Advancing production of climate-neutral hydrogen through additive manufacturing technologies for solid oxide cells

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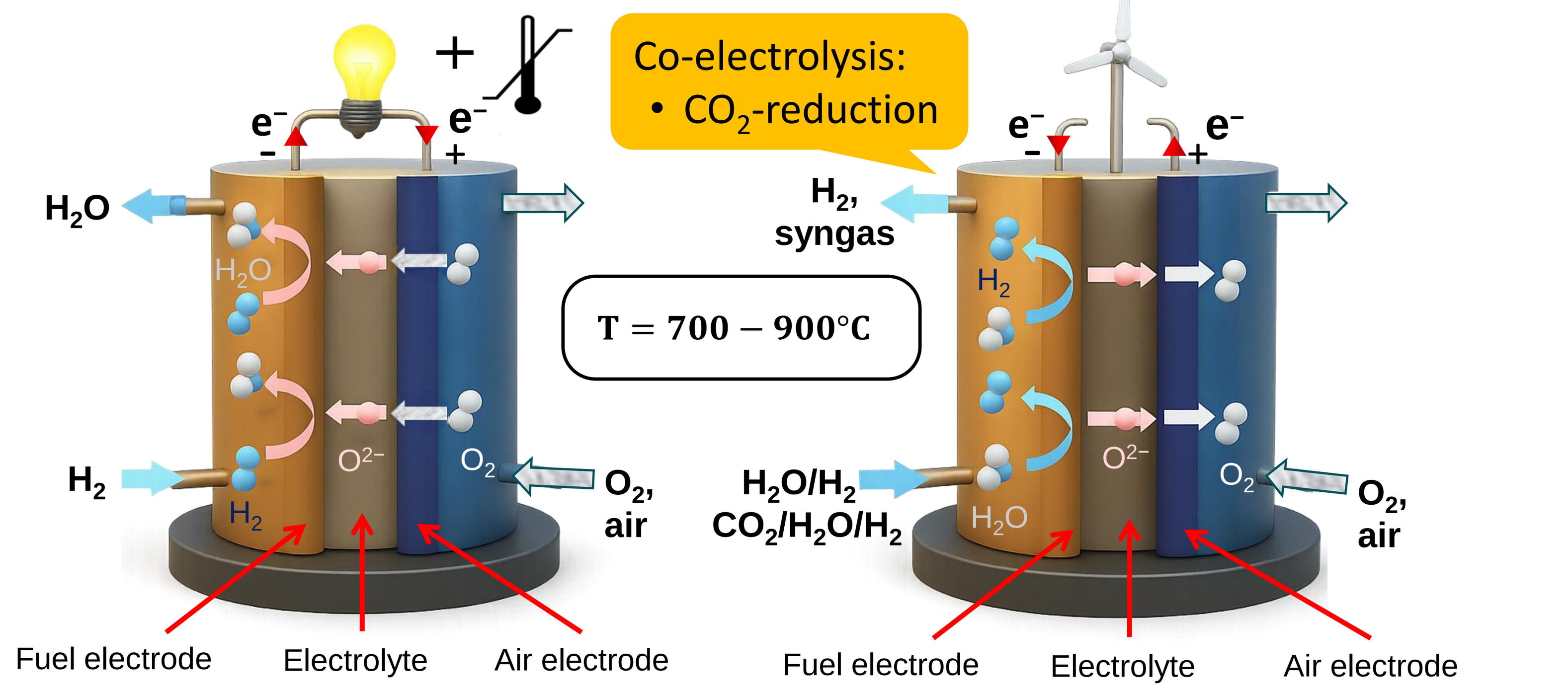
Background and motivation

- The energy transition requires scalable, efficient, and carbon-neutral solutions for hydrogen production. Solid Oxide Cells (SOCs), including both fuel cells (SOFCs) and electrolysis cells (SOECs), offer high efficiency and fuel flexibility.
- Conventional fabrication is limited by: Complex, costly manufacturing , design restrictions (2D geometries), dependence on critical raw materials (CRM). Additive Manufacturing (AM) offers a path toward design freedom, cost reduction, and sustainability.

