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MEA Development for a 2MWe PEM Fuel Cell Power Plant Fuelled with By-product Hydrogen from the Chlor-Alkali Process, and its Design, Build and Operation

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EuCheMS, Aug 26-30, Liverpool UK

DEMCOPEM-2MW: demcopem-2mw.eu

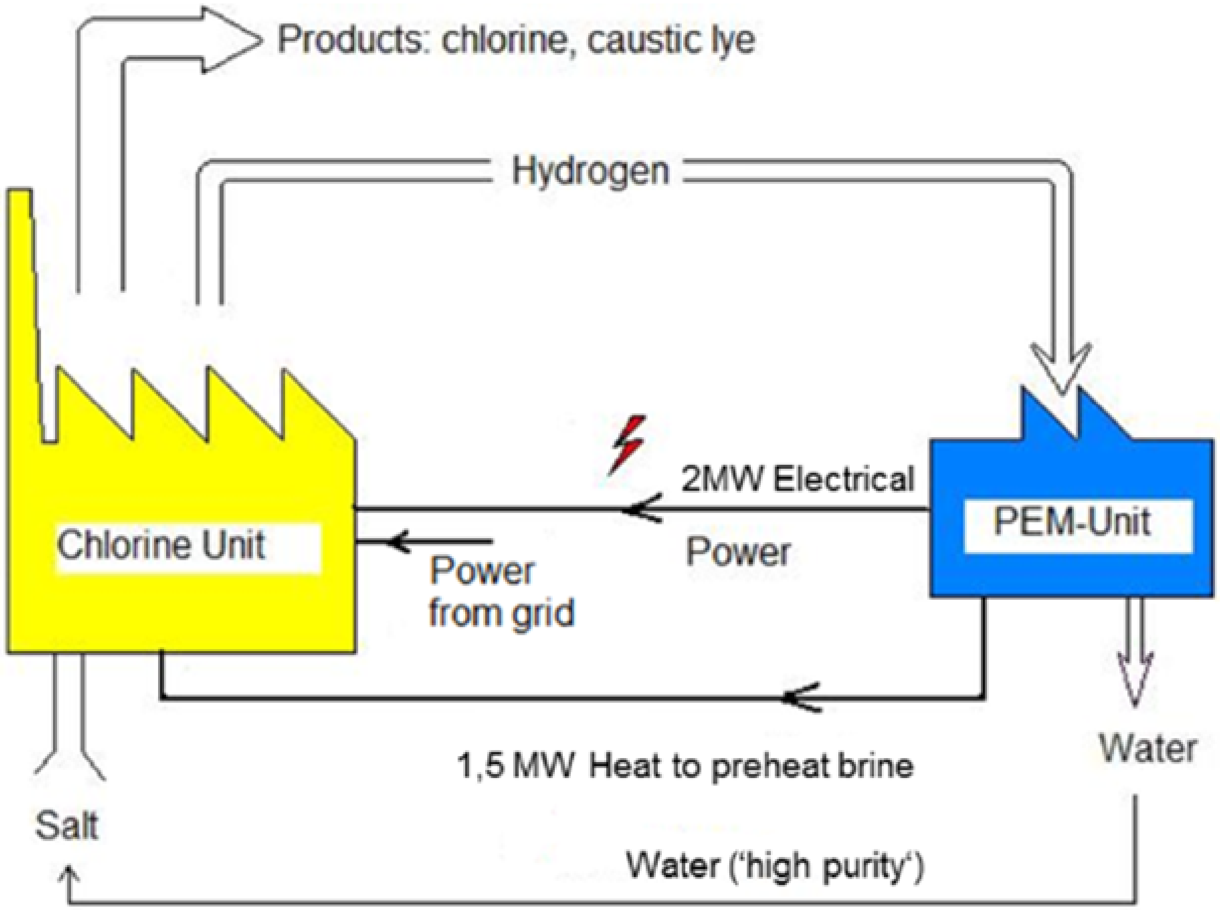
DEMonstration of COmbined heat and power PEM power plant

- European funded (FP7, FCH-JU).
  - Grant no. 621256.
- Consortium:
  - Johnson Matthey Fuel Cells, Swindon, UK: MEA design, development, manufacture, testing & diagnostics.
  - Nedstack, Arnhem, Netherlands: Stack design and assembly.
  - MTSA Technopower, Arnhem, NL: Plant design and construction.
  - Politecnico di Milano, Italy: Power plant simulation, model development and validation.
  - AkzoNobel, Amsterdam, NL: Project Co-ordination.

Background & Objectives

- Chlor-alkali plants have high energy costs – up to 50% of chlorine cost is due to electricity consumption.
- Chlorine production through electrolysis produces by-product hydrogen: 340Nm³/tonne H_2.
  - This hydrogen can be fed to PEM fuel cells to recover energy.
  - Waste heat from the PEM power plant can be used eg to preheat brine.
  - China produces 42% of the world’s Cl_2. 25Mt Cl_2/yr, 180 plants nationwide; up to 1100MWe equivalent hydrogen available. Generally high electricity prices *cf*. Europe.
  - Project aims to build world’s largest PEM power plant (2MWe) at 50% electrical efficiency, 85% efficiency total, including heat.

Project Concept



MEA Design and Development

Fuel Cells at Johnson Matthey

- World's first dedicated MEA production facility, est. 2002.
- 2005-07: automated volume production of direct methanol fuel cell MEAs introduced.
- 2007-09: automated volume production of phosphoric acid fuel cell components introduced.
- 2012: development of high-volume continuous hydrogen PEM fuel cell manufacture.
    - Including coating, converting, in-line quality inspection.

