FUTURE & VESI DISSEMINATION SEMINAR – EPSRC (IDP5)

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14 January 2014

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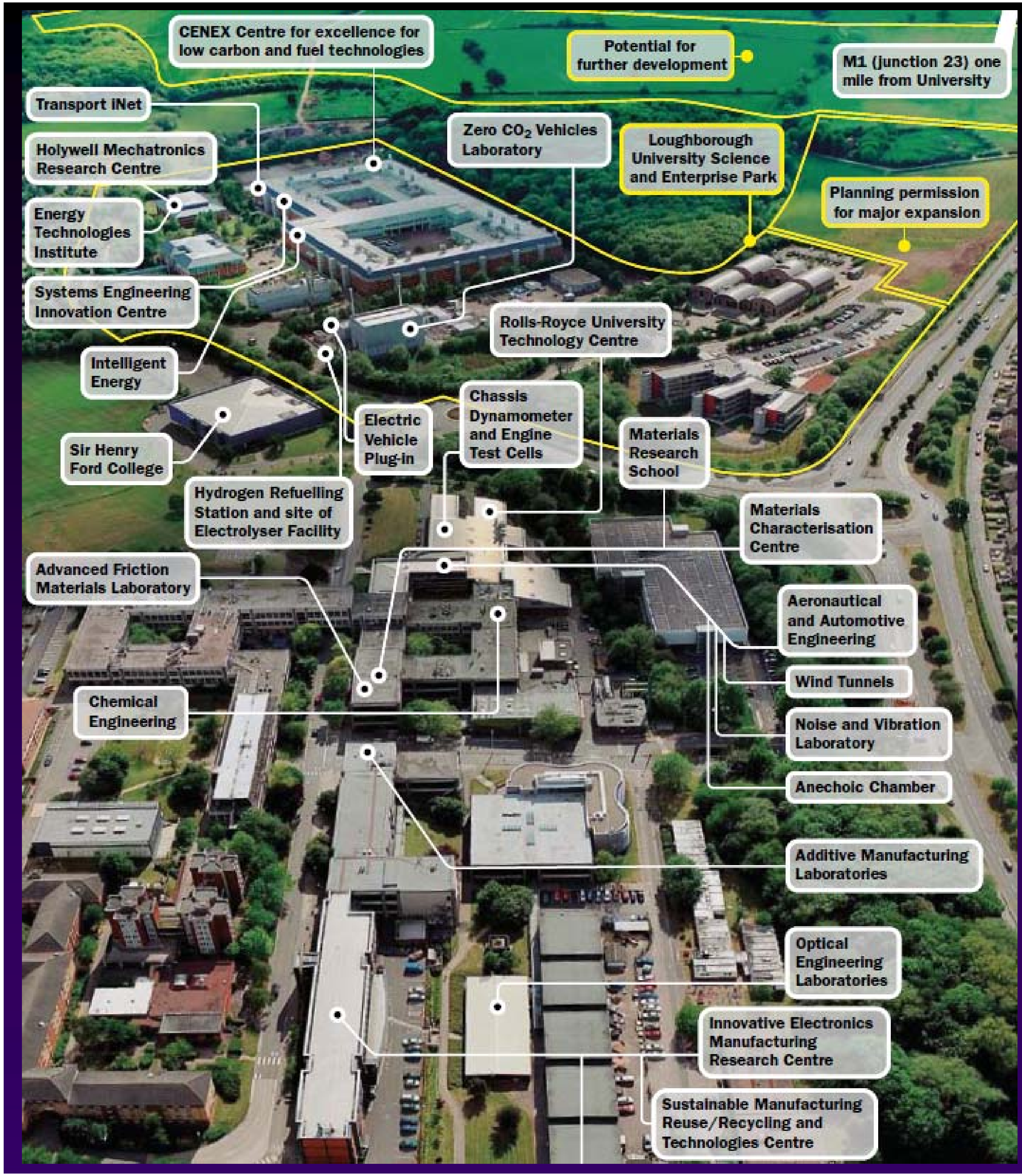
Low Carbon Research



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AAE FC Research Areas

- Tom Fletcher T.P.Fletcher@lboro.ac.uk is working to reduce the energy consumption of Fuel Cell Hybrid Electric vehicles by the application of dynamic programming and model predictive control.
- Michael Whiteley M.Whiteley@lboro.ac.uk is working on reliability of PEMFC using computational simulation and experimental methods
- Andrey Vasilyev A.Vasilyev@lboro.ac.uk Fuel Cell ‘Health Monitoring’ for Extended Lifetime Performance
- Ben Davies B.Davies2@lboro.ac.uk Enhancing fuel cell lifetime performance through effective health monitoring and decision support
- Simon Howroyd *S.Howroyd@lboro.ac.uk* Using a practical methods to design, test and verify a custom fuel cell controller to enable quick and easy hybridisation of a commercial, ‘off the shelf’, remote controlled plane or UAV.
- Ash Fly a.fly@lboro.ac.uk is studying evaporative cooling of FC stacks for automotive applications
- Manoj Ranaweera R.A.M.P.Ranaweera@lboro.ac.uk Developing a sensor array to assemble a 3D temperature map of a SOFC stack while assuring minimum disturbance to the normal operation of it.
- Indea Choi i.choi@lboro.ac.uk In-situ investigation of curvature change induced by stress in multilayer structure during co-sintering for new design SOFC

