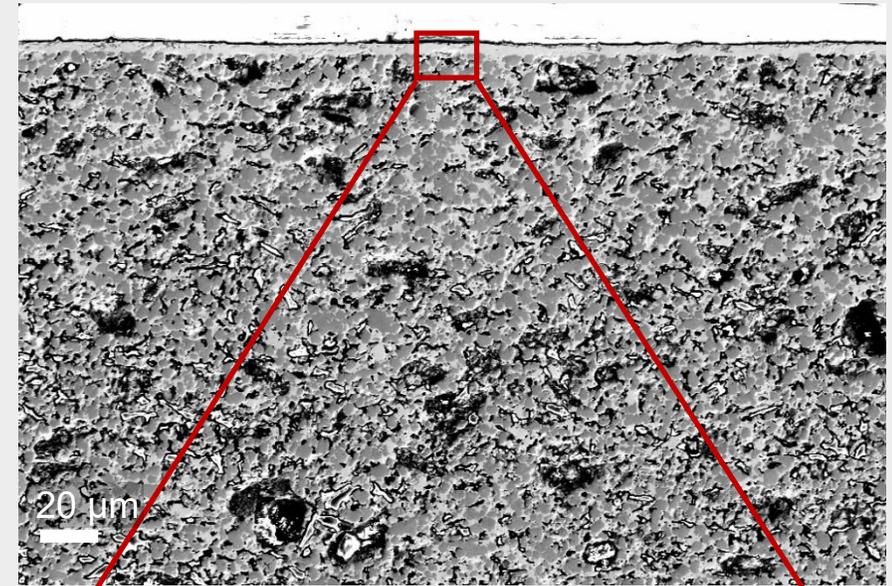
# Cell production "Gen 0"



Co-sintering



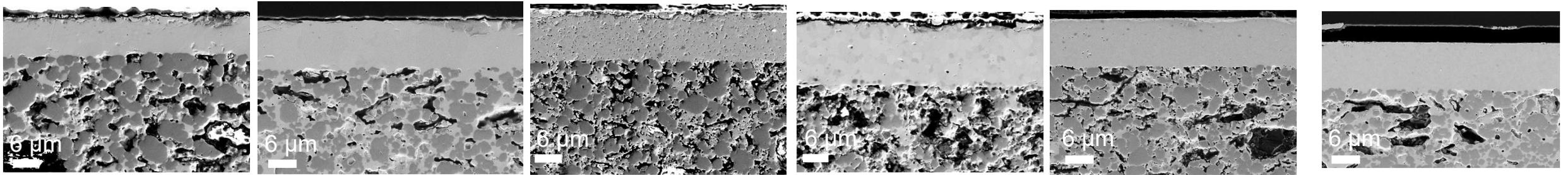
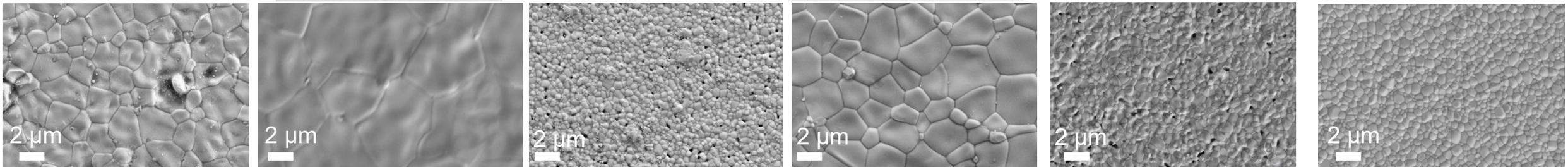
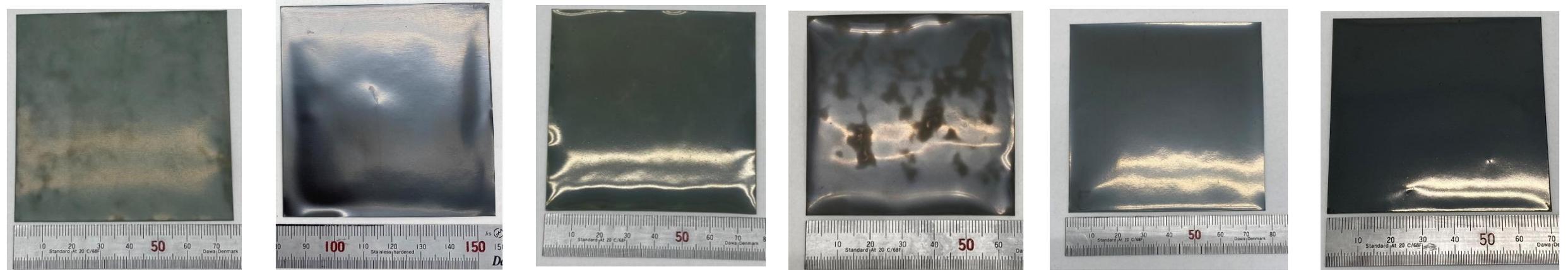
based on  $\text{BaCe}_{0.7}\text{Zr}_{0.1}\text{Y}_{0.1}\text{Yb}_{0.1}\text{O}_{3-\delta}$