Johnson Matthey Fuel Cells
Swindon

Research and Test Centre
Sonning Common

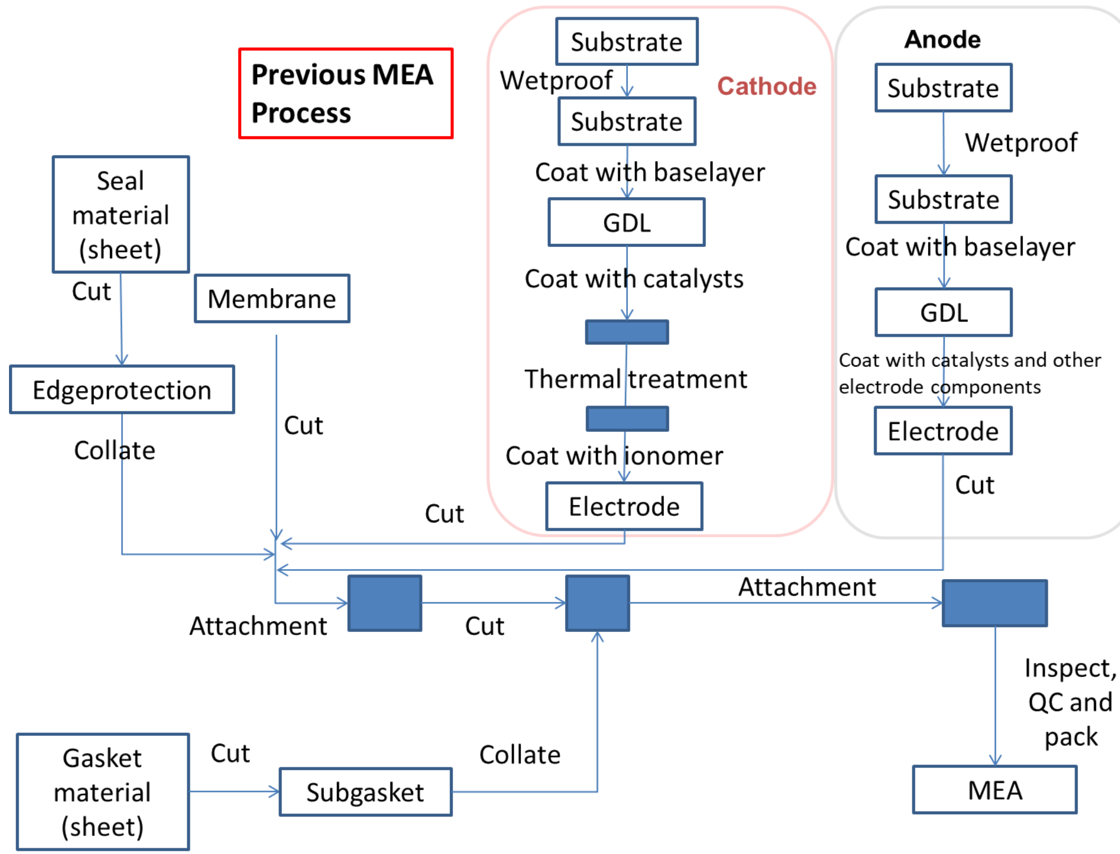
MEA Design and Development

Previous MEA for Long Life Stationary Power

JMFC previously made an ultra-durable BCS MEA.

- Operating lifetime >20,000hrs[1].
- Manufactured by individual static processes largely by hand.

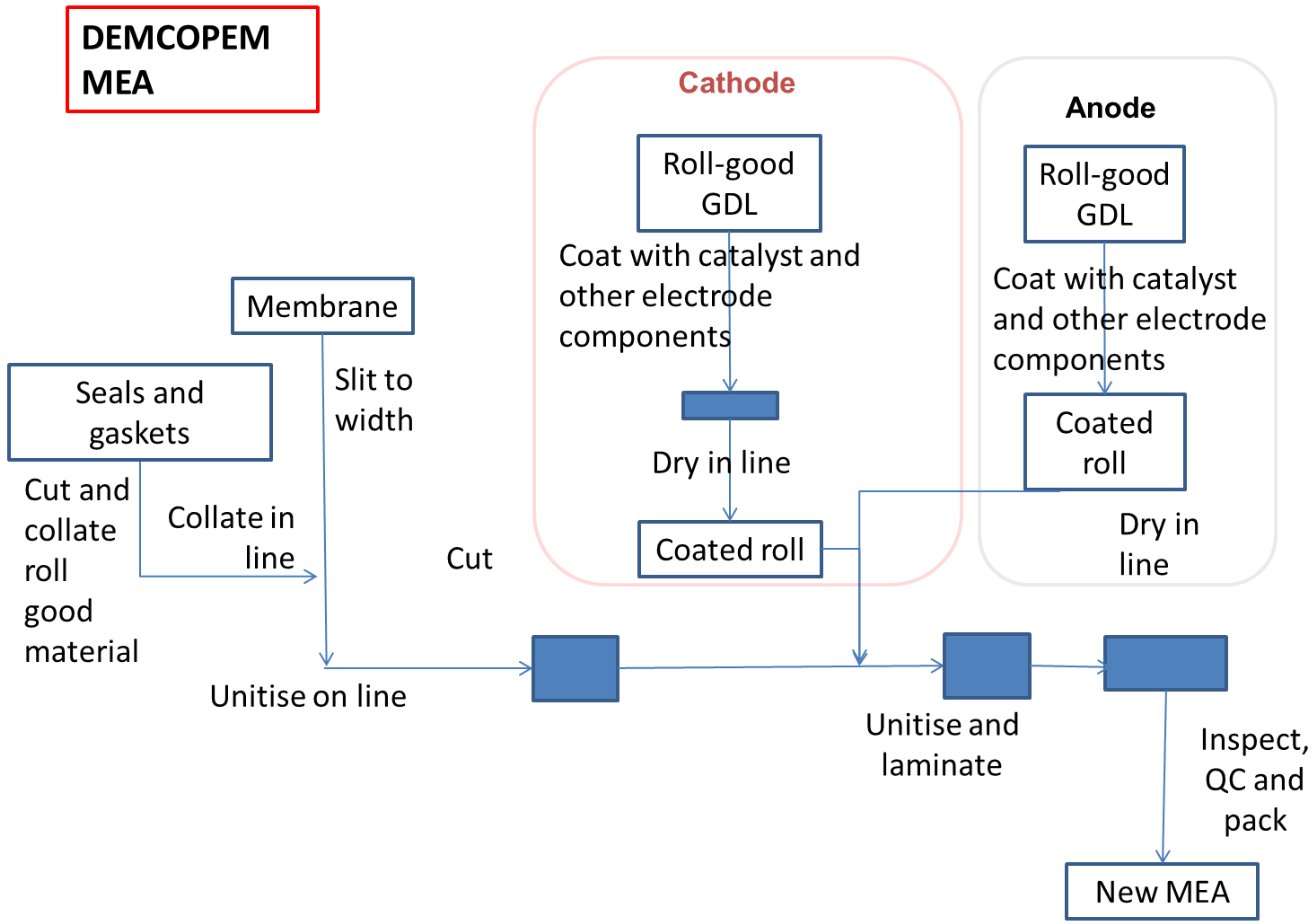
(1) *Int. J. Hydrogen Energy*, 38 (2013) 4714-4724



