



University of St Andrews



Reversible Fuel Cells: Energy storage for renewable electricity

Stephen Gamble, John T.S. Irvine and Paul Connor

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Outline of presentation

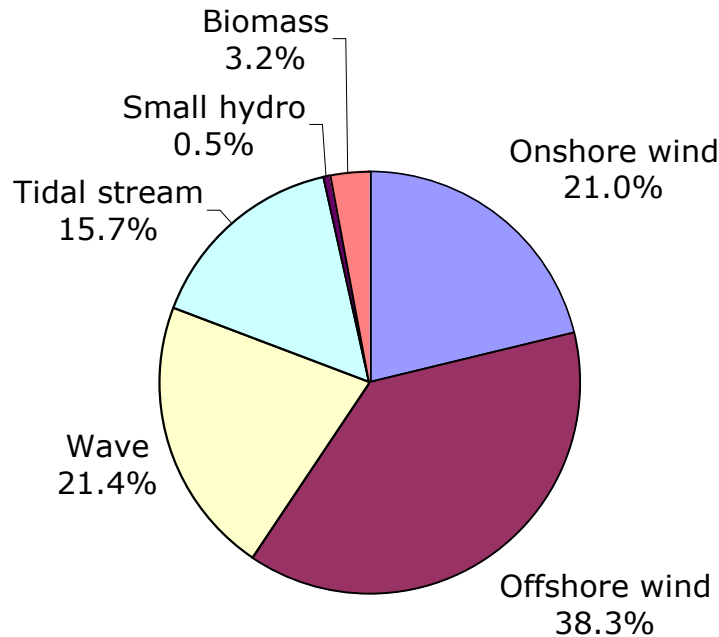
Reversible Fuel Cells: Energy storage for renewable electricity

1. Context
2. Reversible fuel cell introduction
3. Present work
4. Conclusions and further work
5. Acknowledgements

Context: Renewable energy supply

Large potential of renewable energy

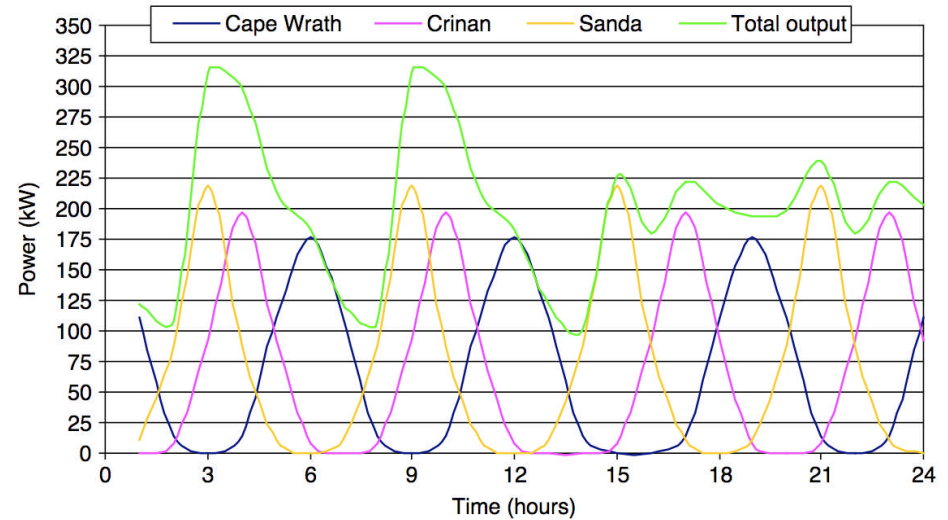
Scotland's Annual Renewable Energy Resource (GWhr, est 2001)



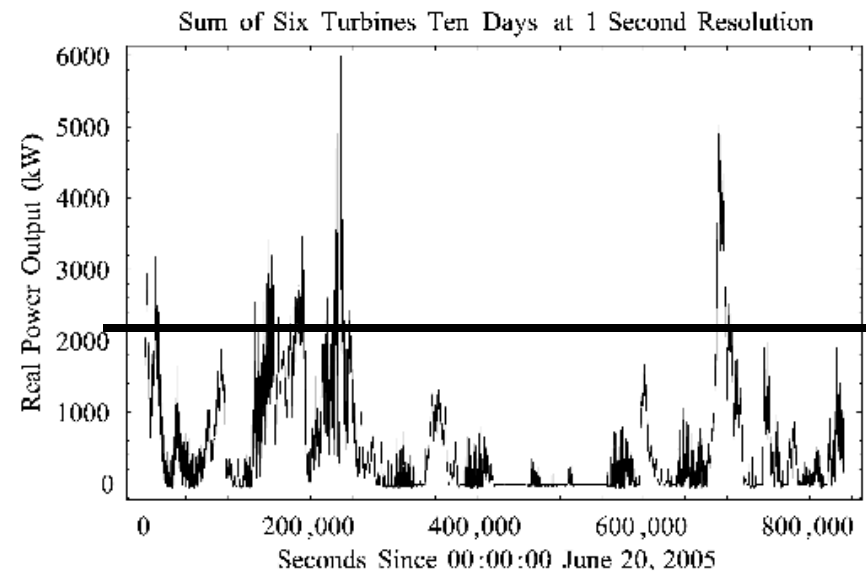
Scotland's annual renewable energy potential: 214,000 GWhr

