Contribution to green hydrogen production cost reduction by cold gas spray additive manufacturing

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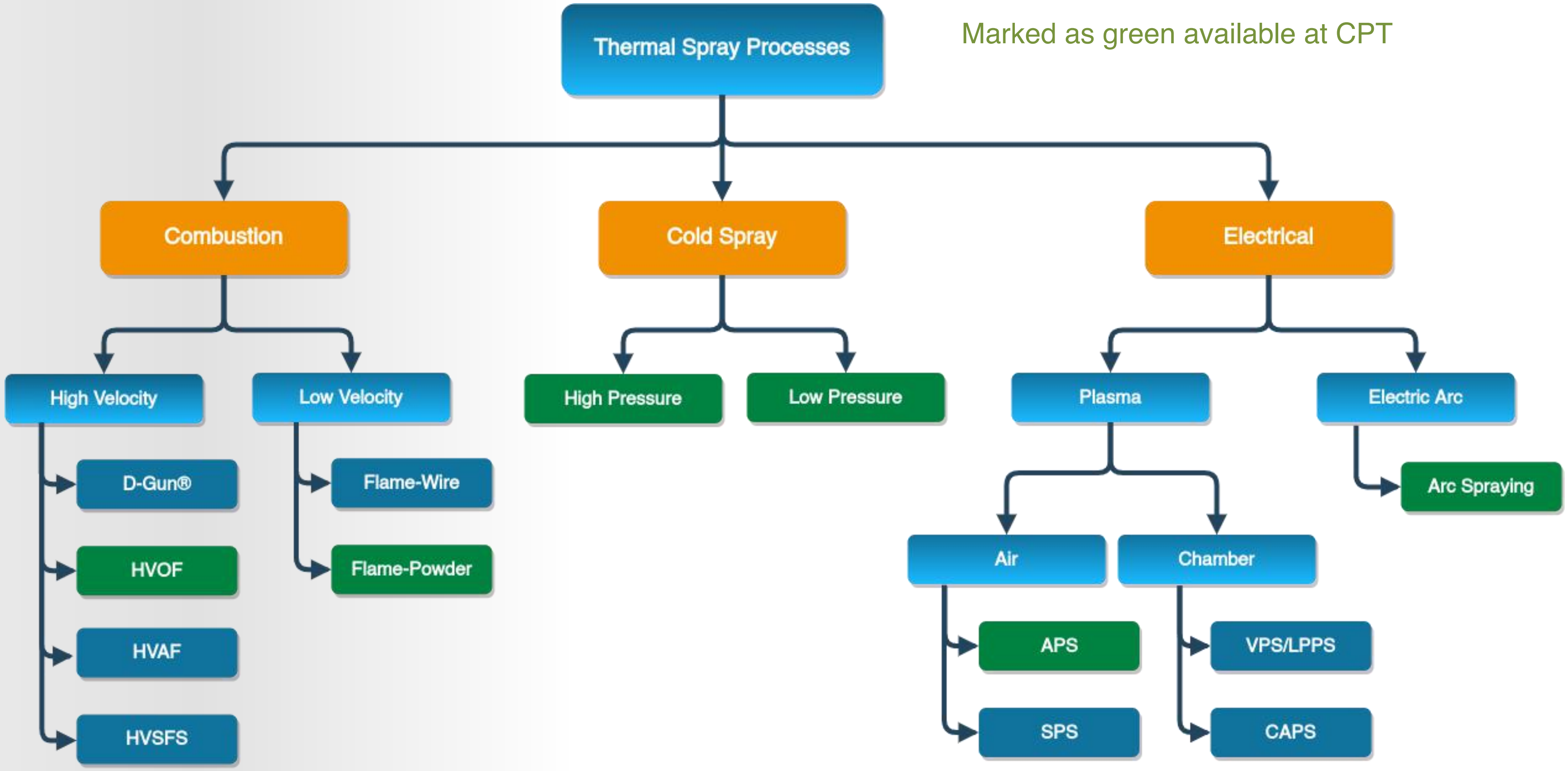
CPT. Thermal Spray Center

Nearly 30 years of experience in Thermal Spraying

- Founded in 1994
- 22 researchers in 3 divisions
- The best available thermal spray technologies
- > 400 papers published in Thermal Spray
- 65 PhD thesis presented

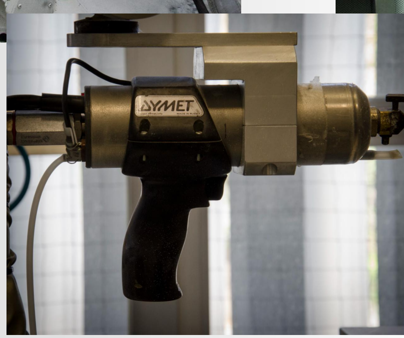
CPT. Thermal Spray Center

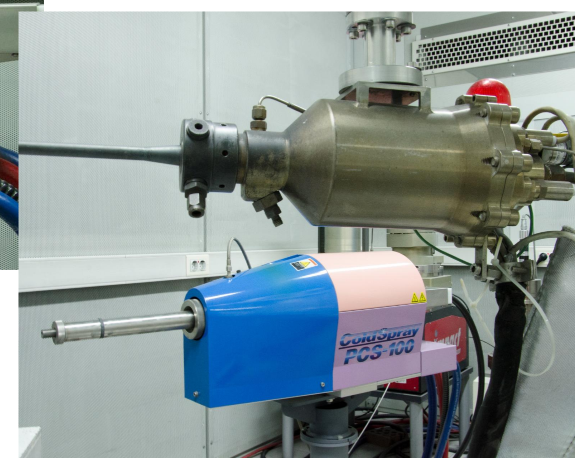
Marked as green available at CPT



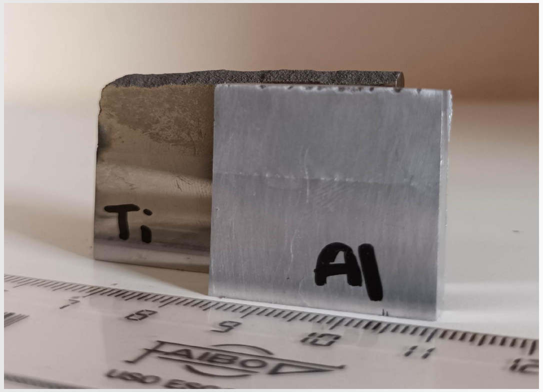
Cold Gas Spray equipments

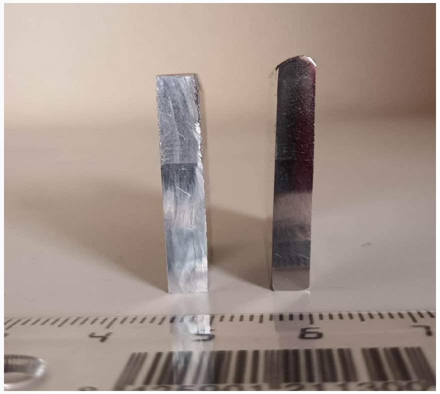
- PCS100 Plasma Giken
- CGT KINETICS 4000
- DYMET 423





Cold Gas Additive Manufacturing





Cold Gas Additive Manufacturing

Advantages

- High productivity
- Dense final materials
- Great variety of starting materials
- Suitable for large parts
- Multimaterial

Limitations

- Restricted to metals
- Post-treatment
- Control of final geometry
- Properties. Anisotropy

