Development and evaluation of an electrolyser model for techno-economic analysis

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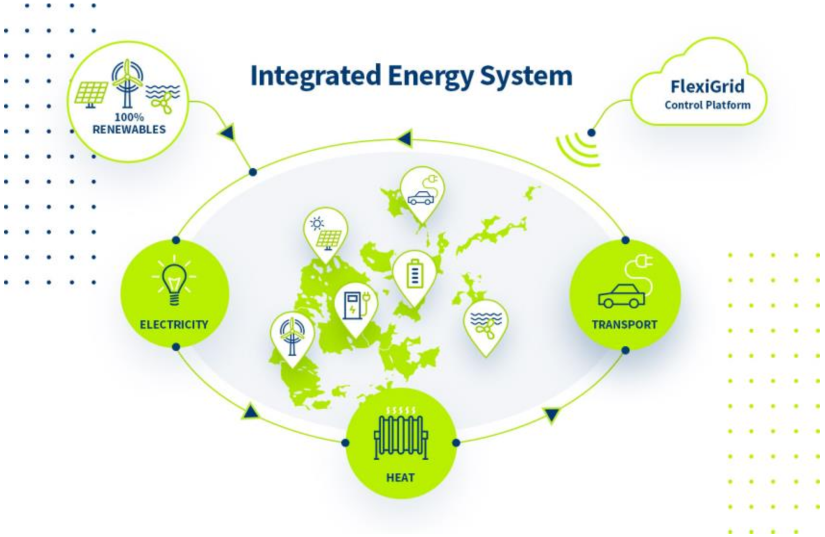
IDCORE

- EPSRC and NERC Centre for Doctoral Training in Offshore Renewable Energy

- Trains research engineers to solve industry problems in offshore renewable energy

The European Marine Energy Centre Ltd.

- World's leading wave and tidal energy generator test site – 32 devices from 11 countries
- Expanded into hydrogen and energy systems
- Based in Orkney Islands



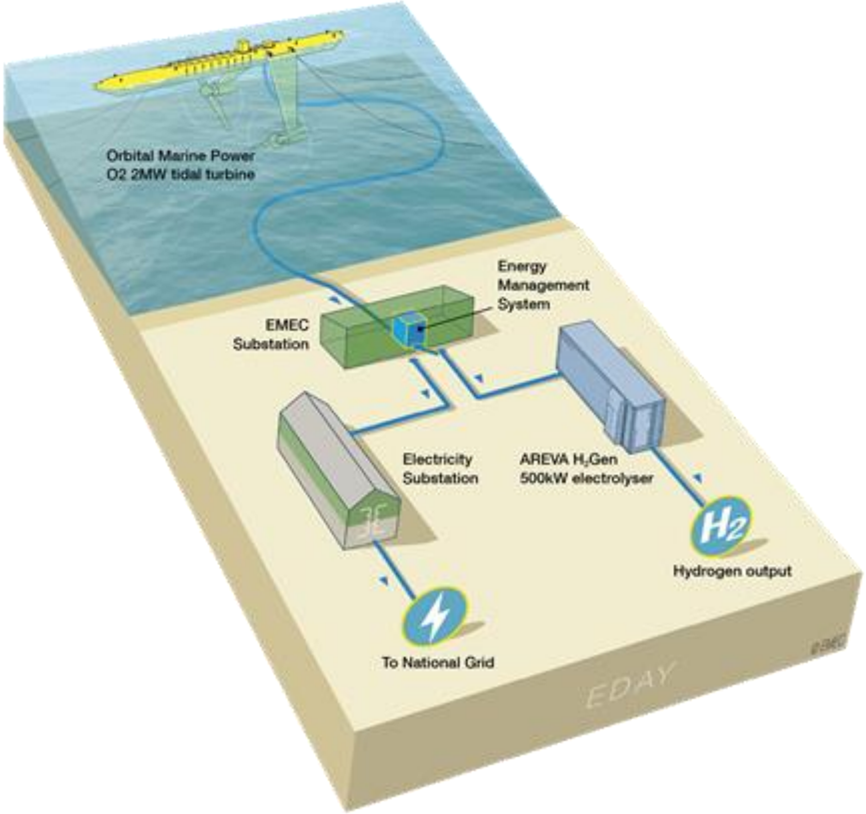
Orkney context

- Orkney is now a net exporter of electricity
- However, grid not designed for renewables – results in curtailment
- EMEC has 4 MW export limit on tidal test site
- Deployed electrolyser to increase capacity limit, reduce curtailment

ITEG project

- Integrating Tidal Energy into the European Grid
- What is the behaviour of the electrolyser?
- How much electricity (kWh) is required to make 1 kg of hydrogen?