Total UK electricity demand in 2001: 390,000 GWhr

Intermittent supply of renewable energy



Tidal energy (above) and wind energy (below)



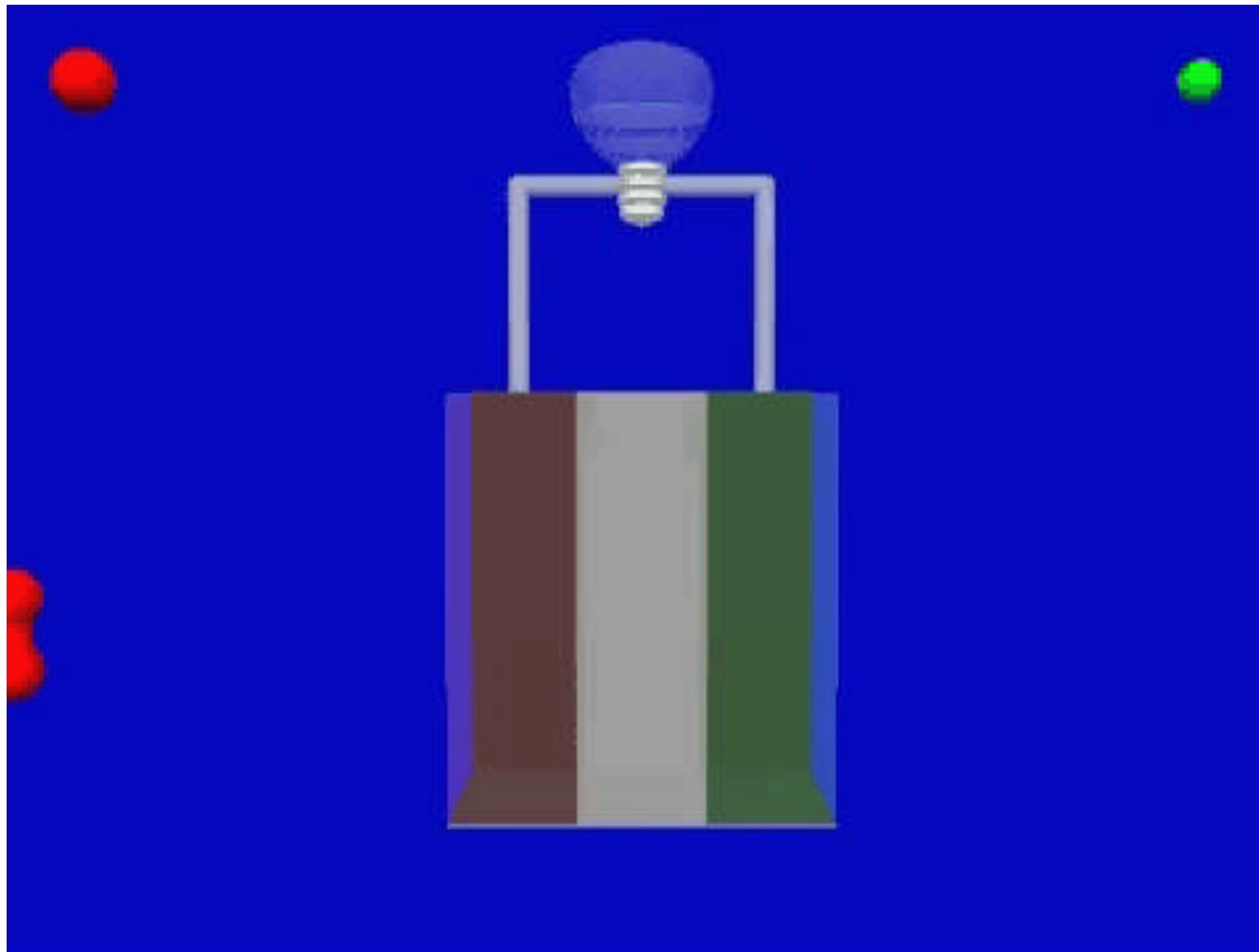
Wind energy developments and energy storage

- Two sites in Scotland: Moray Firth (1.3 GW) and Firth of Forth (3.5 GW), approved by government, construction begins 2014 at earliest
- Large scale: compare with Longannet Power station, Fife (2.4GW, coal)
- Need to store this energy when generated until it is needed - otherwise it is lost
- Currently, supply peaks are either lost or stored as pumped hydro, and peaks in demand are met from spinning reserve