Hendrik Bohn

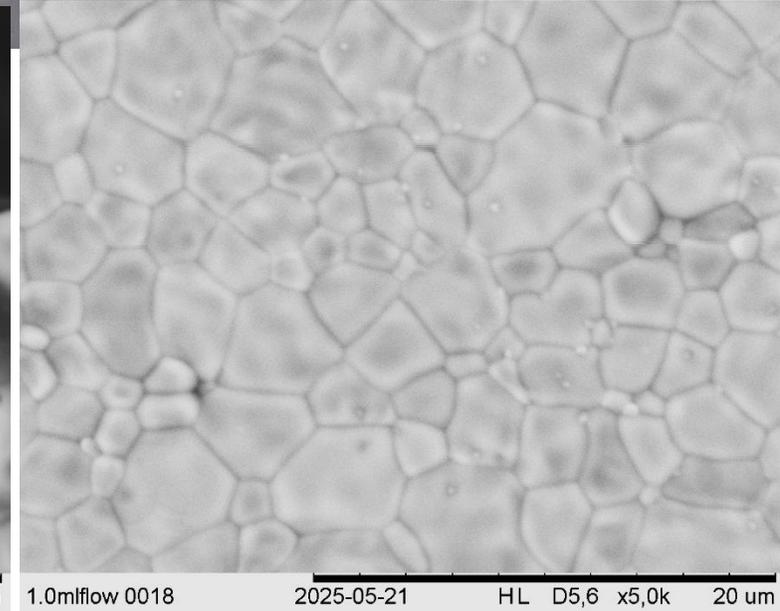
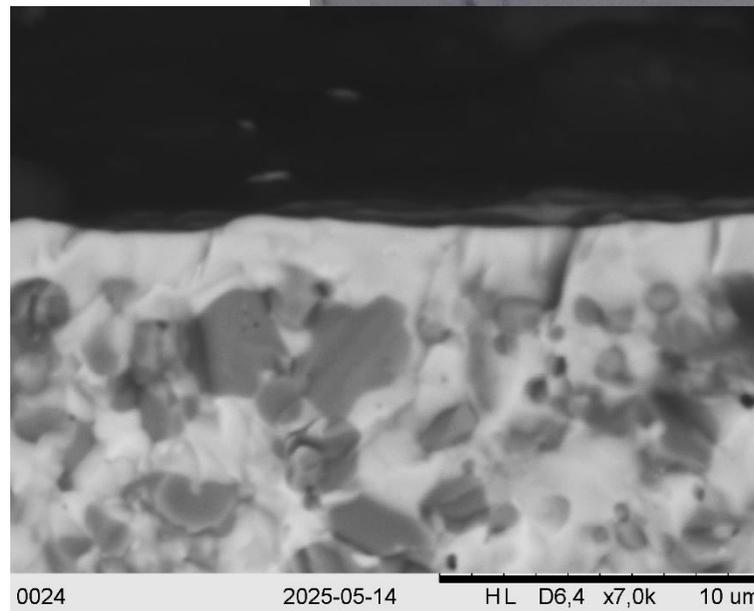