MEA Design and Development

Volume manufacture-capable MEA

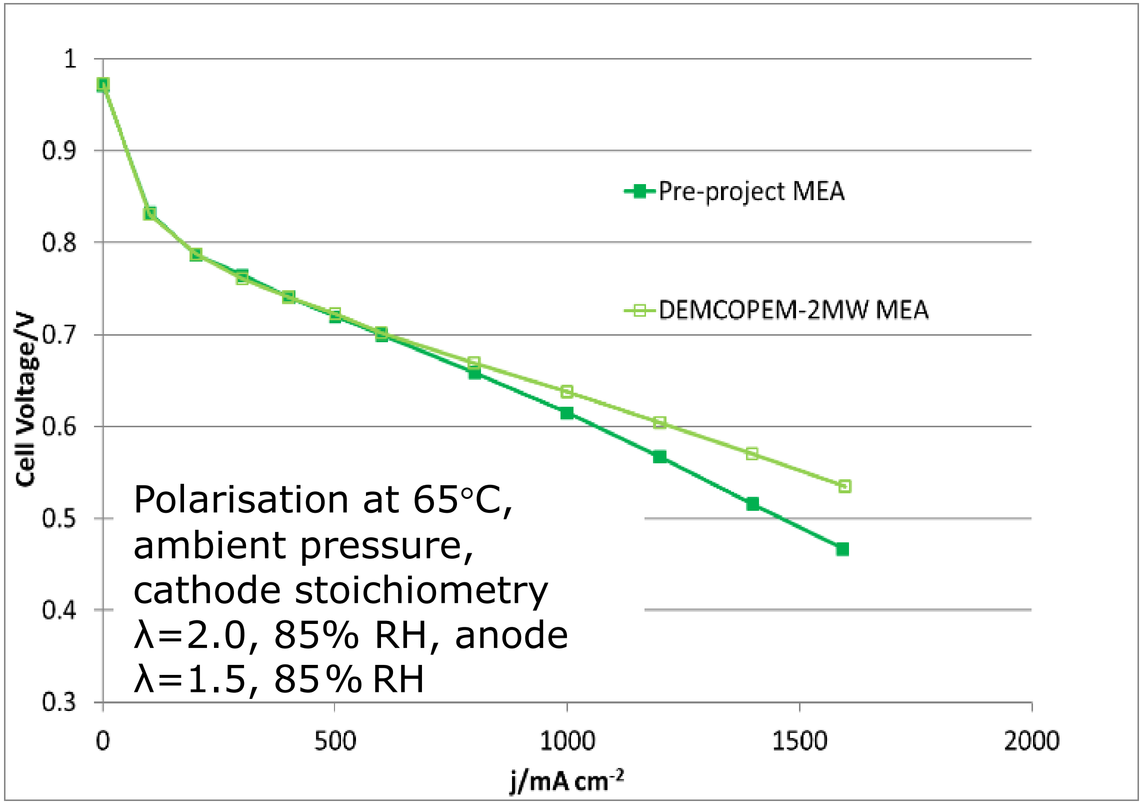
- JMFC developed a continuous roll to roll electrode production method – 27,000 MEAs produced.



MEA Design and Development

Beginning of life MEA performance

- New MEAs matched the performance of the pre-project long life MEA at lower current densities, and exceeded it at higher current densities.
- Possibly due to enhanced gas access to the catalyst-electrolyte interface.
  - more open gas diffusion medium.
  - possibly also an increased porosity of the catalyst layer.