Offshore UK wind farm zones



2: Reversible fuel cell introduction: Fuel cell animation



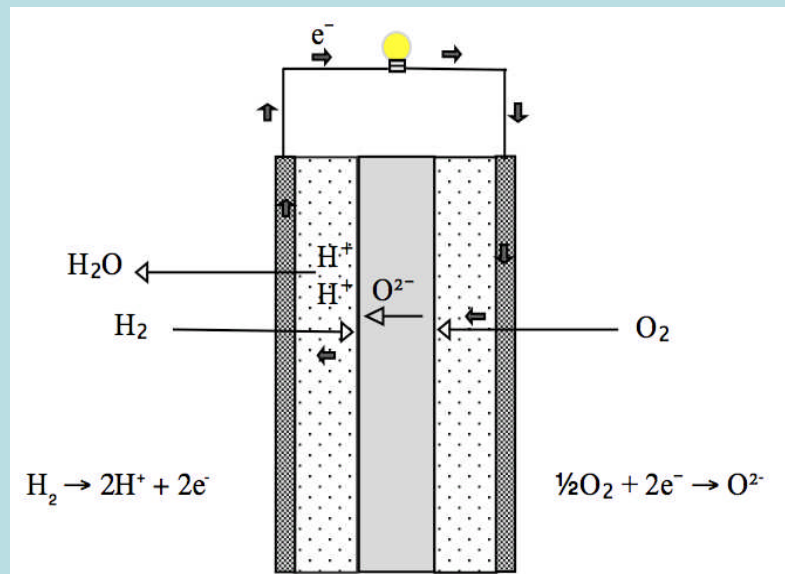
Electrolysis cell animation



Reversible fuel cells: principle of operation

Fuel cell reaction

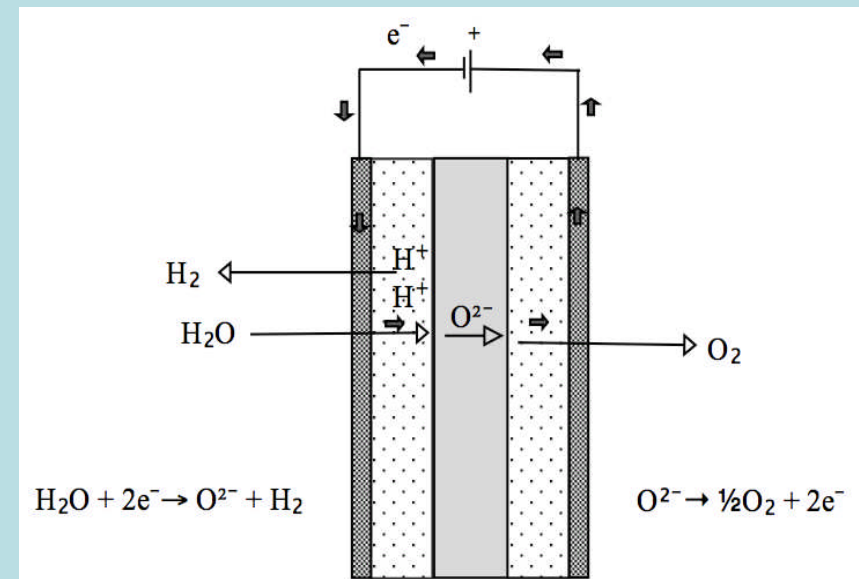
hydrogen + oxygen \rightarrow steam + heat + electricity



Solid Oxide Fuel Cell

Electrolysis cell reaction

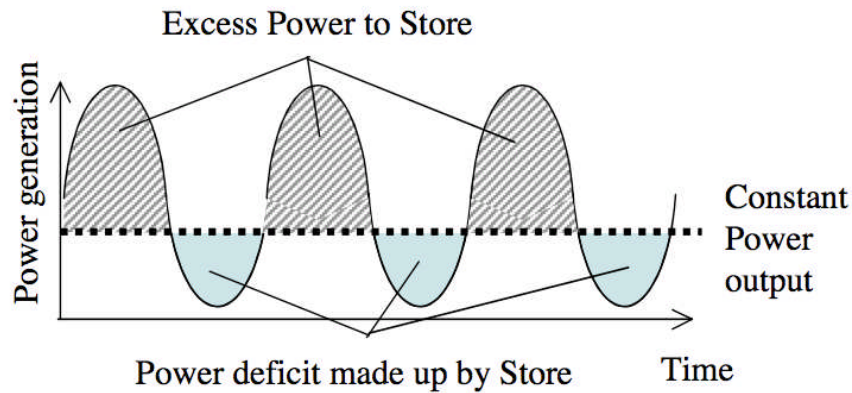
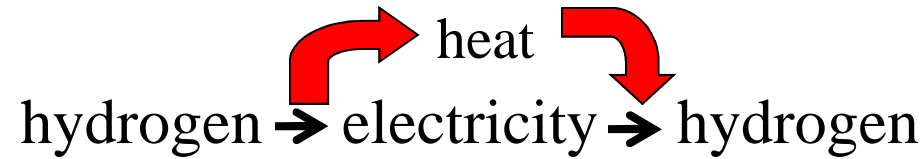
steam + heat + electricity \rightarrow hydrogen + oxygen



