Energy research Centre of the Netherlands

Reduction of cost per kW for PEM fuel cells

N.P. Lebedeva

Presented at the ECN colloquium, May 18, 2009, Petten, The Netherlands

ECN-L--09-181 December 2009

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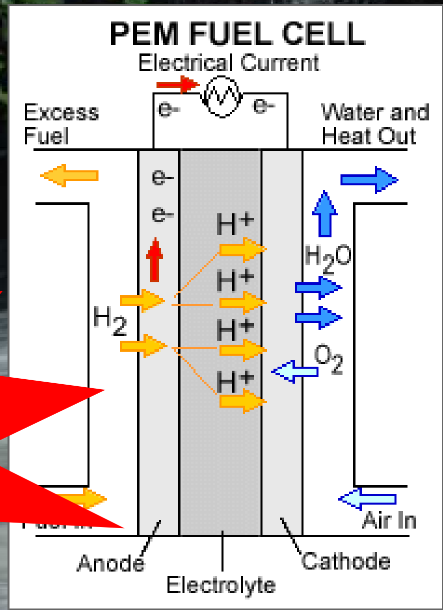
Energy research Centre of the Netherlands (ECN), Petten, The Netherlands

PEM Fuel Cell – a “green” power source

$$2\,H_2 \longrightarrow 4H^+ + 4e$$
$$O_2 + 4H^+ + 4e \longrightarrow 2\,H_2O$$

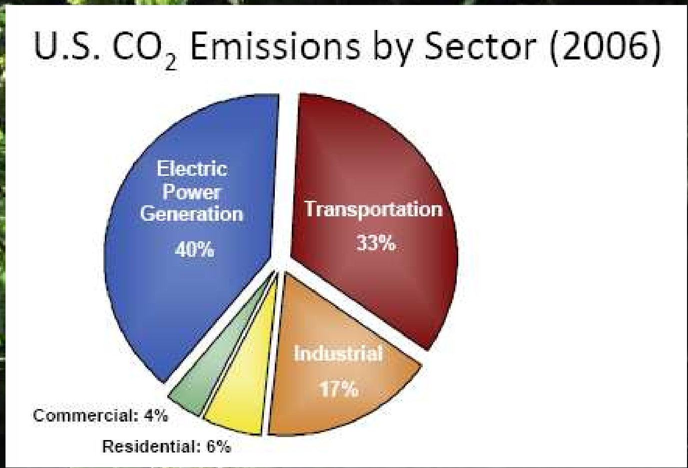
$$2\,H_2 + O_2 \longrightarrow 2\,H_2O$$

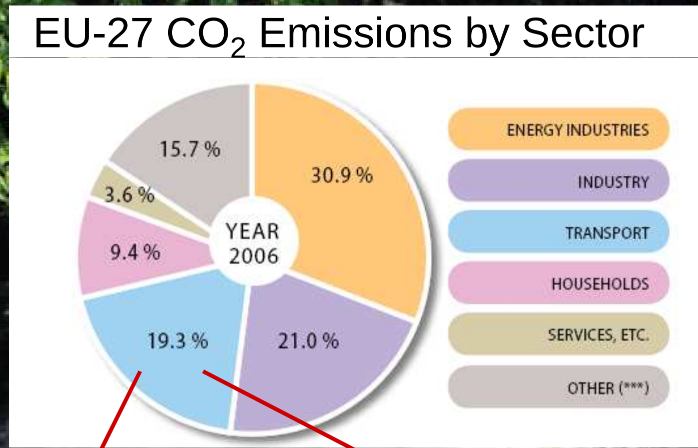


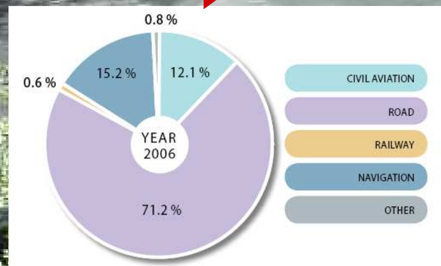
Catalyst:
Precious Metals Group

Platinum Pt

PEM fuel cell – a “green” power source







PEMFCs can benefit two largest energy sectors:
- *transportation*
- *power generation*

Source: *European Environment Agency (EEA), http://ec.europa.eu/energy/publications/statistics/statistics_en.htm*
US Energy Information Administration, http://www.eia.doe.gov/environment.html