Integrated tidal energy and hydrogen production solution



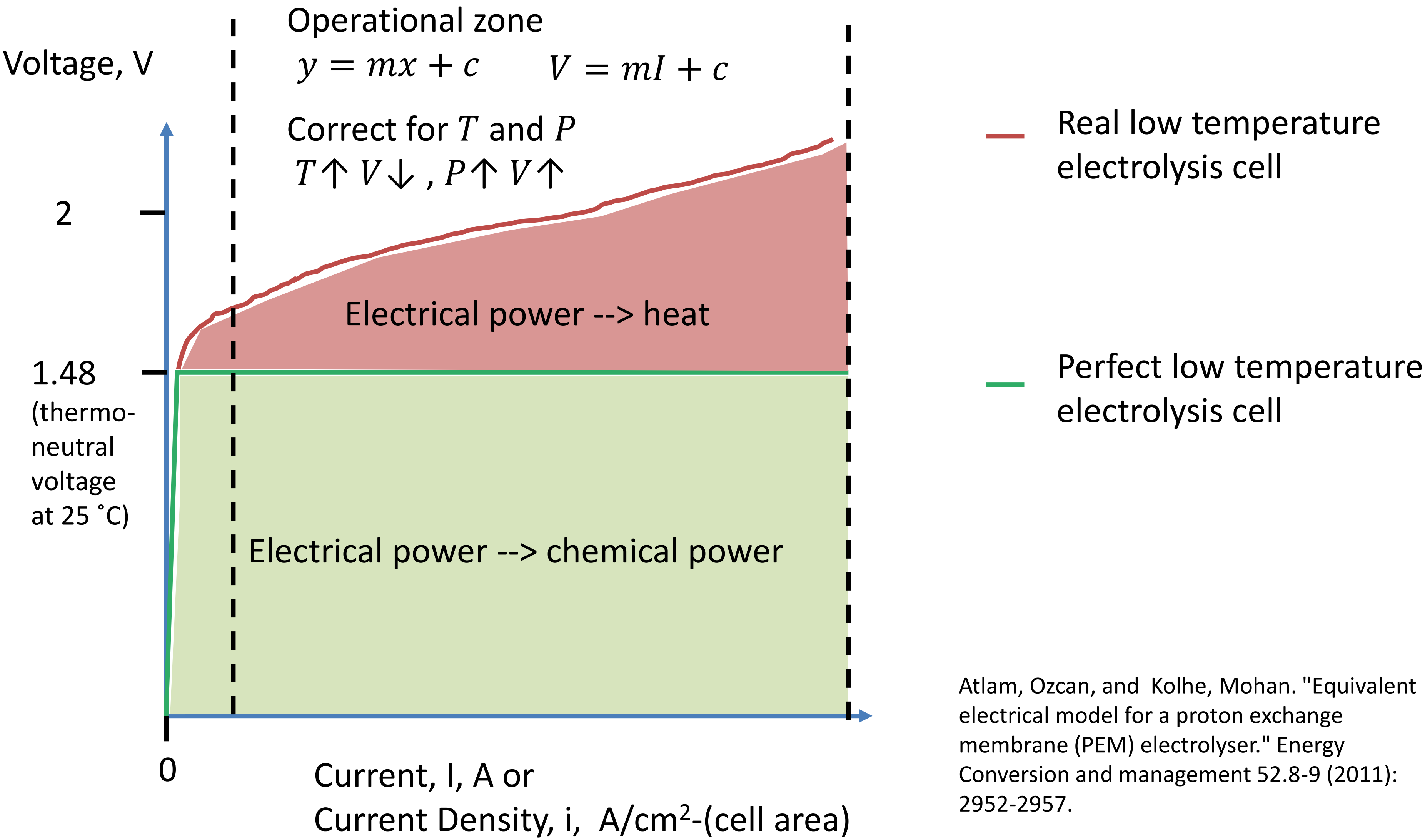
What are the main features of an electrolyser?

