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Materials challenges and opportunities in high-temperature steam electrolysis with geothermal heat

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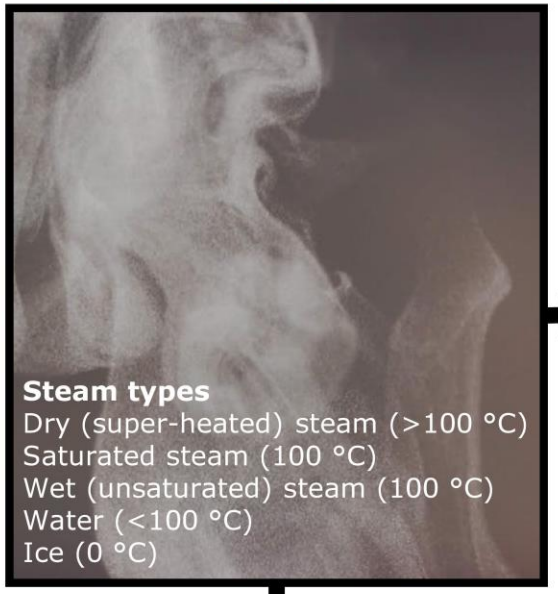
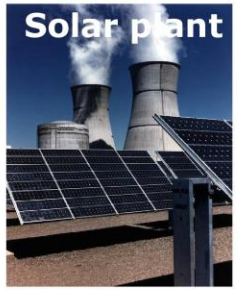
High temperature steam and water

STEAM

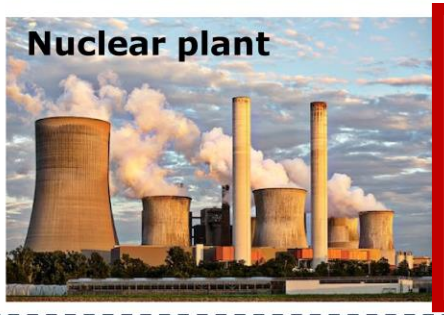


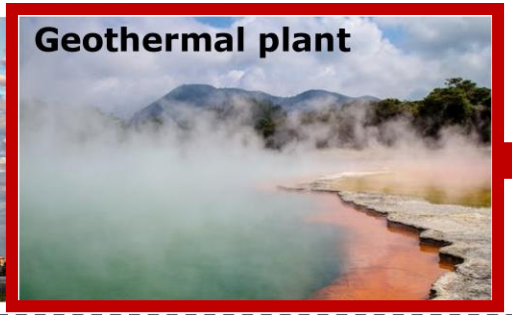
APPLICATIONS & OPPORTUNITIES



Other examples

Sugar industry
Dairy industry
Paper industry
Food processing
Heating
Sterilisation
Propulsion
Atomisation
Cleaning
Moisturisation
Humidification





CHALLENGES Coating and structural materials degradation

Temperature ranges of geothermal sources

- **Low-temperature resources:** Below 150 °C (closer to the Earth's surface)
- **Moderate-temperature resources:** 150–200 °C (typically 1–3 km)
- **High-temperature resources:** Above 200 °C, with some reaching 370 °C (regions with volcanic activity)