PEM Fuel Cell – a “green” power source

R&D for transportation fuel cells is focused on components rather than systems

KEY TARGETS:

- **$45/kW by 2010; $30/kW by 2015**
- **5,000-hour durability by 2015**
- **60% efficiency**

Early markets for stationary, backup power, and specialty applications will lower costs and grow the manufacturing and supplier base

KEY TARGETS:

- **Distributed Power:** $750/kW and 40,000-hour durability (with 40% efficiency) by 2011
- **APUs:** Specific power of 100 W/kg and power density of 100 W/L by 2010
- **Portable Power:** Energy density of 1,000 Wh/L by 2010

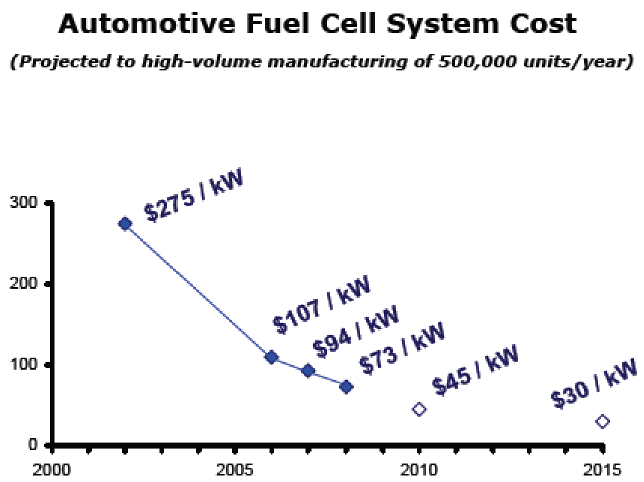
Nancy L.. Garland, DoE, ’08 Electric Drive Transportation Association Conference & Exposition, 2-4 December 2008, Washington DC, USA

PEM Fuel Cell – challenges to commercialization

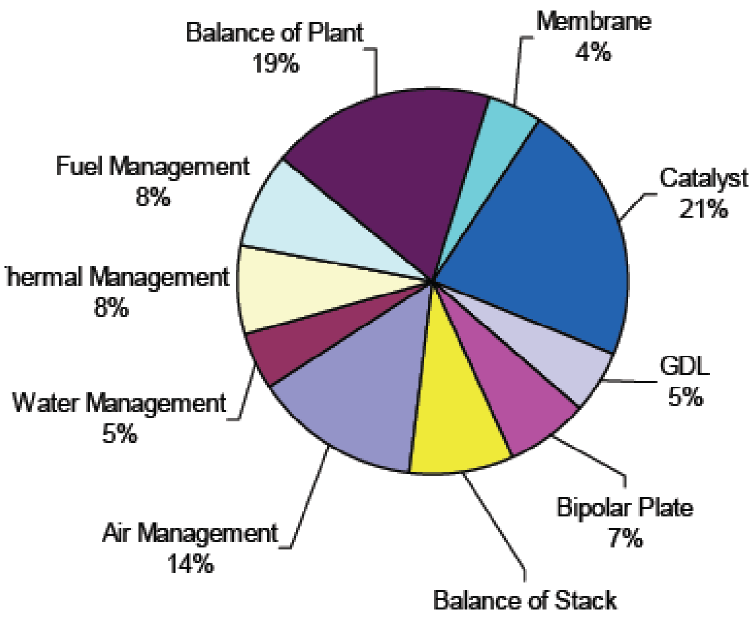
- Durability
- Cost
- Performance (efficiency)

PEM Fuel Cell – cost

Fuel Cell system costs decreased to $73/kW but need further reductions



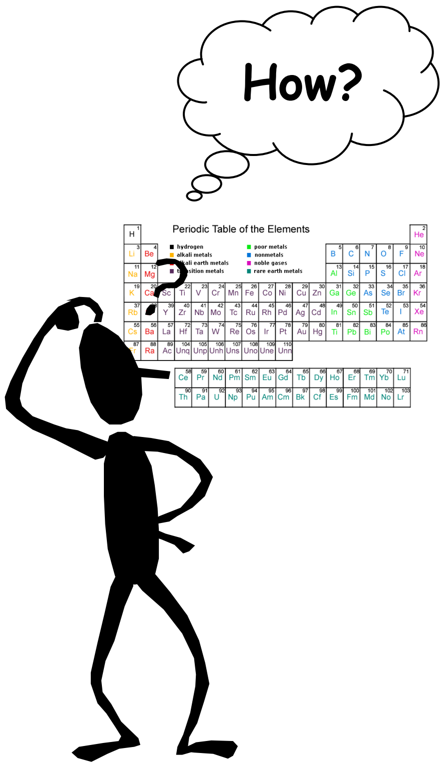
80 kW, direct hydrogen, automotive fuel cell system cost breakdown*