- Electrolysis reaction
  - Hydrogen production (Faraday's law with losses)
  - Current-voltage curve (lots of modelling approaches)
  - Power supply unit (PSU)

- Balance of plant (BoP)
  - Modelled here as a constant aggregate load
  - 200 bar compression included

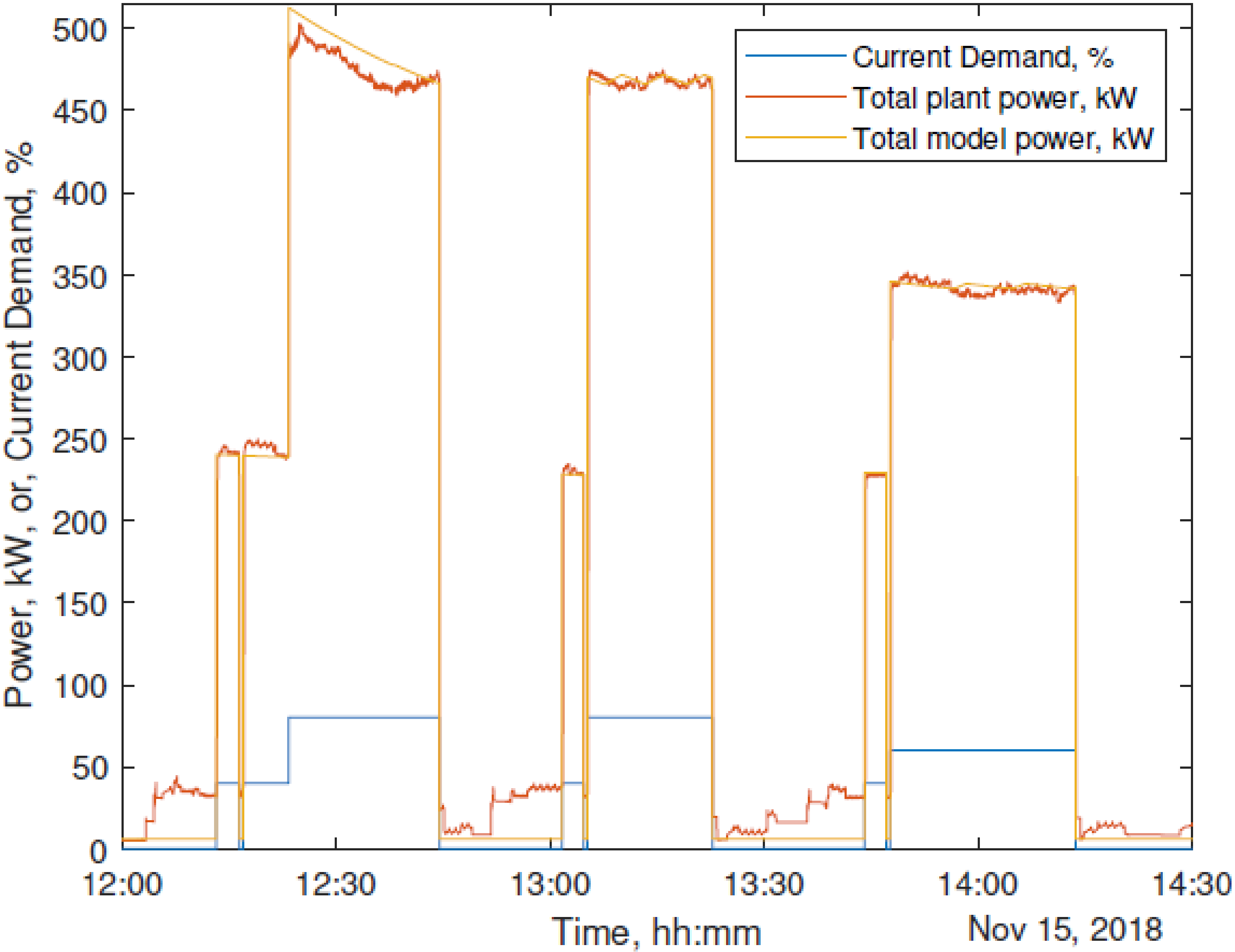
ITM Power stacks in 2017 plant

What is the behaviour of the reaction regarding electricity and heat?



