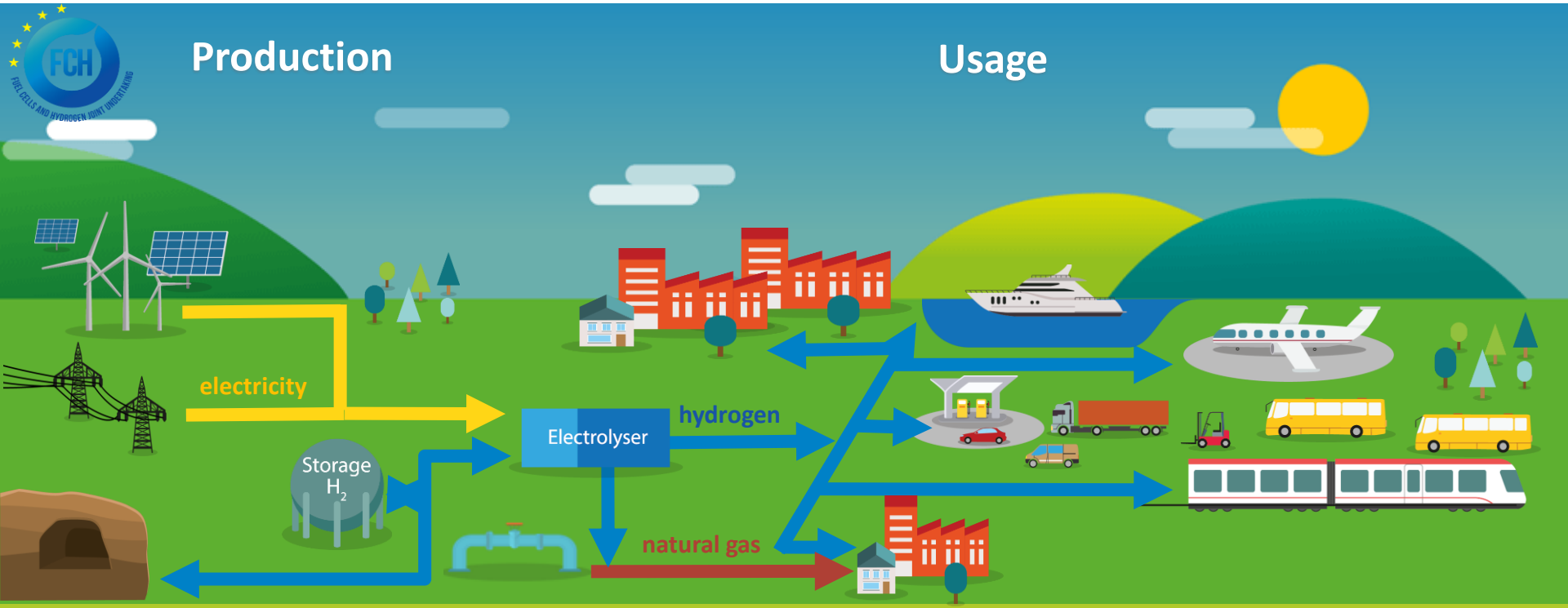
Research on Polymer Electrolyte Fuel Cells (PEFC)

Rakel Wreland Lindström

Kemiteknik, KTH

Energiforsks bränslecellskonferens 2019-05-07



Ongoing research projects on PEFC at KTH

FFI: 2018-2021 Durable polymer membrane fuel cells for vehicles - Lifetime studies on components, cells and stacks

KTH, Lund University, Chalmers, Sandvik, Cell Impact, Scania, MyFC, PowerCell, Intertek, Vätgas Sverige

FFI: 2019-2021 BränslecellsElSopbil för Test i verklig drift

Renova, Powercell, JOAB, Scania, KTH

EM: 2018-2022 A**lkaline polymer electrolyte fuel cells**

LU, KTH

EM: 2016-2019 Noble metal-free polymer electrolyte fuel cells

KTH

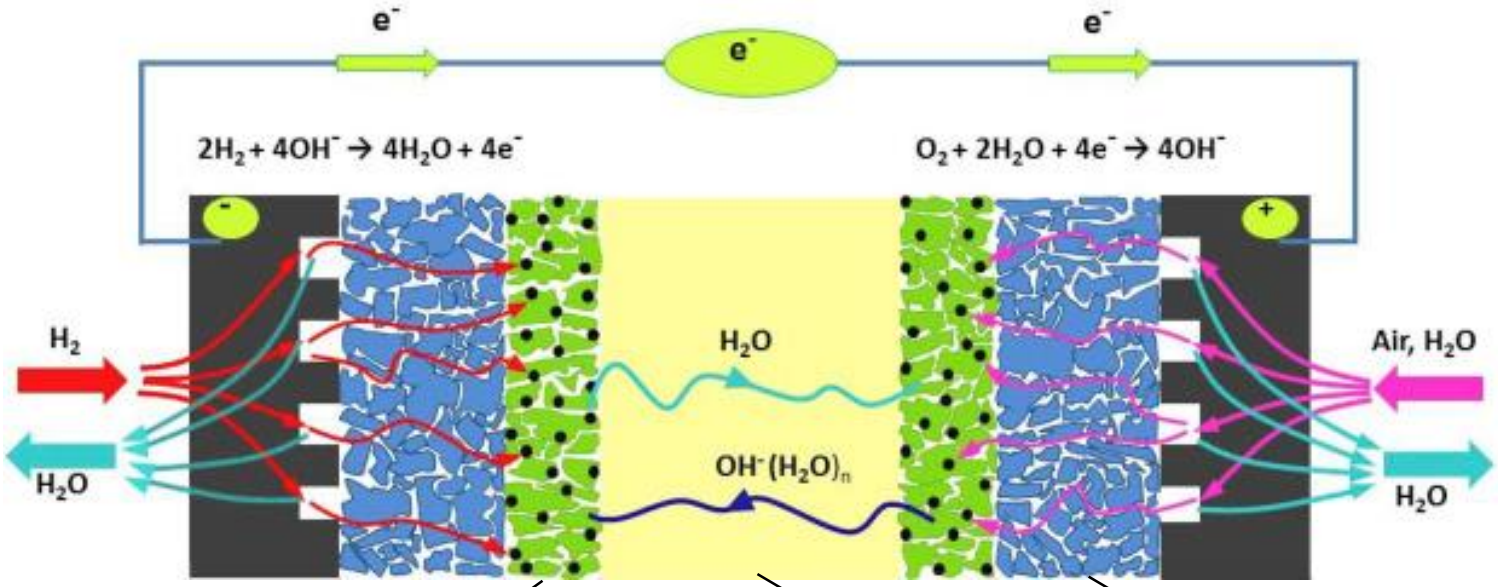
SSF: 2018-2022 Materials enabling efficient and cost effective fuel cells

KTH, Lund University, Chalmers

SSF: 2018-2022 In situ-analysis of Big Data for flow and climate simulations using submarine autonomic vehilces 2018-2022

Swedish Maritime Robotics Center: KTH, FOI, SAAB, MMT, Stockholm and Göteborg Universities

Polymer electrolyte fuel cell



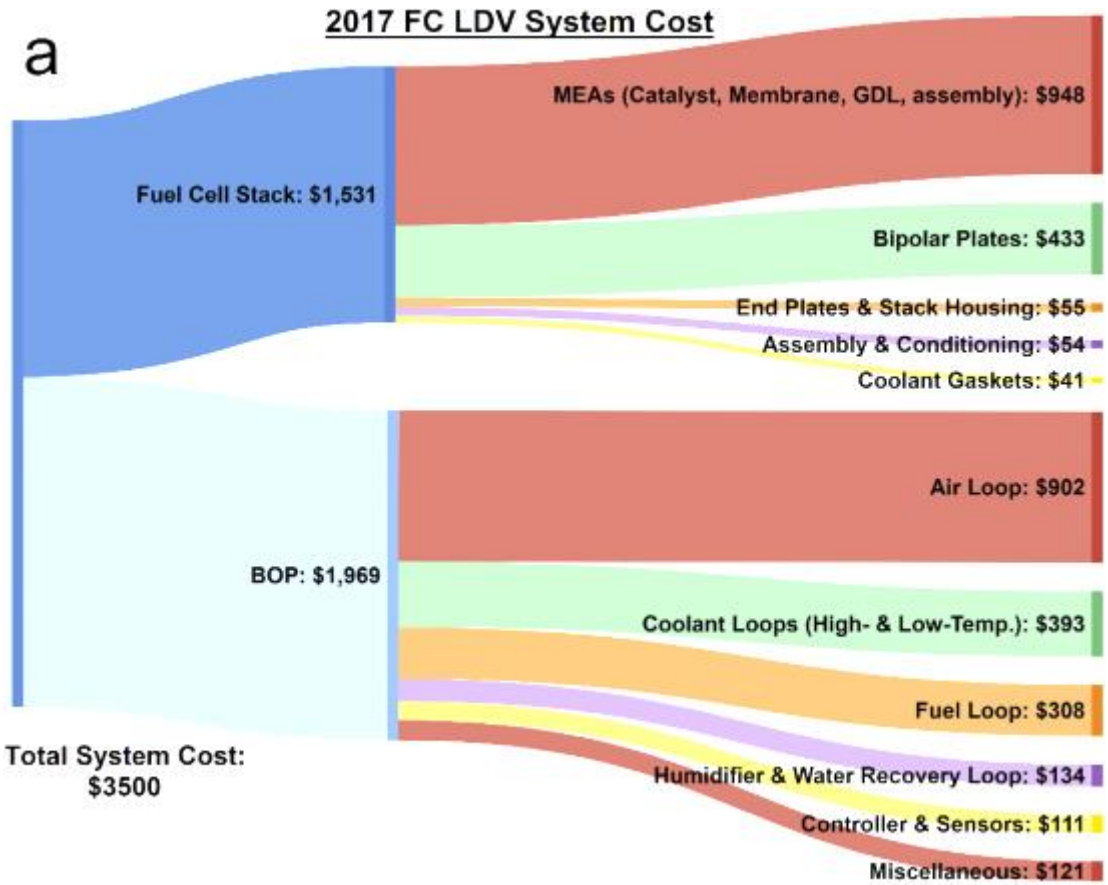
Bipolar Plates (BPP)