* *Based on DTI DFMA 2008 cost analysis projected to volume of 500,000 units per year, using Pt cost of $1100 per troy ounce*

Nancy L.. Garland, DoE, '08 Electric Drive Transportation Association Conference & Exposition, 2-4 December 2008, Washington DC, USA

PEM Fuel Cell – how to reduce the catalyst cost?



- *Use **less Pt** and improve its utilization*

  catalyst - porous structure
  electrode - catalytic layer structure

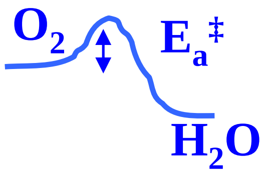
- ***Alloy Pt** with transition metals: Pt M*

- ***Combined** approach*

Sluggish oxygen reduction reaction (ORR) causes major performance losses

Focus on the ***CATHODE***

Processes at the cathode

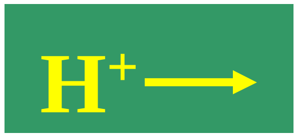


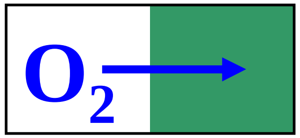
- ***ORR kinetics***:
  - high ECSA
  - high specific activity, i.e. 3 nm Pt particles

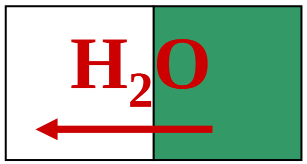
High SA carbon support

Risks: micro-pores:

– no wetting – no Pt / not utilized





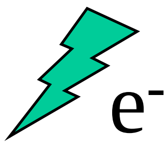


- ***Transport of H^+, O_2 and H_2O***:
  - thin electrode
  - sufficiently large pores
  - thin ionomer layer
  - hydrophobic / hydrophilic pathways

Knudsen diffusion in the pores with diameter < ca. 100 nm @ p = 1 bara

$D_k = 97 \cdot r\sqrt{T/M}$

Risks:
- too low surface area
- capillary condensation @ low P/P_0 in small mesopores
- non-efficient ionomer pathways



- ***Electron transport***:
  - conducting carbon network

Rational design of the porous structure

Approach #1

• <u>*Catalyst porous structure*</u>

- Sibunit carbon
- Boreskov Institute of Catalysis (BIC) in Novosibirsk, Russia

EU FP6 project “IPHE-GENIE”

Carbons of Sibunit family

Sibunit BIC, Novosibirsk
IHP, Omsk

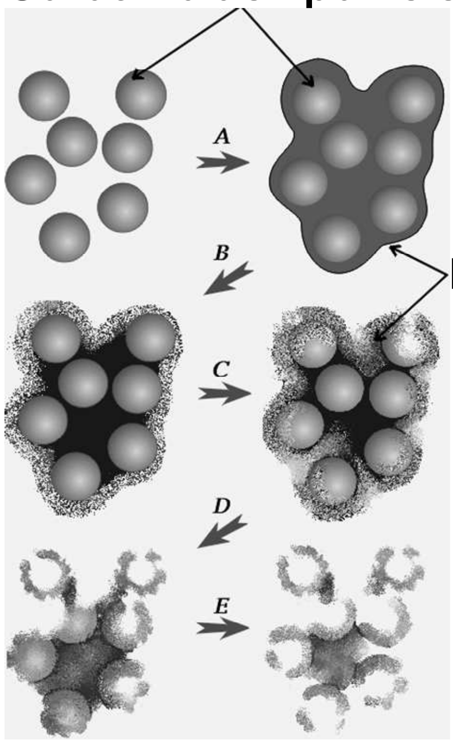
Synthesis and formation of Sibunit texture

A – condensation (deposition of pyrocarbon onto carbon black particles)