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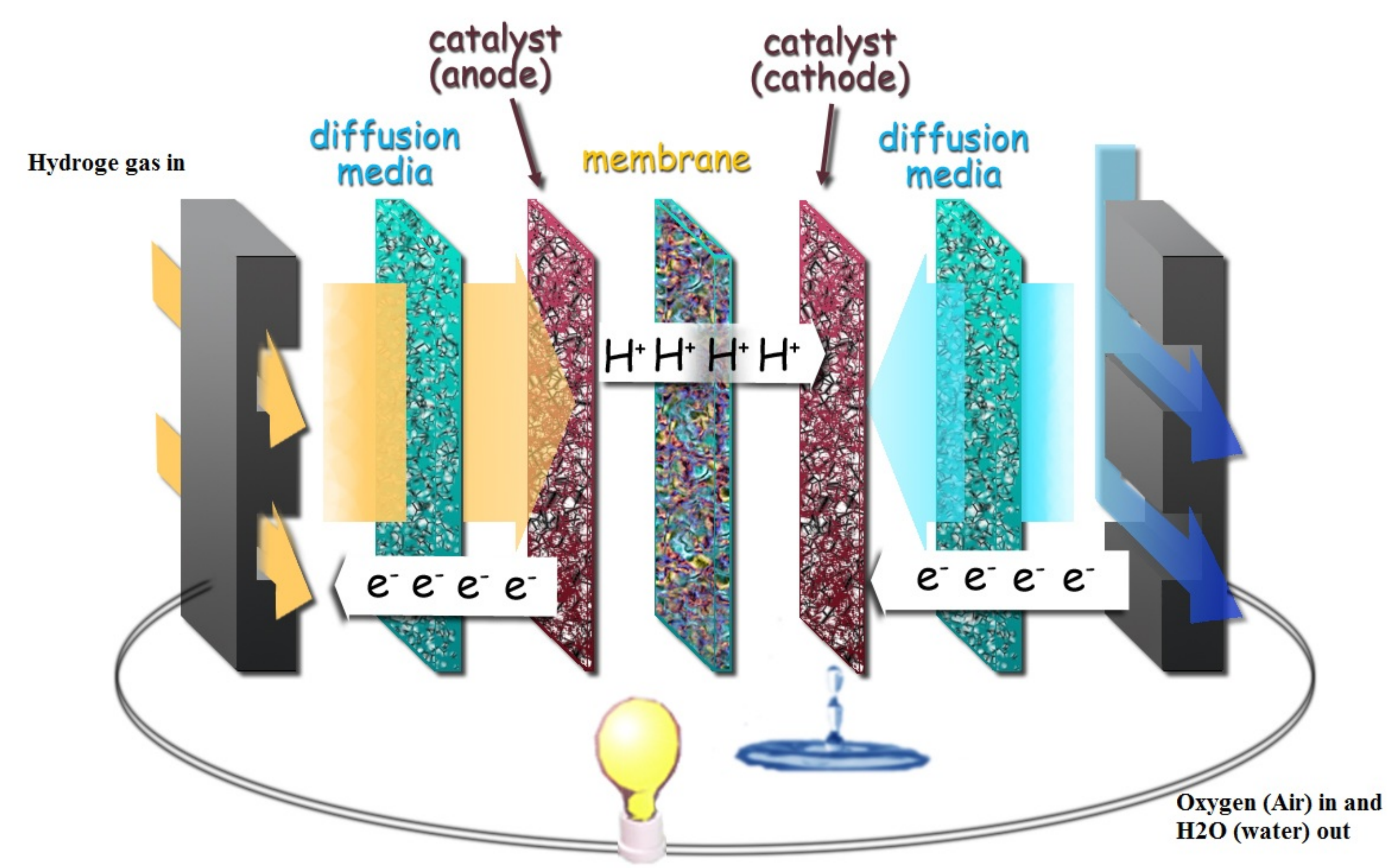
Todays Topics

- Introduction to Fuel Cells (FCs)
- Degradation in FCs
  - Mechanisms, Load Cycles & Scaling
- Cathode ‘Gas diffusion layer’ (GDL) degradation
- Optimising Catalyst layer distribution and its impact on degradation

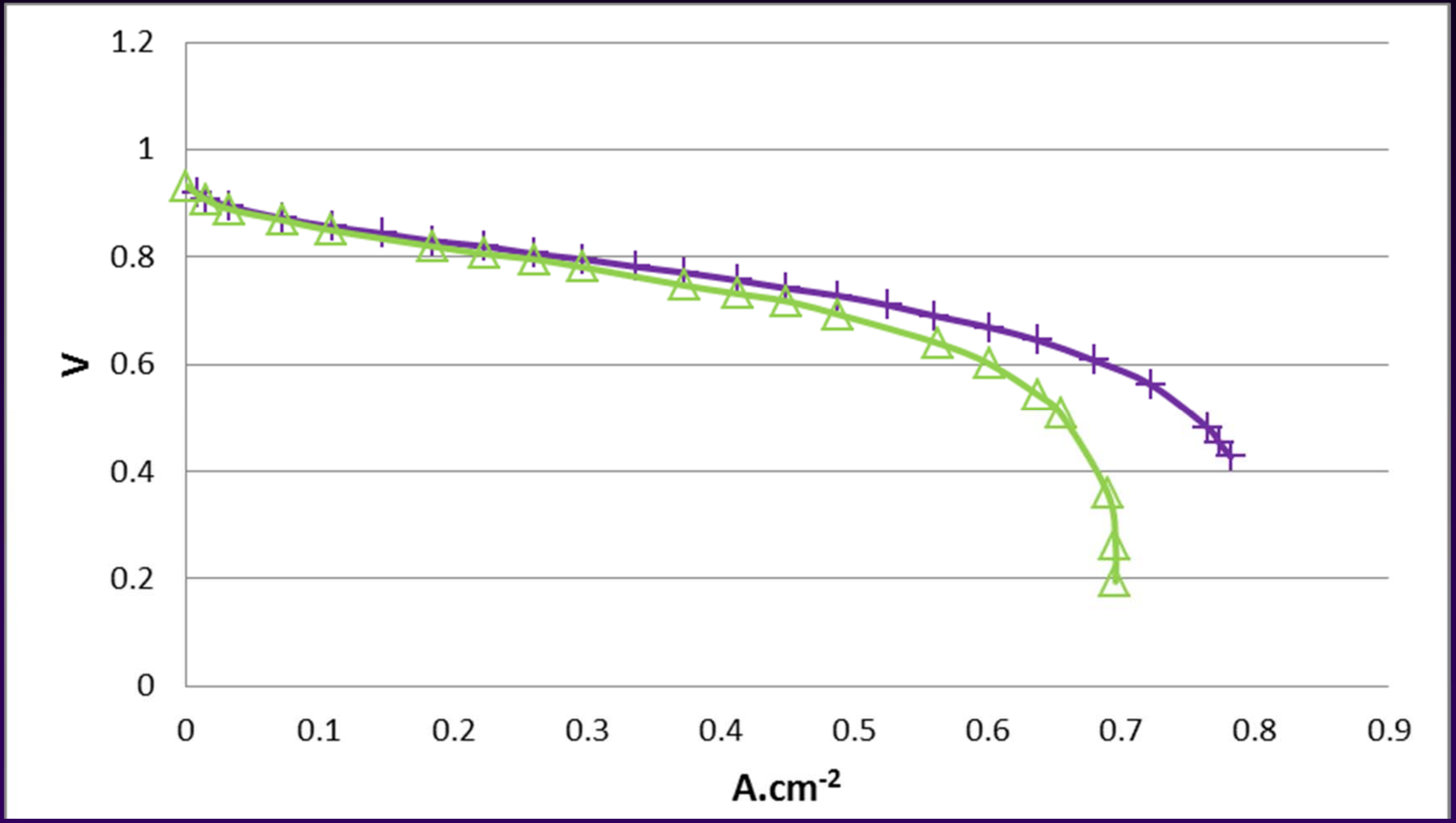
Fuel cells, and why GDLs?