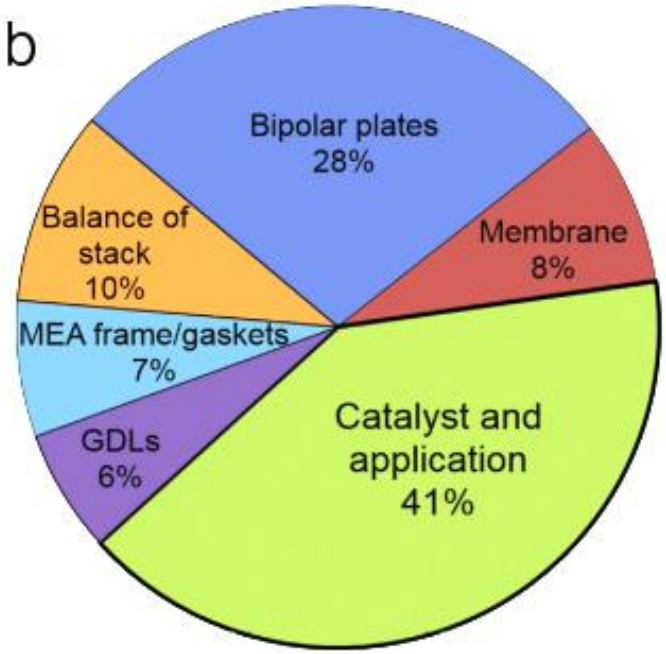
Porous Electrodes Catalyst layer (CL)

Membrane (PEM / AEM)

Gas diffusion layer (GDL)

Cost for PEMFC stack and system





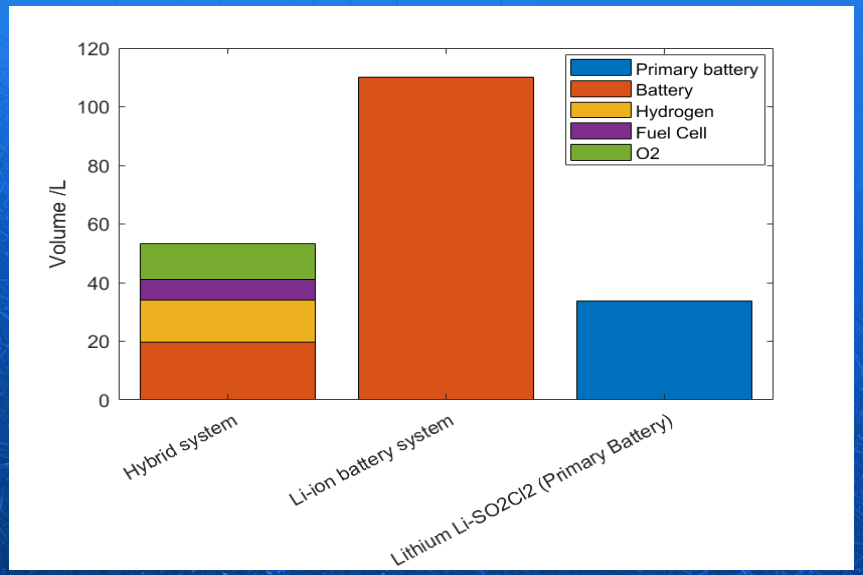
S. T. Thompson, B. D. James, J. M. Huya-Kouadio, C. Houchins, D. A. DeSantis, R. Ahluwalia, A. R. Wilson, G. Kleen, D. Papageorgopoulos (2018) "Direct hydrogen fuel cell electric vehicle cost analysis: System and high-volume manufacturing description, validation, and outlook," *Journal of Power Sources*, (2017) 399, 304-313

SMaRC
SWEDISH MARITIME ROBOTICS CENTRE

Autonomic Underwater Vehicles

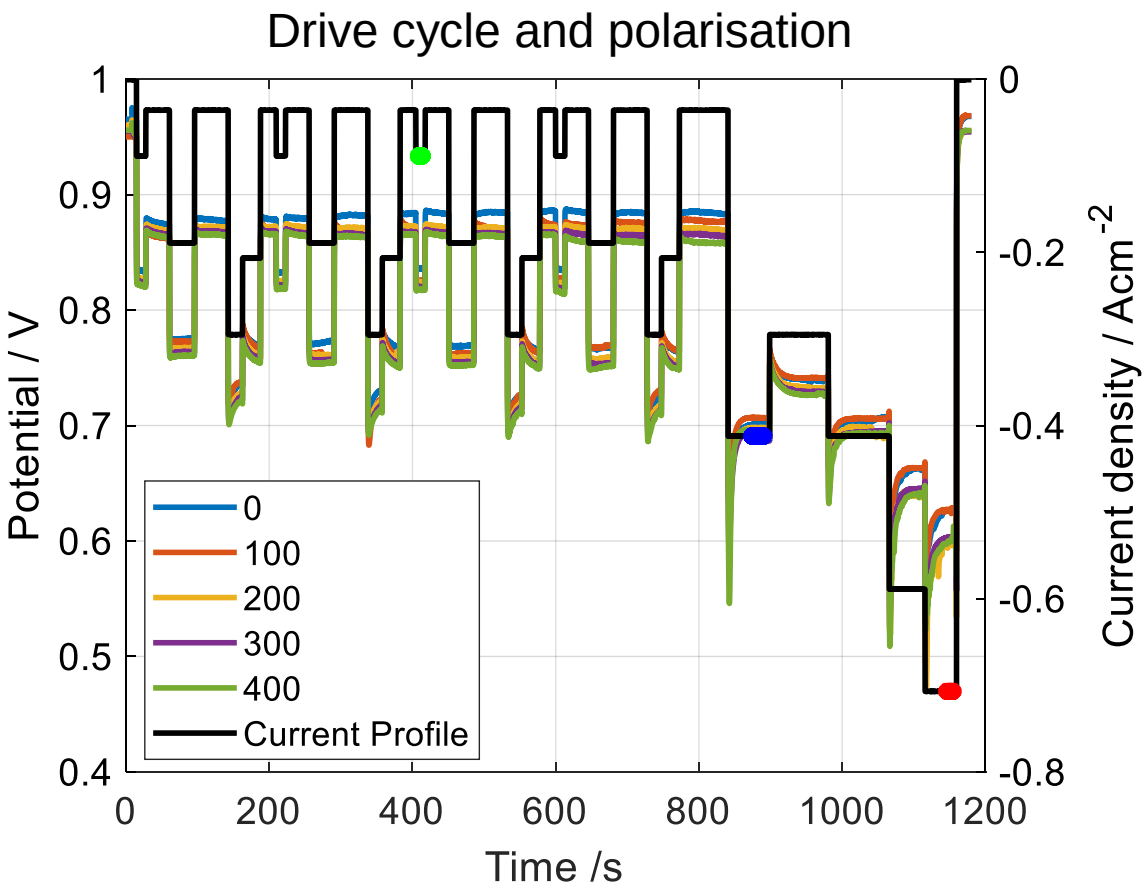
- Ocean agriculture
- Environmental monitoring
- Safeguarding society

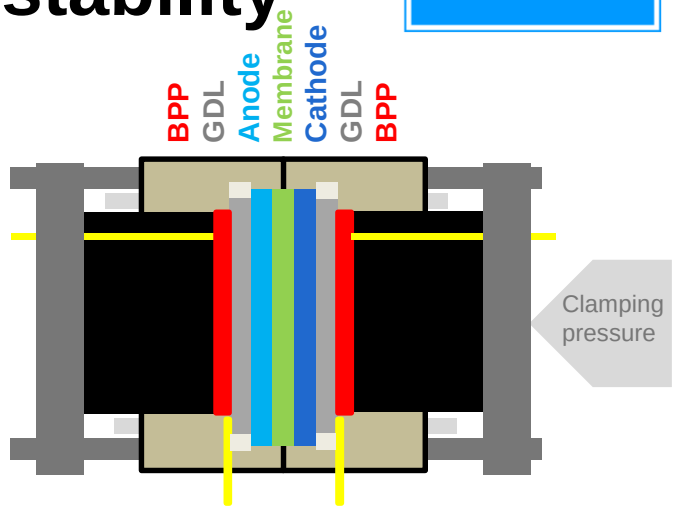
Based on FC-electric hybrid system for long-term presence (> 1000 km or 30 days)