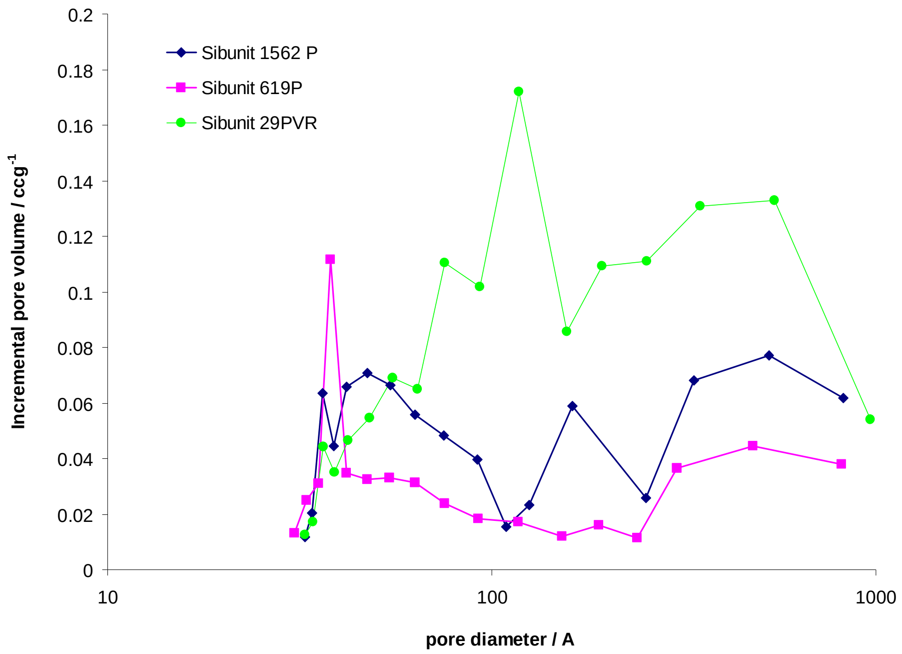
B,C,D,E – activation (oxidative gasification of the PC/CB composite)

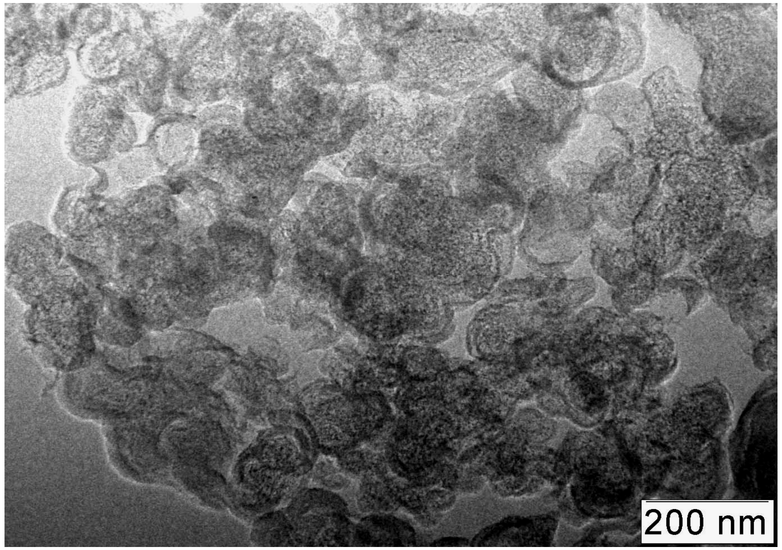
Likholobov V.A., et.al.
React. Kinet. Catal. Lett. 54, 381 (1995)