Solid Oxide Electrolysis Cell

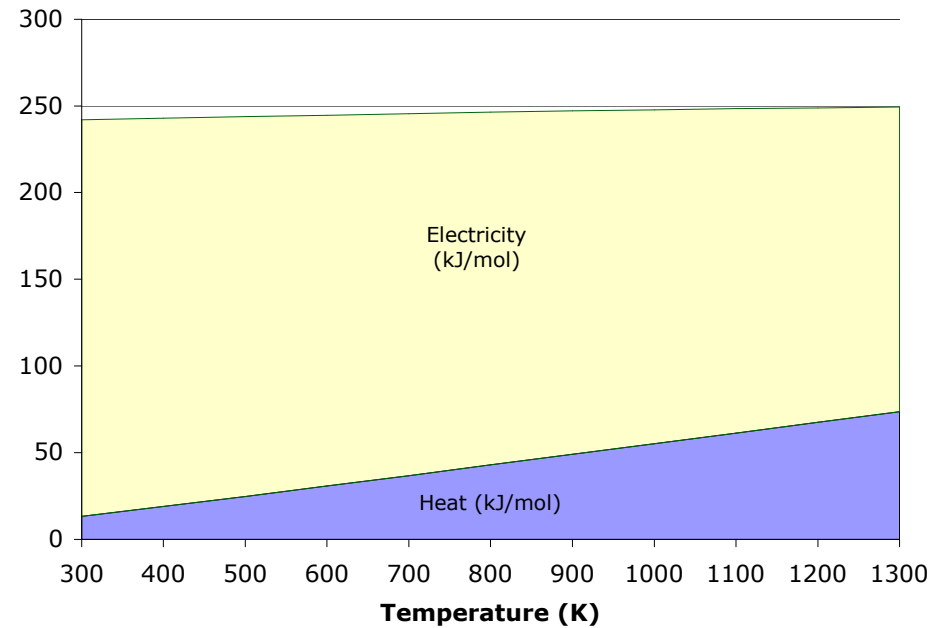
- Energy storage device - like a large scale battery
- Together these make a reversible fuel cell

Energy storage and efficiency



A reversible solid oxide fuel cell (RSOFC) stores electrical energy as hydrogen and heat, releasing it when needed

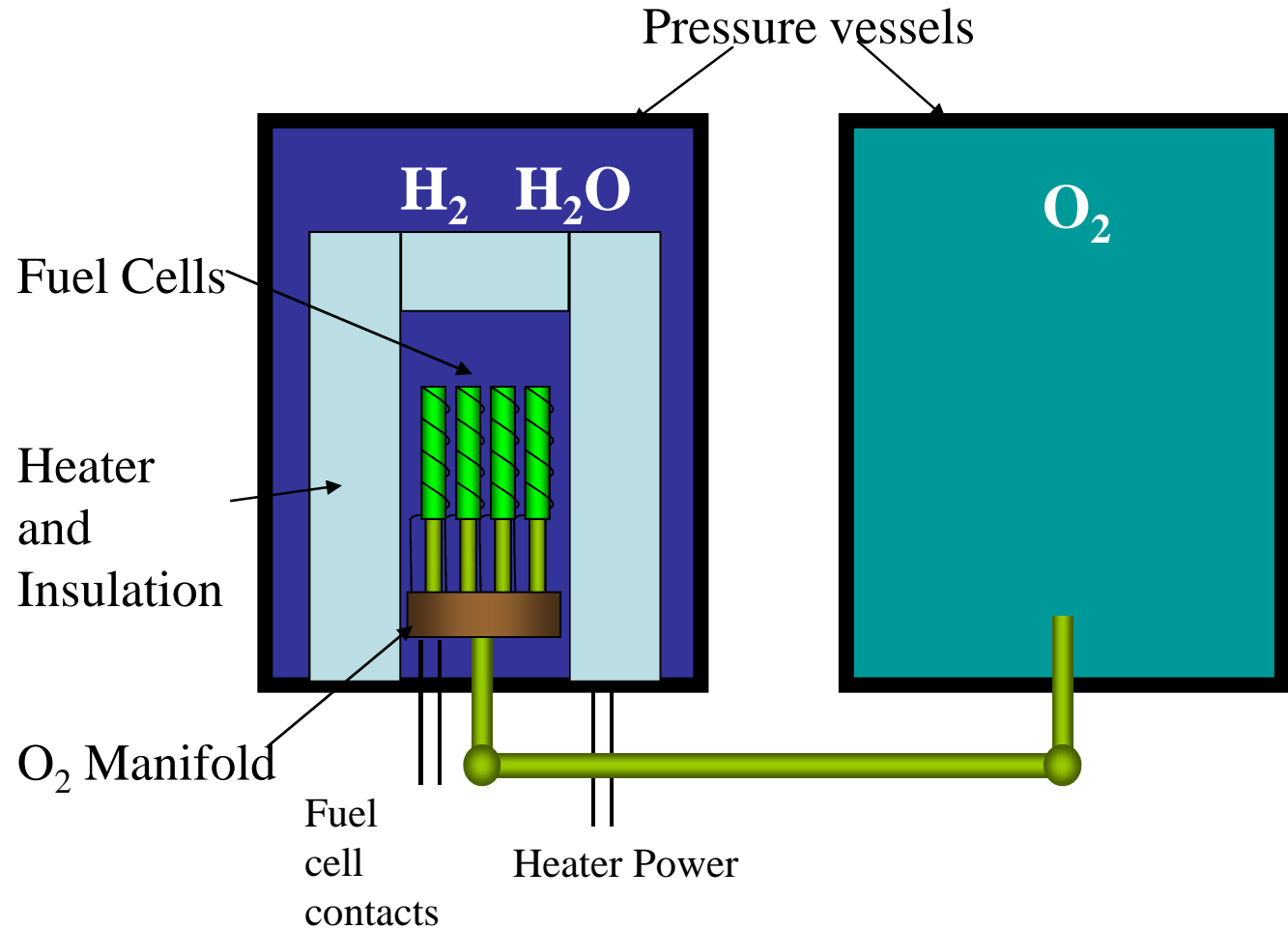
Total energy required for water electrolysis vs temperature (K)