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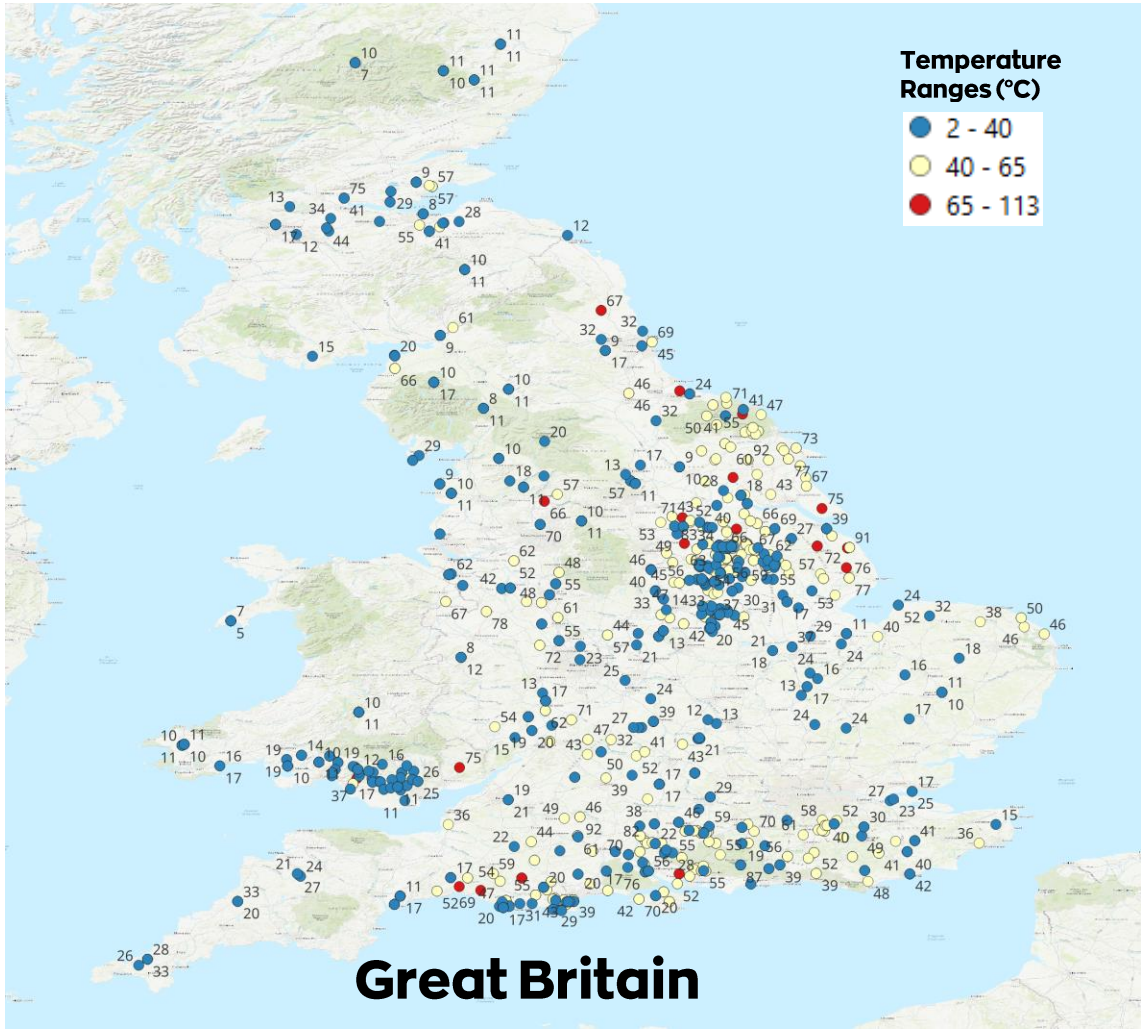
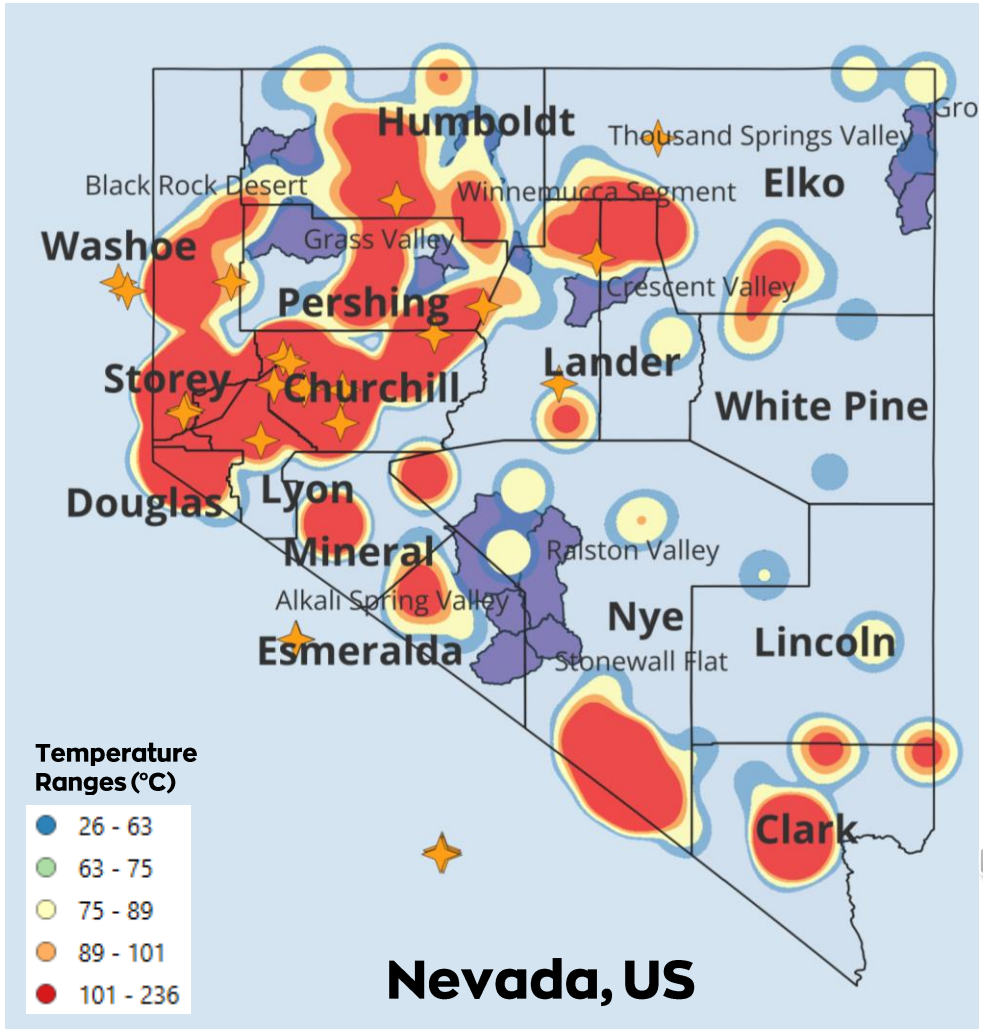
Geothermal GIS – Temperature spread