Typical FC schematic

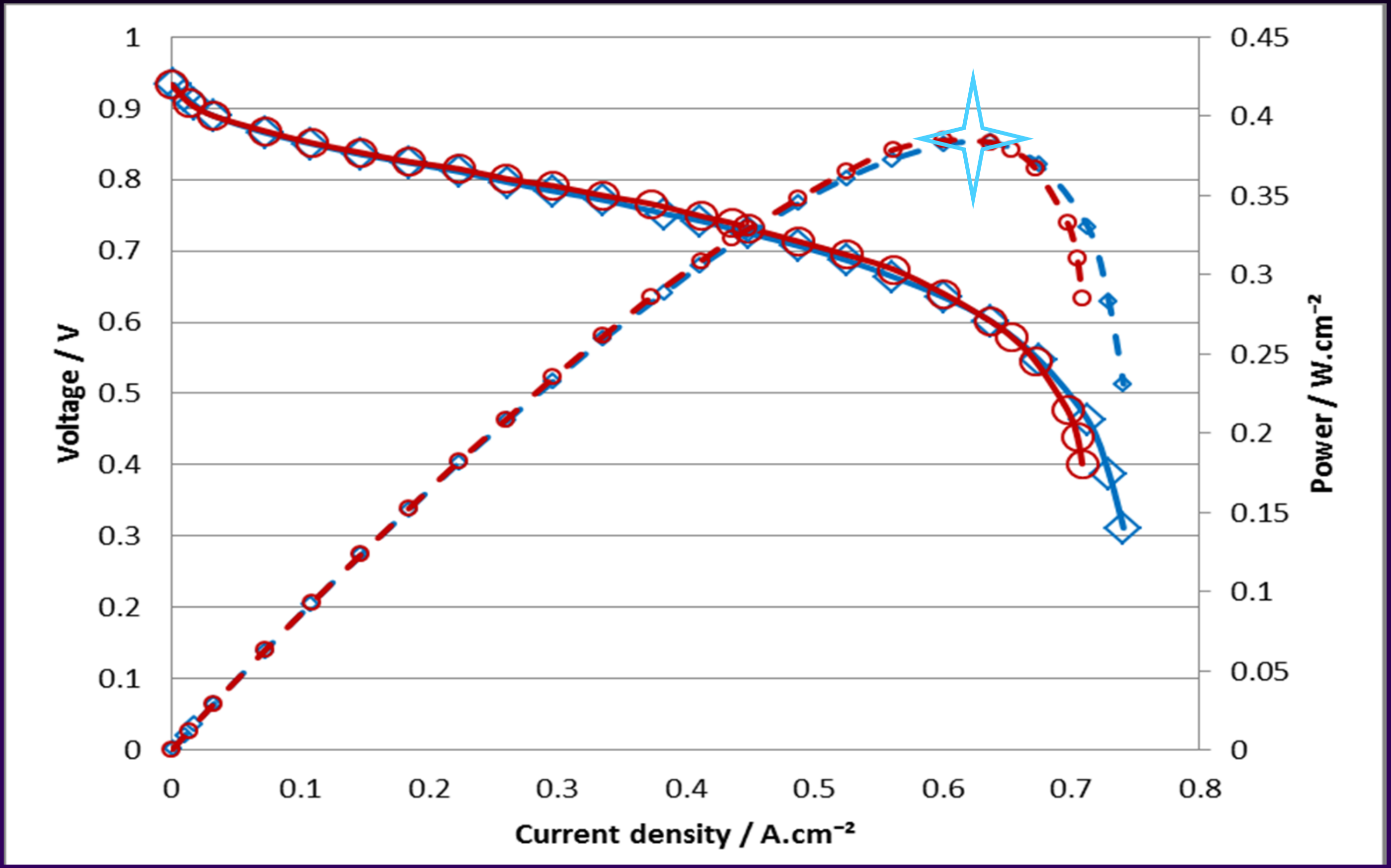
Polarisation Curves (.cm-^{2})

(e.g. Woven Vs. Non-woven Cathodes form the same manufacturer)



Peak Power

(e.g. density difference in Cathode GDLs from same manufacturer)