Carbon black particles



Texture of the Sibunit support materials

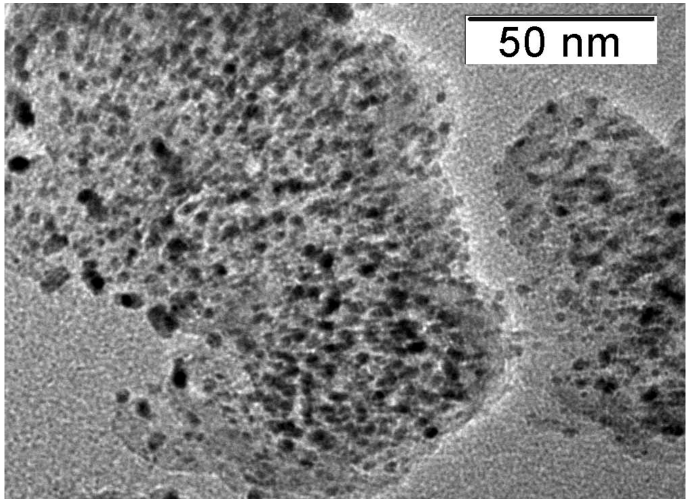




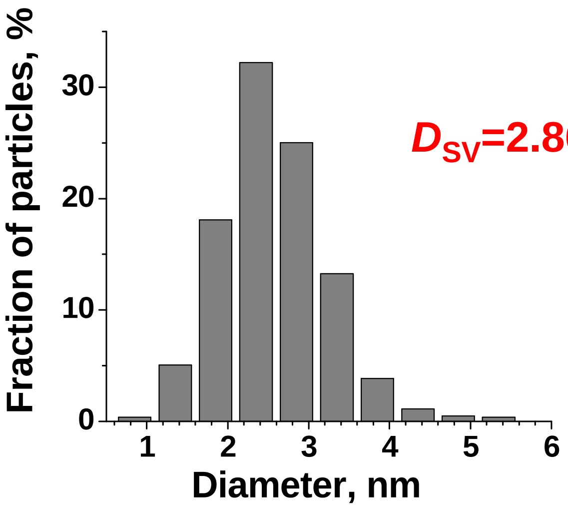
BET surface area - 450 -500 m^2/g, total pore volume - 0.6 – 1.4 cm^3/g

Porous carbon of the Sibunit family used as the catalyst support: pore size distributions calculated from the desorption branch of the nitrogen adsorption isotherm in accordance with the *BJH* model.