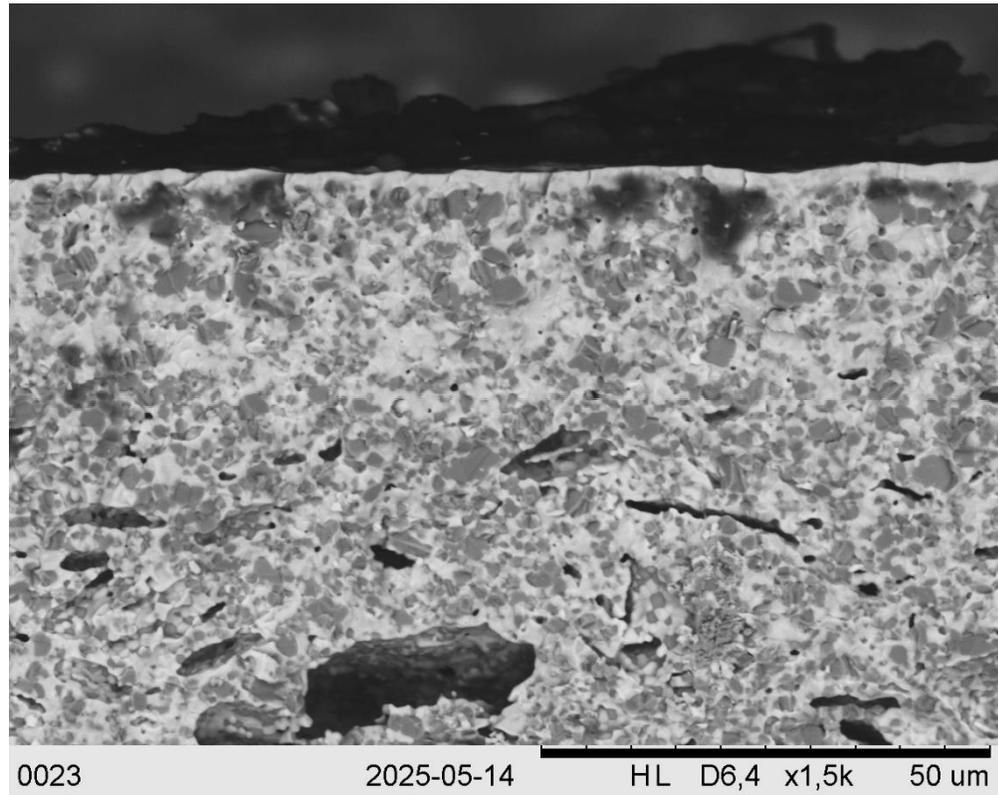
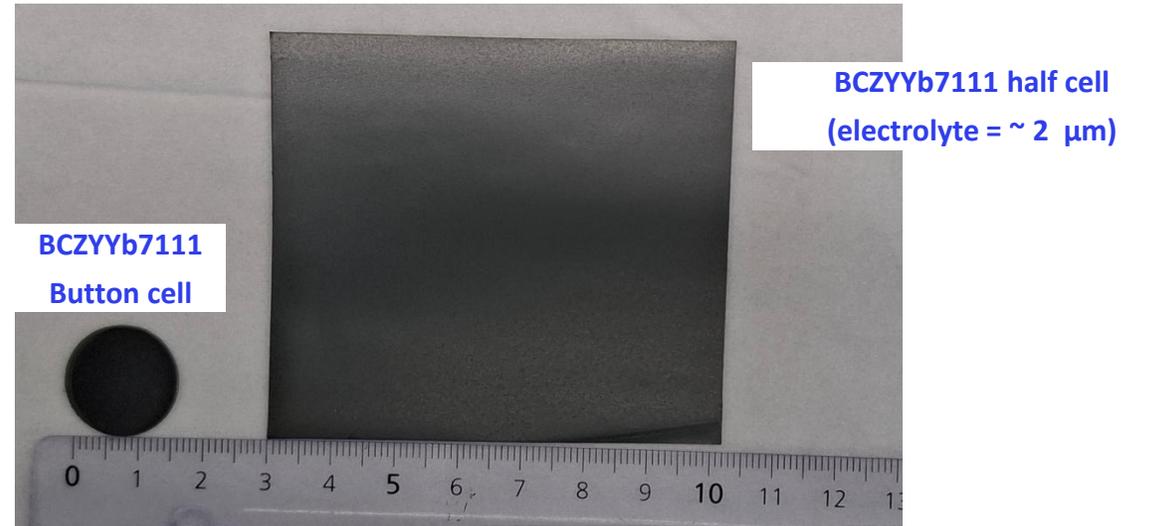
Ce content