Acknowledgement: MAHMOUD ALGAIAR, PhD student, Robert Gordon University
(UK Data source: BGS)

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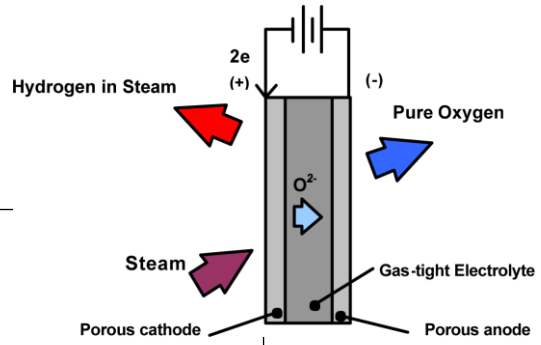
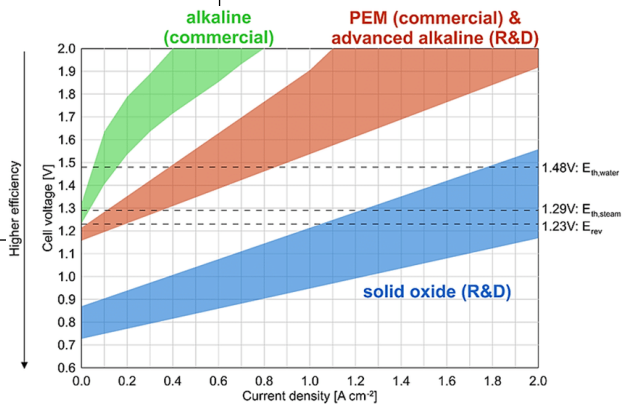
Main electrolyser types

Feedstocks	Technologies (water based)
Water & electricity	Proton exchange membrane (PEM) 50–80°C
Water & electricity	Anion exchange membrane (AEM) 40–80°C
Water & electricity	Alkaline water electrolysis (AWE) 60–90°C
Water, electricity & heat	Solid oxide water electrolysis (SOWE) 700–900°C
Water & heat	Thermochemical water splitting (TWS) Over 500°C
Water & sunlight	Photolysis water splitting (PWS) 20–80°C
Water & sunlight	Photoelectrochemical (PEC) water splitting 25–80°C



Hydrogen production (water splitting)