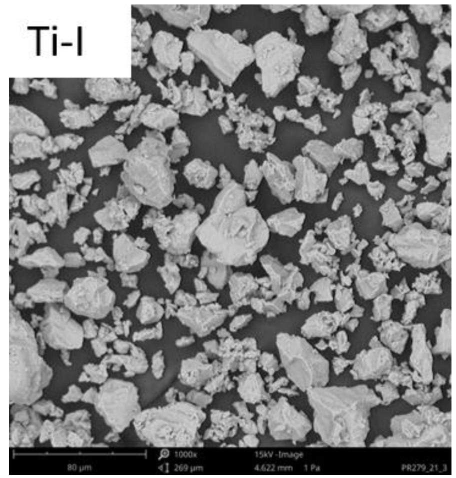
Feed rates

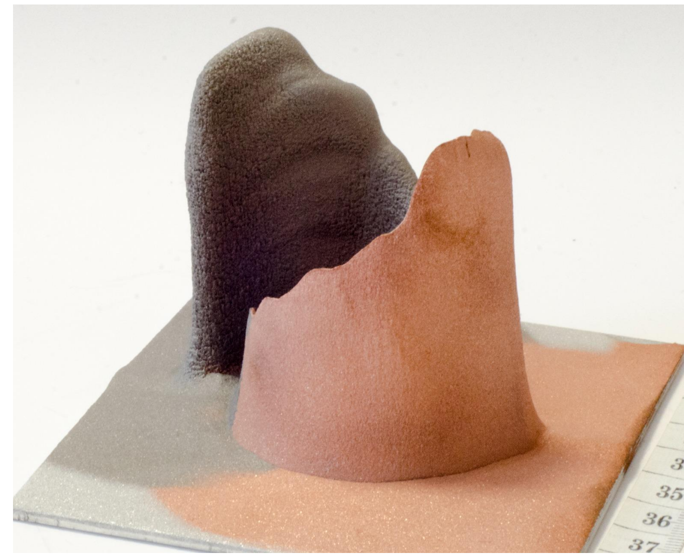
- 150 g/min (CPT)
- 500 g/min (large industrial equipment)

Cold Gas Additive Manufacturing of Titanium

Irregular Ti powder (Ti-I)

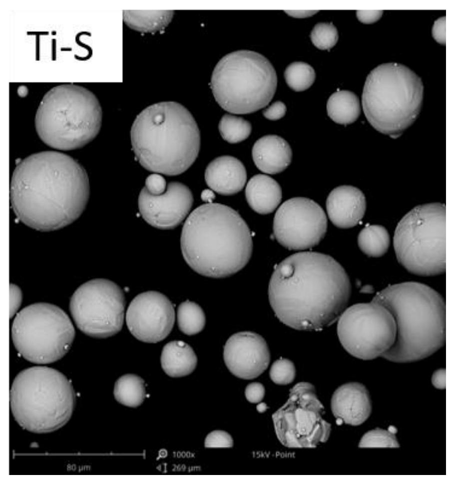
- HDH powder
- PSD (10-90 μm)
- High DE
- Low Cost





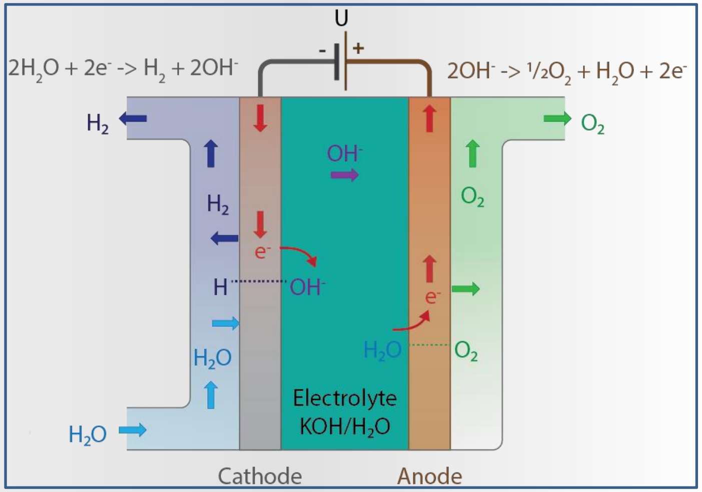
Spherical Ti powder (Ti-S)

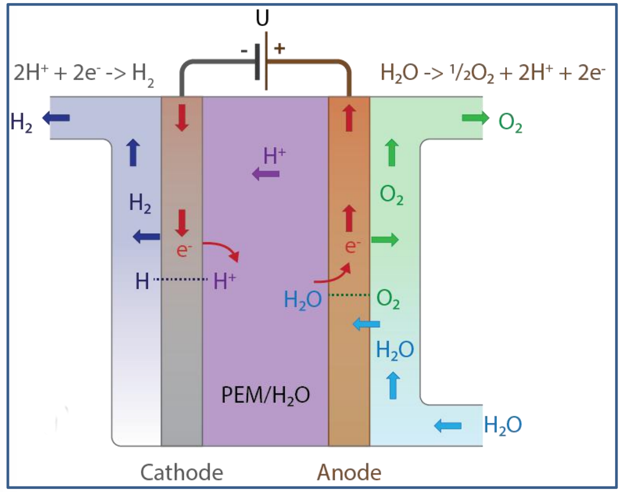
- Gas atomized powder
- PSD (20-63 μm)
- Extremely high DE
- High Cost

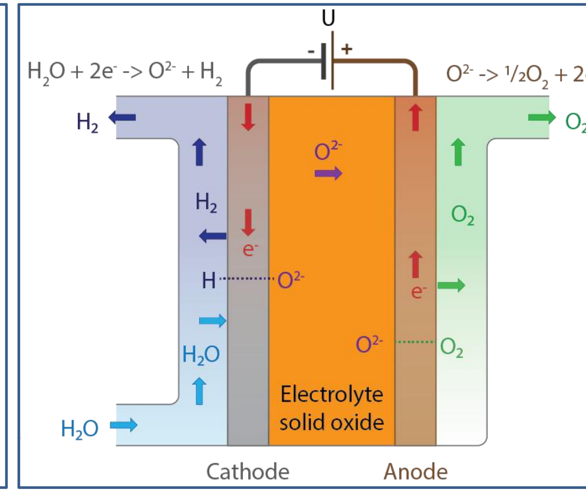


Electrolyzers

N. Gallandat et al. Journal of Power and Energy Engineering, 2017







AEL

+ $ 800 – 1000 /kW
+ Reliability and durability
+ High nominal output
+ Mature technology
- Not compact
- Moderate current densities
- Low flexibility

PEM

+ High flexibility to load changes
+ High H_2 output pressure and purity
+ Compact design
- $ 1400 – 1700 /kW
- Requires rare and expensive materials