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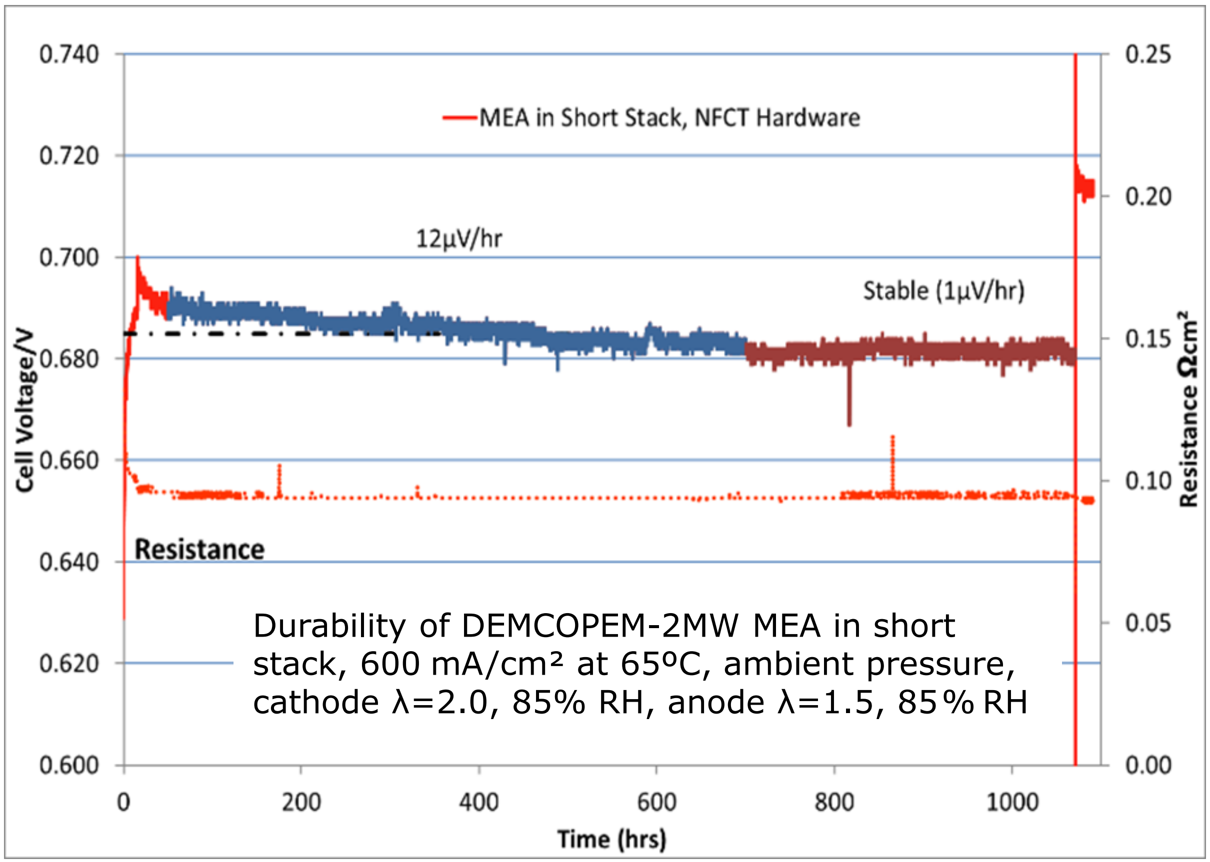
MEA Performance Stability

- Stability testing:
  - initial 700 h of decay at 12 µV/hr,
  - rate of decay levels off to create highly stable performance.
- Following an interruption for diagnostic testing at 1050 hr, voltage climbed by around 34 mV.



- Regeneration in performance may be due to reduction of oxides or other surface contaminants when cathode potential drops when air supply is interrupted, hydrogen crosses the membrane

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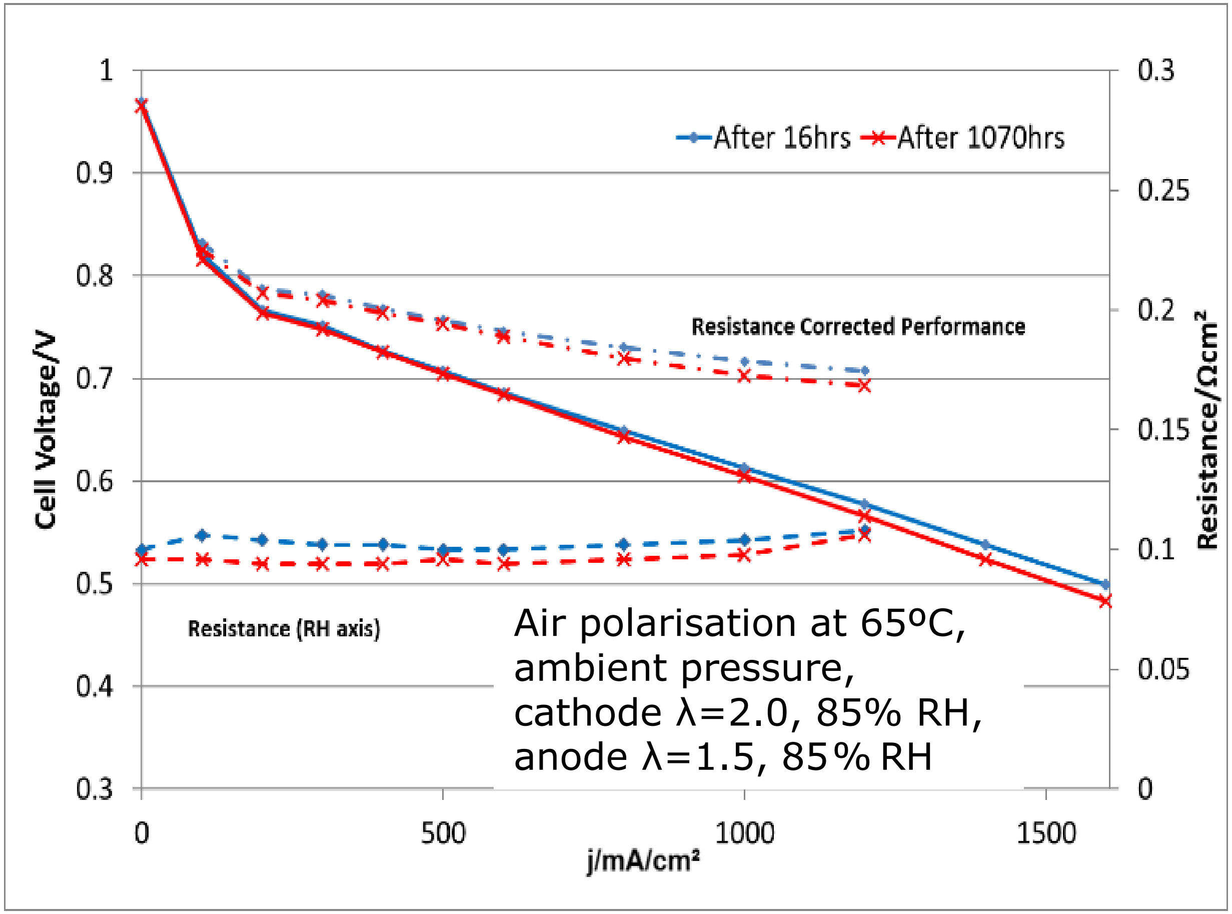
MEA Design and Development