Water, electricity, sunlight & heat → H_2



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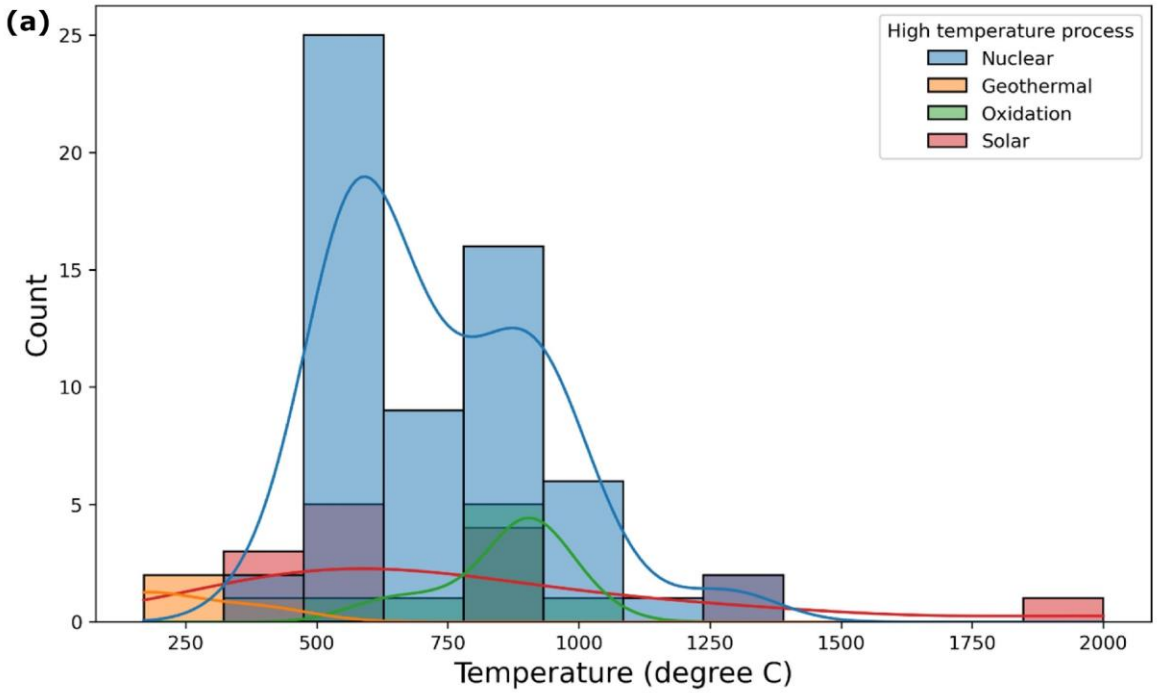
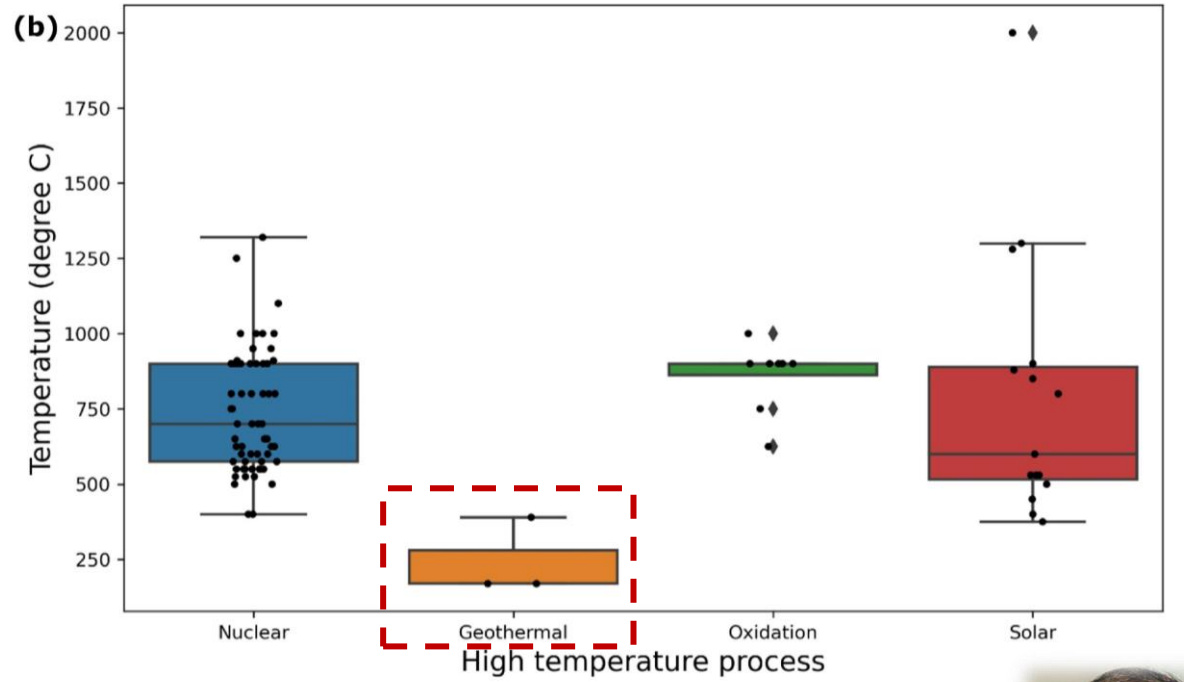
High temperature processes

Increase in temperature eliminates the need for expensive catalysts.