Energy storage is 30% efficient if heat is lost, if kept then could be 80-90% efficient.

Reversible fuel cell system

- Reversible cells can be built into a stack
- Energy storage capacity scales with system pressure
- High performance insulation keeps stack hot, boosts efficiency of energy storage



Reversible Fuel Cell System,
Patent no: WO2007091050- A1

Reversible fuel cell system modelling

Requirements for a grid connected reversible fuel cell system

- Electrical power control and inverter system

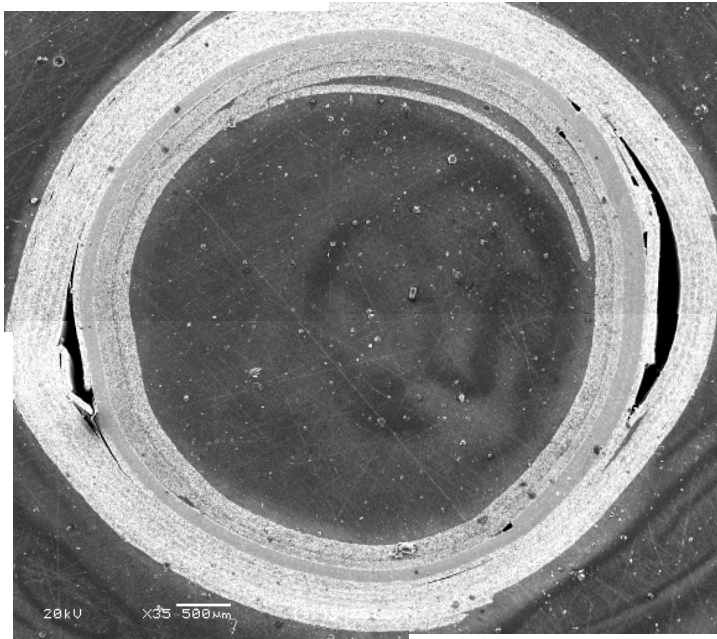
Work done so far in collaboration with the University of Strathclyde:

- Software and hardware model of electrical controls
- Software model of reversible fuel cell system

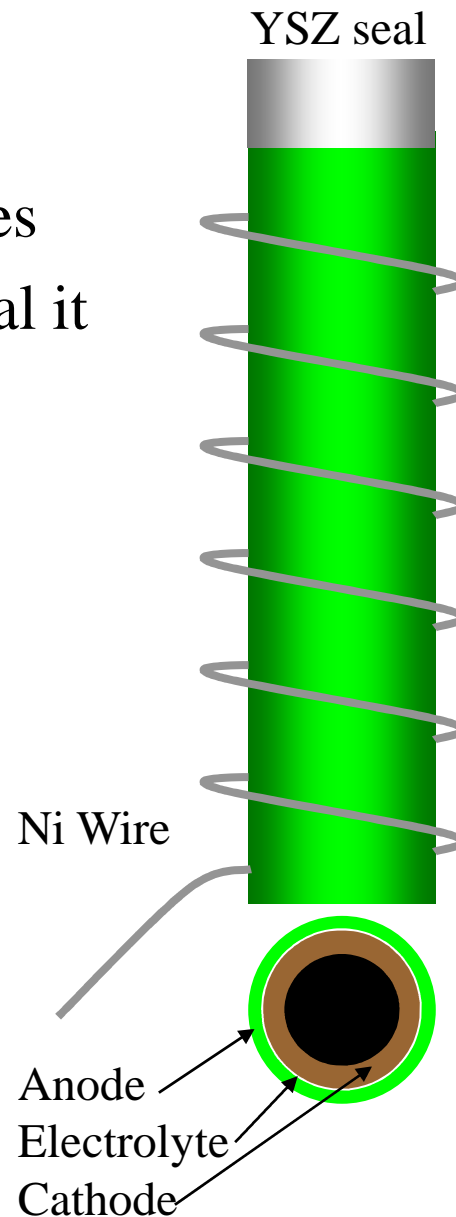
This work is essential to understand, develop and commercialise the reversible fuel cell system