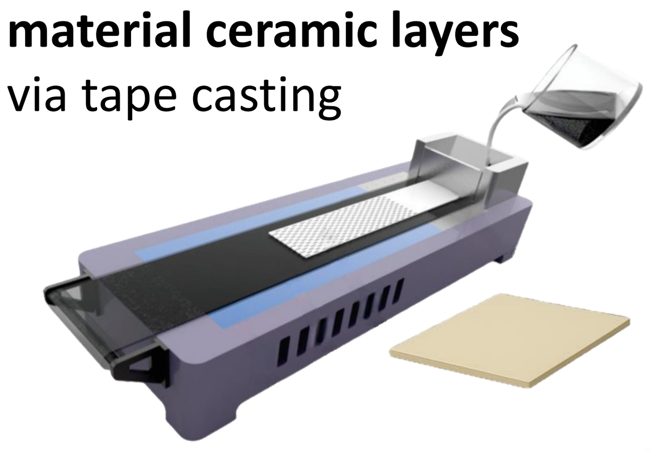
Solid oxide fuel cell (SOFC) **Solid oxide electrolyzer cell (SOEC)**



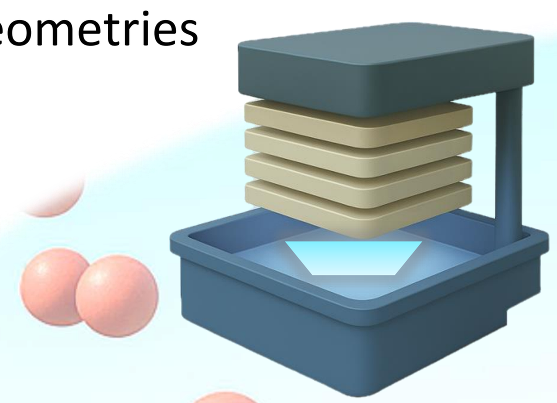
$\eta_{el} = 50 - 60\,\%, \eta_{tot} = 90 - 95\,\%$ $\eta_{el} = 80\,\%$

Goals

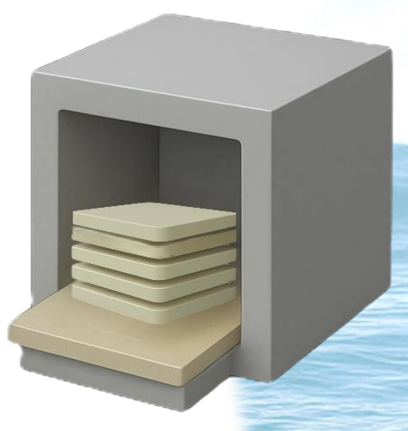
A) Develop **co-sinterable, multi-material ceramic layers** via tape casting



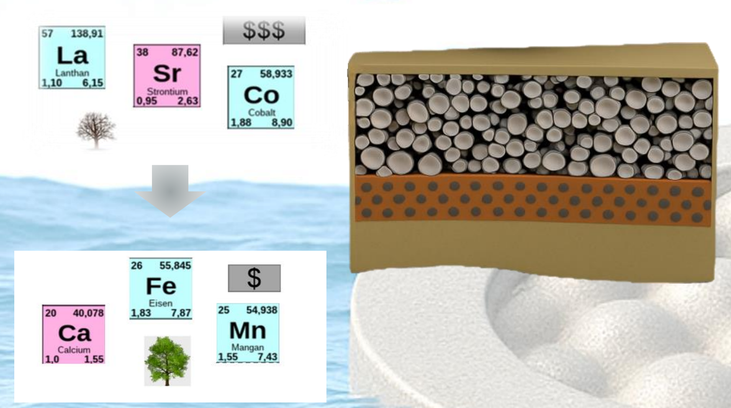
B) Implement **lithography-based 3D printing** for complex SOC geometries