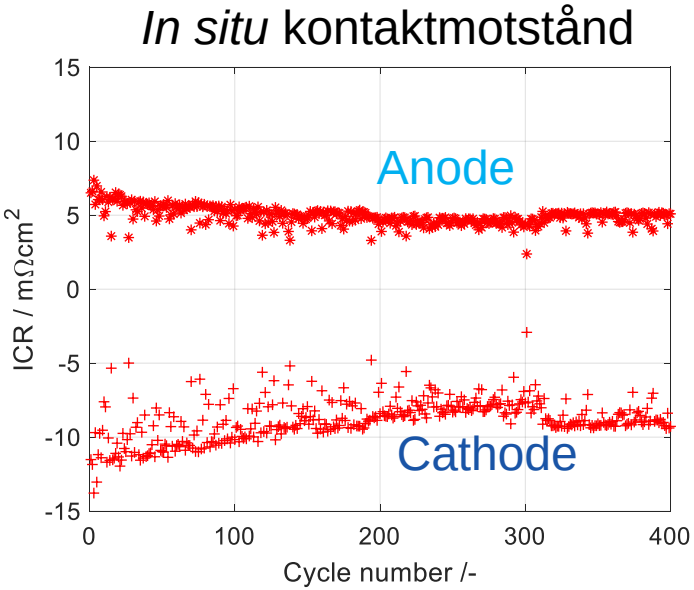


KTH
Stockholm University
UNIVERSITY OF GOTHENBURG
FMV
FOI
SAAB
MMT

Effect of BPP on the MEA stability



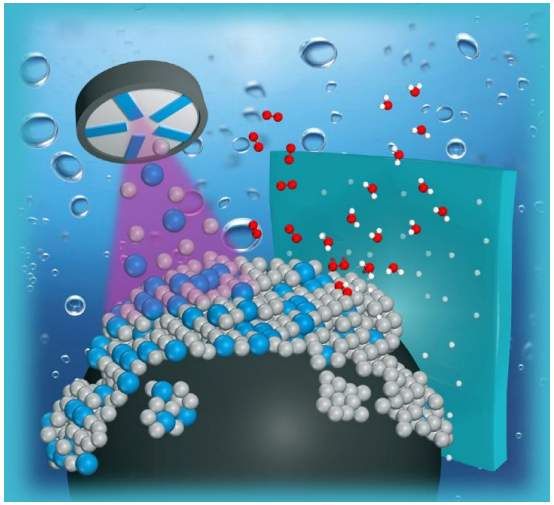




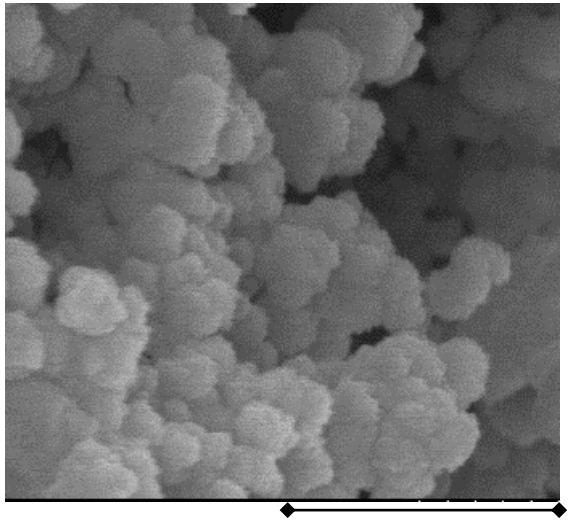
Model Pt-REM catalysts for PEMFC

Thin film electrodes sputtered on the gas diffusion layer (GDL)
- Make possible the measure of activity direct in a fuel cell

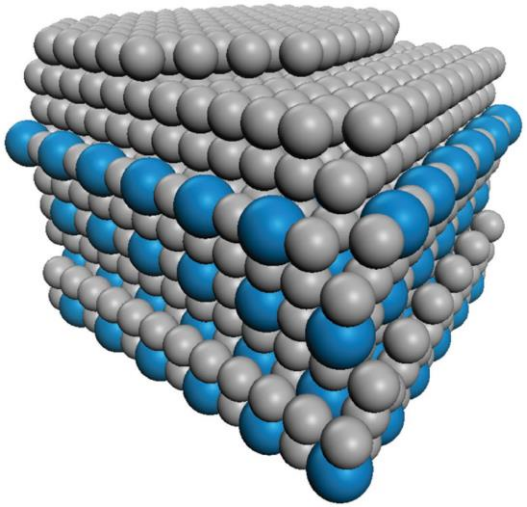
Sputter deposition



Gas diffusion layer



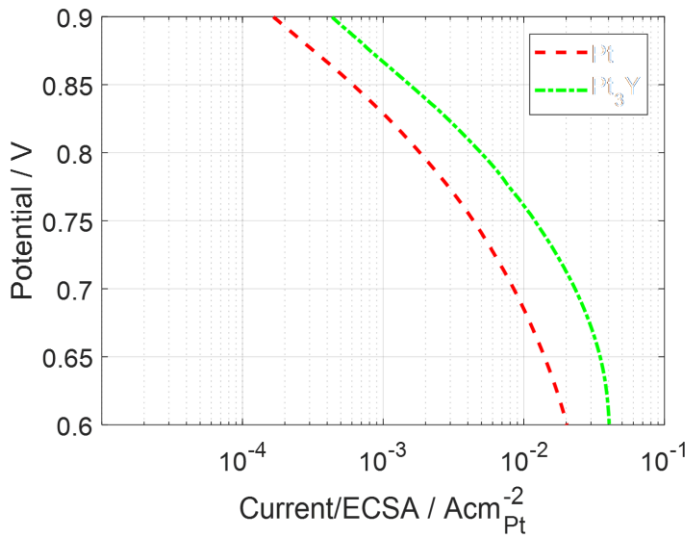
Core shell structure

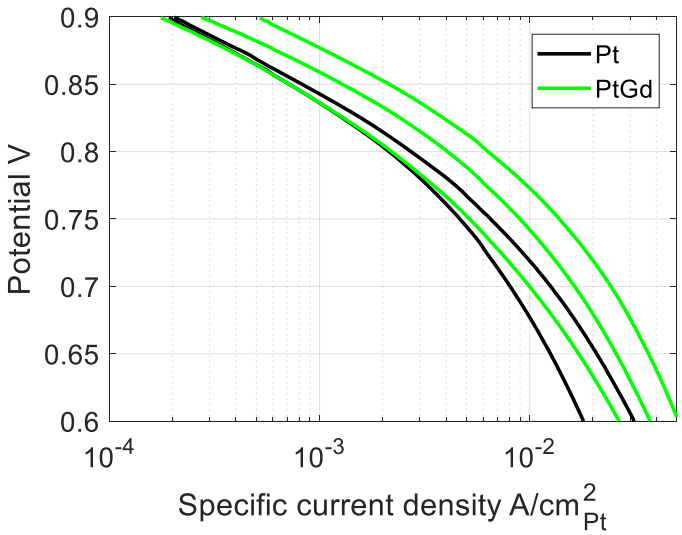


N. Lindahl, E. Zamburlini, L.G. Feng, H. Grönbeck, M. Escudero-Escribano, I.E.L. Stephens, I. Chorkendorff, C. Langhammer, and B. Wickman, *Advanced Materials Interfaces*, 2017, 4(13), 1700311.

Model Pt-REM catalysts for PEMFC

Promising results with Pt-REM core shell alloys in PEMFC

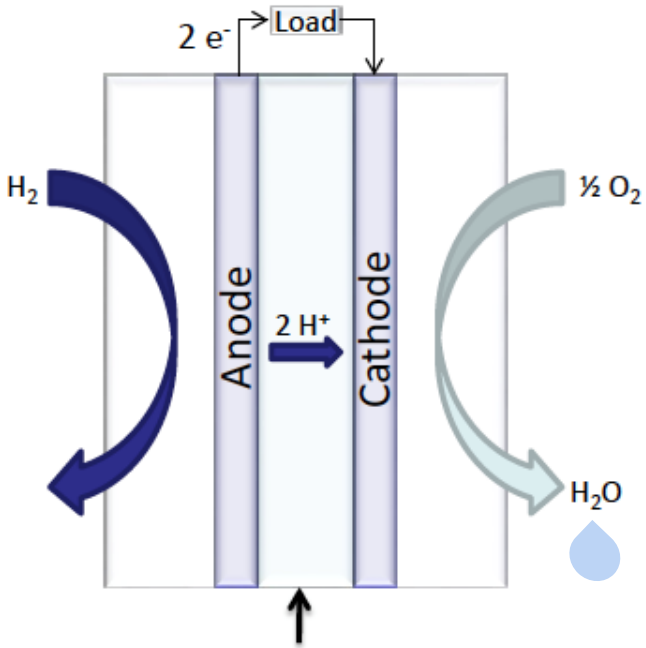




N. Lindahl, B. Eriksson, H. Grönbeck, R. Wreland Lindström, G. Lindbergh, C. Lagergren, and B. Wickman, *ChemSusChem*, 2018, 11, 1438

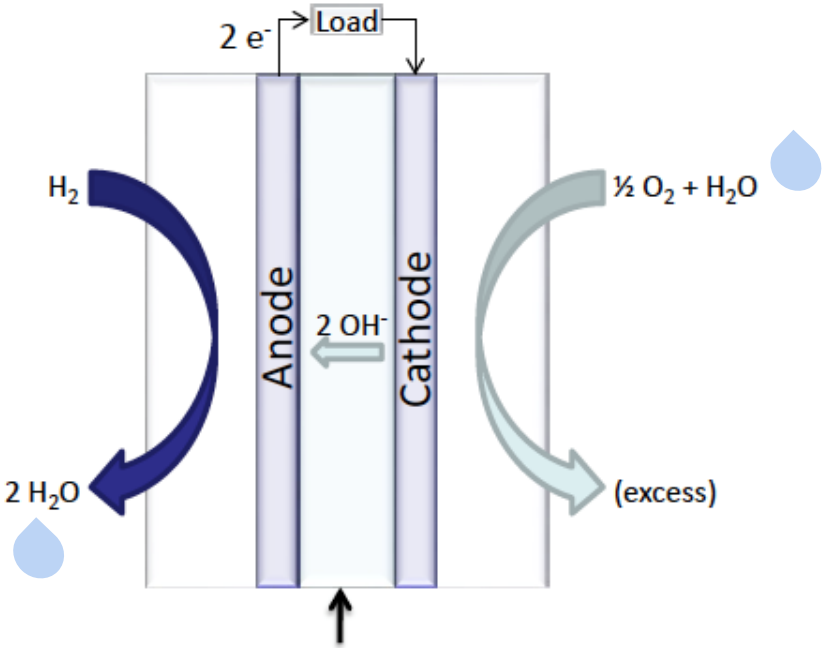
Cation or Anion Exchange Membrane?