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FC Degradation

- With the possible exception of whiskey, all systems degrade over time
- Degradation can be characterised as a decrease in the peak power of the system over time
- Despite the relative simplicity of FCs, there are a huge number of factors involved in their degradation

- Chemical attack (catalyst poisoning, corrosion)
- Chemical blocking (G-II metal ions, Ammonia, sulphonic side chains in Nafion reduced)
- Mechanical stress (excess clamping, abnormal loading, Volume changes in Nafion/gaskets)
- Thermo-Mechanical attack (thermal cycling)
- Direct pathways for reactants through the membrane (Pinholes, cracks etc. lead to run-away O2 / H2 reactions)
- Hydration cycling (flooding of reactant pathways, drying of membranes)
- Short circuit between conductive layers (creep, fibre penetration, membrane thinning)
- Catalyst site reduction (poisoning, ACSA loss)
- GDL (wetting changes, structural changes)

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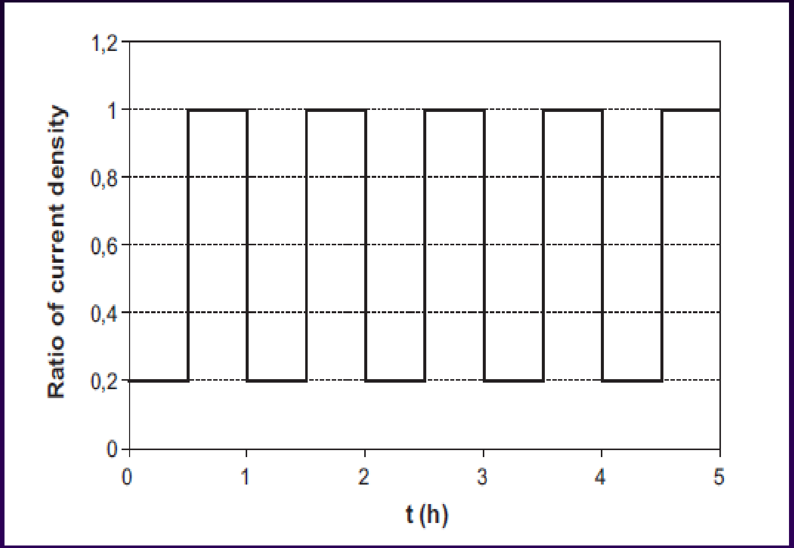
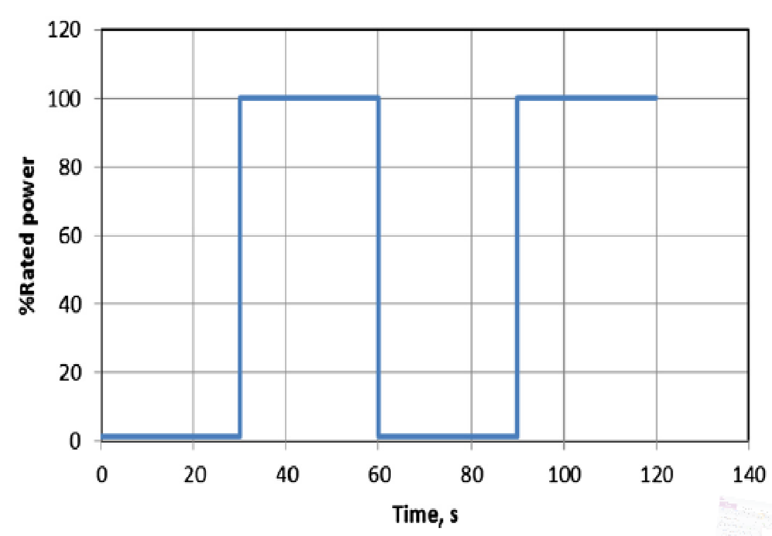
Degradation and Load Cycles

Different load cycles can impact the speed and type of degradation, and this is of critical importance for FCs in automotive applications