$\text{BaCe}_{0.8}\text{Zr}_{0.1}\text{Y}_{0.1}\text{O}_{3-\delta}$	$\text{BaCe}_{0.7}\text{Zr}_{0.1}\text{Y}_{0.1}\text{Yb}_{0.1}\text{O}_{3-\delta}$	$\text{BaCe}_{0.55}\text{Zr}_{0.30}\text{Y}_{0.15}\text{O}_{3-\delta}$	$\text{BaCe}_{0.4}\text{Zr}_{0.4}\text{Y}_{0.2}\text{O}_{3-\delta}$	$\text{BaCe}_{0.4}\text{Zr}_{0.4}\text{Y}_{0.1}\text{Yb}_{0.1}\text{O}_{3-\delta}$	$\text{BaCe}_{0.2}\text{Zr}_{0.7}\text{Y}_{0.1}\text{O}_{3-\delta}$
NiO- $\text{BaCe}_{0.8}\text{Zr}_{0.1}\text{Y}_{0.1}\text{O}_{3-\delta}$	NiO- $\text{BaCe}_{0.7}\text{Zr}_{0.1}\text{Y}_{0.1}\text{Yb}_{0.1}\text{O}_{3-\delta}$	NiO- $\text{BaCe}_{0.55}\text{Zr}_{0.30}\text{Y}_{0.15}\text{O}_{3-\delta}$	NiO- $\text{BaCe}_{0.4}\text{Zr}_{0.4}\text{Y}_{0.2}\text{O}_{3-\delta}$	NiO- $\text{BaCe}_{0.4}\text{Zr}_{0.4}\text{Y}_{0.1}\text{Yb}_{0.1}\text{O}_{3-\delta}$	NiO- $\text{BaCe}_{0.2}\text{Zr}_{0.7}\text{Y}_{0.1}\text{O}_{3-\delta}$



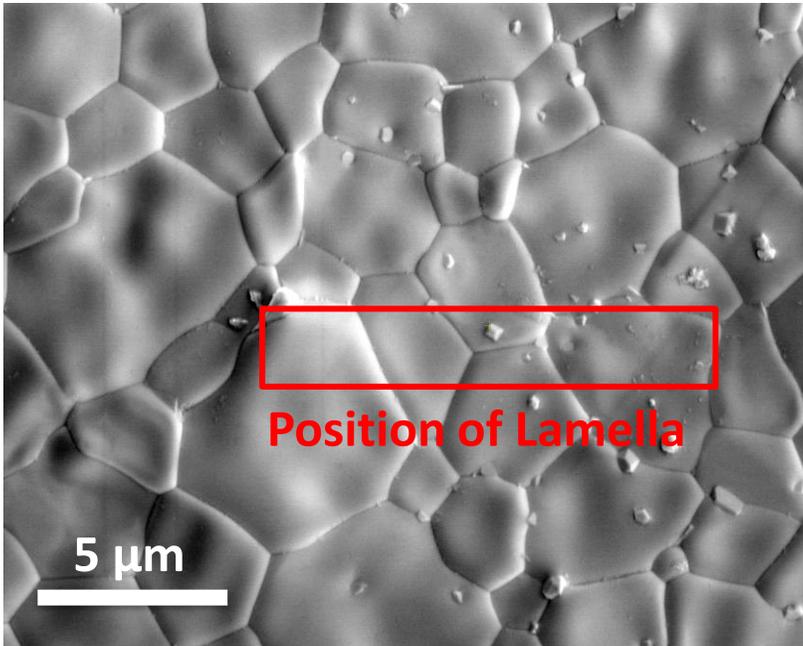
# Coated BCZYYb7111 with ultrathin electrolyte layer