C) Optimize **sintering and densi-fication** to reduce processing energy

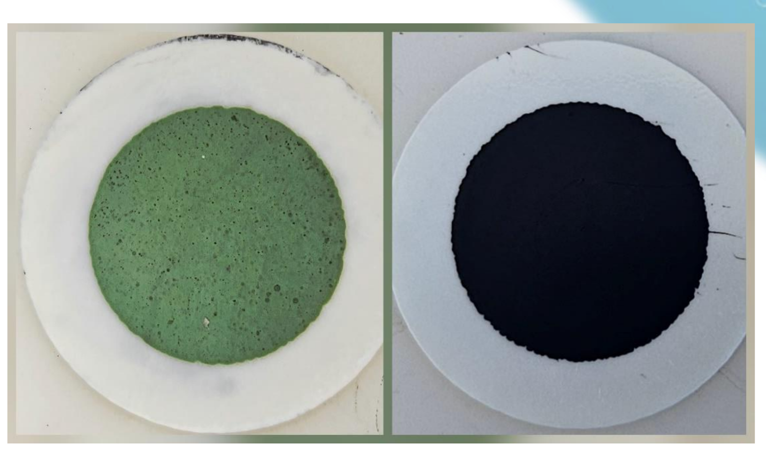


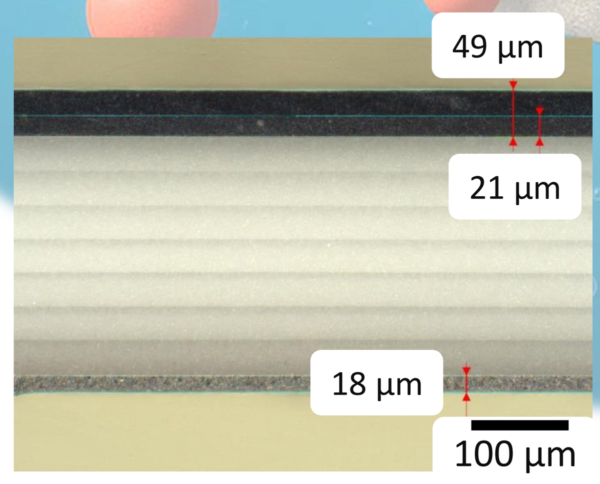
D) Design **electrodes without critical raw materials**