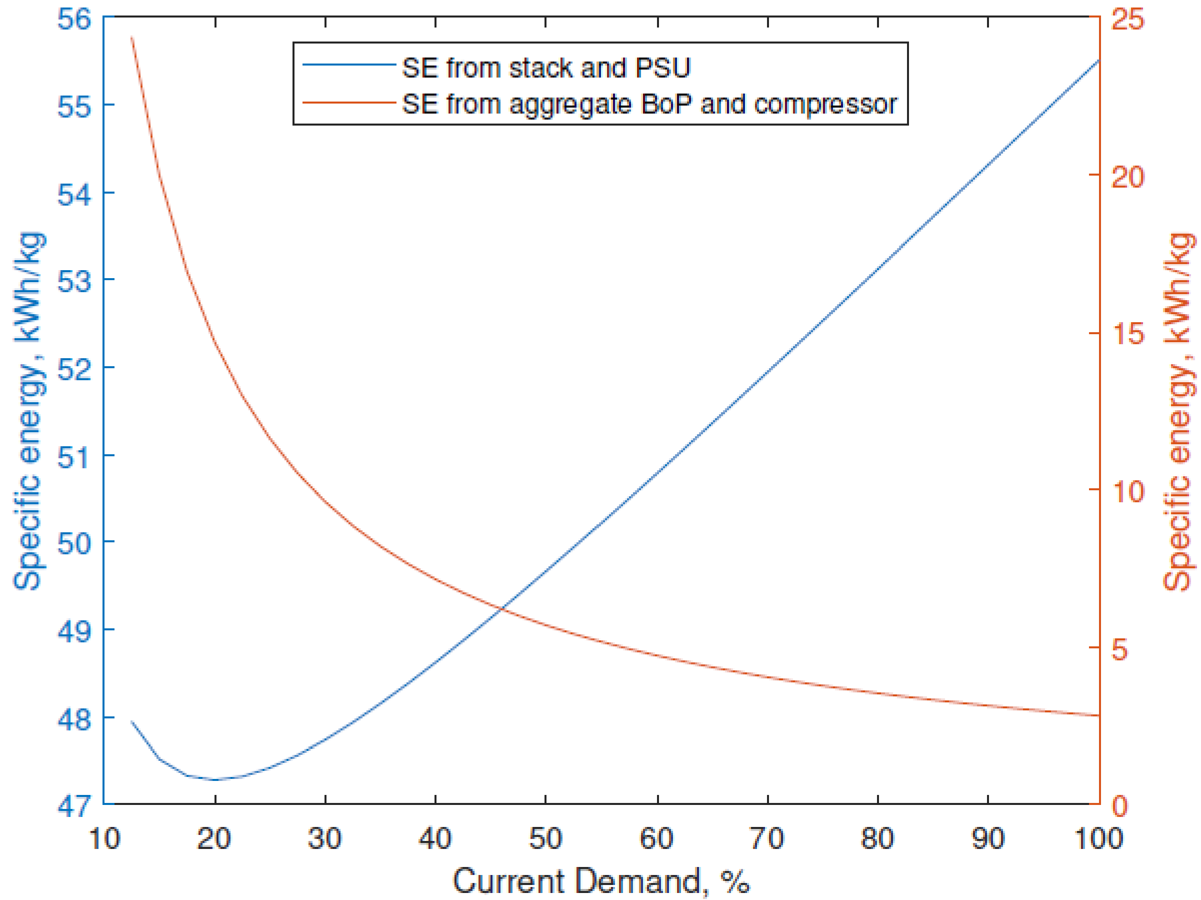
Atlam, Ozcan, and Kolhe, Mohan. "Equivalent electrical model for a proton exchange membrane (PEM) electrolyser." Energy Conversion and management 52.8-9 (2011): 2952-2957.

Plant and model power consumption



Total plant power for data and model results with variable Current Demand.

Simplifying hydrogen plant model to find kWh/kg



The modelled contribution to specific energy (SE) at 54 °C from: the stack and PSU; the remaining, aggregate BoP and compressor.