-Successful fabrication of button cell and 7x7 cm<sup>2</sup> large PCC

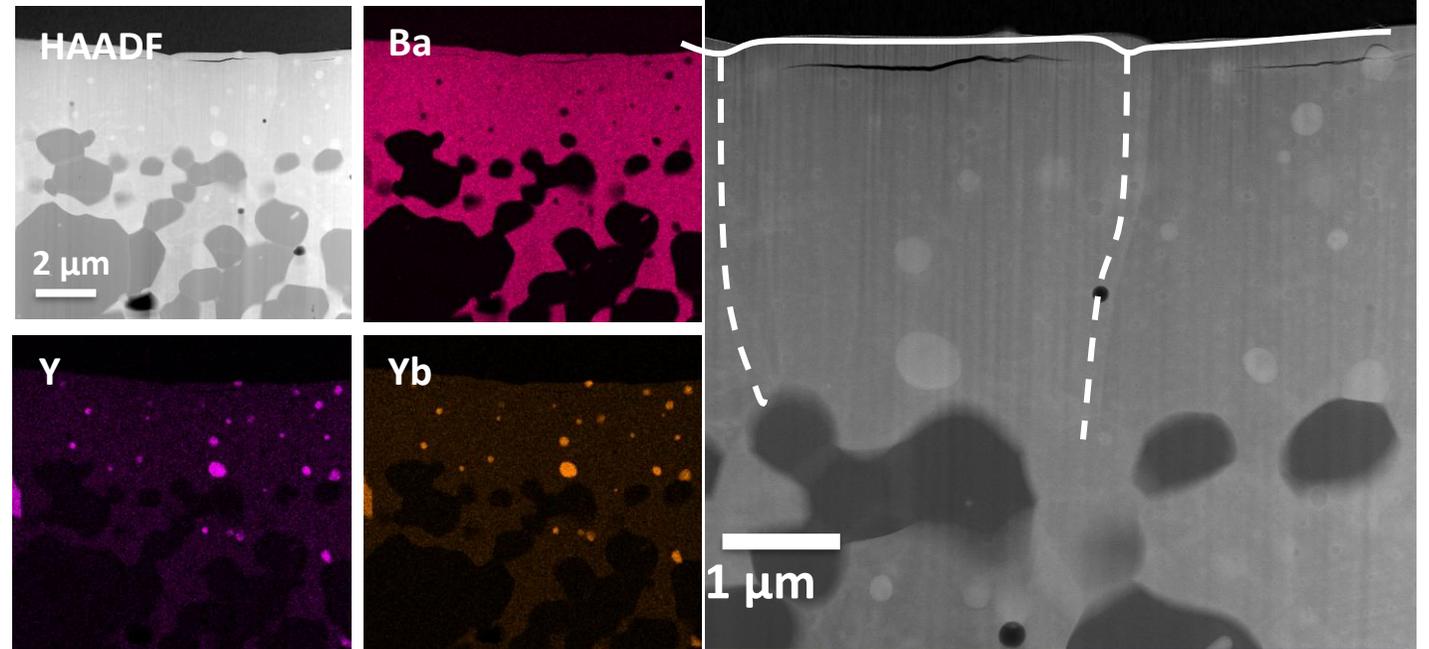


Umer Muhammad Abdullah

# STEM – EDS of ultra thin electrolyte prepared by coating



SEM of surface and TEM lamella position



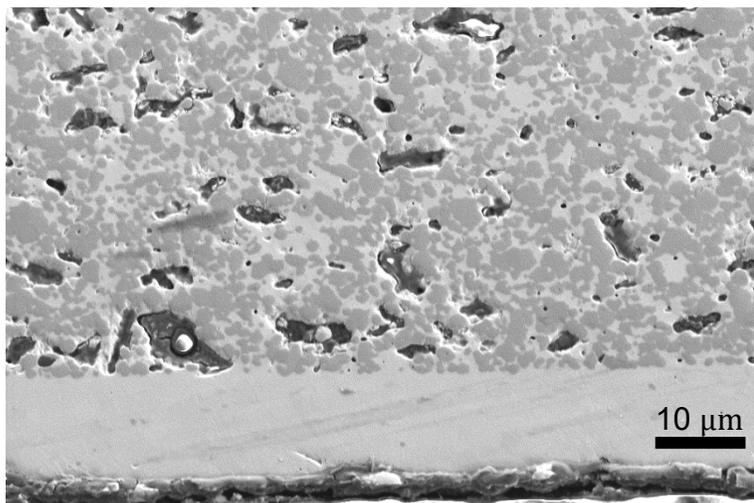