SOEL

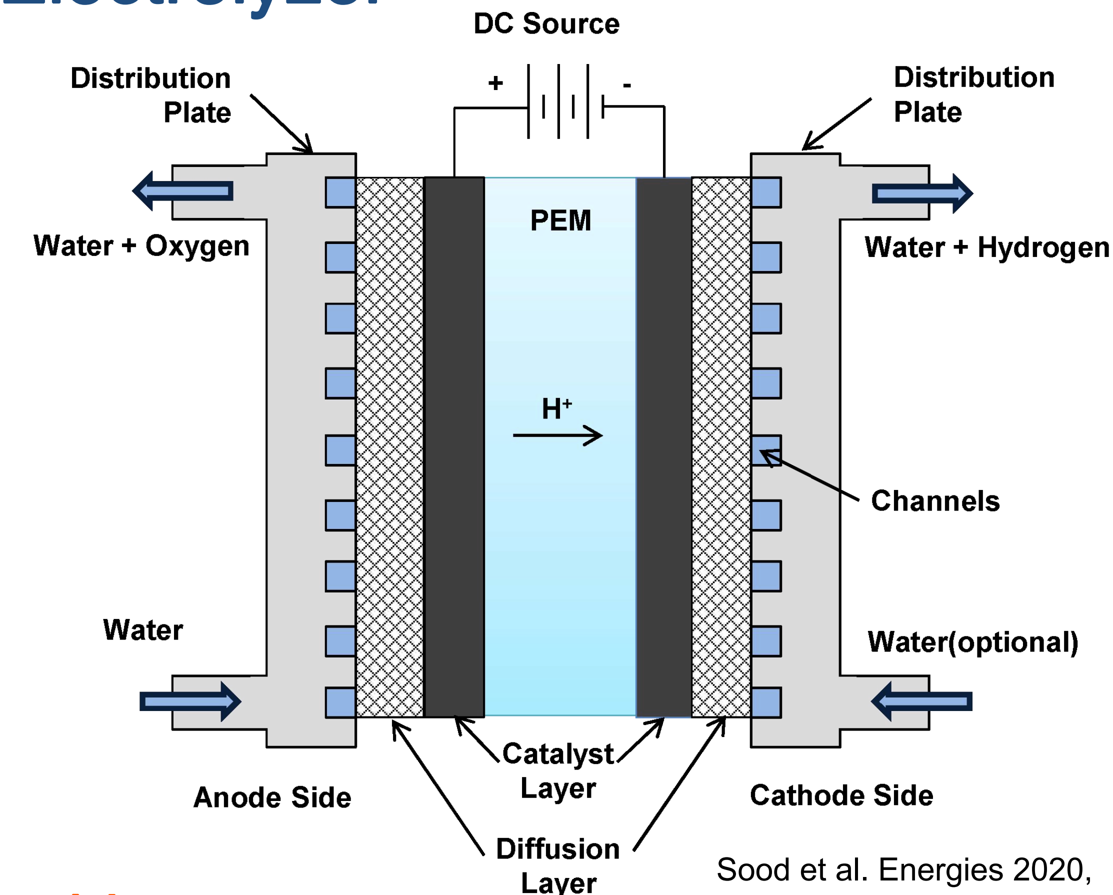
+ Highest efficiency
+ Suitable for co-electrolysis
- $ 2200 – 2500 /kW
- Long cold start
- Not mature technology

PEM Electrolyzer

Current manufacturing choices for PEM BPP

- Ti + PGM coating
  (-) Cost + Poor Ti machinability

- SS + PGM coating
  (-) Prone to corrosion

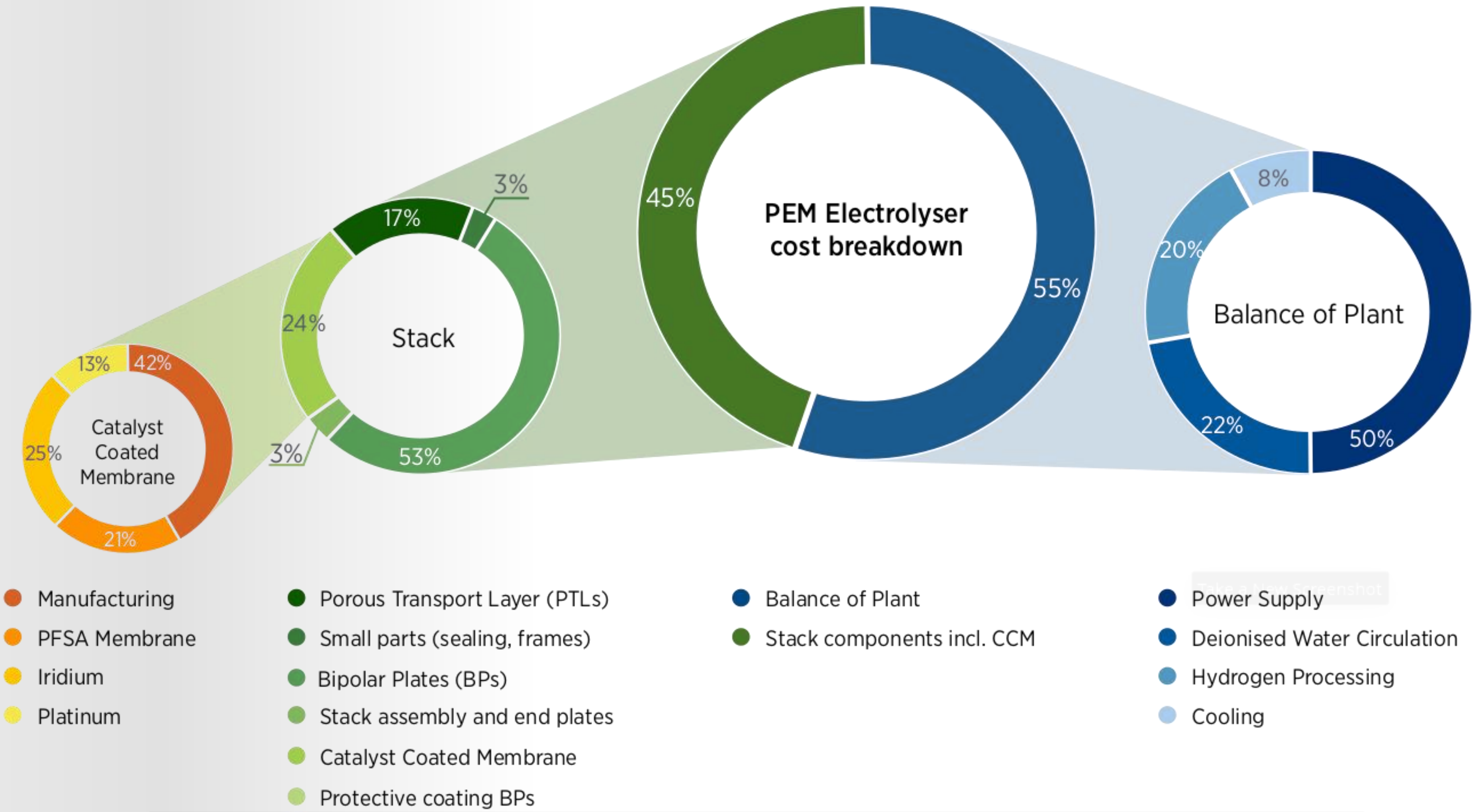


Sood et al. Energies 2020,

The problem:

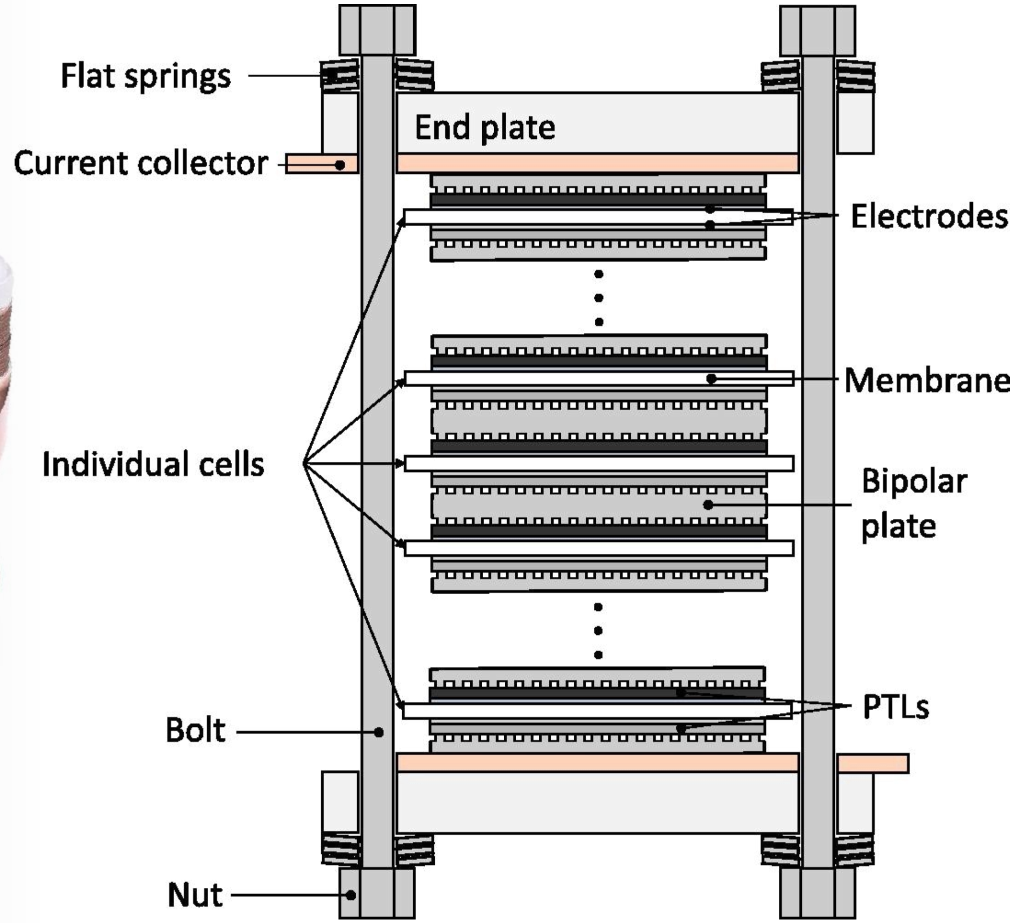
To reduce the cost of the PEM BPP keeping its corrosion resistance and electrical conductivity

The big problem

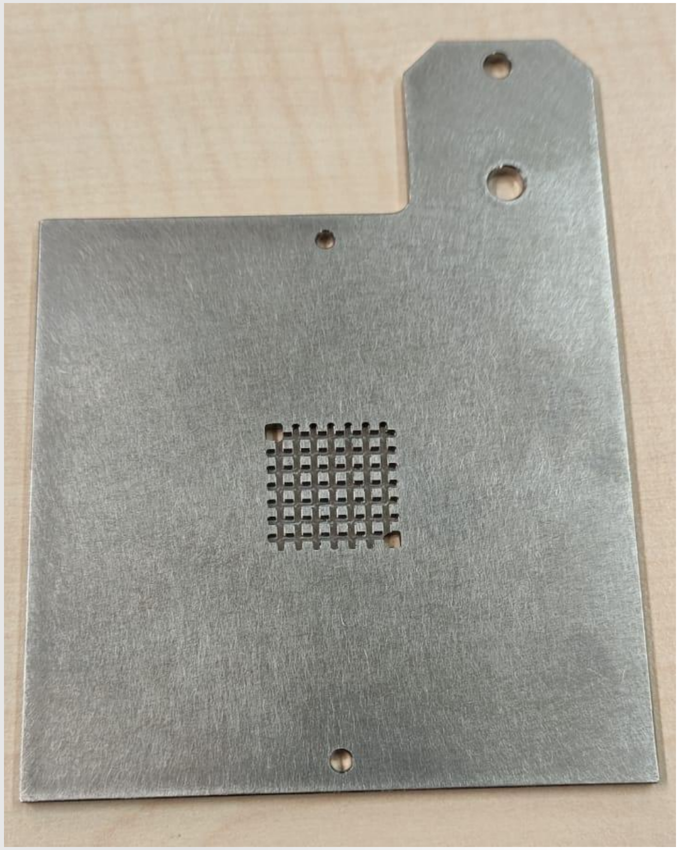


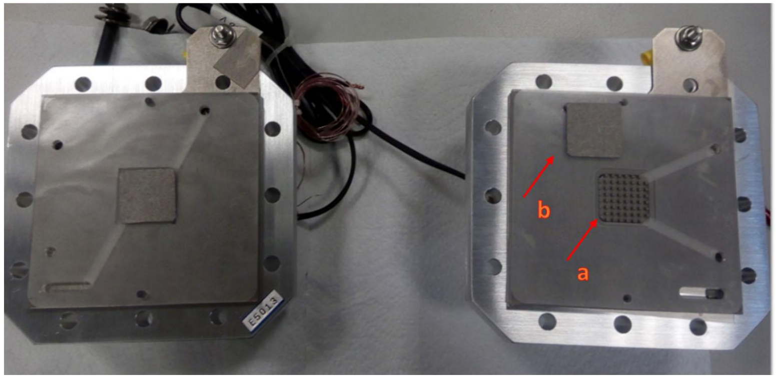
IRENA (2020), Green Hydrogen Cost Reduction: Scaling up Electrolysers to Meet the 1.5ºC Climate Goal, International Renewable Energy Agency, Abu Dhabi