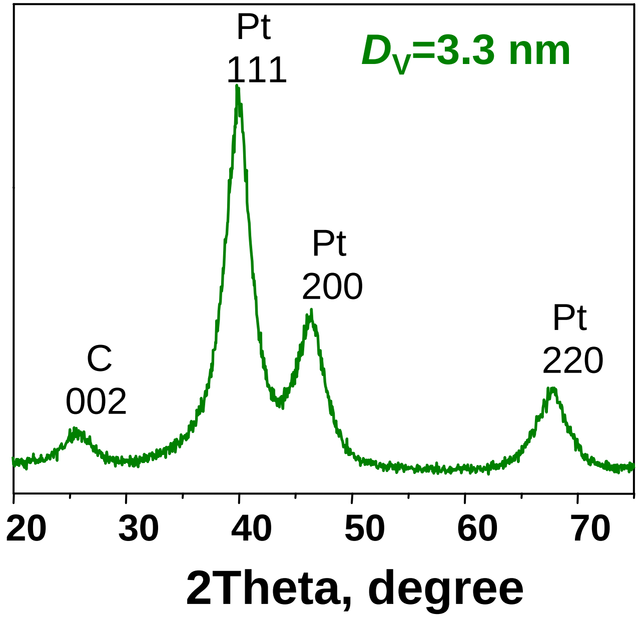
40wt% Pt/Sibunit 1562P catalyst



TEM



D_{SV}=2.86 nm



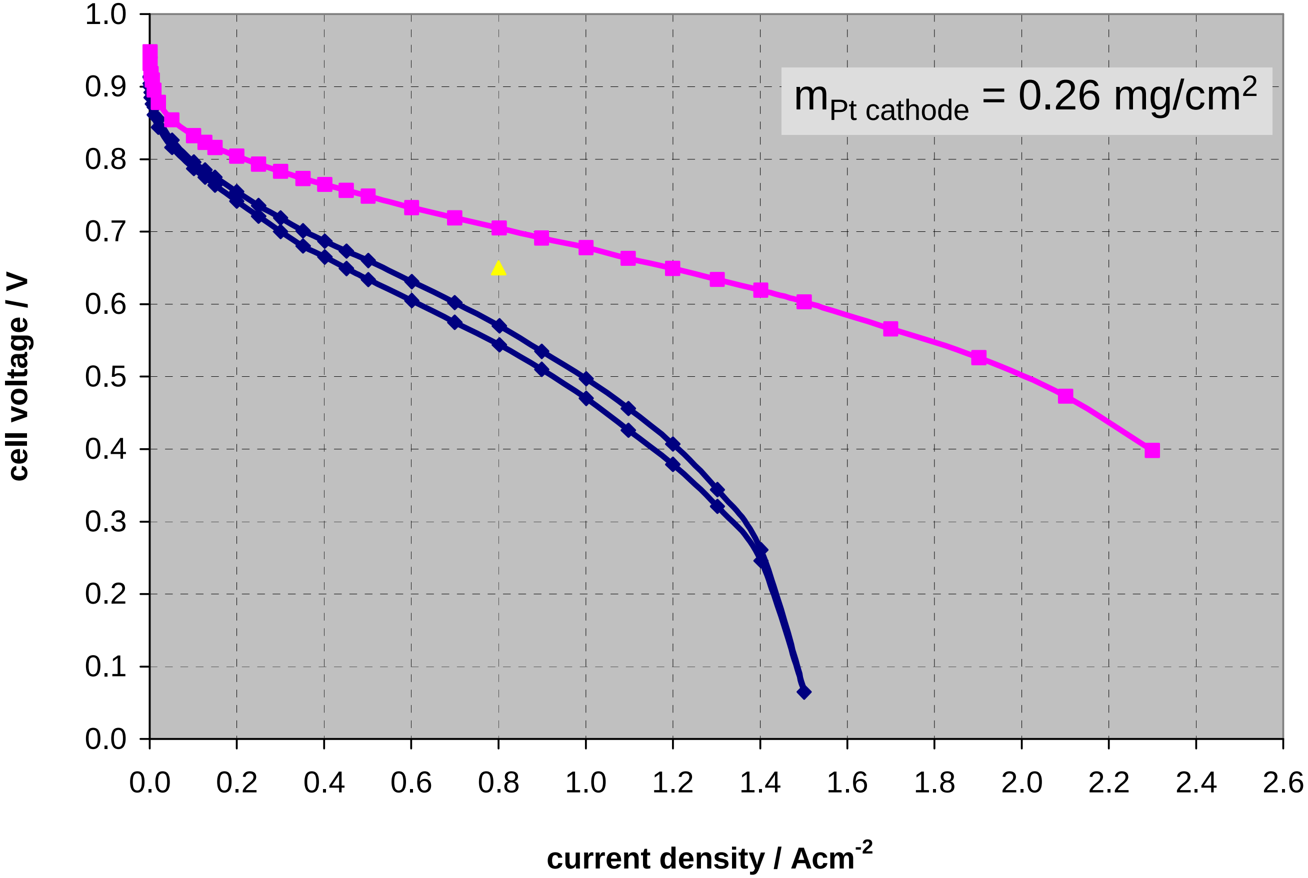
D_V=3.3 nm

XRD

CO chemisorption

D_S=3.37 nm

Polarisation measurements



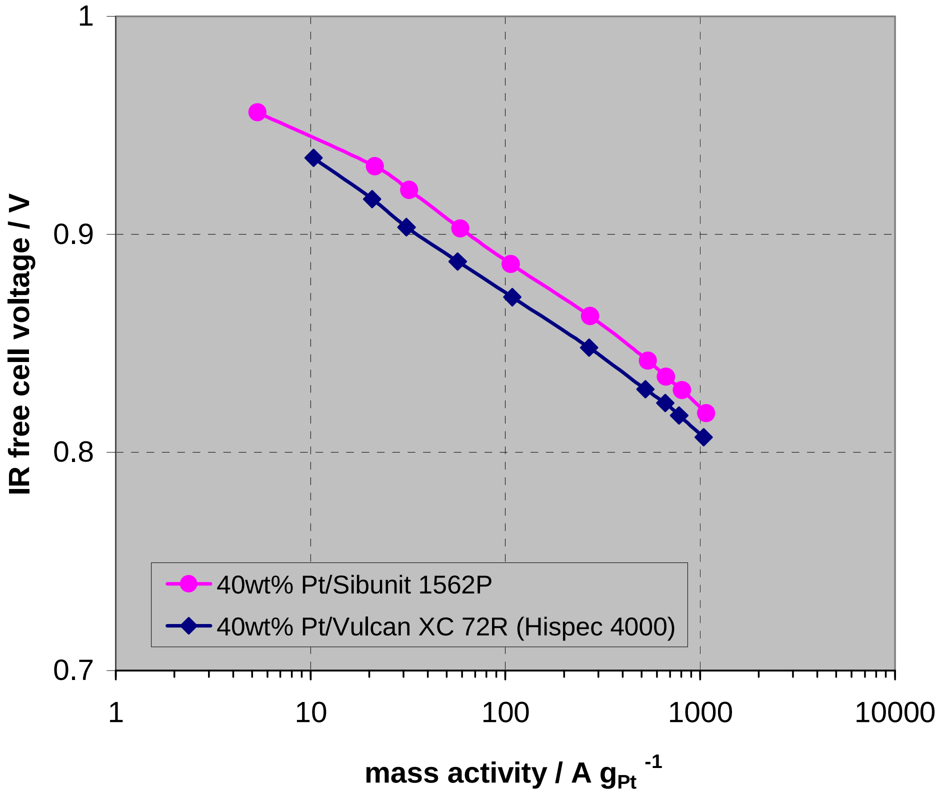
65℃, 100% RH, 1 bara
λ_{H2} = 1.5, $\lambda_{air,\ O2}$ = 2.0