Reversible fuel cell design and production

- Cell made by tape casting, rolling and co-firing - standard industry techniques
- Ceramic caps applied to seal it



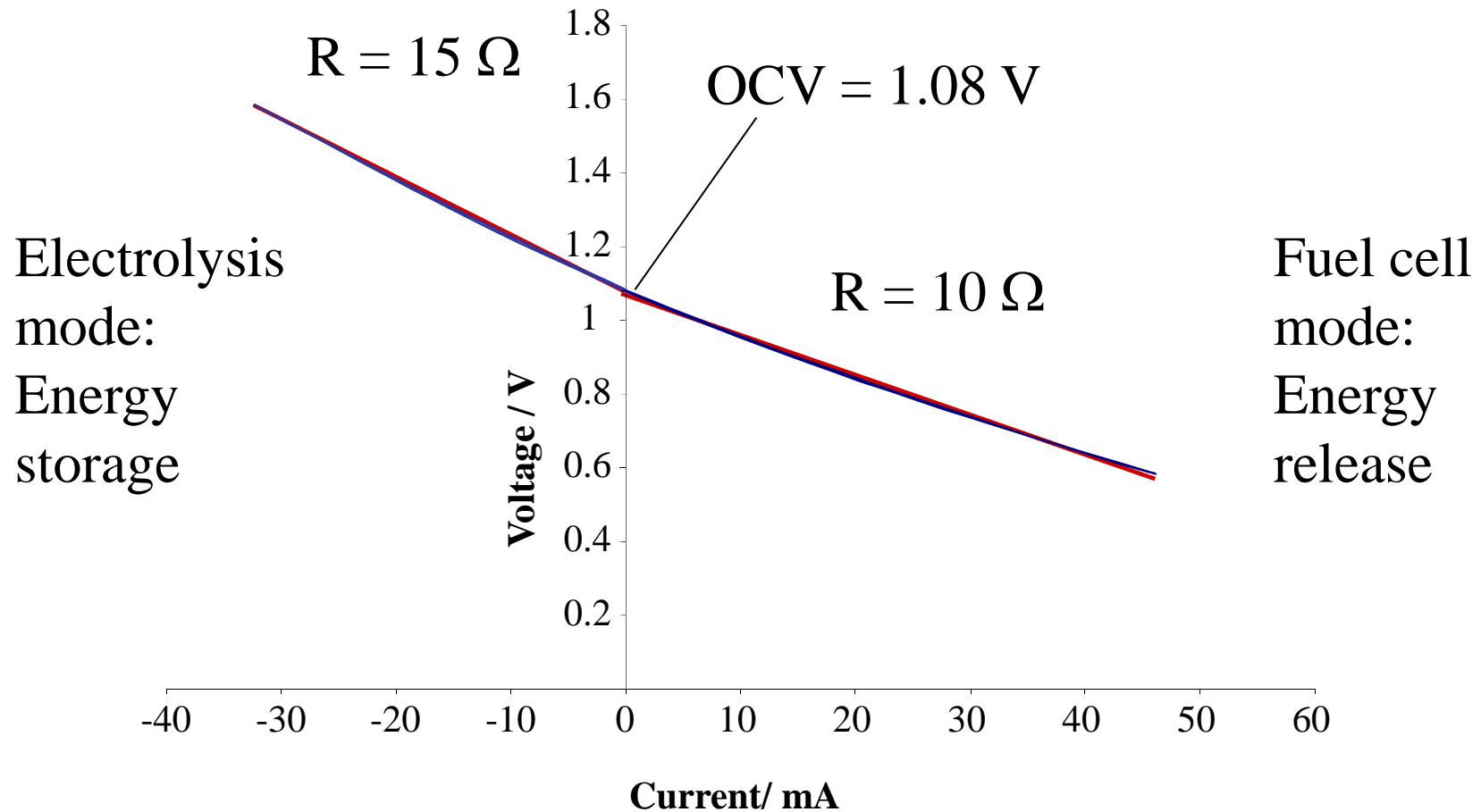
Cross-section of initial cell