Graphical explanation:

$$y_1 = ax + b$$

(approximately)

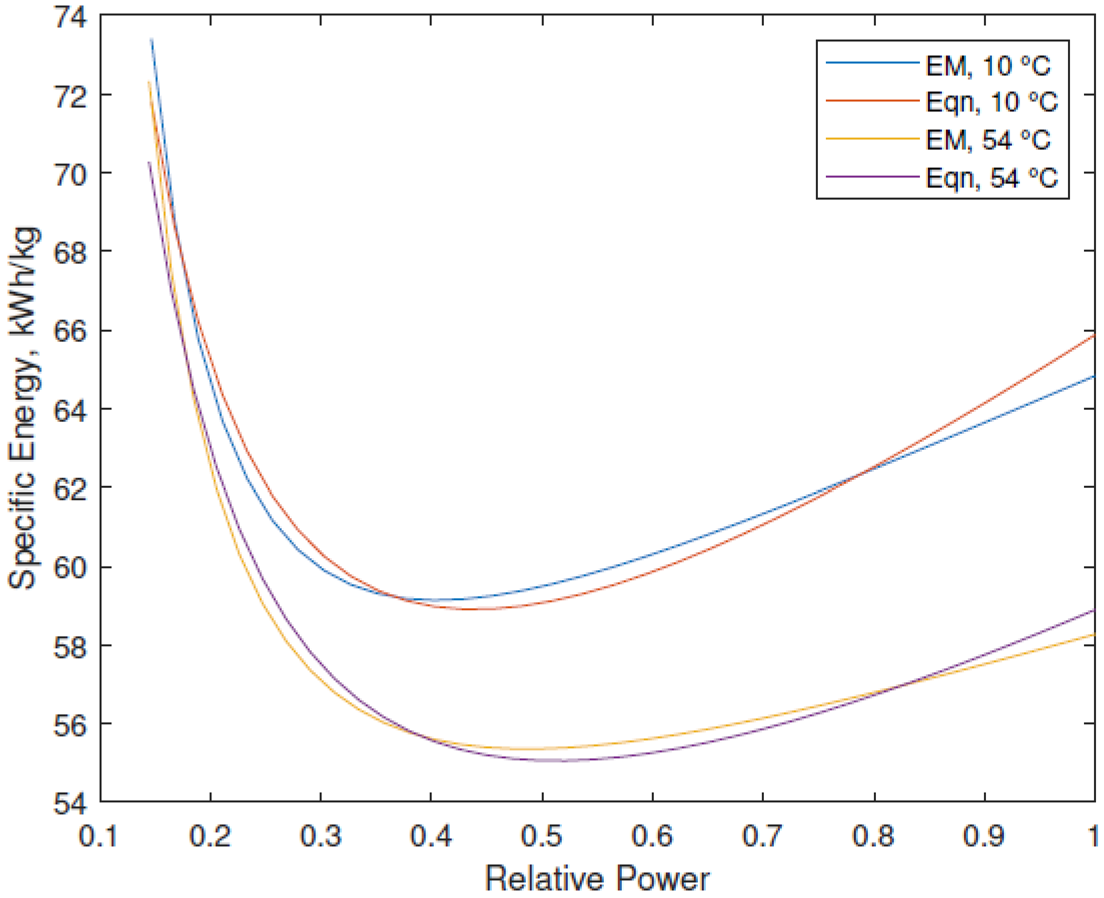
$$y_2 = \frac{c}{x}$$

$$y_t = ax + b + \frac{c}{x}$$

Also developed mathematical explanation

Simplifying hydrogen plant model

EMEC HYDROGEN



Specific energy vs relative power from the detailed electrolyser model and Eqn 6.2 at two temperatures.