Ramkumar Muthukrishnan, Yakubu Balogun, Vinooth Rajendran, Anil Prathuru, Mamdud Hossain, Nadimul Faisal, **High Temperature Corrosion of Materials**, 101, 309–331, 2024. https://link.springer.com/article/10.1007/s11085-024-10312-4

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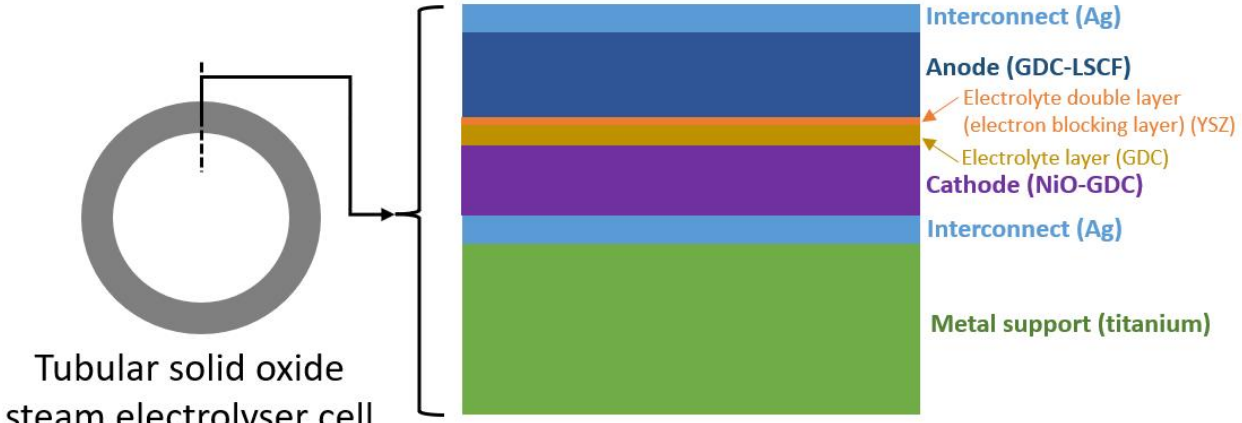
METASIS project

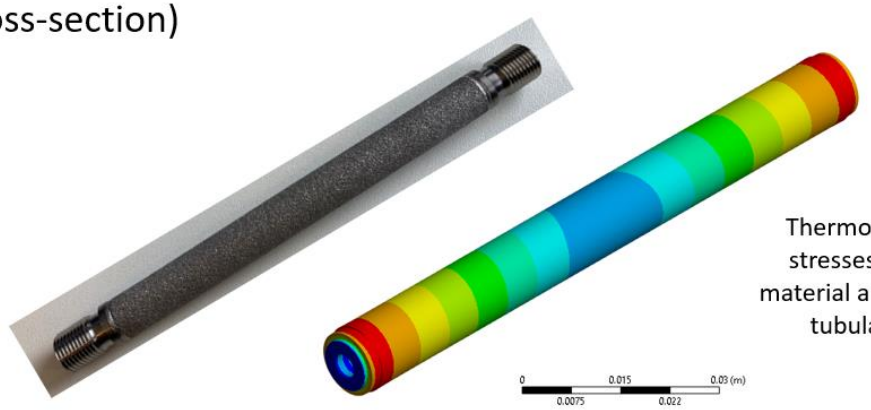
EP/W033178/1

Engineering and Physical Sciences Research Council

Design & modelling

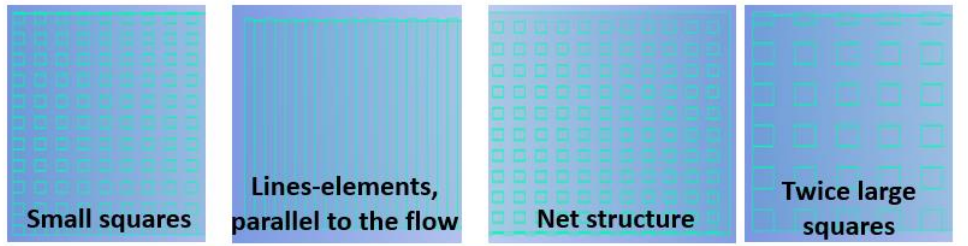


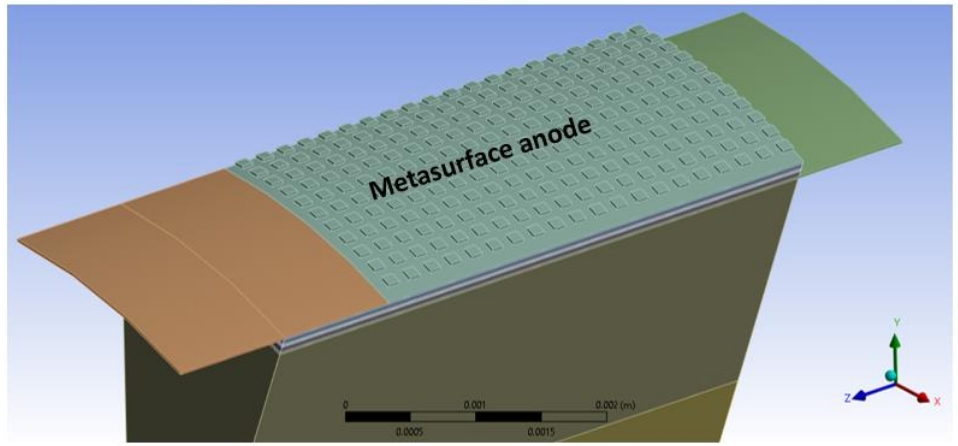
Tubular solid oxide steam electrolyser cell (cross-section)