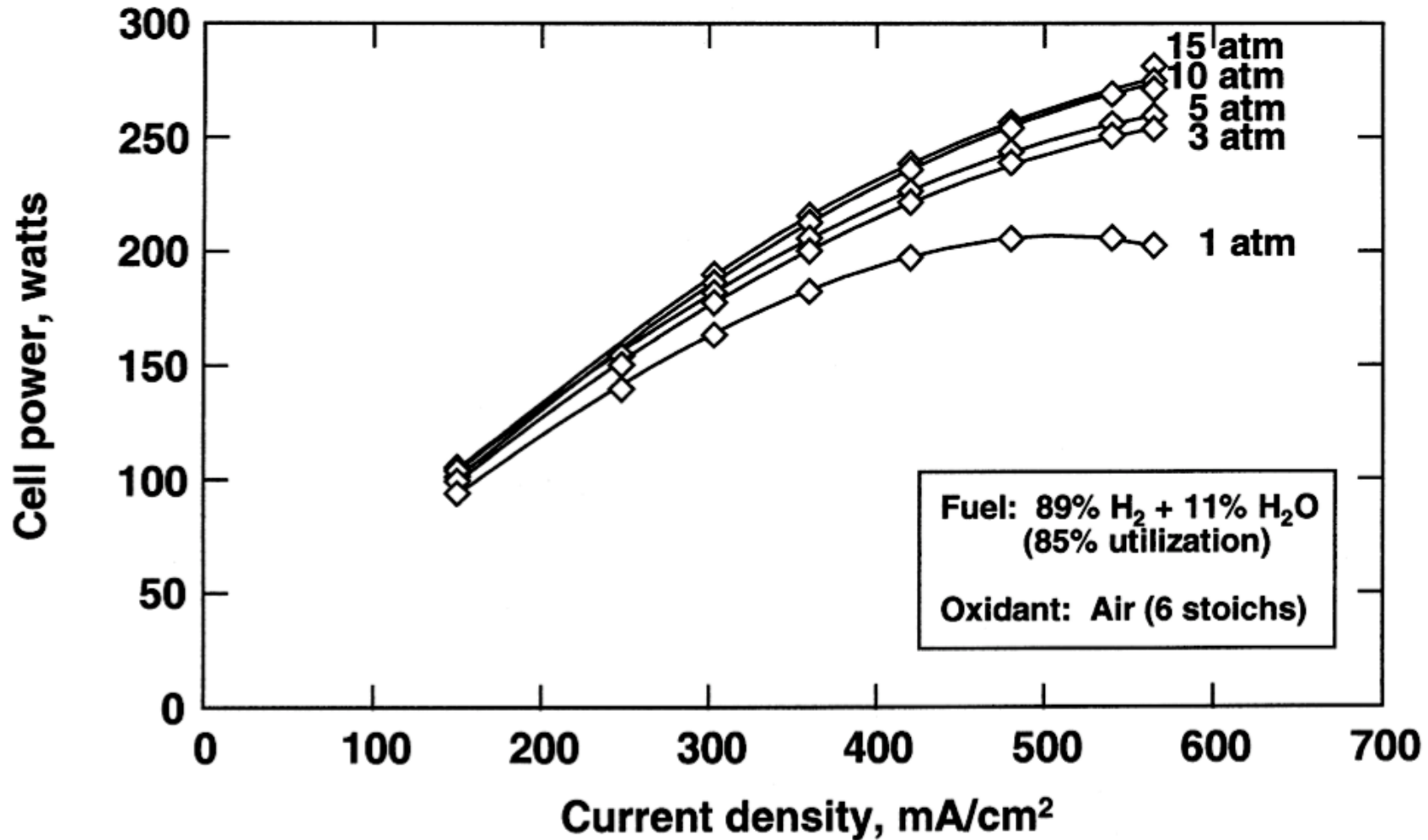
Assembled cell

Reversible fuel cell performance

- The cell goes smoothly from fuel cell to electrolysis mode
- The resistance is high - cell needs to be optimised