PEMFC (acidic)



Proton-Exchange Membrane (PEM)

AEMFC (alkaline)



Anion-Exchange Membrane (AEM)

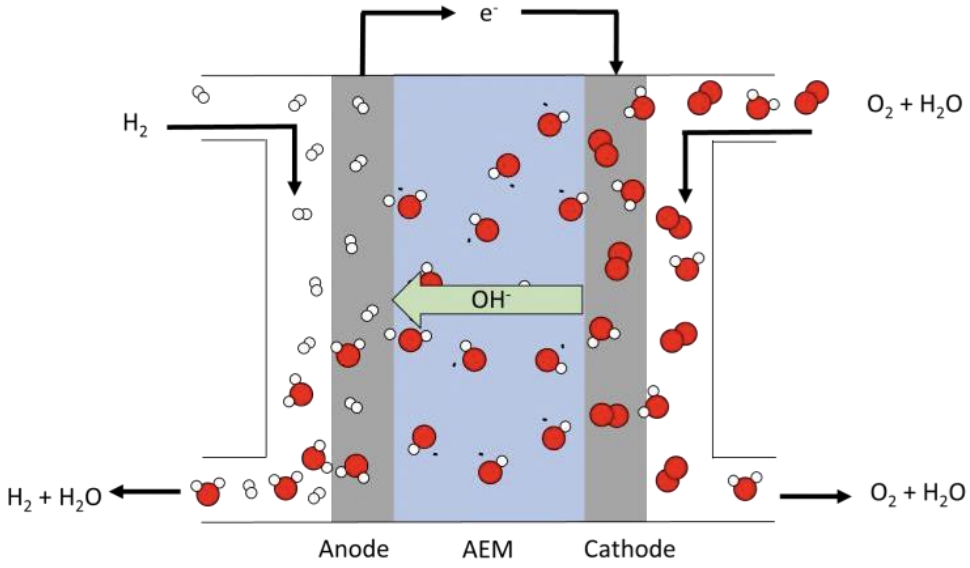
Anode: $H_2 \rightarrow 2\,H^+ + 2e^-$

Cathode: $\frac{1}{2}\,O_2 + 2H^+ + 2e^- \rightarrow H_2O$

$H_2 + 2\,OH^- \rightarrow 2H_2O + 2e^-$

$\frac{1}{2}\,O_2 + H_2O + 2e^- \rightarrow + 2\,OH^-$

Anion exchange membrane fuel cells, AEMFC



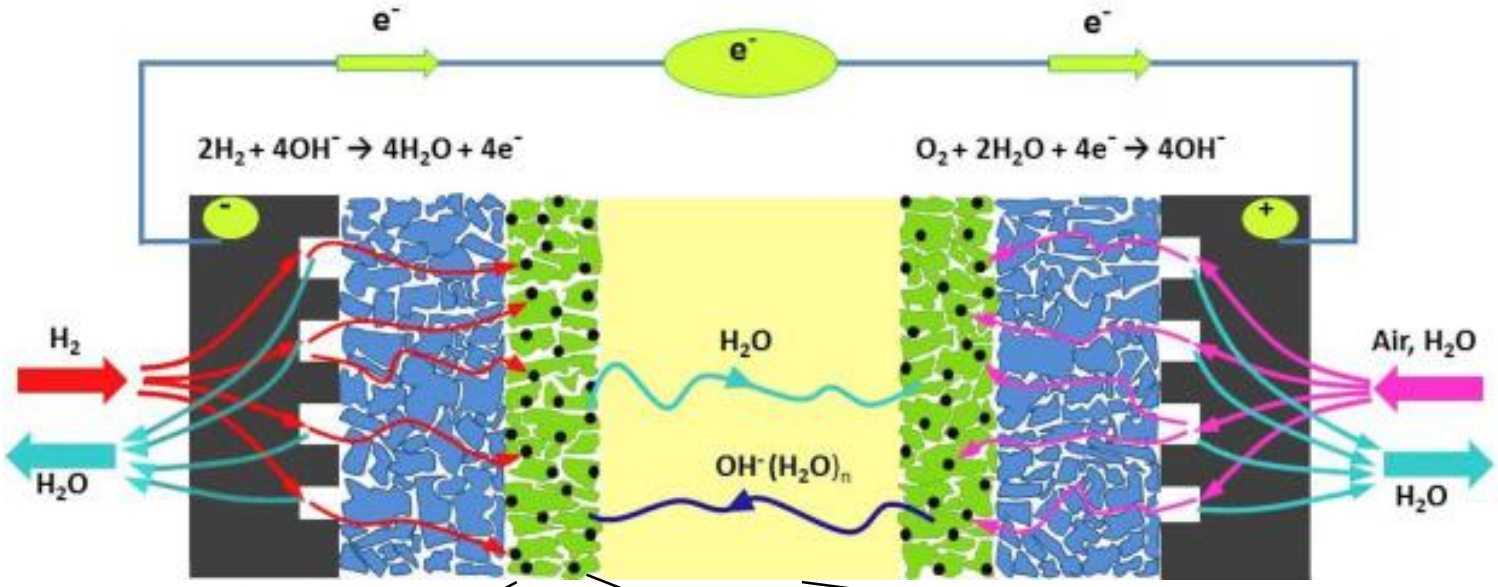
Possible benefits:

- Better kinetics for the cathode reaction
- Non-precious metals possible (Ag, Ni, Fe-N-C)
- New types of membranes possible
- Less corrosive environment
- Potentially lower costs for material and cells

Challenges:

- Limited ion-conductivity
- Poor durability
- Catalyst activity?
- Water management?

Research focus in the projects



Metallic Bipolar plates

Porous electrodes

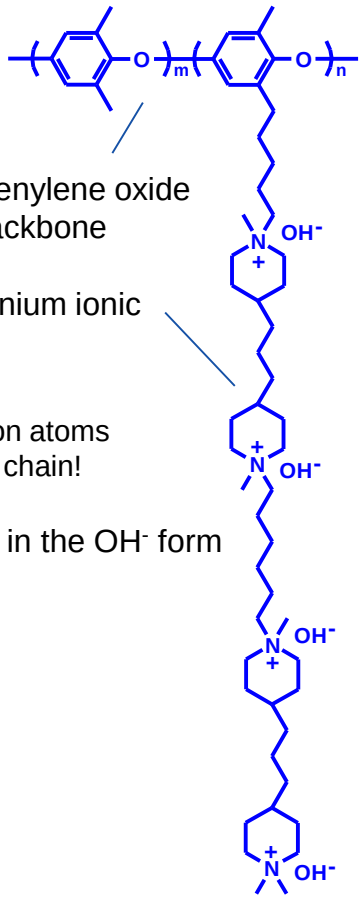
Catalysts

Ionomer/ Membranes

- Synthesis and material characterisation
- Electrode and cell composition
  Electrochemical characterisation in cell
- Mathematical modelling

Synthesis of ionomers and membranes

PPO5-4QPip-*x*

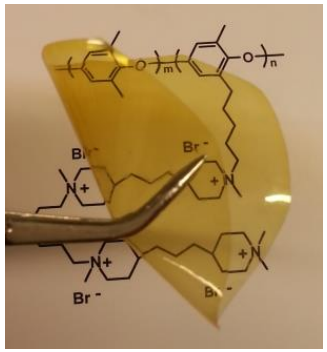


poly phenylene oxide PPO backbone

Piperidinium ionic groups

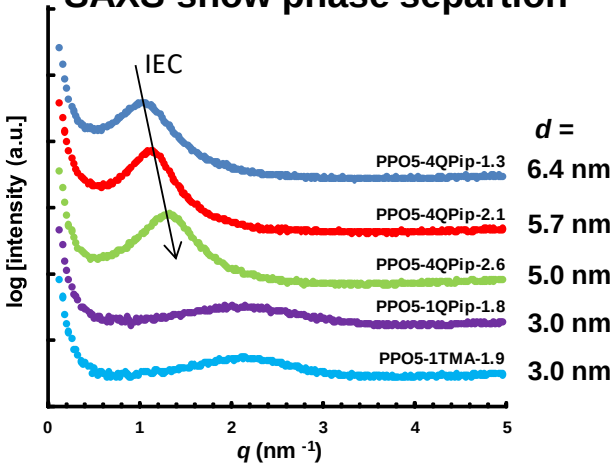
42 carbon atoms per side chain!