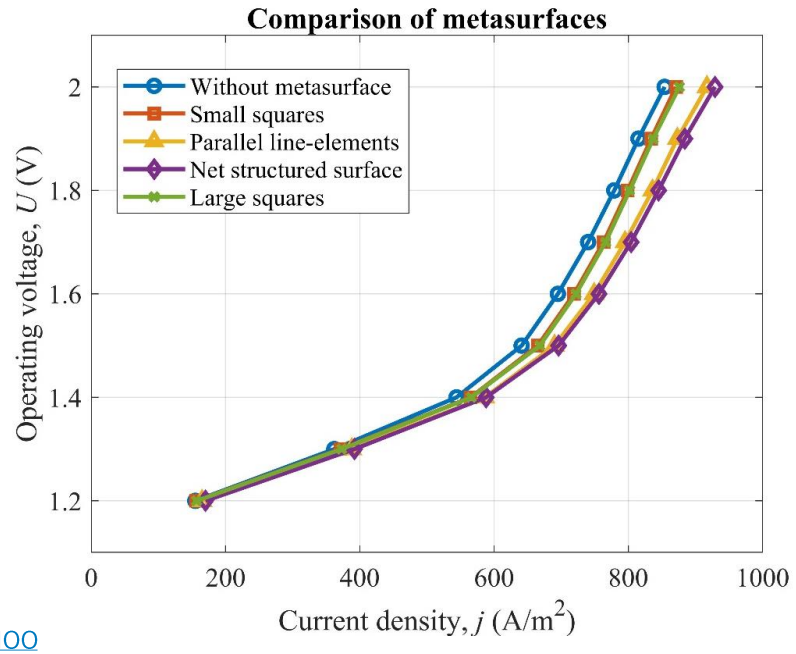


Thermomechanical stresses in a multi-material and multi-layer tubular system

Metasurface patterned anode for enhanced performance of solid oxide electrolyser







Victoria et al. Journal of Power Sources (2025); https://papers.ssrn.com/sol3/papers.cfm?abstract_id=5015628
Victoria et al. Engineering Fracture Mechanics (2025); https://papers.ssrn.com/sol3/papers.cfm?abstract_id=5021100

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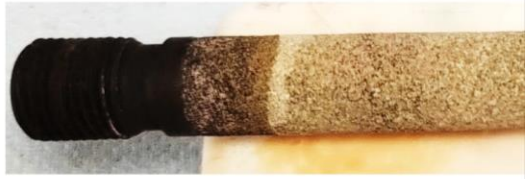
Cell fabrication stages



Electrodeposition of silver on SS & Ti tubes

Half cell fabrication (dip coating slurries, current collector & cathode functional layer)

Full cell fabrication (electrolyte and anode layers, anode current collector and sealing)

Ultrasonicated slurries, high-temperature sintering (950-1100 C)