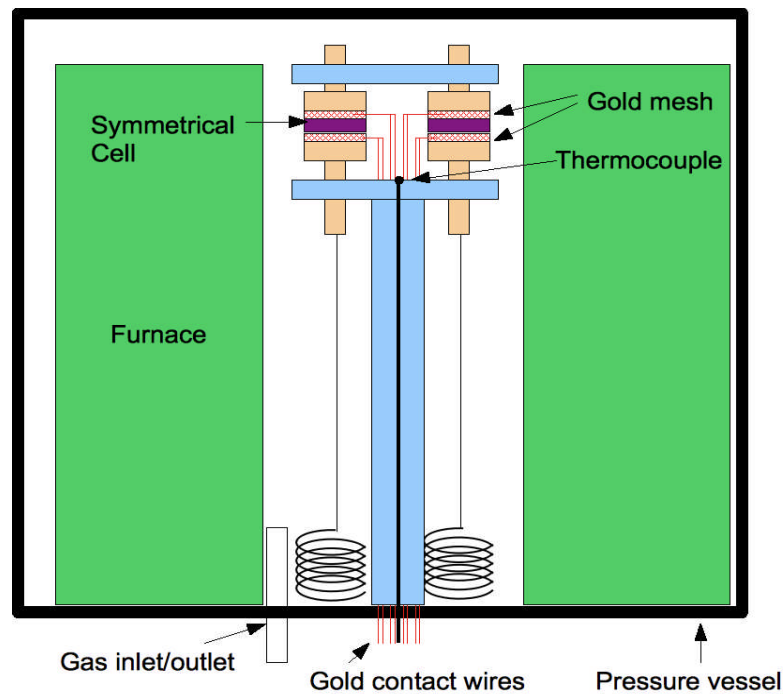
Effect of pressure on performance - e.g. Siemens Westinghouse tubular fuel cell



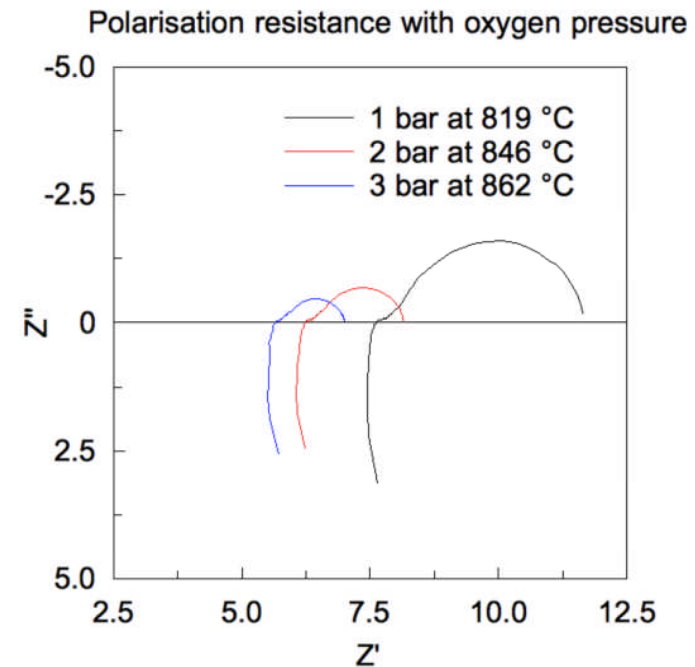
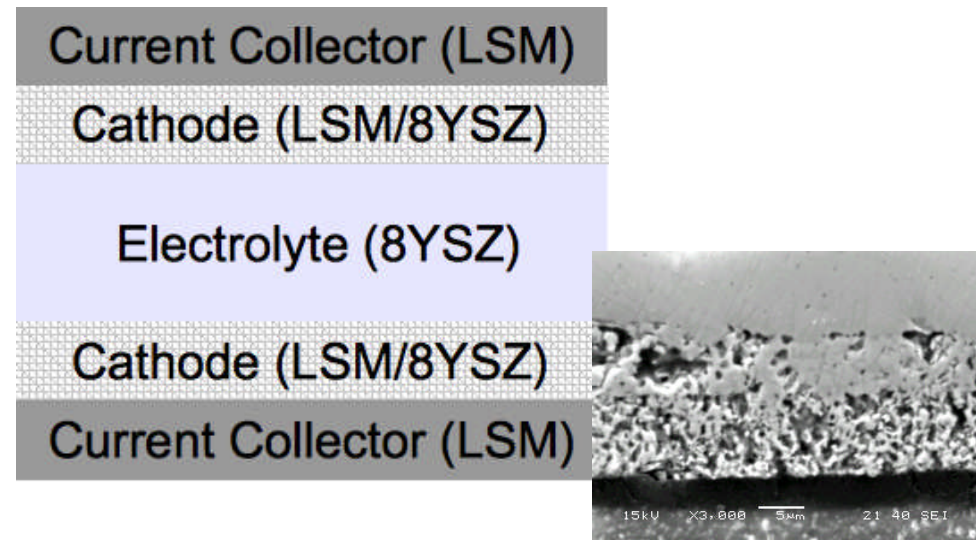
Siemens-Westinghouse, Solid State Ionics 135 (2000) 305 – 313

Effect of pressure: symmetrical cell testing

- Symmetrical cells show how electrode performance depends on oxygen gas pressure
- As pressure increases, electrode resistance decreases



Test setup



4. Conclusions and further work

- Reversible cells could provide high efficiency energy storage
- This is becoming more important as more renewable energy is added to the grid
- Cell performance improves with pressure
- Modelling work addresses issues of system integration into an electrical grid
- More work is needed to lower cell resistance

5. Acknowledgements



The University of St Andrews
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EPSRC



Carbon Trust

Thank you for listening! Any questions?