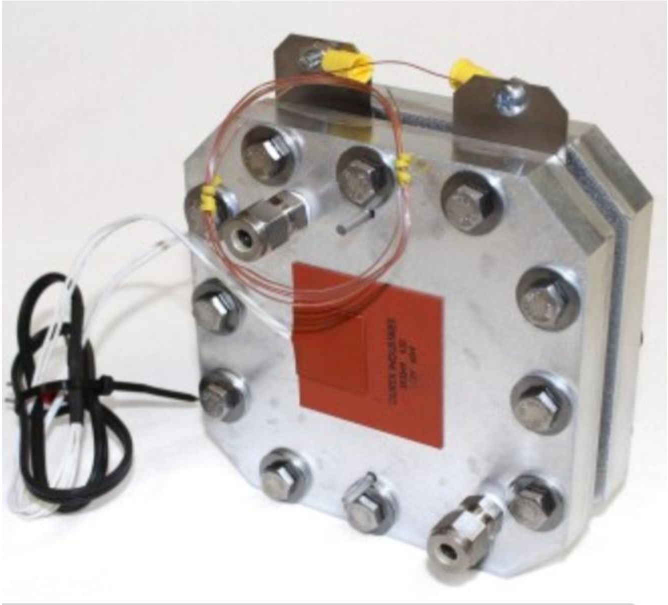
The PEM electrolyzer stack



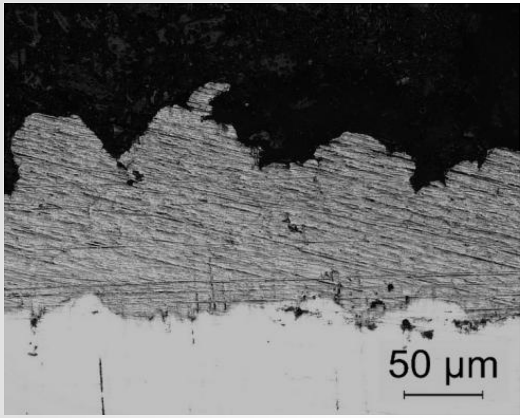
Our system

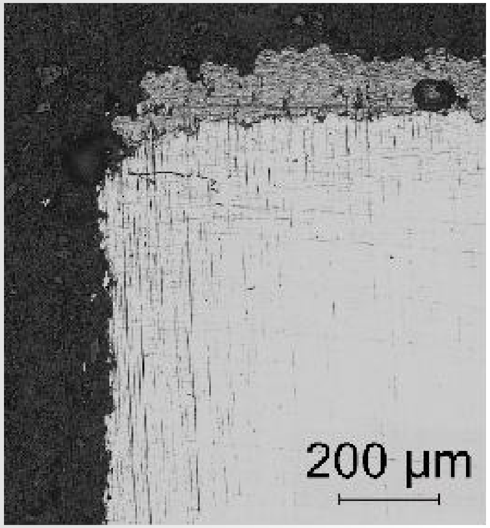




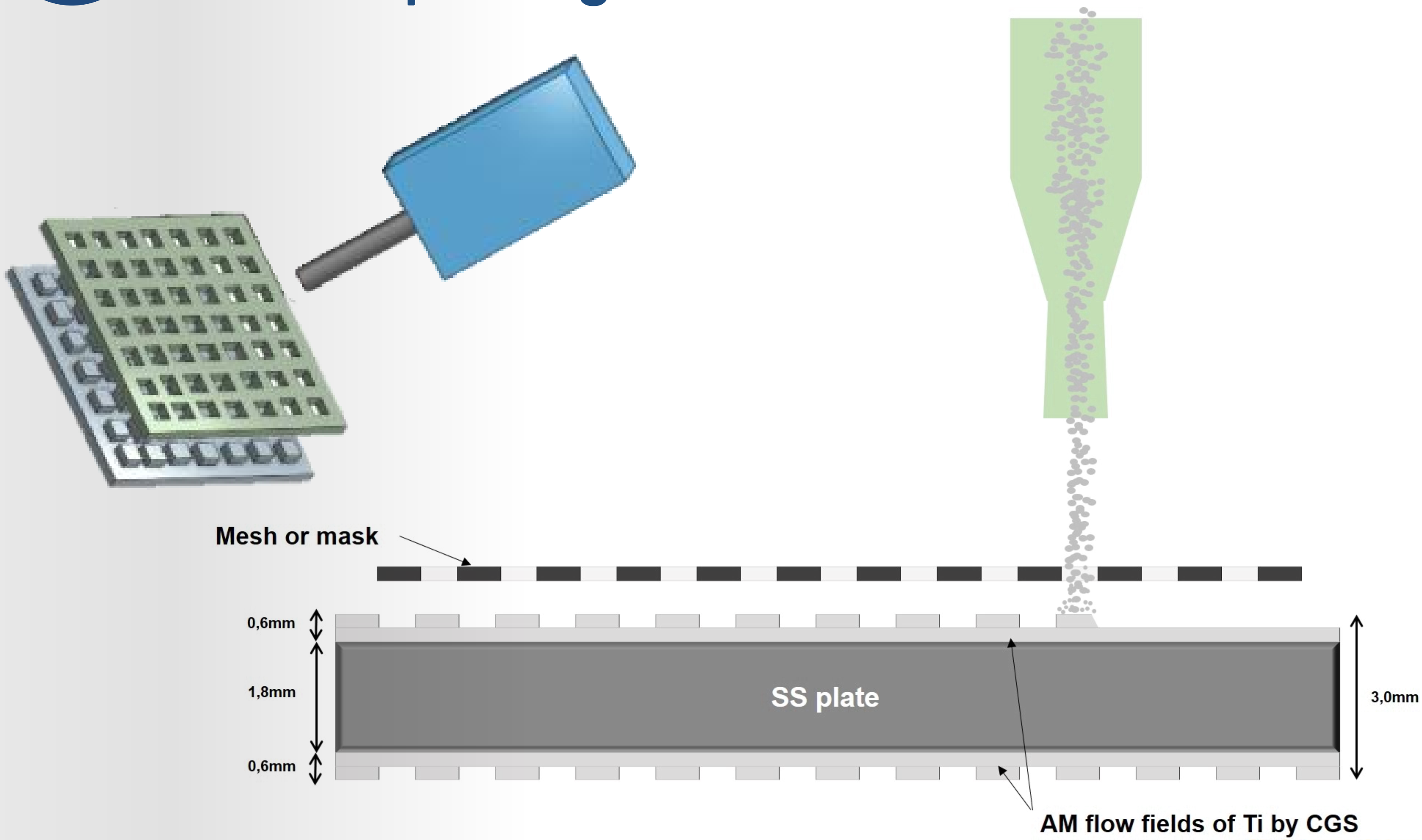


The solution. I
Ti CGS coating of a SS base material





The solution. II. CGS metal 3D printing of the BPP flow field



Four lines of work

Manufacturing of the PEM BPP by CGS using masks

- Different BPP flow-fields geometries
- Double side BPP for stack integration

Characterization of the deposited Ti flow-field

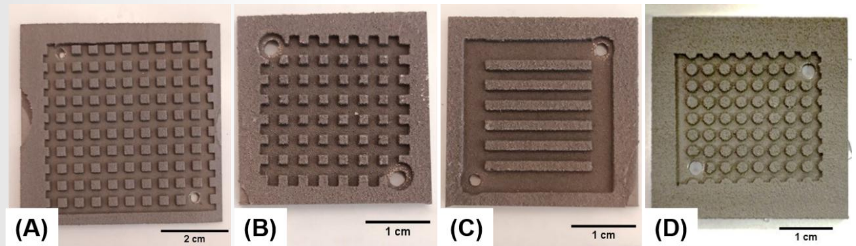
- Topography
- Structural

Properties relevant to the BPP performance

- Corrosion resistance
- Interfacial contact resistance (ICR)