Polarisation before and after stability testing

First 1000hrs shows stable performance, some effect of conditioning with resistance lowered.



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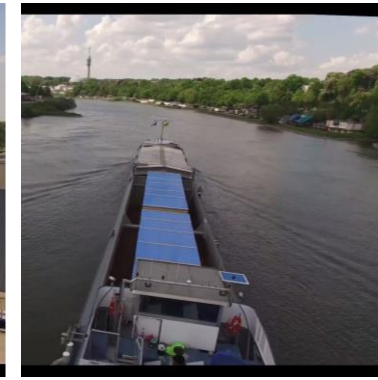
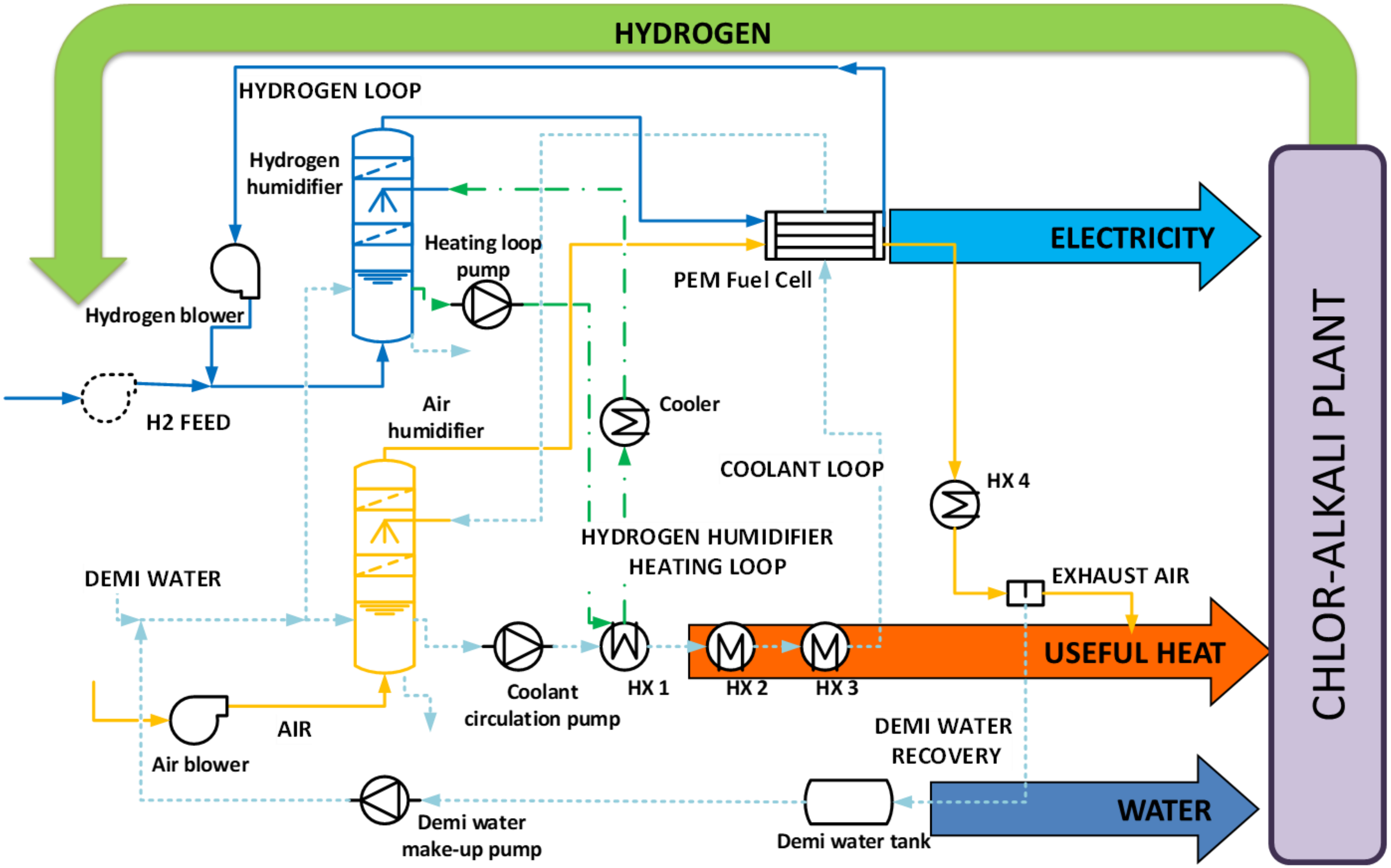
Power Plant Construction, Shipping, Commissioning

- Built & Tested at MTSA, Arnhem:
- Shipped to Ynnovate Sanzheng Chemicals, Yingkou, China.
- Opening ceremony October 2016

Power Plant Design:



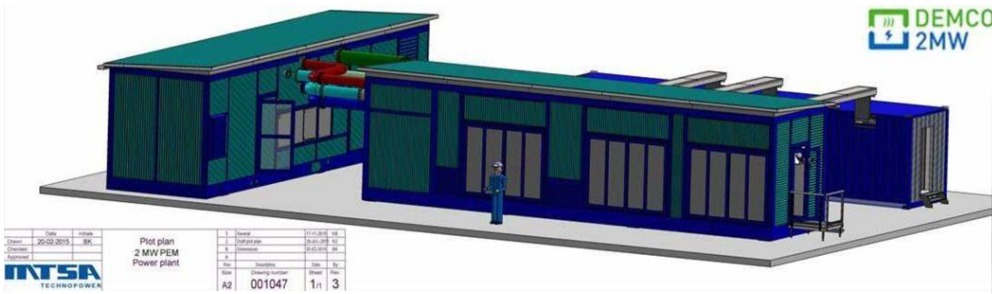
Power Plant Layout

Three shipping containers:

- Fuel cell stacks and control room.
- Inverters and power handling.
- Mechanical and thermal balance of plant, including humidifiers.

Modular arrangement of cells:

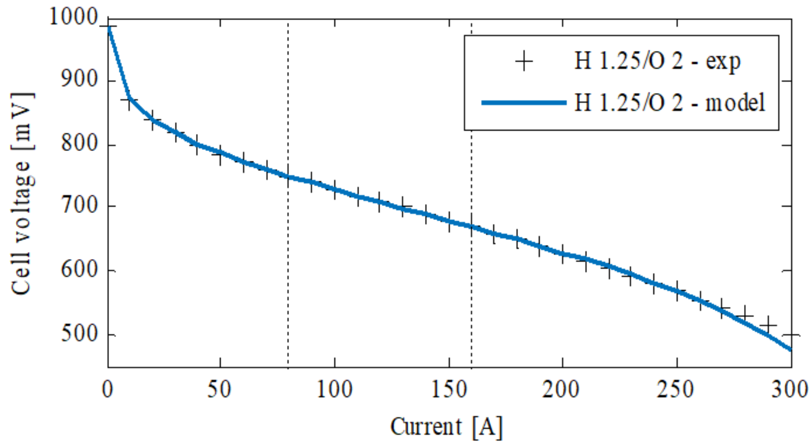
- Six groups of modules, each with a 360kVA inverter.
- Each group has four modules, fourteen stacks per module.

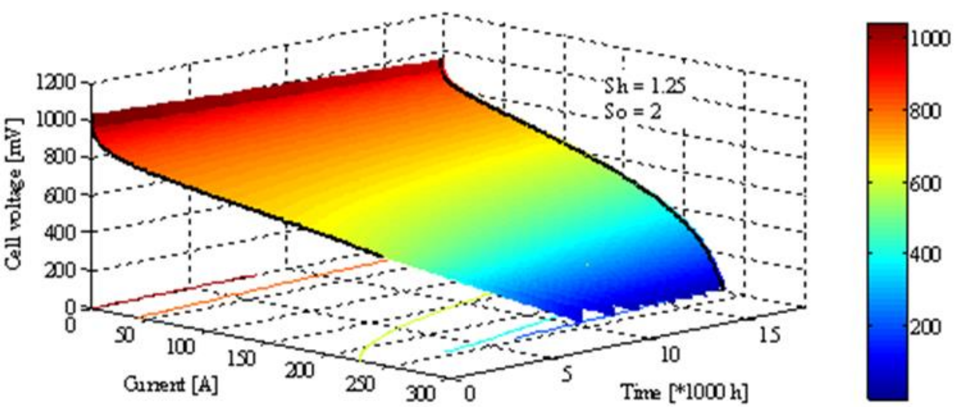


Power Plant - Modelling

Polarisation curve regression

- Power plant simulated in Aspen PLUS.
- Stacks are treated as 0D, made up of average cells, in model block.
- Cell performance is modelled in Aspen Custom Modeler, to give a semi-empirical polarisation curve.
- Coefficients calculated by regression to experimental data from Nedstack FCT's installations.
- Top right: example of regressed model polarisation curve. Below right: change in polarisation performance over lifetime.
- Details in Campanari et al, *J. Electrochem. Energy Convers. Storage*, in preparation.