x = IEC in the OH^- form

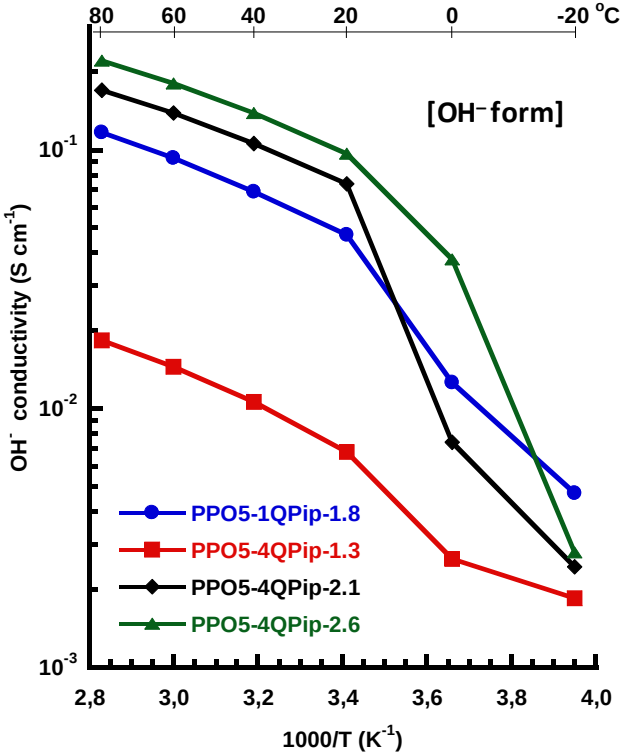


- AEMs cast from NMP
- Solubility in MeOH
- Foldable, creasable

SAXS show phase separtion



High OH-conductivity in solution

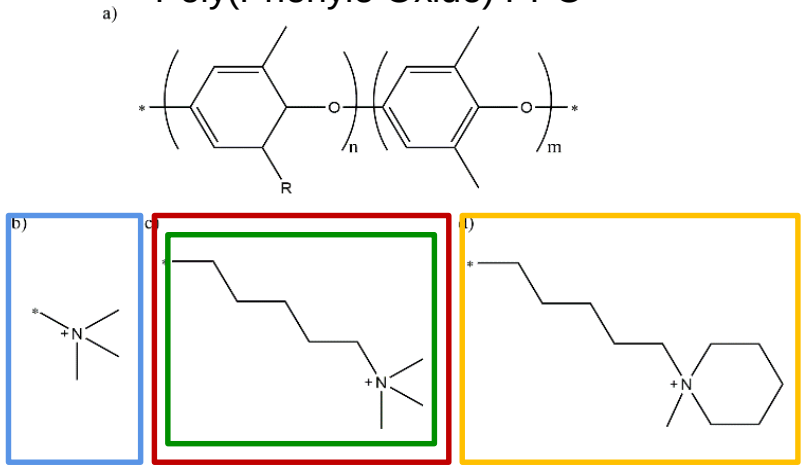


Very high conductivity – exceeding 220 mS cm^{-1} at 80 °C

H.-S. Dang; P. Jannasch, *ACS Appl. Energy Mater.*, **2018**, *1*, 2222-2231.

Comparison between different membranes

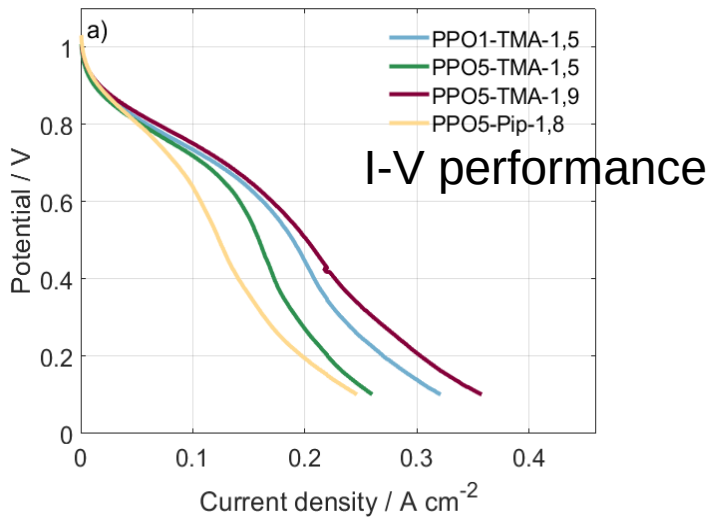
Poly(Phenyle Oxide) PPO

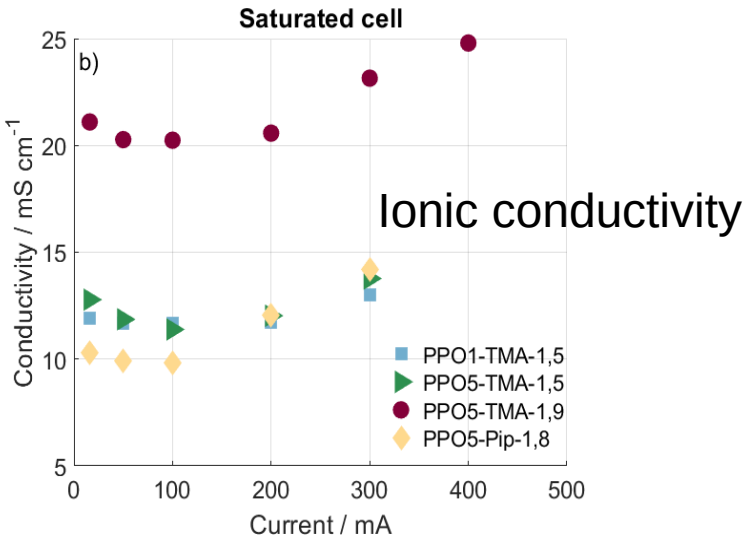


1-TMA 5-TMA 5-Pip

Important properties?

- Ionic conductivity
- Water and gas permeability
- Mechanical and chemical stability
- Water uptake and swelling
- Interaction with catalyst
- Thickness

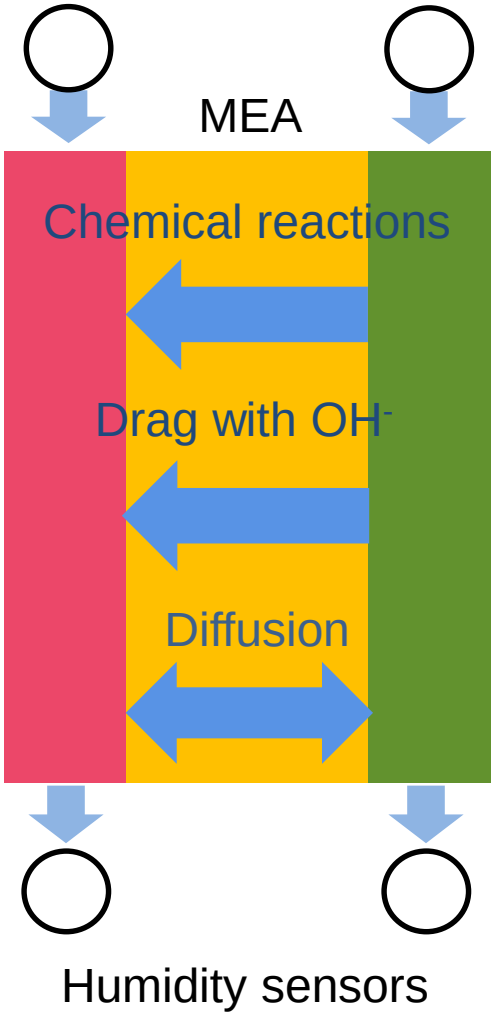




Causes for water transport in AEMFC

Anode reaction:

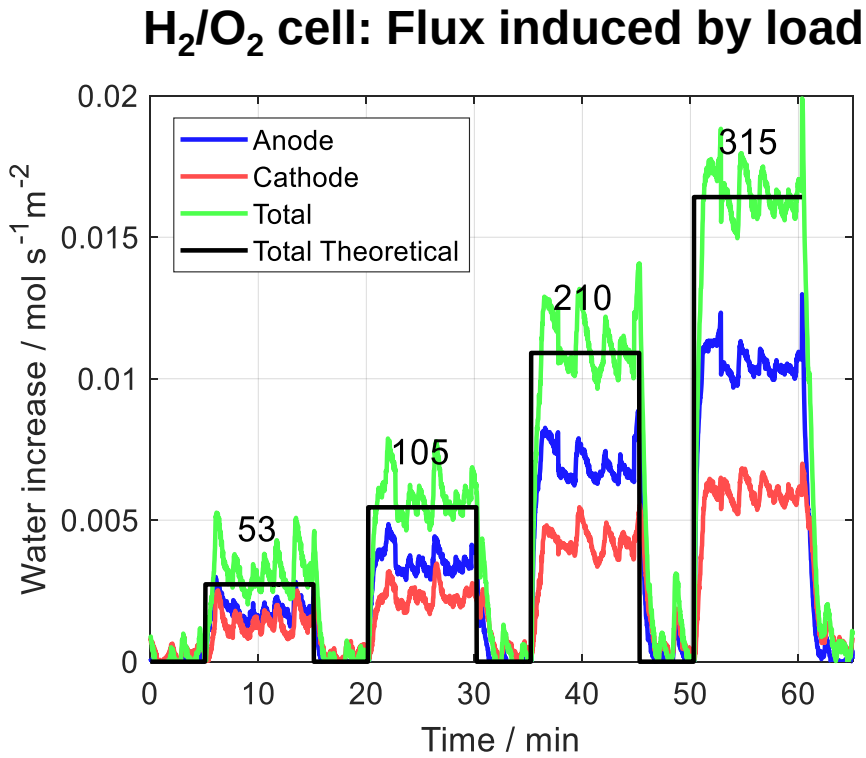
$2H_2 + 4OH^- \rightarrow 4H_2O + 4e^-$

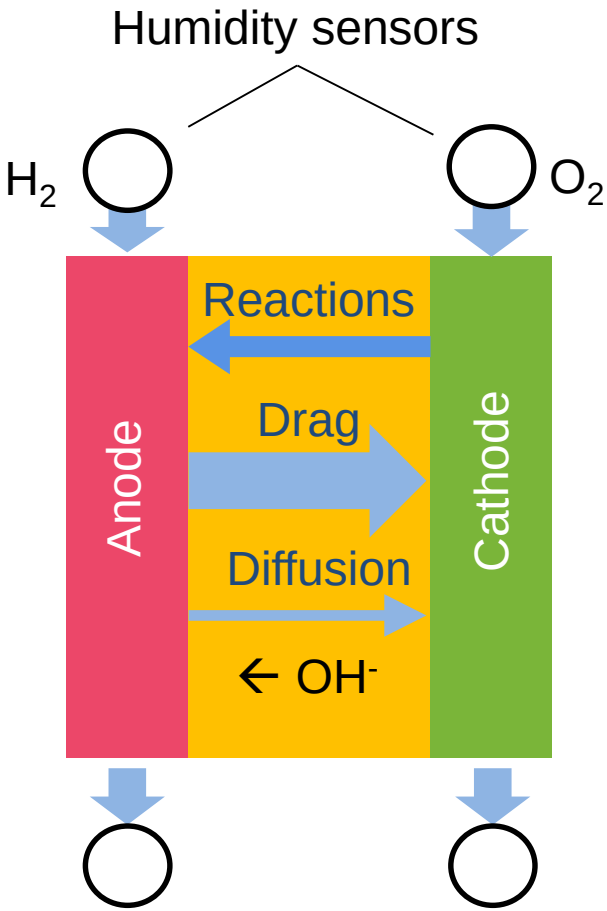


Cathode reaction:

$O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$

Water distribution when a current is drawn

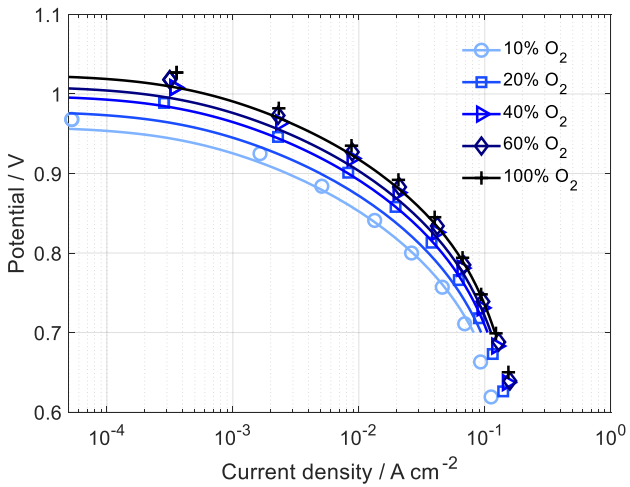


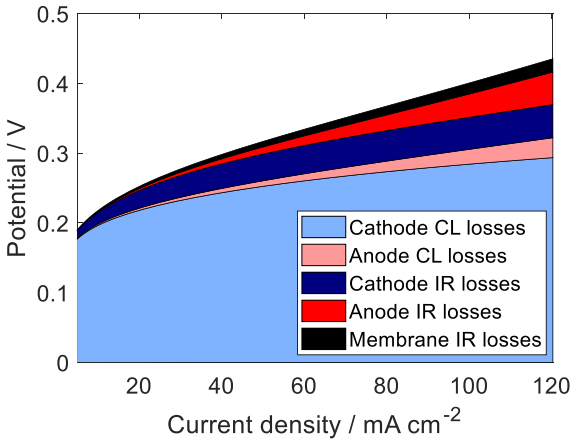


Water is transfered in opposite direction to the hydroxide ions.
About 2/3 of the produced water is transfered from the anode to the cathode.

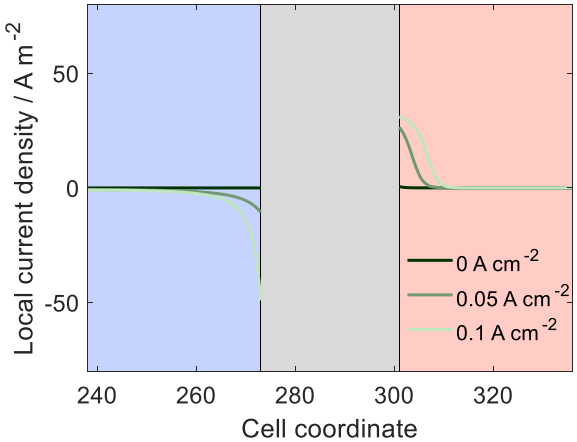
Quantifying water transport in anion exchange membrane fuel cells, B. Eriksson, H. Grimler, A. Carlson, H. Ekström, R. Wreland Lindström, G. Lindbergh, C. Lagergren, *Int. J. Hydrognen Energy 2019*

Physics-based modelling to evaluate data





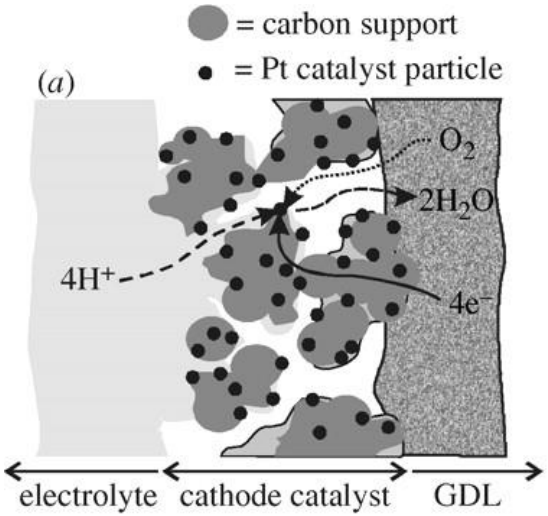
Porous electrode model to identify limiting processes in the cell



Cathode Membrane Anode

Making well-functioning porous electrodes

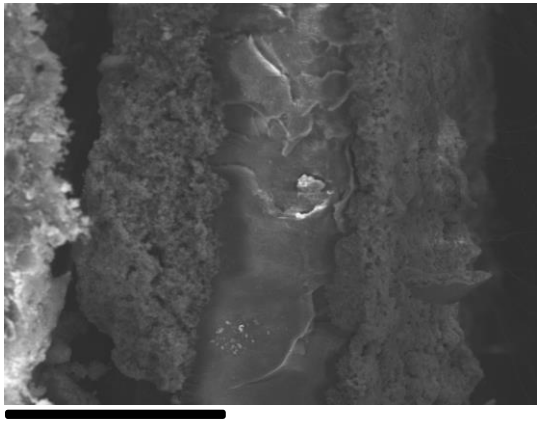
Composition



Optimized properties:

- porosity,
- catalyst usability
- Ionic conductivity,
- Electrical conductivity

Applying method

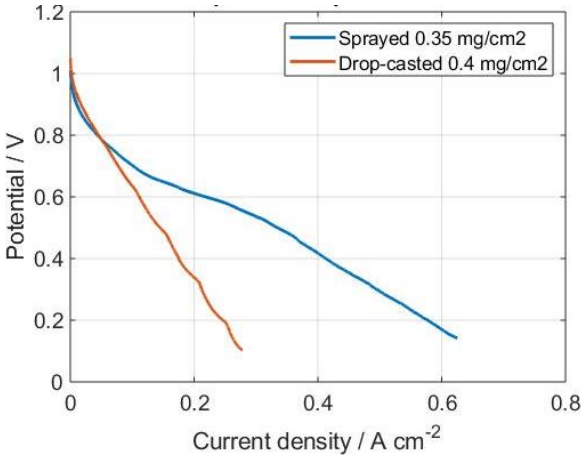


50 µm

Ink application on GDL or membrane:

- Spraying
- Drop-casting
- Brush painting

Performance



I-V curve for

- 60°C, 95% RH
- 75% Pt/C (37%) catalyst
- 25% FumaTech FAA-3 ionomer/membrane
- Solvents: butyl-acetate

Conclusions

For PEMFC:

- Effect of metallic BPP
- More active catalysts with less Pt content

For AEMFC:

- Find stable membranes/ionomers
- Understand how AEMs function
- Prepare well-performing porous electrodes
- Find suitable catalysts for the anode and cathode reaction

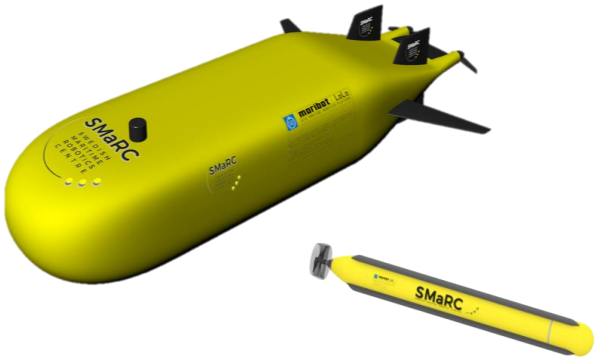
For system:

- Find optimal energy system

Thanks for the attention!