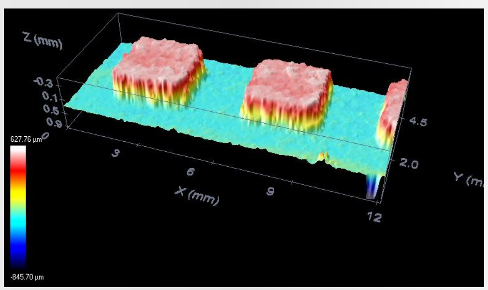
Bipolar plate performance

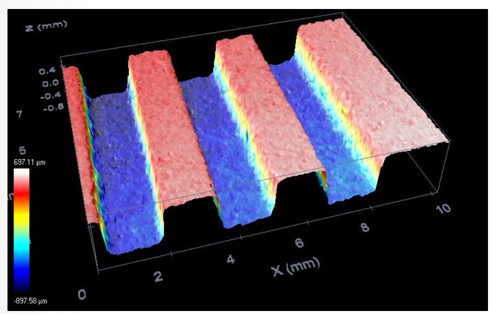
Structure of CSAM-ed BPPs

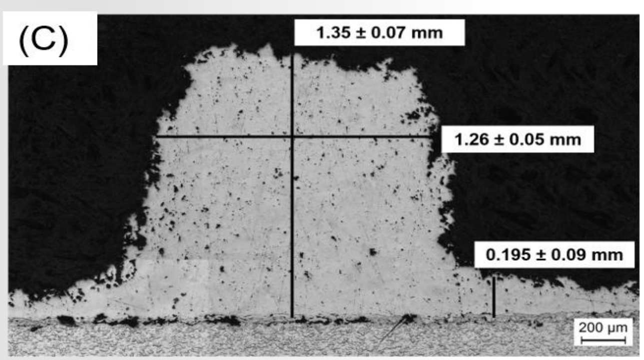


CSMA 3D printed patterns

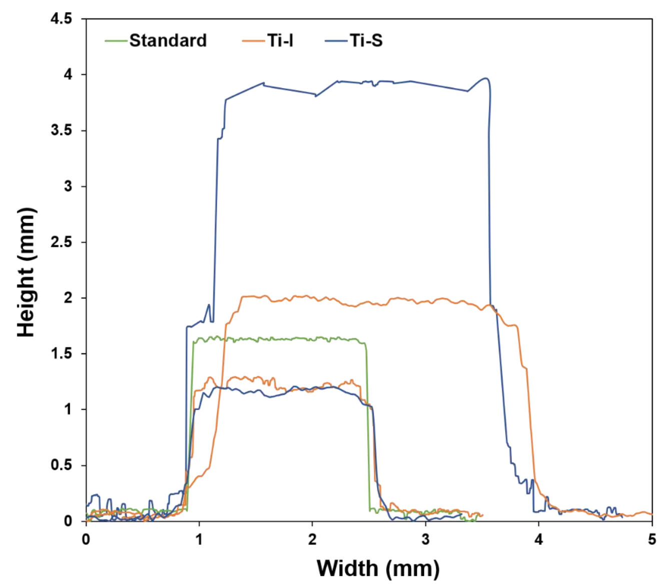
Pins 3D topography and structure



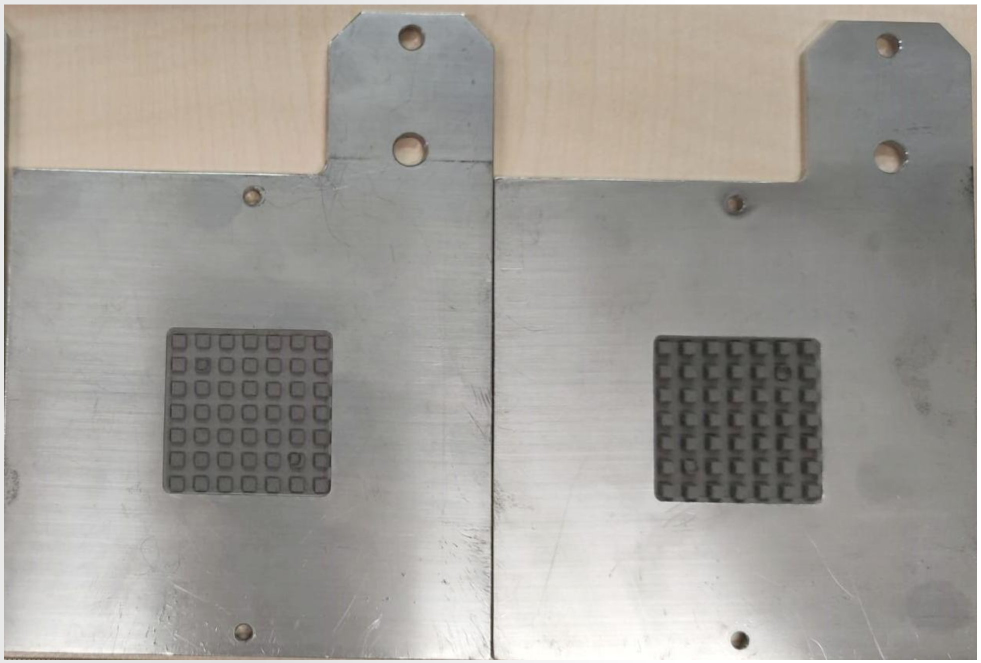


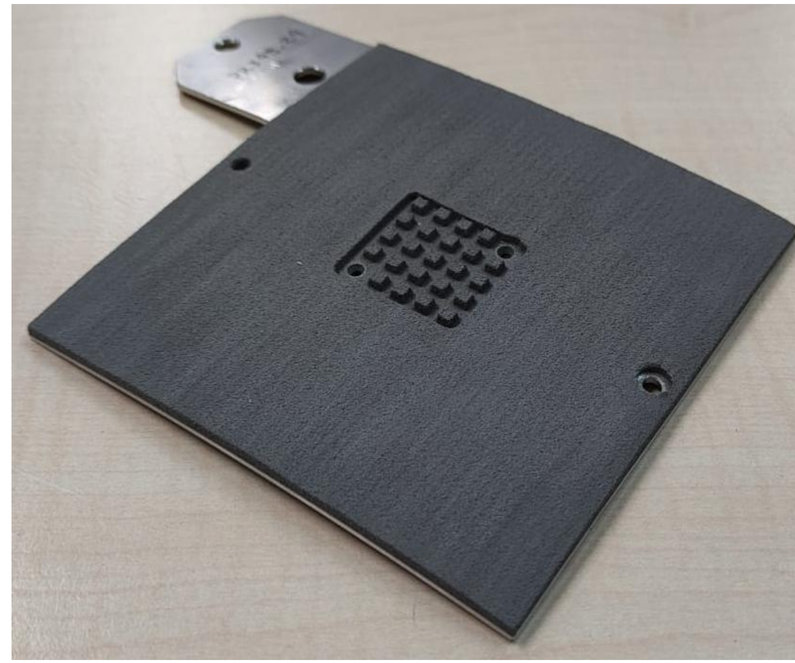


Pins profile



Manufacturing of BPP by CGS using masks





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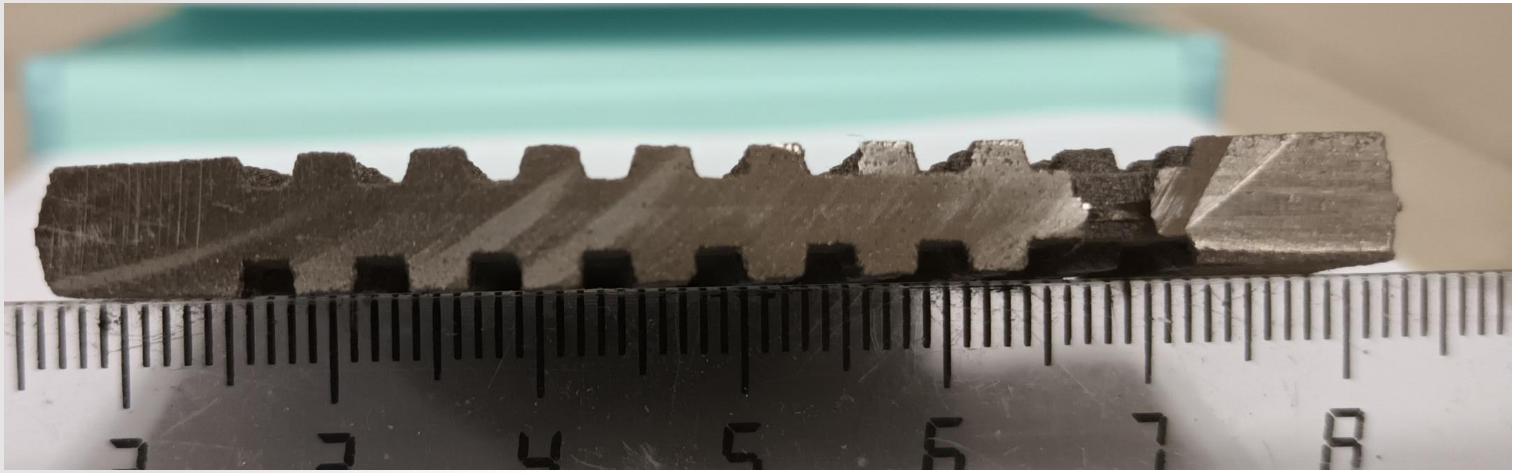
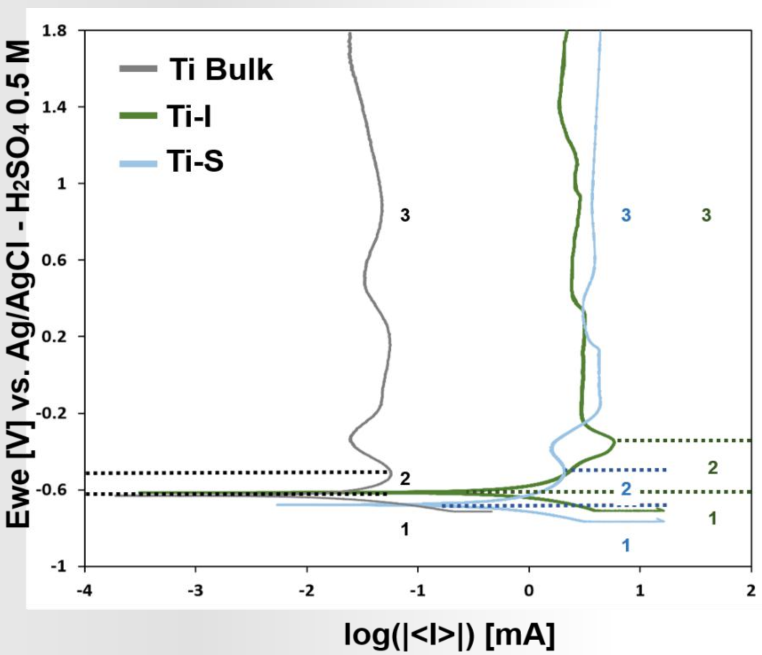