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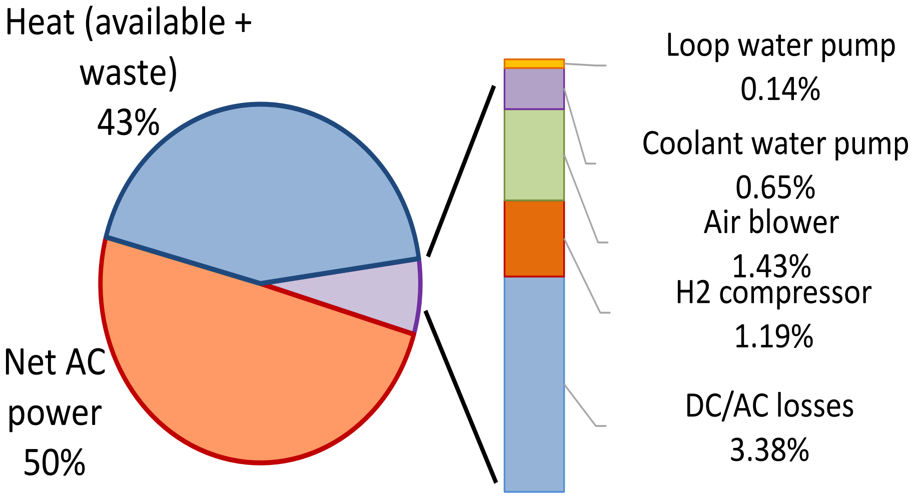
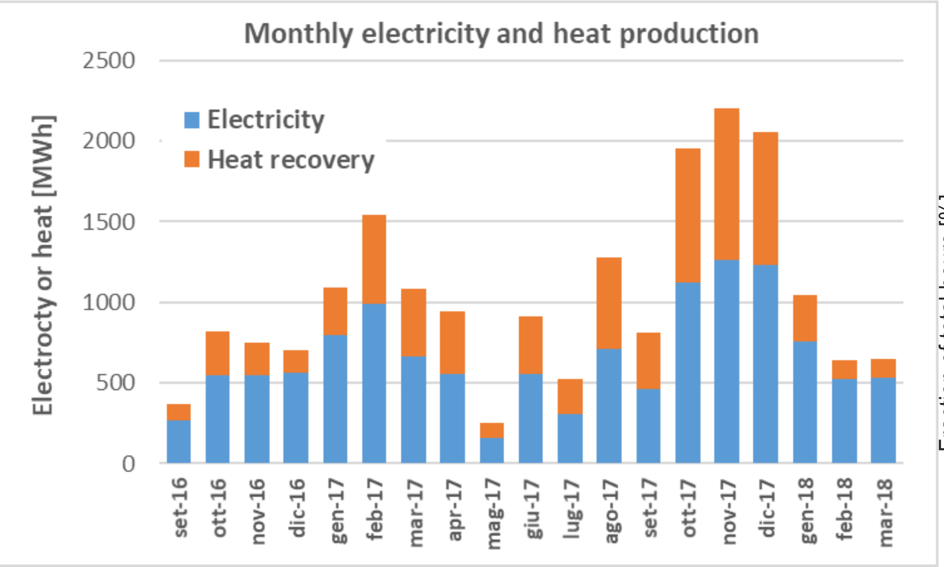
Plant Operation

- Initially, 5 stack groups functioning, 1.7MWe available – one group not started due to inverter failure, repaired early 2017.
- Below left: energy available by month



Above: BoL energy balance, 5/6 groups Below: Plant availability



Plant Performance and Model Validation

At BoL

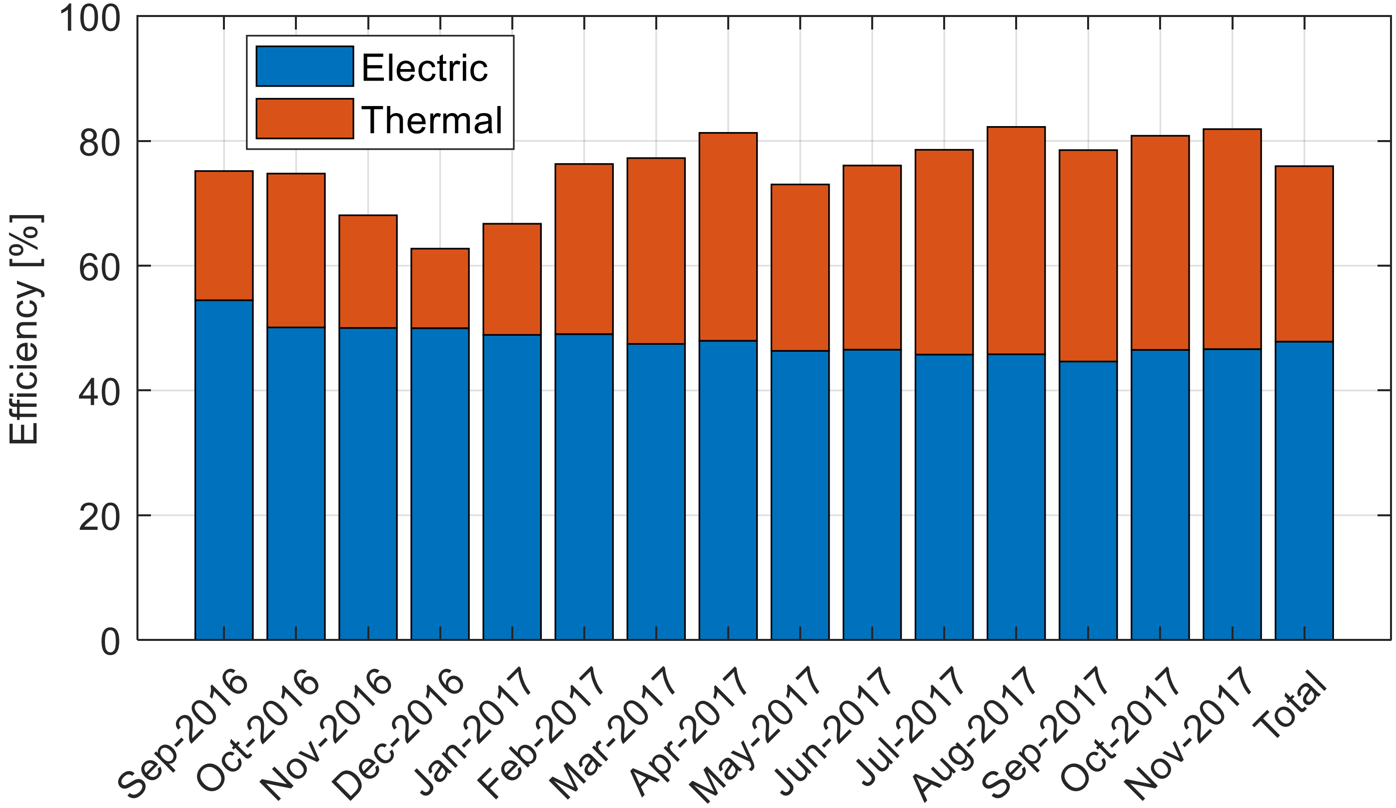
- Right: Operating conditions from beginning of life, compared to model.