Endurance – one important capability

Endurance to map and monitor a glacier front (extending 20km) in one sweep as fast as possible (preferably at speeds > 5kn) without re-charging.



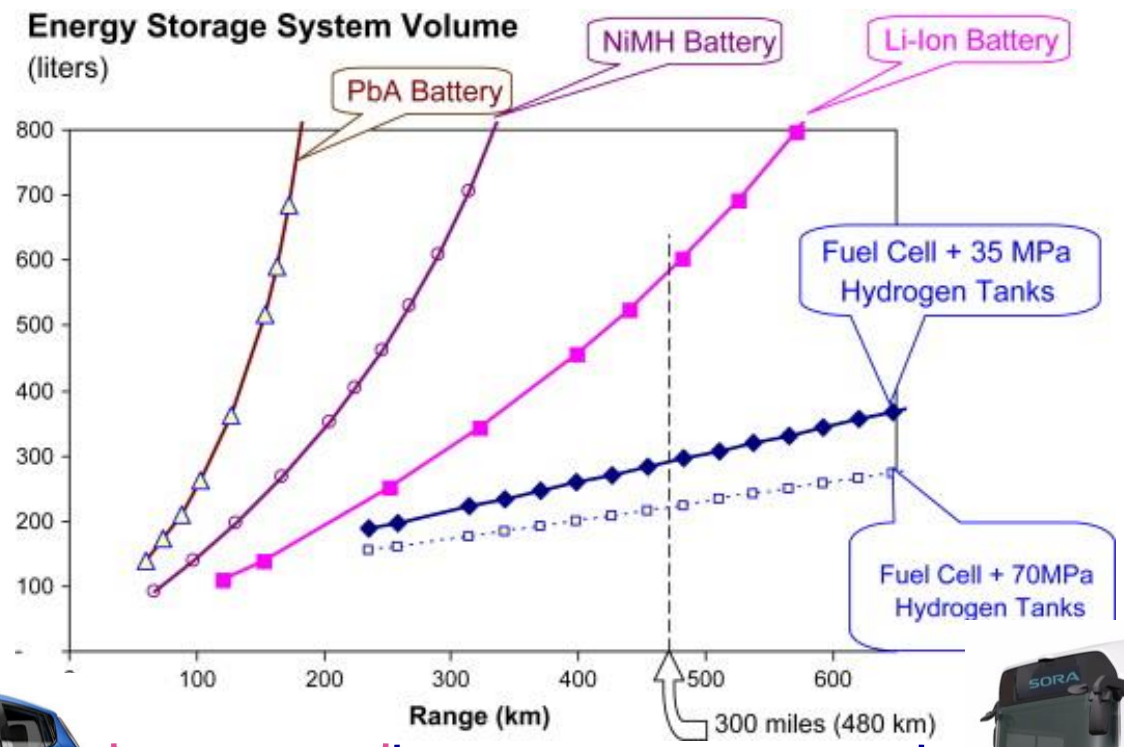
Ability to perform long-term continuous operations in a predefined area (perform multiple missions: dock, transfer data, recharge and repeat mission)

Increased range of AUV to > 1000 km or 30 days @ optimal speed and >400km @ 5kn

<u>SMaRC demonstrator platforms</u>

- Long range large AUV (LoLo) (3.8x1.05x0.6 m)
- Small & affordable AUVs (SAM) (l=1.3 m, d=0.126 m)

Which system to chose?



Shorter range
Light vehicles

Longer range
Commercial vehicles

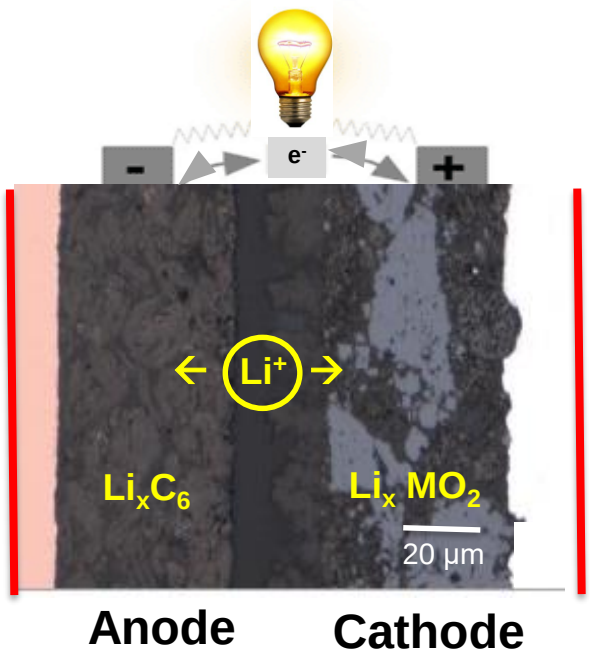
International journal of hydrogen energy 34 (2009) 6005–6020

Demostrationsprojekt med Scania

REGIONAL DISTRIBUTION	REFUSE COLLECTOR	
		
4 trucks to ASKO Trondheim	1 truck to Renova Gothenburg	GVW 27 ton Wheel configuration 6x2*4 Wheelbase 3950/5500 mm
33 kg H_2 @350 bar	23 kg H_2 @350 bar	Battery capacity 56 kWh installed energy 3 Li-ion NMC packs
400-500 km range	200-300 km range	
90 kW FC from Hydrogenics	100 kW FC from Powercell	eMachine 210 kW cont. power 290 kW peak power 2100 Nm peak torque
15 kW AC E-PTO	60 kW DC E-PTO	Charging CCS interface 22 kW AC

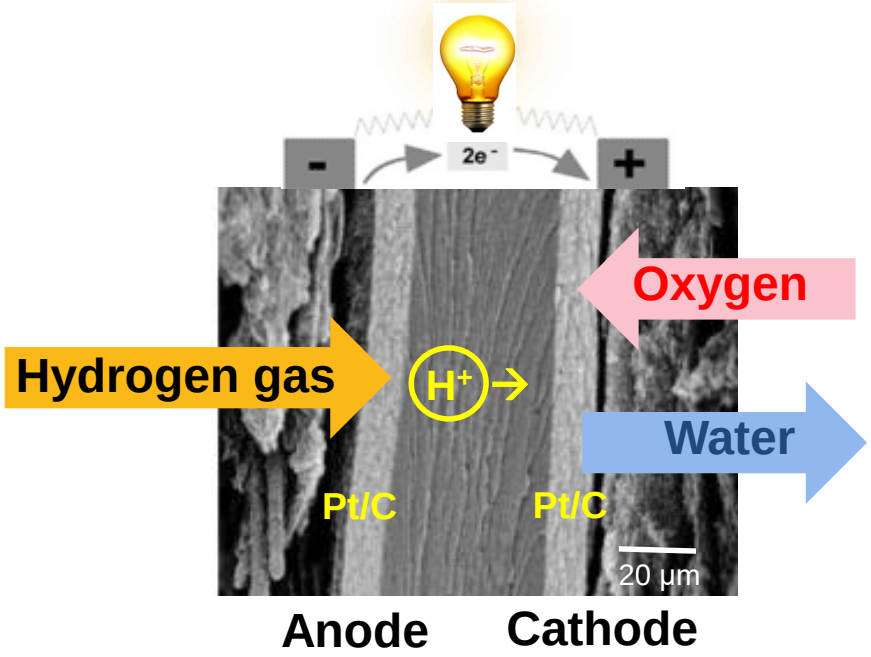
Vad är en bränslecell?