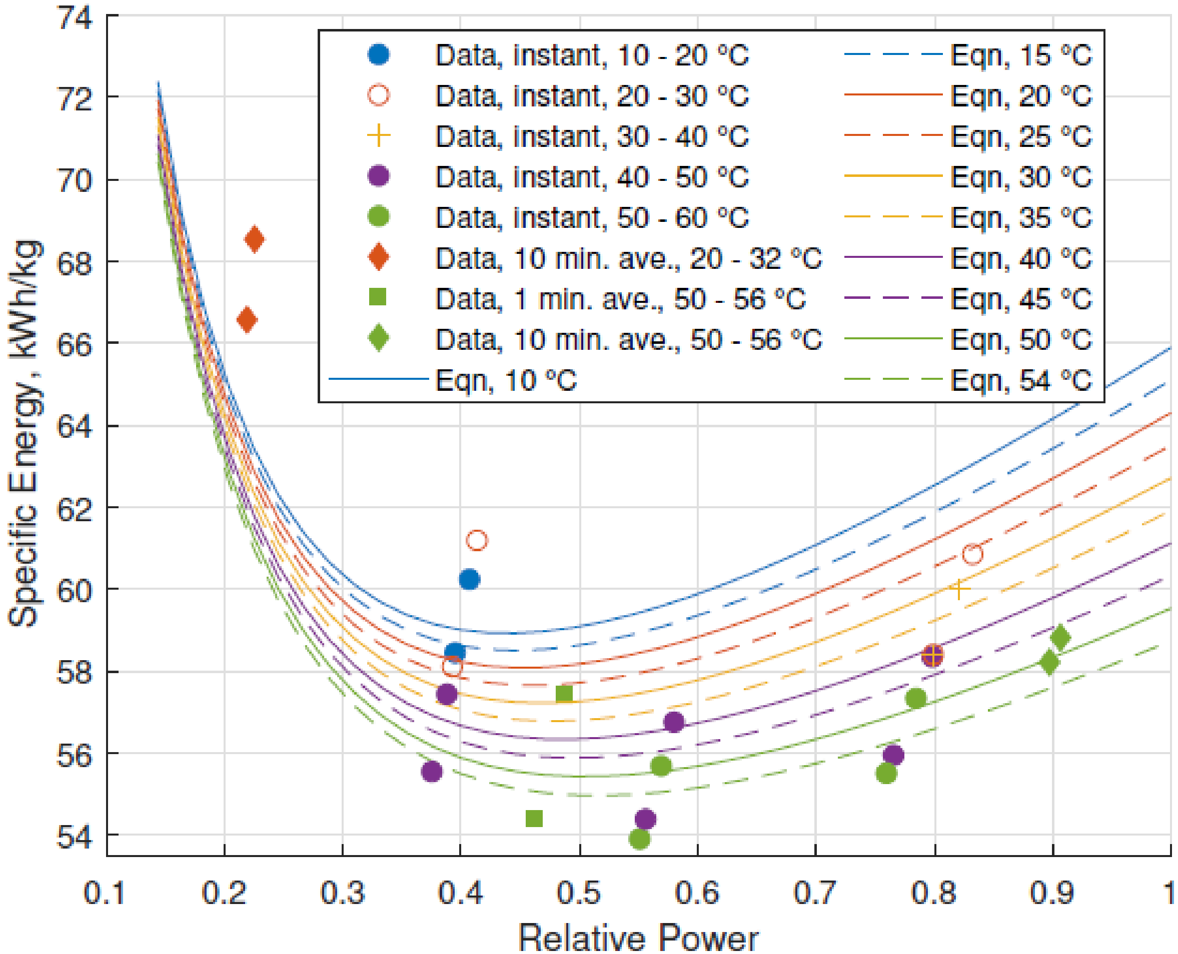
Eqn 6.2:

$$y = ax + b + \frac{c}{x}$$

Simplifying hydrogen plant model

Apply temperature correction, and done!

$$y = \left(a + a_c(T - T_s)\right)x + \left(b + b_c(T - T_s)\right) + \frac{c}{x}$$



Specific energy vs relative power from Eqn 6.3 at various temperatures as well as range of calculated specific energy values, derived from real plant power data and calculated hydrogen flowrate values. Each set of specific energy values corresponds to a single value of Current Demand, but shows how the relative power changes within a given band of temperature.

What difference does this make compared to a constant value?