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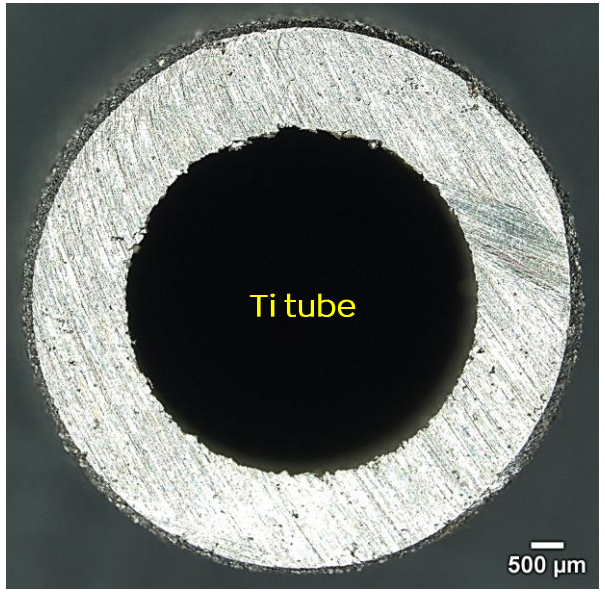
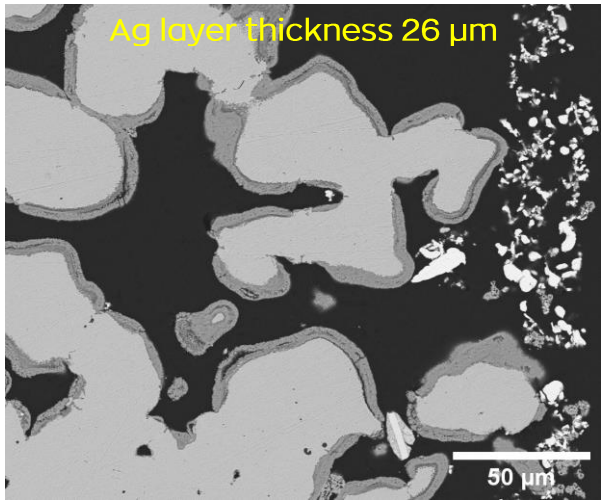
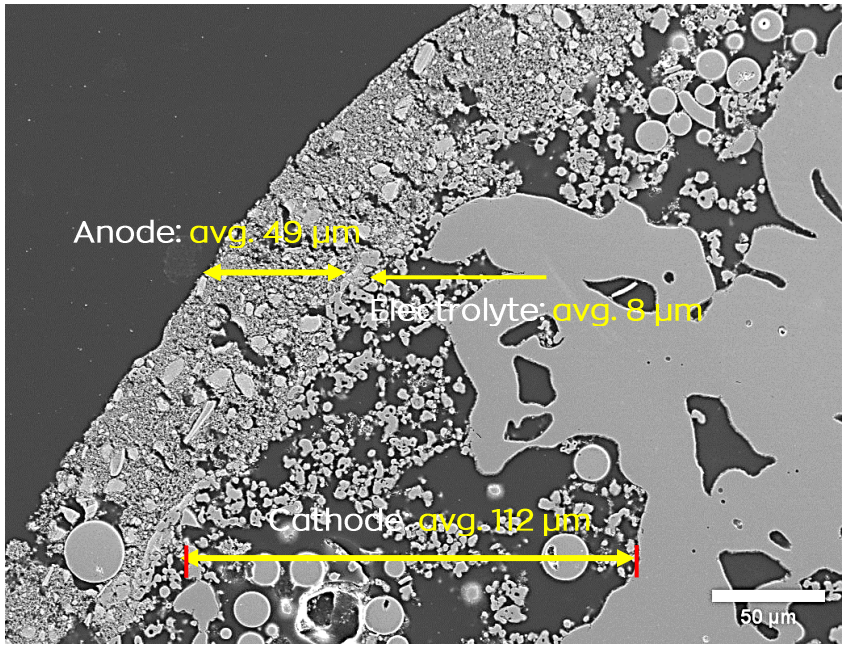
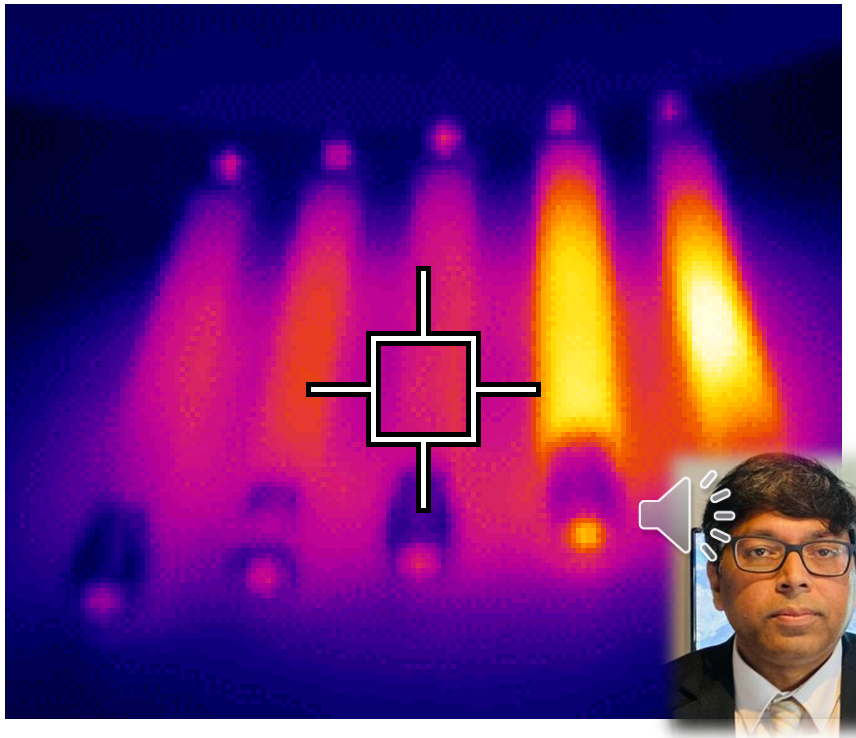
Investigation