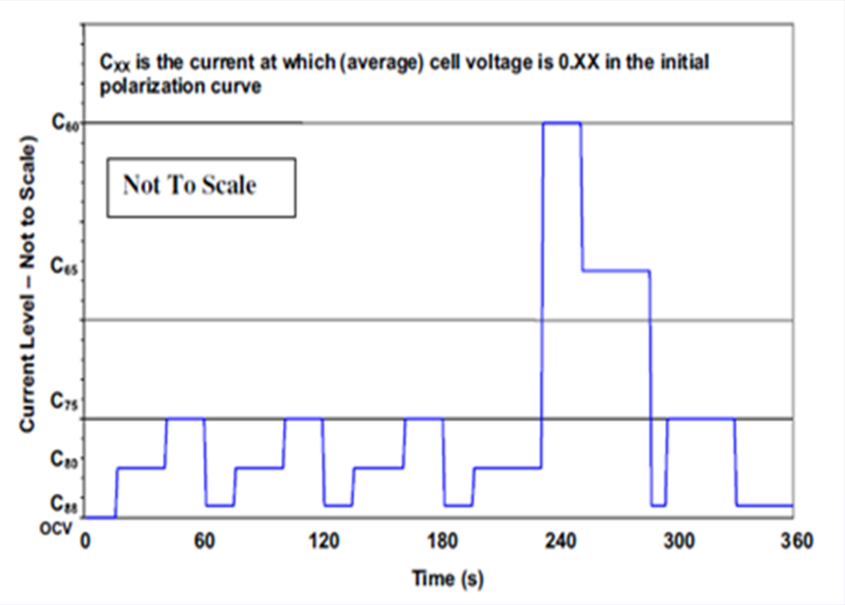
IEC/FC testnet & FCTT (wet) Duty Cycles

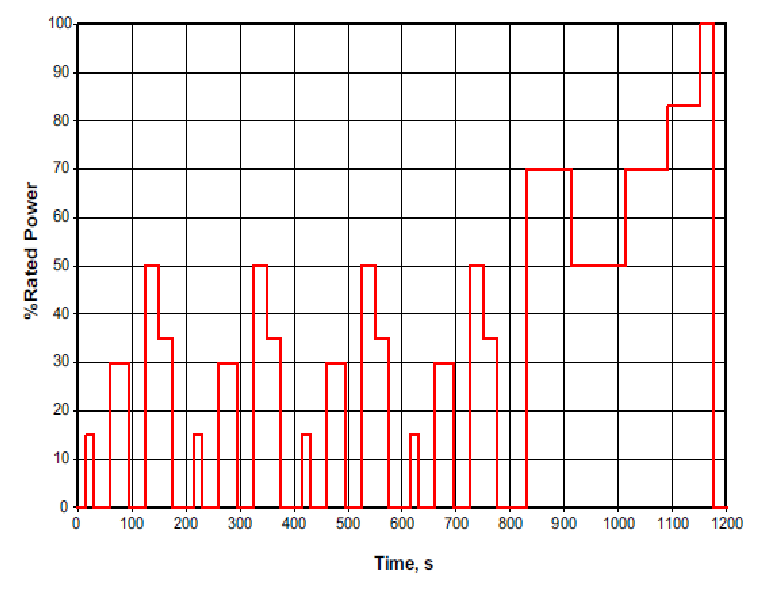




[1]

DST & NEDC (squared pulses) cycles





[1]

Drive cycles and hybridisation

- The above drive cycles for fuel cell stack testing all assume a ‘100%’ Fuel Cell drive train
- Many in the field of FC research would argue that a FC hybrid (battery / capacitor) system is likely to be preferable
- Assessment of the FC : battery/capacitor ratio needs to be undertaken
    - This would then enable an optimised Drive cycle test regime for the hybrid power train

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Alternate Degradation Criteria

- Duty cycles give us a new way to consider the aging of FCs
  - Time at Open Circuit
  - Time at Low Voltage Load
  - Steady State – Midrange Load
  - Rapid cycling – frequency duty cycle dependant
  - Time at High voltage
  - Air Quality
  - Fuel quality
- Hybridisation can give us a degree of control on the time spent at certain voltage loads

(Bloom, Walker et al. 2013)

Degradation Mechanisms and Experimentation

- Several authors have attempted to model and verify degradation in FCs, often with some success, but there are difficulties in identifying the contribution of each mechanism
  - Multiple basic factors
  - Different environmental conditions
  - Different duty cycles

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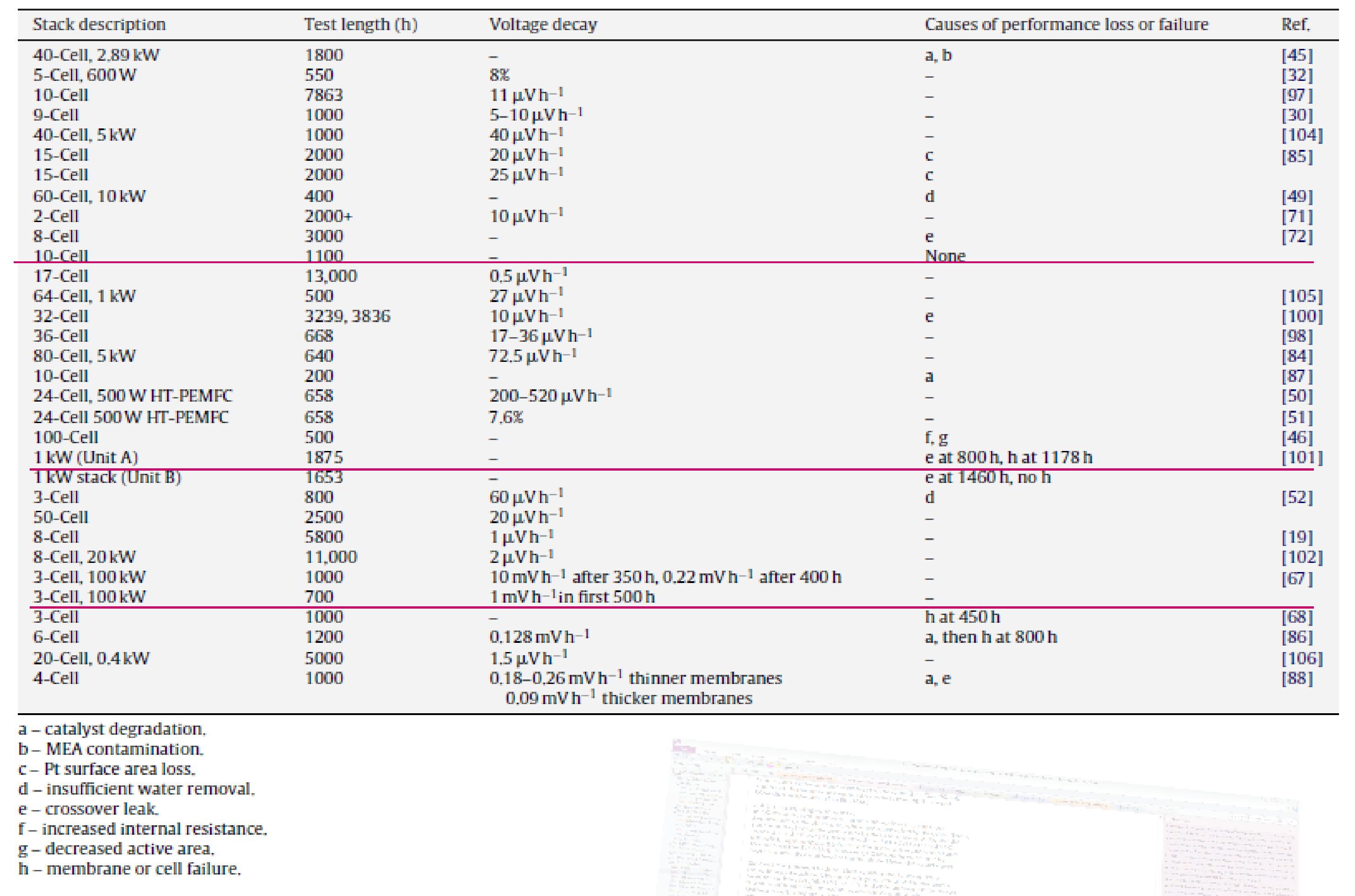
Stack - Degradation Mechanisms