STEM – EDS of the cross-section with single grain electrolyte and  $Y_xYb_{2-x}O_3$  secondary phases

Single grain/bamboo structure columnar electrolyte

Umer Muhammad Abdullah  
Moritz Kindelmann (TEM)

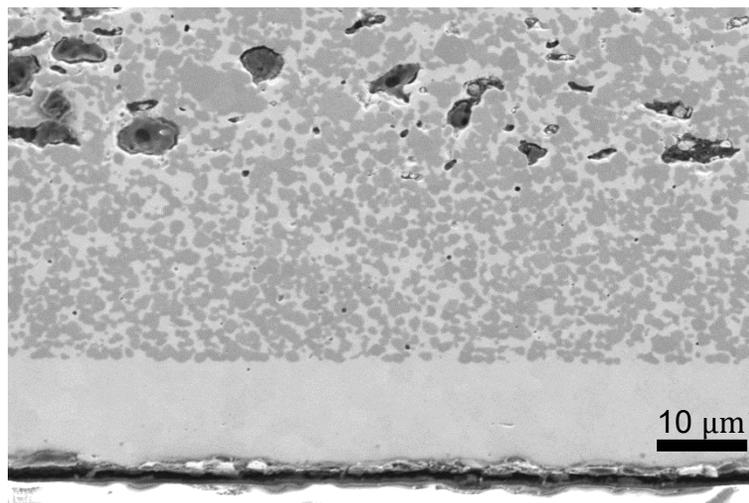
# Further improvement by integration of an anode functional layer (AFL)