Litiumjon-batteri



Converts energy stored in the solid material

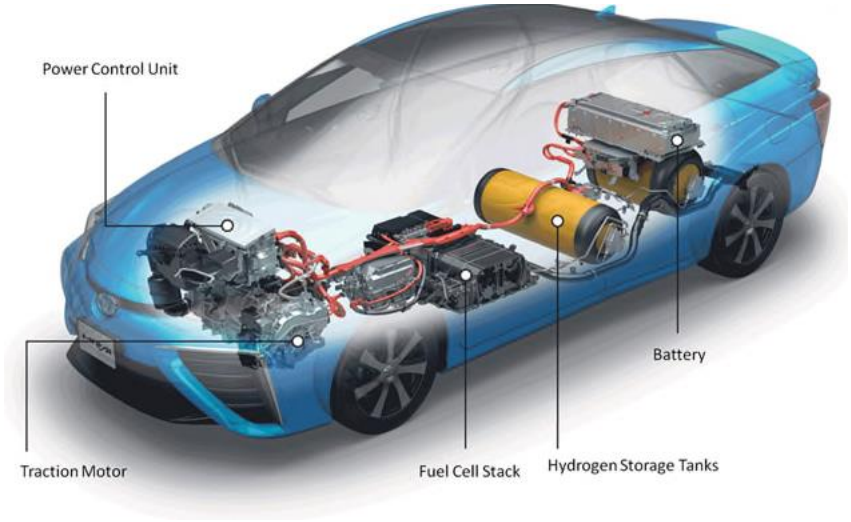
Polymer bränslecell



Converts energy in a supplied fuel

Skillnad i design, vikt och volym

Fuel Cell Electric Vehicle (FCEV)



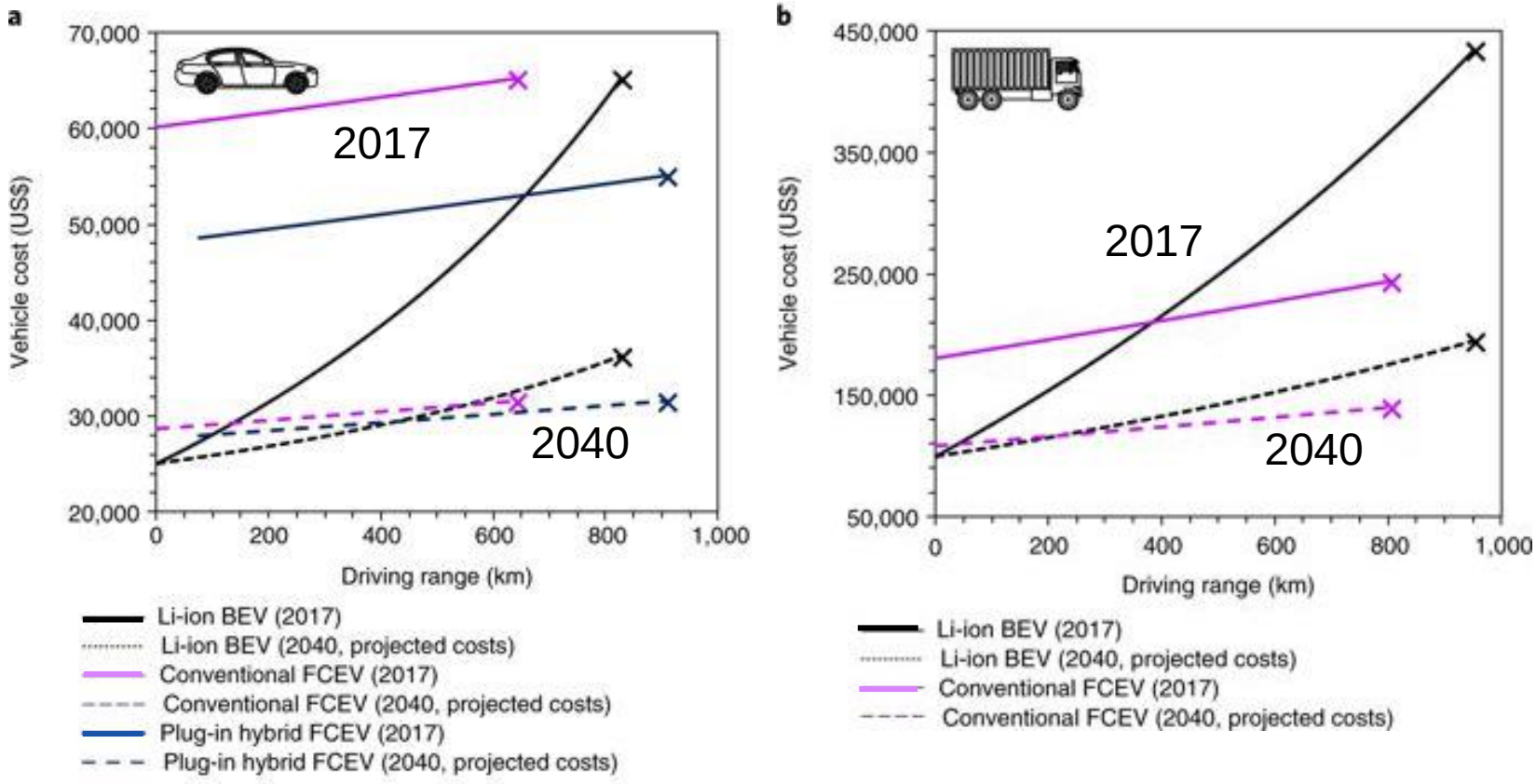
Longer range → larger tanks or higher pressure

Battery Electric Vehicle (BEV)

Longer range → larger battery

Kostnadsjämförelse:

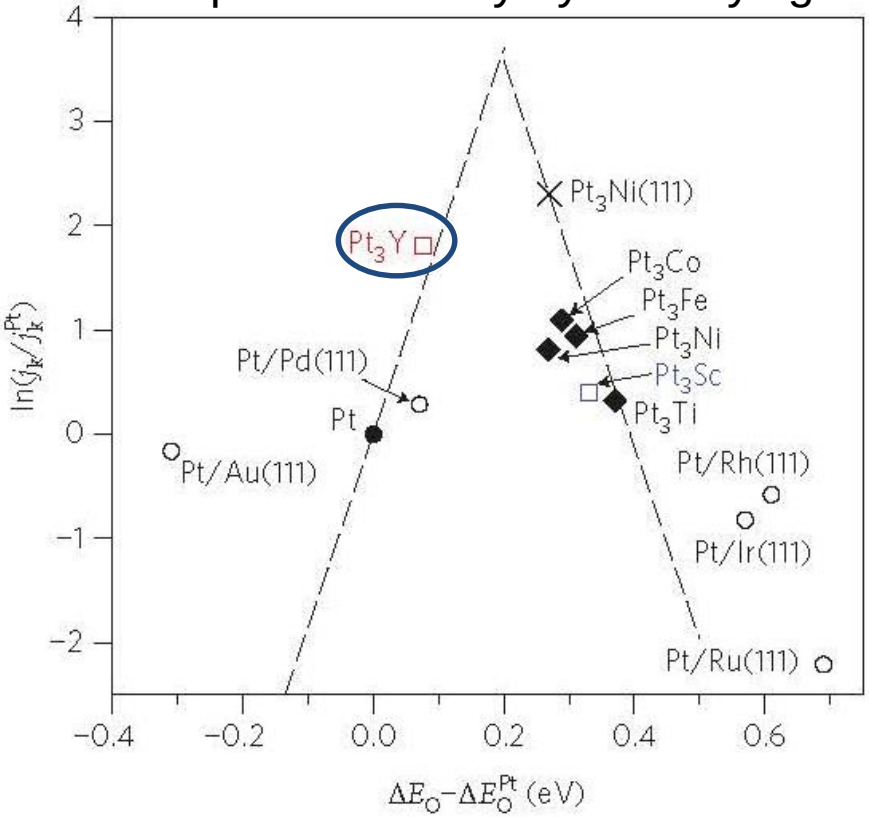
LIB (BEV) versus PEMFC(FCEV)



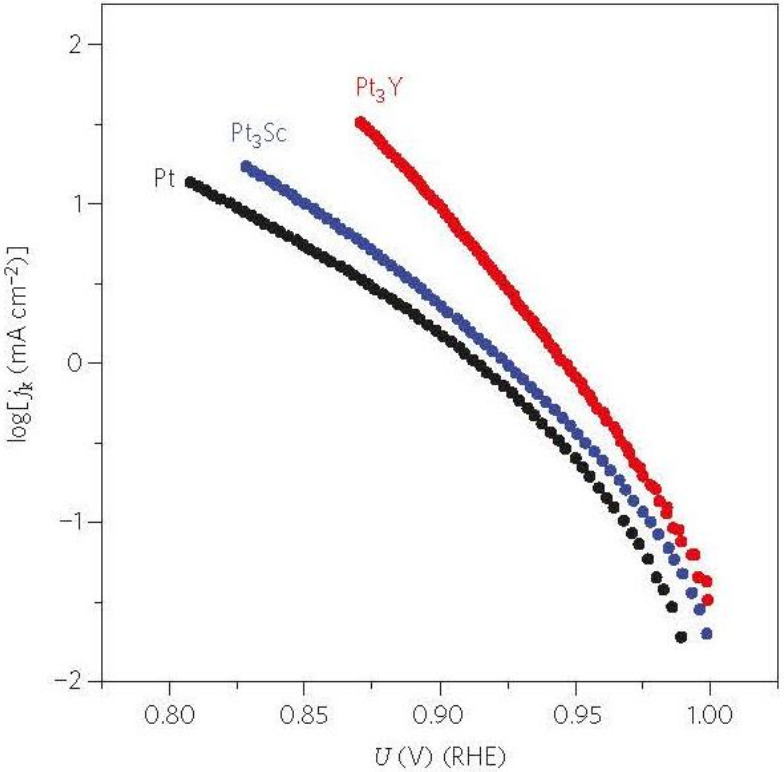
Z. P. Cano, et al. ”Batteries and fuel cells for emerging electric vehicle markets” Nature Energy 3, 279–289 (2018)

Alternative cathode catalysts for PEMFC

Improved activity by Pt alloying



Pt_3Y promising in RDE measurments



J. Greeley, I. E. L. Stephens, A. S. Bondarenko, T. P. Johansson, H. A. Hansen, T. F. Jaramillo, J. Rossmeisl, I. Chorkendorff and J. K. Nørskov , Nature Chemistry, 2009, 1, 552-556