Stack description	Test length (h)	Voltage decay	Causes of performance loss or failure	Ref.
40-Cell, 2.89 kW	1800	–	a, b	[45]
5-Cell, 600 W	550	8%	–	[32]
10-Cell	7863	11 $\mu V\,h^{-1}$	–	[97]
9-Cell	1000	5–10 $\mu V\,h^{-1}$	–	[30]
40-Cell, 5 kW	1000	40 $\mu V\,h^{-1}$	–	[104]
15-Cell	2000	20 $\mu V\,h^{-1}$	c	[85]
15-Cell	2000	25 $\mu V\,h^{-1}$	c	
60-Cell, 10 kW	400	–	d	[49]
2-Cell	2000+	10 $\mu V\,h^{-1}$	–	[71]
8-Cell	3000	–	e	[72]
10-Cell	1100	–	None	
17-Cell	13,000	0.5 $\mu V\,h^{-1}$	–	
64-Cell, 1 kW	500	27 $\mu V\,h^{-1}$	–	[105]
32-Cell	3239, 3836	10 $\mu V\,h^{-1}$	e	[100]
36-Cell	668	17–36 $\mu V\,h^{-1}$	–	[98]
80-Cell, 5 kW	640	72.5 $\mu V\,h^{-1}$	–	[84]
10-Cell	200	–	a	[87]
24-Cell, 500 W HT-PEMFC	658	200–520 $\mu V\,h^{-1}$	–	[50]
24-Cell 500 W HT-PEMFC	658	7.6%	–	[51]
100-Cell	500	–	f, g	[46]
1 kW (Unit A)	1875	–	e at 800 h, h at 1178 h	[101]
1 kW stack (Unit B)	1653	–	e at 1460 h, no h	
3-Cell	800	60 $\mu V\,h^{-1}$	d	[52]
50-Cell	2500	20 $\mu V\,h^{-1}$	–	
8-Cell	5800	1 $\mu V\,h^{-1}$	–	[19]
8-Cell, 20 kW	11,000	2 $\mu V\,h^{-1}$	–	[102]
3-Cell, 100 kW	1000	10 $mV\,h^{-1}$ after 350 h, 0.22 $mV\,h^{-1}$ after 400 h	–	[67]
3-Cell, 100 kW	700	1 $mV\,h^{-1}$ in first 500 h	–	
3-Cell	1000	–	h at 450 h	[68]
6-Cell	1200	0.128 $mV\,h^{-1}$	a, then h at 800 h	[86]
20-Cell, 0.4 kW	5000	1.5 $\mu V\,h^{-1}$	–	[106]
4-Cell	1000	0.18–0.26 $mV\,h^{-1}$ thinner membranes 0.09 $mV\,h^{-1}$ thicker membranes	a, e	[88]

a – catalyst degradation.
b – MEA contamination.
c – Pt surface area loss.
d – insufficient water removal.
e – crossover leak.
f – increased internal resistance.
g – decreased active area.
h – membrane or cell failure.

PEMFC stack Durability [2]

Degradation Mechanisms and Experimentation

- Degradation mechanisms do not scale uniformly
  - Fundamental scale (e.g. Micron and smaller scale effects – Note pm, nm & µm scale models have issues informing each other)
  - E-chem lab scale (e.g. 1cm^{-2} rotating disc electrode)
  - Small Test bench scale (e.g 25cm^{-2} single cell)
  - Large Test bench scale (e.g 25cm^{-2} stack of 5 cells)
  - Stack scale (e.g. ‘real life’ scale for most automotive applications with 200 cells or more)

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Standardising New Test and Characterisation Procedures for PEMFCs in Support of Longer Life and Improved Reliability