No AFL



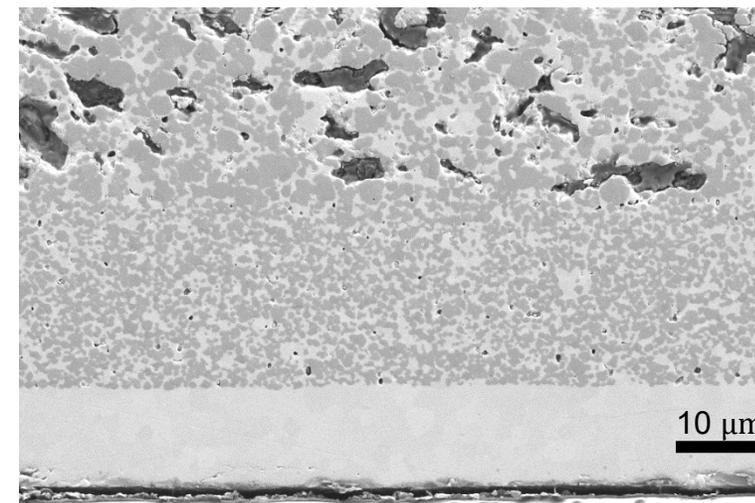
Porosity before reduction: 6.6 %

AFL Gen1



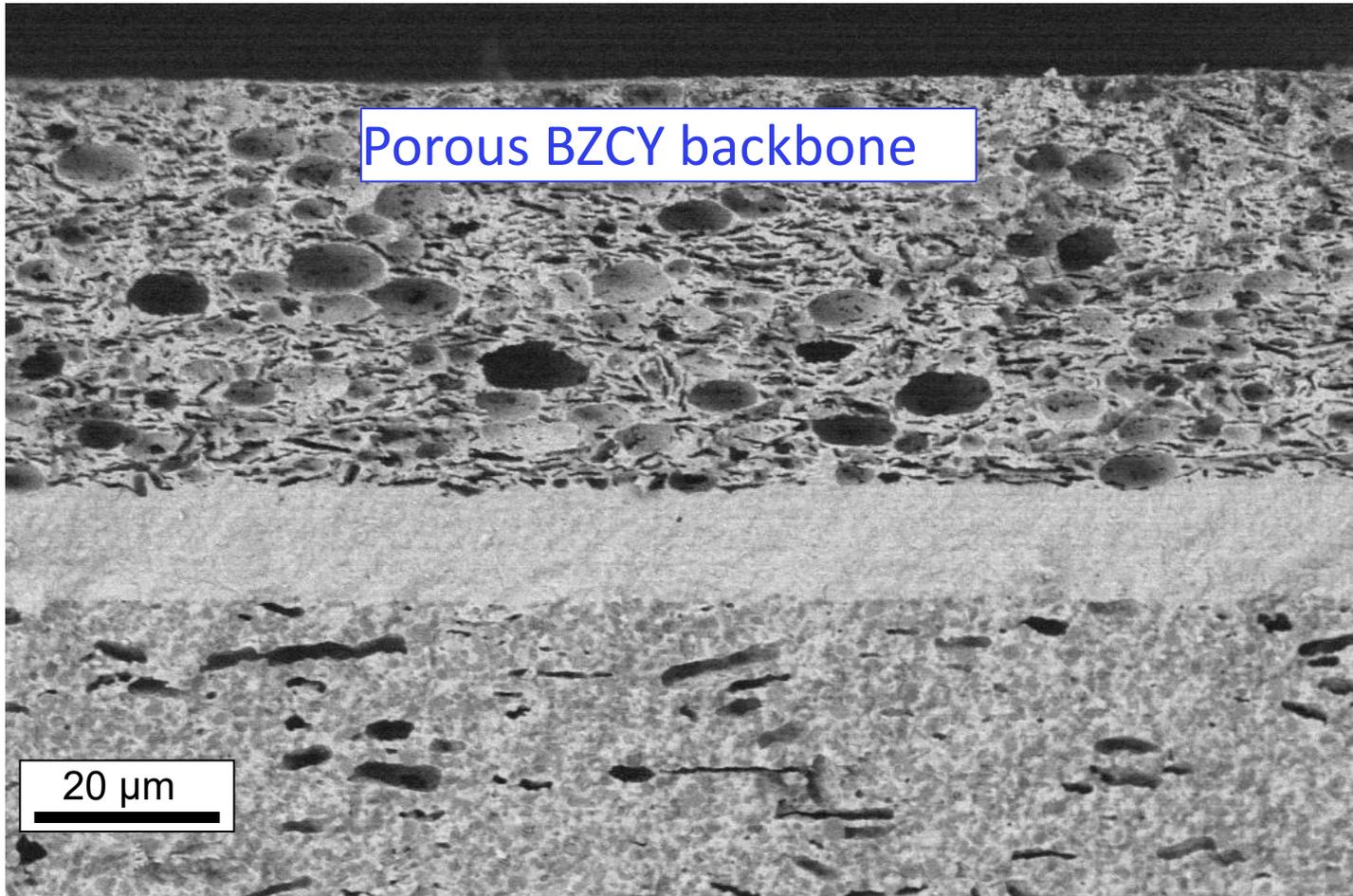
Porosity before reduction: 0.19 %

AFL Gen 2



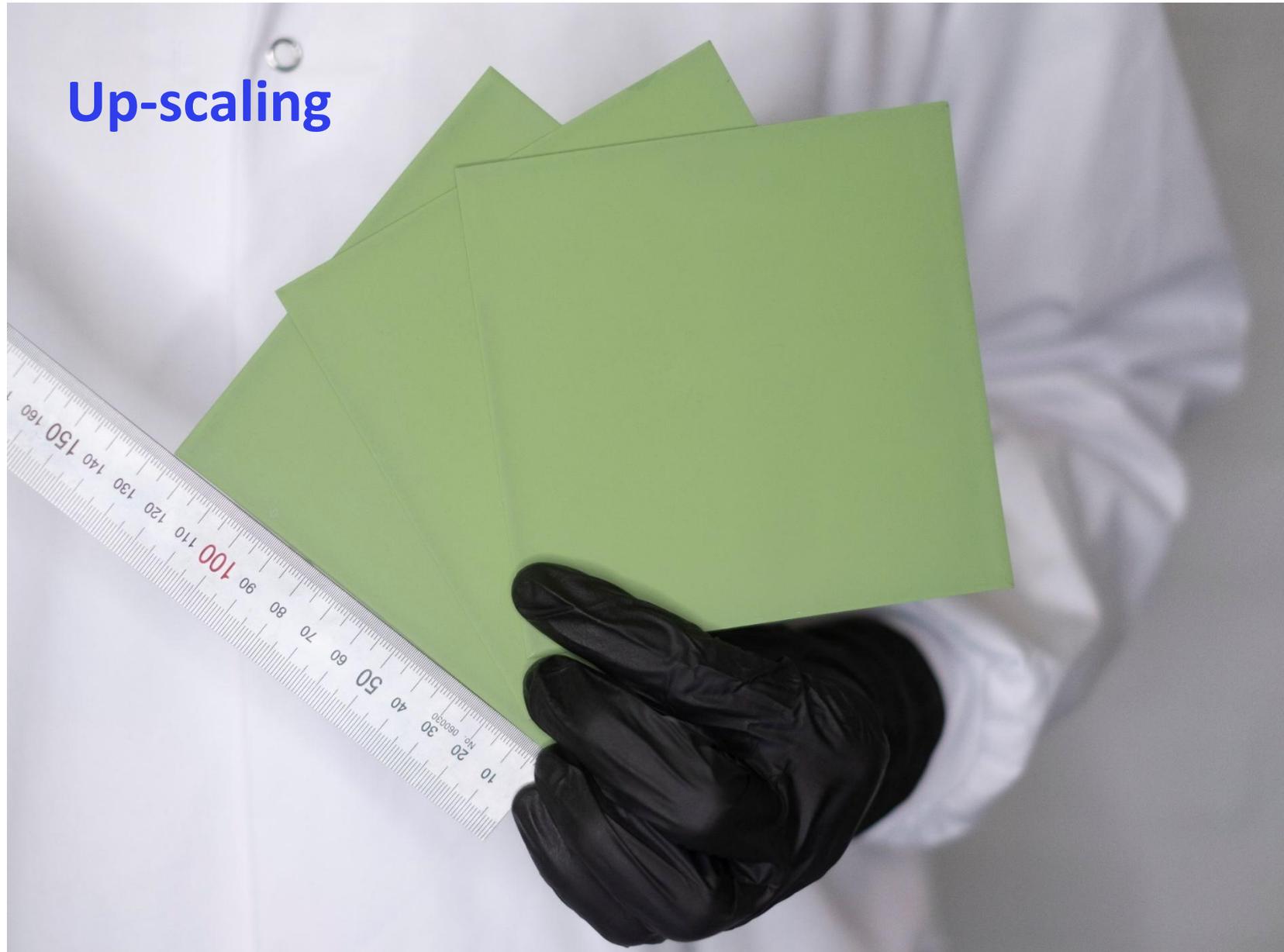
Porosity before reduction: 0.55 %

## Backbone enhanced cells



- Robust structure for oxygen/steam electrode
- Can be infiltrated with a large variety of nano –catalyst
- Excellent architecture for fast screening of electrode materials

- Cells successfully up-scaled > 140 cm<sup>2</sup> (12 cm \* 12 cm)
- Batches of > 20 cells can be produced currently
- All used processes compatible with mass production



## Electrochemical performance ?



 Hy-SPIRE

<https://hy-spire.eu/>

**...we are working on it!**

**Collaborations welcome**

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