- 1.5 mm SS
- + 200 μm Ti (each side)
- + 1.5 mm Ti flow field (each side)

Potentiodynamic Polarization

- **Polarization curves** → three electrode cell
- 0.5 M H_2SO_4 O_2 saturated solution
- -0.1 V – 1.8 V vs EOCP

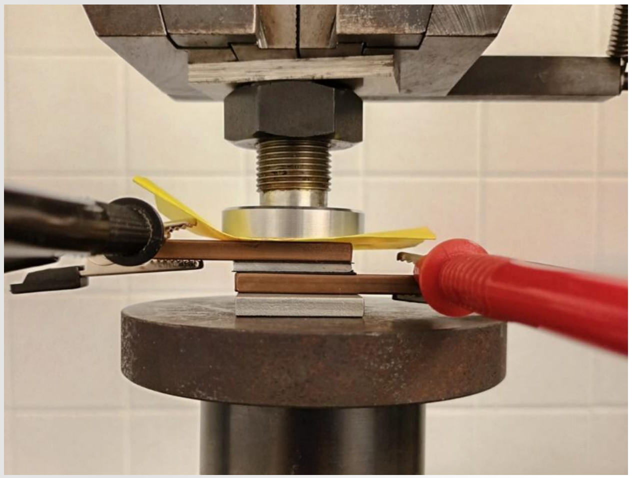
Sample	E_{corr} (mV)	I_{corr} (μA)
Ti-I	-614 ± 9	250 ± 14
Ti-S	-665 ± 14	220 ± 10
Ti Bulk	-640 ± 17	15 ± 4



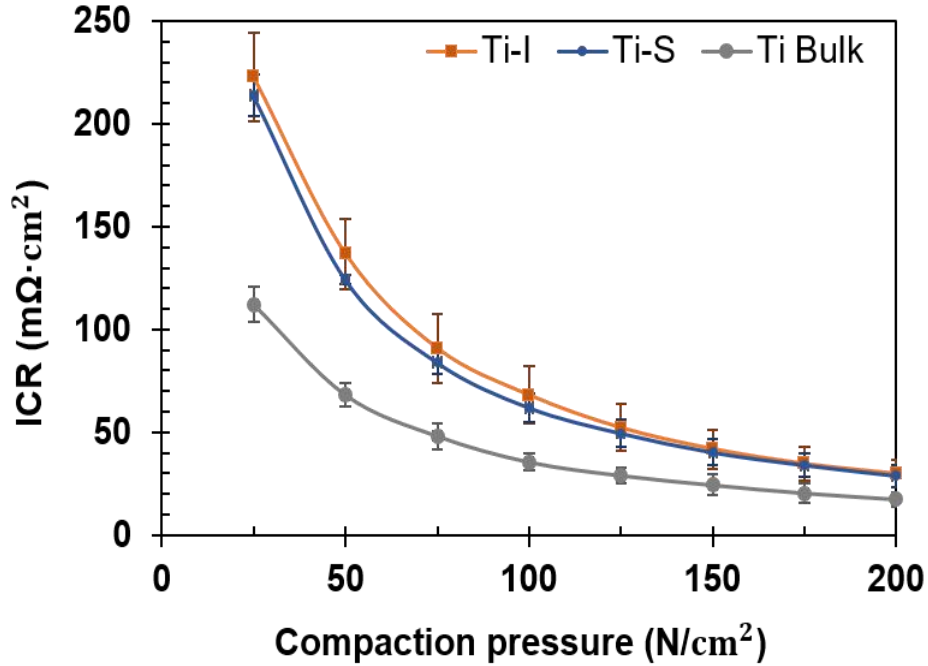
- Resistance to corrosion

  Ti Bulk > CSAM Ti due to Intrinsic defects in the CSAM process
- Oxide film stability