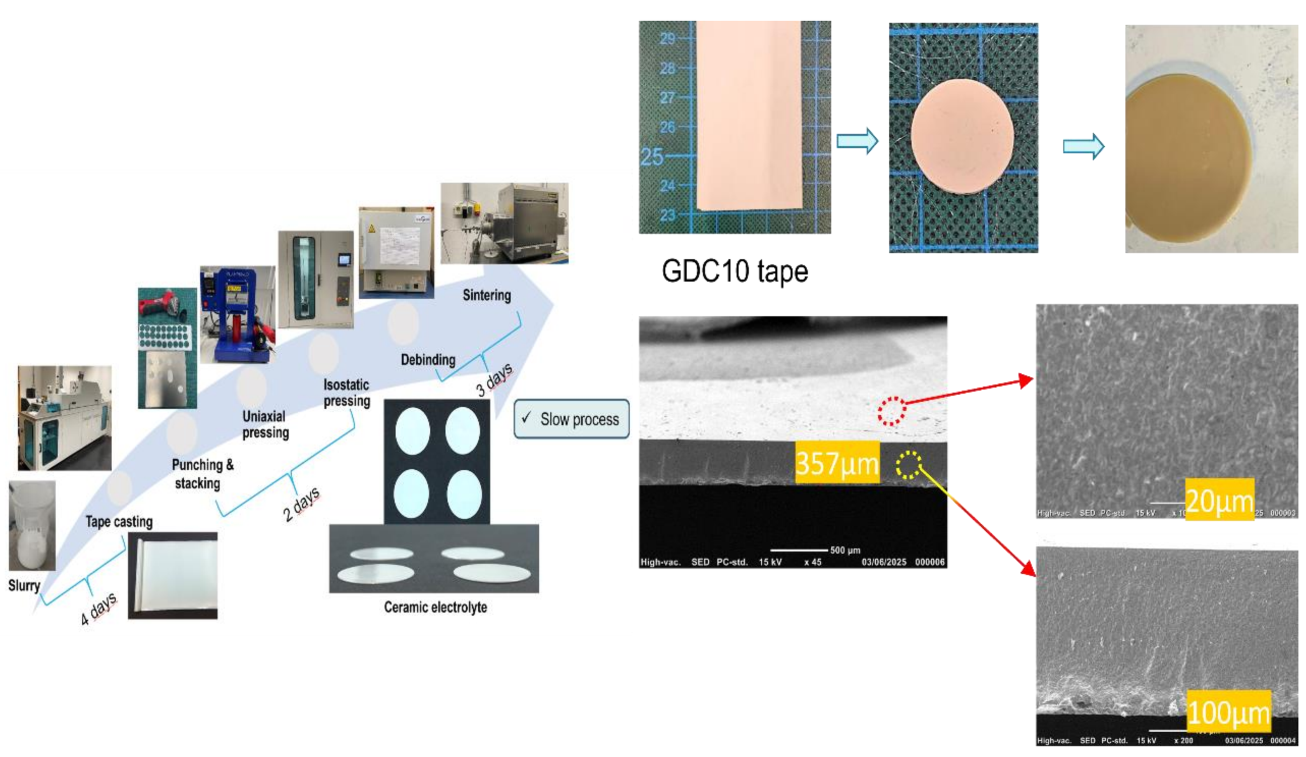
Methodology

1. Optimisation of inks for LSM-8YSZ (air electrode), LSM (current collector) and NiO-8YSZ (fuel electrode)

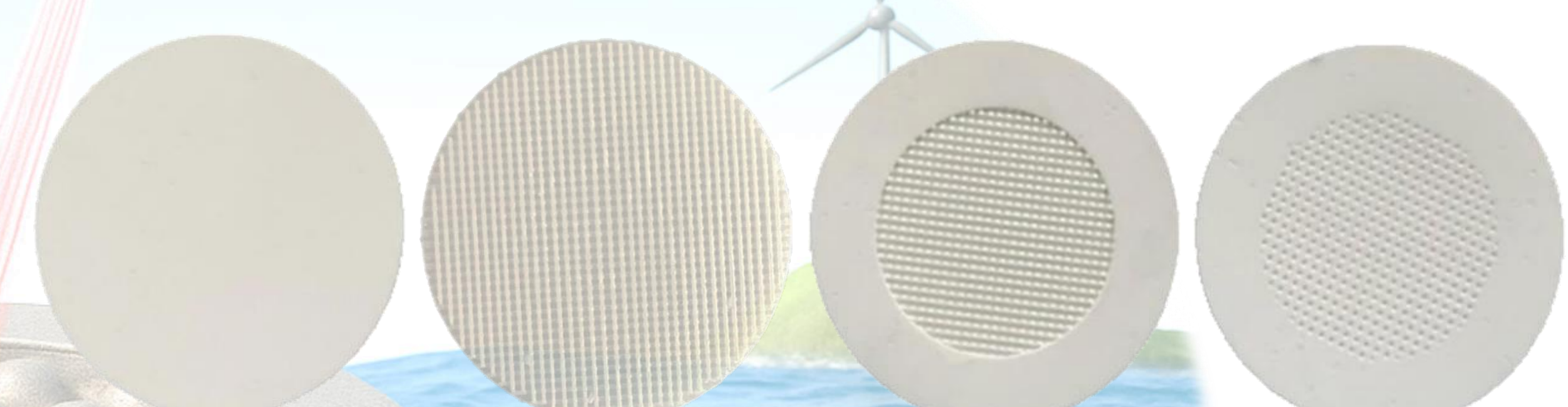




2. Optimisation of tapes for electrolyte (8YSZ) and diffusion barrier (GDC) for multilayer tape casting.



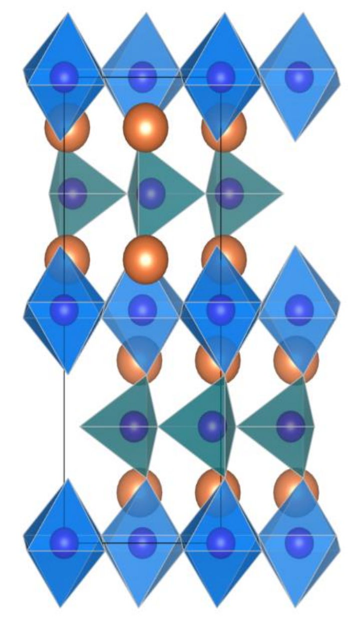
3. Developing **3D printed electrolytes** with patterned interfaces to optimize adhesion, mechanical stability and cell performance.



4. Optimisation of **air electrodes based on uncritical, abundant and cost-effective elements**, e.g. $Ca_2Fe_2O_5$-based compounds

CHALLENGES: perovskite structure may not be stable, low electrical conductivity.

MITIGATION: Poor electrical conductivity can be increased by substitution or composite formation. Significant increase in cell performance observed upon B-site substitution with non-critical transition metals (e.g. Mn, Ni).



Brownmillerite, $Ca_2Fe_2O_5$

Outlook and future work

Key Findings: • Produced high-surface-area cell architectures. • Enhanced densification and reduced processing temperature via optimized sintering. • Sustainable electrodes developed without critical raw materials.

Impact: • Improved performance, durability, and manufacturability of SOFCs/SOECs. • Supports cost-effective, climate-neutral hydrogen production for mobility applications. • Advances EU goals for green hydrogen and circular energy systems.

Future work: • Conduct full cell measurement on 3D printed and multi-materials tape-casted electrolytes • Combining sustainable electrode materials with electrolytes obtained by advanced manufacturing.

References

[1] Pesce, A., et al., *3D printing the next generation of enhanced solid oxide fuel and electrolysis cells*, Journal of Materials Chemistry A 8.33 (2020): 16926-16932.

[2] Jana, A., et al., *Tailoring strength and ionic conductivity in zirconia-based solid oxide electrolytes using a multimaterial approach*, Journal of the American Ceramic Society (2025): e20632.

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