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Thank you
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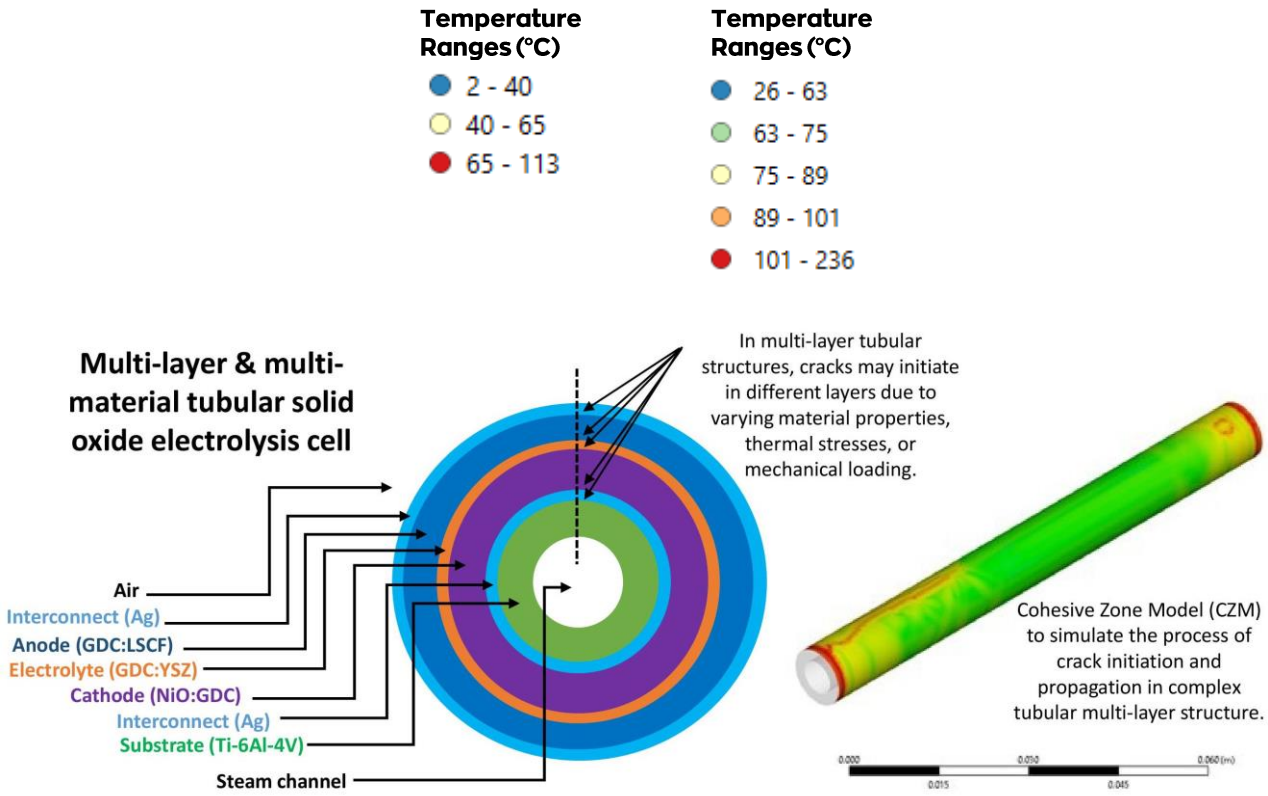
Designing steam electrolysers for geothermal steam applications

- **High-temperature stability**
  Thermal expansion mismatch, creep, deformation
- **Corrosive geothermal environment**
  Dissolved salts (NaCl, KCl), acidic gases (CO2, H2S), mineral deposits (silica, calcium carbonate)
- **Electrolyte materials**
  Materials degradation, contamnation
- **Electrode degradation**
  Nickel oxidation, sulphur poisoning, delamination
- **Durability and longevity**
  Thermal cycling, electrochemical degradation
- **Integration with geothermal systems**
  Variable steam quality, scaling and fouling in heat exchanges
- **Emerging solutions**
  Advanced coatings, new materials, hybrid systems (pre-heating)



Acknowledgement (METASIS team): Dr Victoria Kurushina, Dr Anil Prathuru, Prof Mamdud Hossain, Prof Qiong Cai, Dr Bahman Horri, Vinoth Rajendran