ICR testing



ICR experiments setup



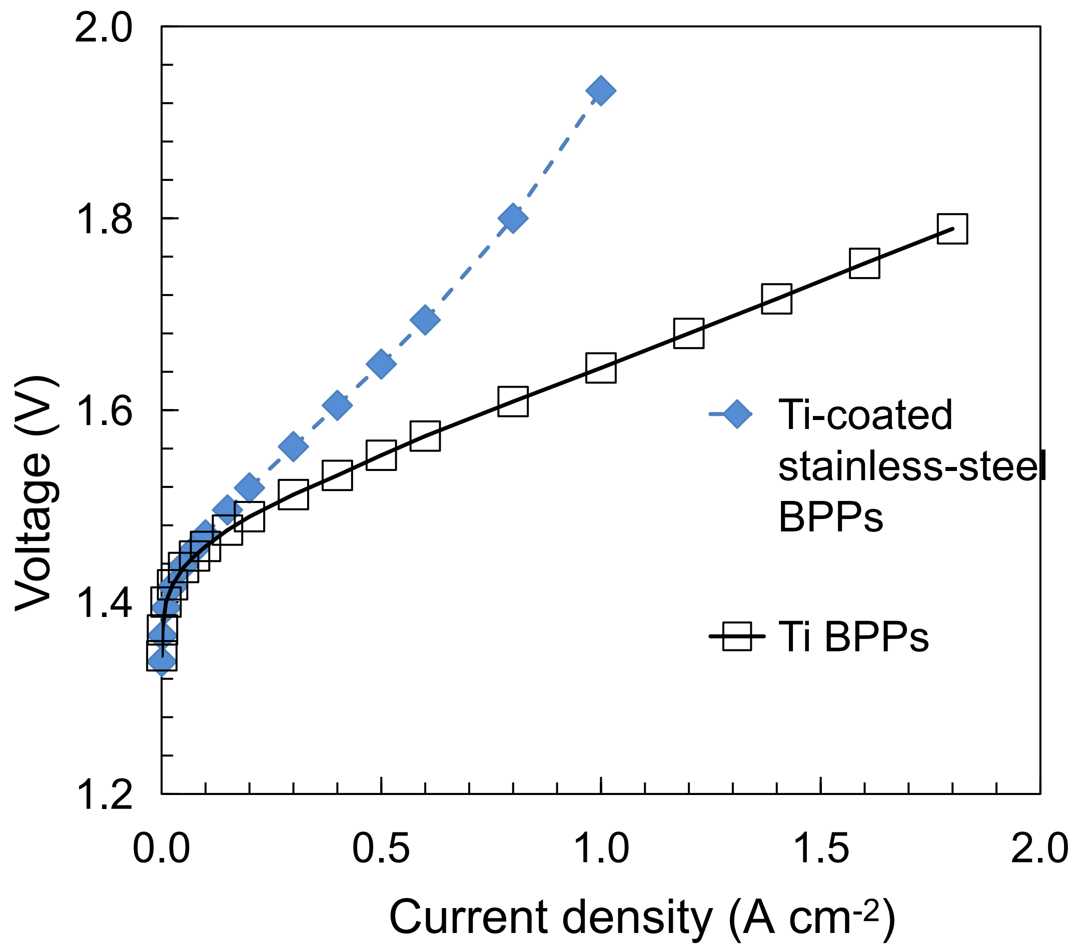
- Double-side CGS-Ti on a 9 cm^2 steel plate vs bulk Ti
- ICR method – Adapted from Wang et al.[2] Compaction force ranging from 25 to 200 N/cm^2
- 1 A current

- ICR values decrease with increase in compaction pressure
- ICR Ti Bulk < ICR CSAM Ti

Bipolar plate performance

Operating Conditions

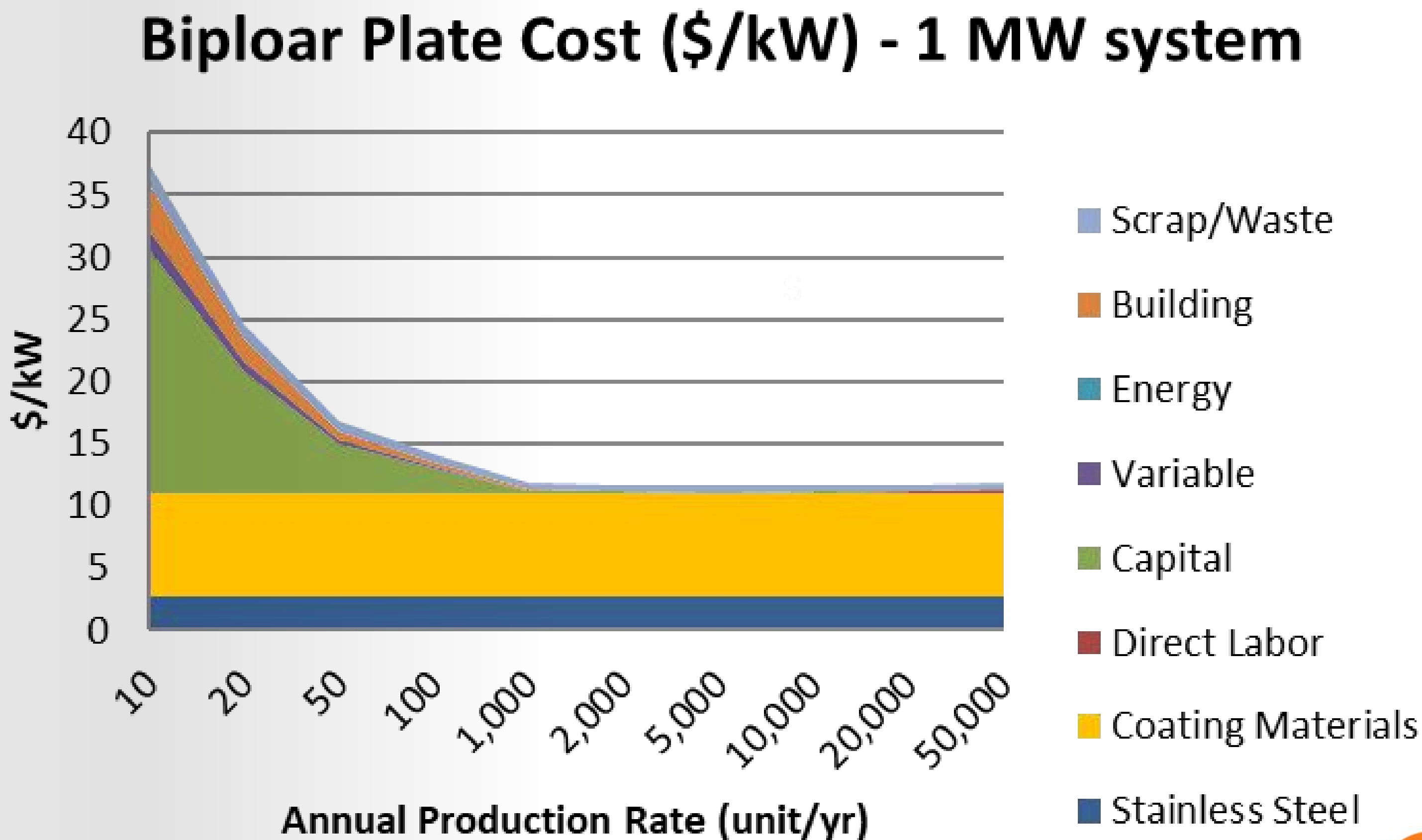
- Cell T: 80ºC
- Nafion 115 Membrane
- 5 cm² active area
- Anode:
  - 2.0 mg/cm² Ir black
  - 90 ml/min
- Cathode:
  - 1.0 mg/cm² Pt/C 60%
  - 0 ml/min



In Collaboration with A. Rocha, R.B. Ferreira, D.S. Falcão, A.M.F.R Pinto
CEFT, University of Porto, Portugal.

Cost reduction

- Calculation based on NREL Cost Analysis (2019)
- 5 mm SS + 100 nm Au BPP



Cost reduction

Assumptions

- SS price: $1.40/kg
- Ti price: $48/kg
- SS density = 2 x Ti density
- Original BPP: 5 mm Ti + 100 nm Au
- Final BPP: 3.8 mm SS + 2 x 0.6 mm Ti + 100 nm Au
- High production rates (Main cost is material cost)

Cost reduction calculation

- Final BP cost : 19.7. Arbitrary units
- Original BP cost : 50.5. Arbitrary units

61% cost reduction

Future work

- Improve surface finishing
- Improve density of flow field Ti
- Nb and Ta coating for ICR improvement
- New flow field geometries
- Scale-up

Looking for suggestions and collaboration!!

Thank you