Poster(s) Introduction

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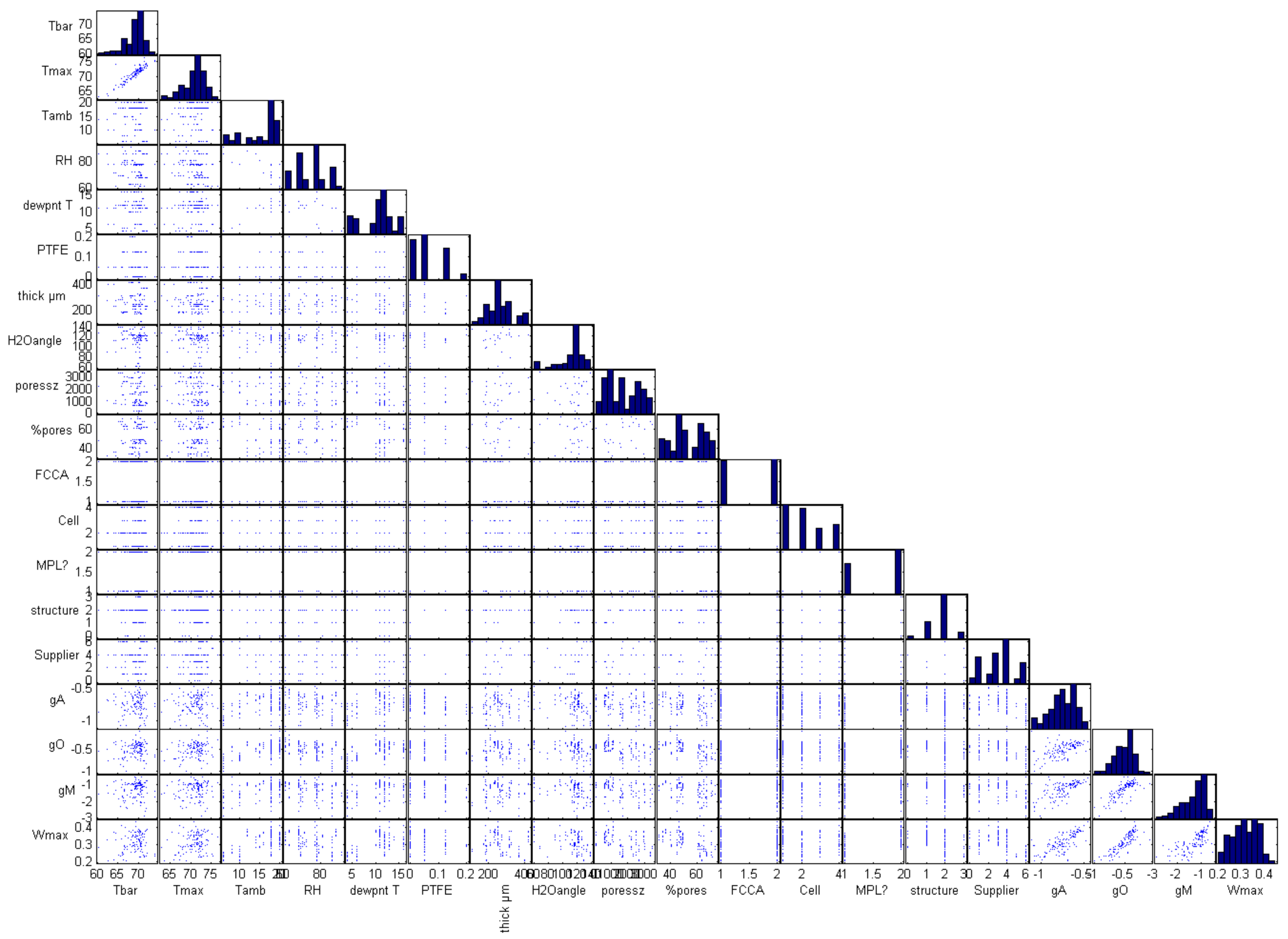
Focus on Cathode GDL - Matrix plot



ANOVAR Model (Wmax.cm^{-2}) from ‘R’®

Coefficients:					
	Estimate	Std. Error	t value	Pr(>|t|)	
(Intercept)	0.4922468	0.0527059	9.339	5.55E-14	***
H_2Oangle	-0.0003779	0.0002174	-1.739	0.08644	.
MPL Mod’	0.0398119	0.0103118	3.861	0.000247	***
PTFE wt%	-0.2254306	0.0731867	-3.08	0.002942	**
RH%	-0.0011252	0.0004949	-2.274	0.026019	*
Structure Mod	-0.0141882	0.0083572	-1.698	0.093942	.
% pores	-0.0014299	0.0003463	-4.129	9.81E-05	***