- It made almost no difference!
- Why? Because a 500 kW electrolyser powered by a 0.9 MW wind turbine or 2 MW tidal turbine will be on at full capacity and operational temperature most of the time, so have near constant performance, plus ferry discretisation.
- However, the model could help optimise large electrolsyer operation, especially if combined with degradation model

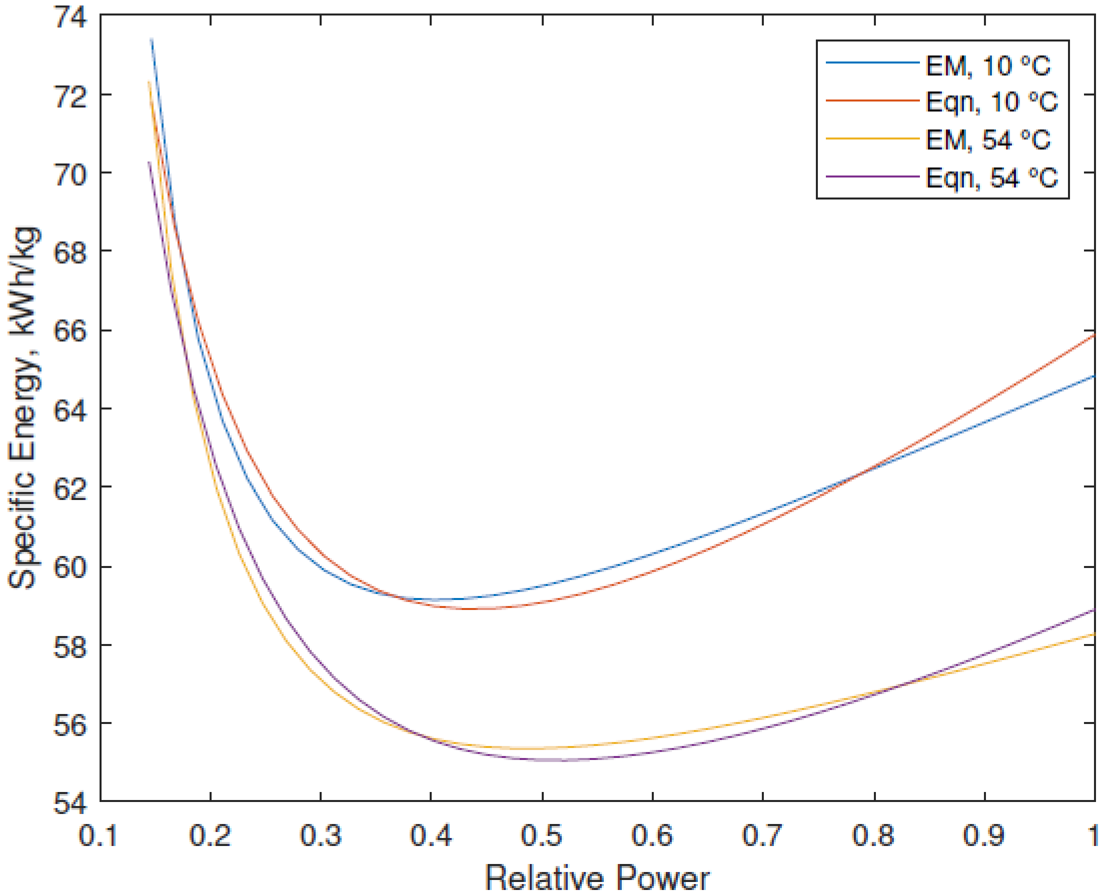
Scenario	Average delivery rate, kg/day, with simplified model	Average delivery rate, kg/day, with constant value, 59 kWh/kg	Difference in ferry deliveries per year
Curtailed wind	55	55	0
Non-curtailed wind	82	81	1 (1.6%)
Tide	159	159	0

Summary

- We can find best hydrogen production routes through techno-economic analysis, which requires models
- This work developed a relatively detailed electrolyser model into a simplified model to find electrolyser performance as a function of load factor and temperature
- In a case study, the results from this model and a constant electrolyer performance were almost equal, suggesting a constant value is suitable when an electrolyser is mostly on at full capacity and operational temperature
- The model may still be useful in optimising the operation of large scale electrolysis plants

Thanks for listening

Simplifying hydrogen plant model



Specific energy vs relative power from the detailed electrolyser model and Eqn 6.2 at two temperatures.

Eqn 6.2:

$$y = ax + b + \frac{c}{x}$$

c is constant
(Future work could approximate b as constant)

Fitted constants from Eqn 6.2 at two temperatures.

Parameter	10 °C	54 °C
a	22.12	16.18
b	39.50	38.46