Operating conditions				
Air inlet flow	Nm^3/h	5314		
Stoichiometry cathode / anode	-	2.3 / 2.0		
T coolant, FC inlet	°C	60.0		
Power DC (gross)	kW	1653		
Results		Measurement	Model	Difference
H_2 inlet flow	Nm^3/h	972	978	0.6%
Temperature air humidifier	°C	63.0	62.7	-0.4%
Coolant flow	m^3/h	317	315	-0.6%
Coolant temperature at stack outlet	°C	64.7	63.9	-1.3%
Voltage (average)	V	728.7	742	1.8%
Current (average)	A	113.4	111	-1.8%
Auxiliary power	kW	106	105	-1.2%
Available Thermal power (HX2)	kW	-	735	-
Power AC (net)	kW	-	1450	-
Efficiency (gross)	%	56.7	56.4	-0.5%
Efficiency (net)	%	-	49.5	-
Net water production	kg/h	-	534	-

Plant Performance and Efficiency

Electrical and available heat.

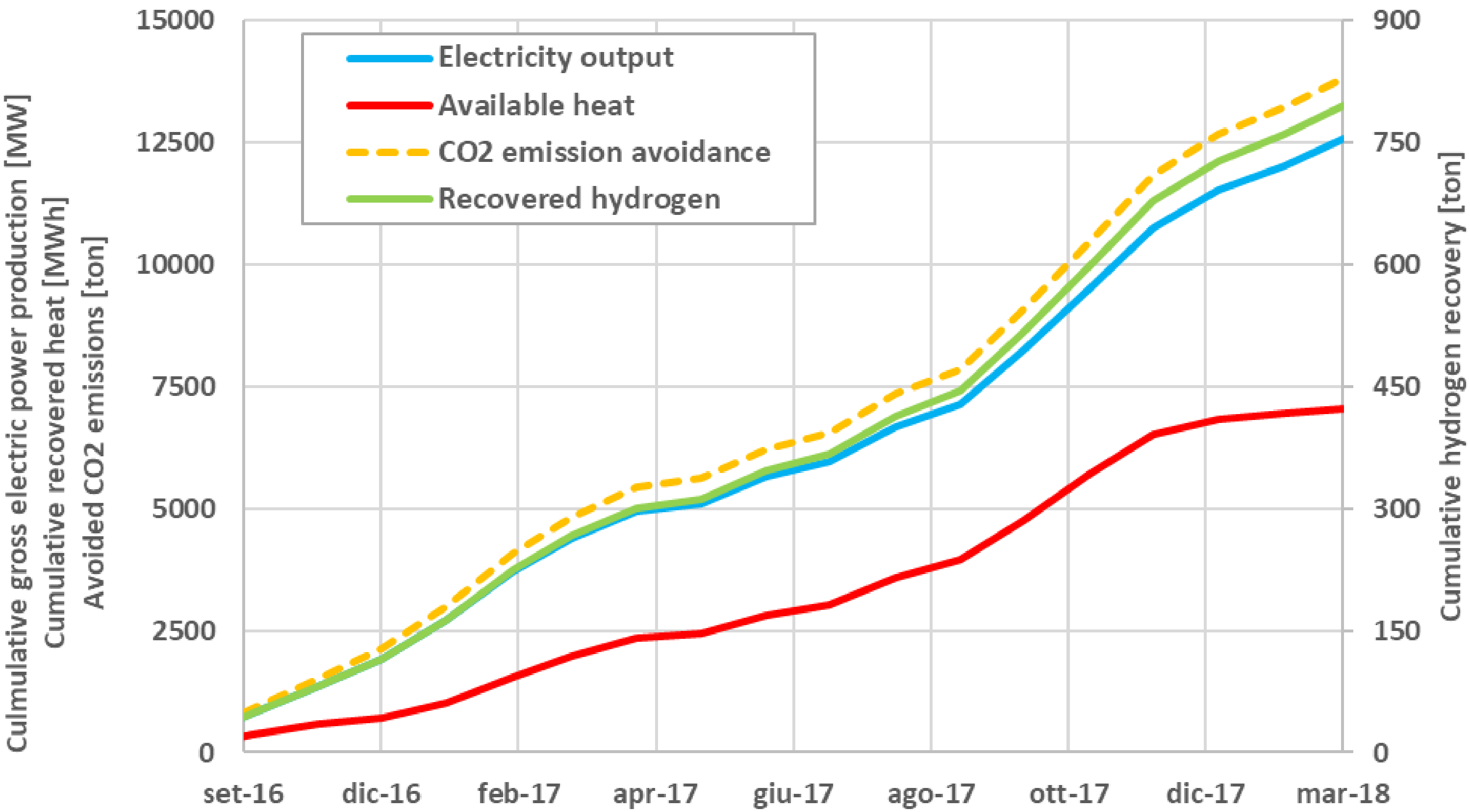
Efficiency (%LHV hydrogen). Average electrical efficiency 49%. Heat available is influenced by ambient temperature on site.



Plant Performance and Efficiency

Cumulative Data

LH axis: electrical power produced (MW); heat recovered (MWh) and CO_2 emissions avoided (ton). RH axis: hydrogen recovered (ton).



Conclusions

- The chlor-alkali industry can recoup significant costs by installing fuel cell PEM power plants to generate electricity and heat from by-product hydrogen.
- A 2MWe demonstration power plant has been built, commissioned and operated for over a year:
  - 800t H_2 used, 13000t CO_2 equivalent emissions avoided.
  - 50% efficient vs LHV H_2, plus around 26% as available heat.
- A long-life stationary power MEA optimised for high volume manufacture has been developed at JMFC, replacing a mature pre-project design.
- A model of the PEM power plant was created and verified.

- This work was carried out in the framework of the FP7-FCH-JU project "DEMCOPEM-2MW", cofounded by the FCH JU under grant agreement n° 621256.