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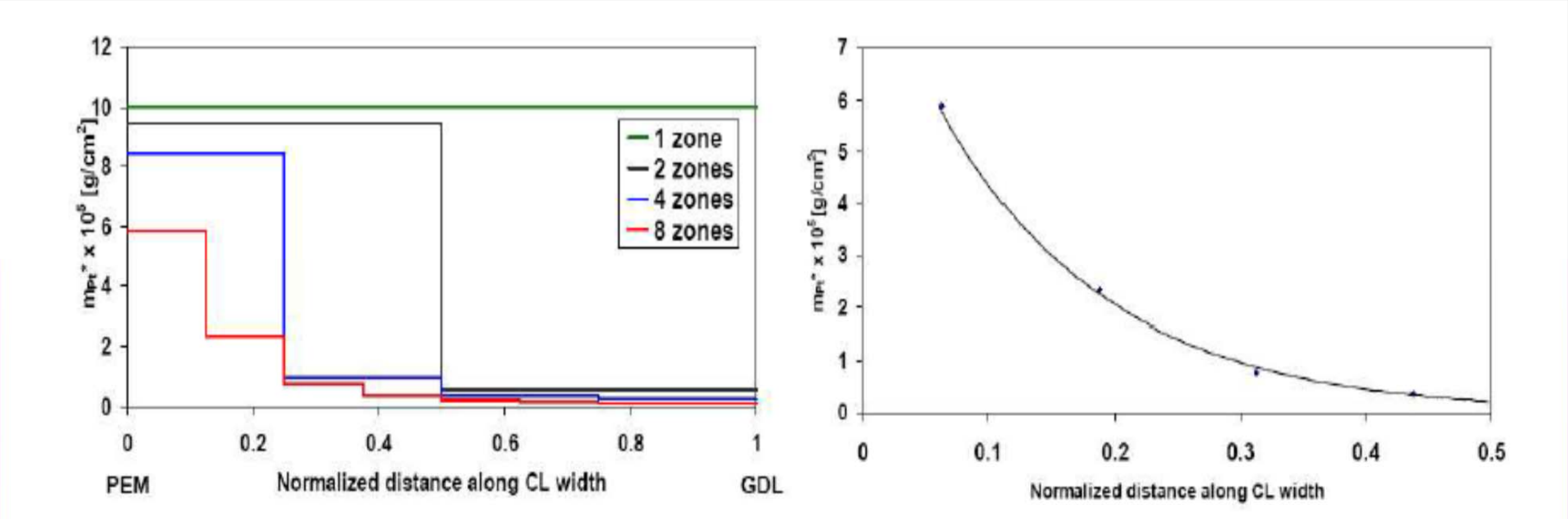
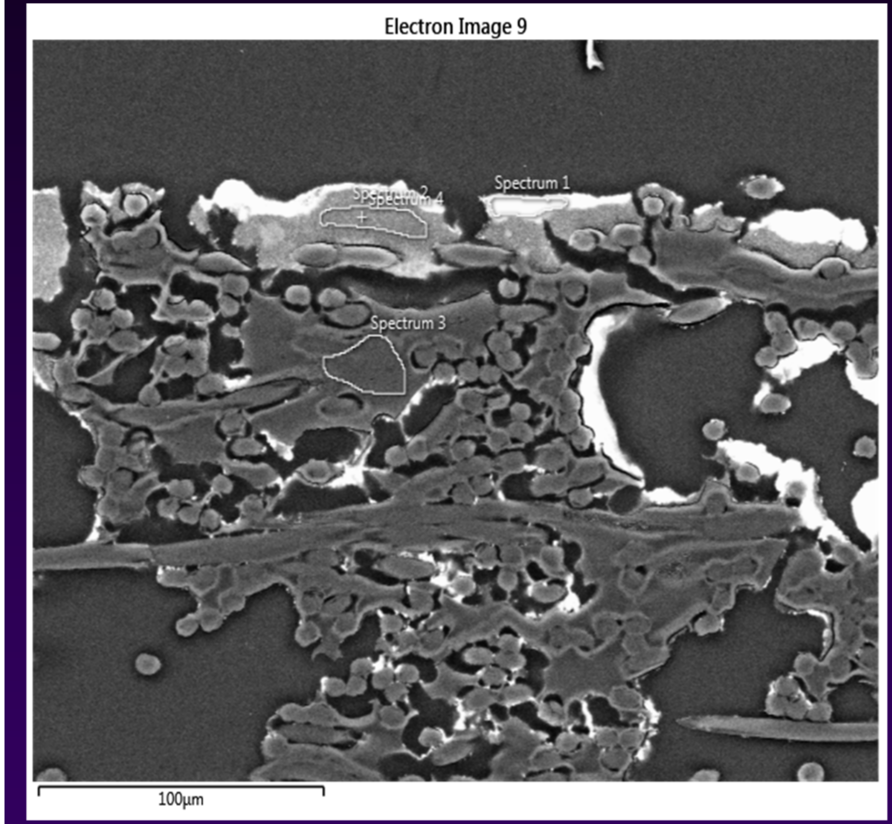
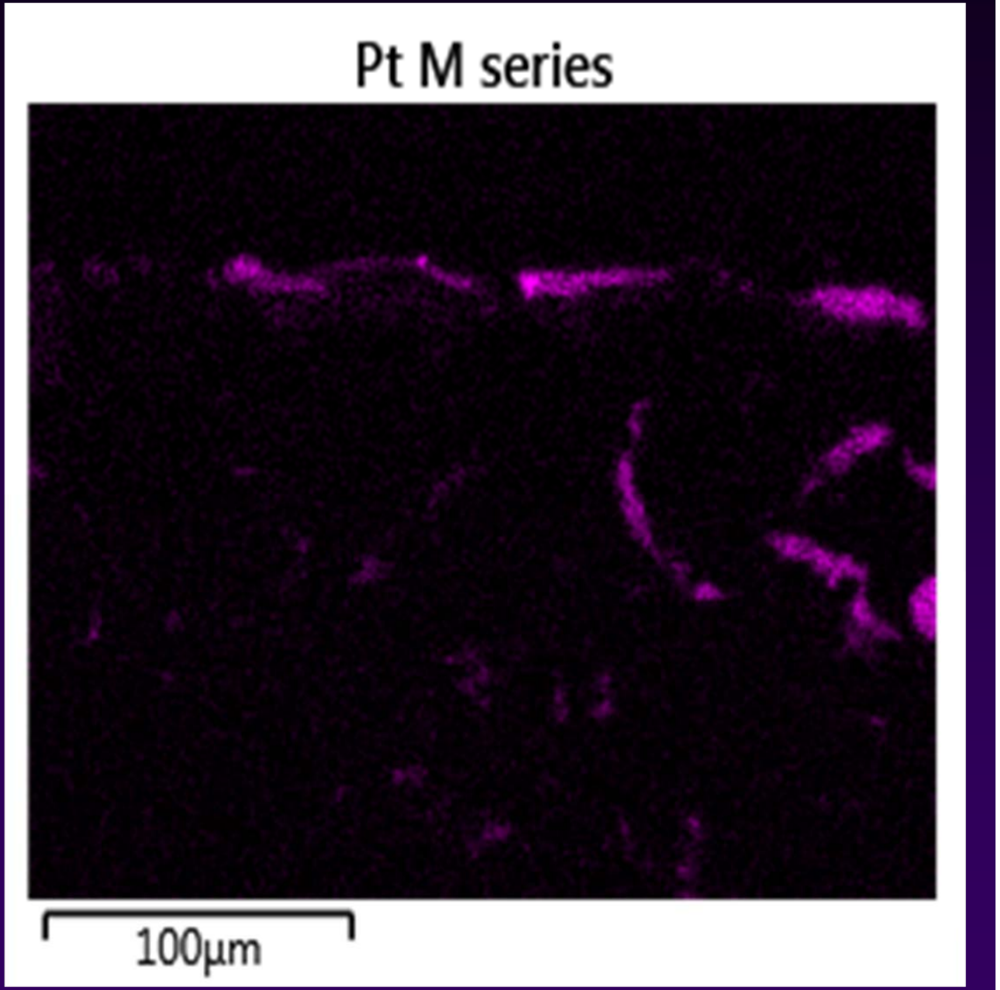
Theoretical Distributed catalyst layers



Jain (2009) , and other authors, have put forward both 2D and 3D catalyst distribution models as a method for optimising the performance of fuel cells and reducing their fabrication costs

Actual Distributed Catalyst Layers





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References

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With thanks to

Ahmad El-kharouf (UoB), Ash Fly (LU) &
Billy Wu (ICL)

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Thank you for listening

QUESTIONS?

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