step time 5 min

40wt% Pt/Sibunit 1562P
H2315 C2
FuMAPEM 950
Fumion ionomer

air
oxygen

Pt kinetic activity



Kinetic activity ORR @ 0.9 V

Mass activity:

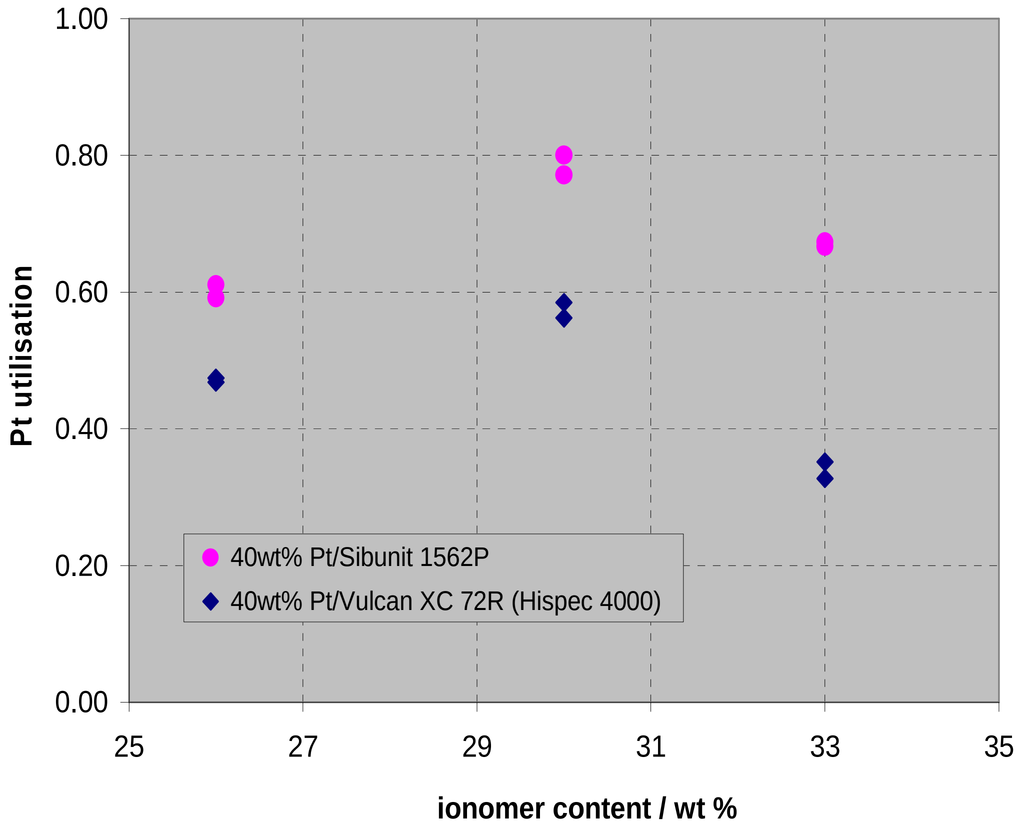
40wt%Pt/Sibunit 1562P	63 ± 5 A/g
40wt% Pt/Vulcan XC72R (Hispec 4000, JM)	30 ± 8 A/g

Specific activity:

40wt%Pt/Sibunit 1562P	104 ± 10 µA/cm^2
40wt% Pt/Vulcan XC72R (Hispec 4000, JM)	114 ± 10 µA/cm^2

ECN

Pt utilisation



Pt utilization = ECSA / SA

ECSA – from in situ CV measurements
SA – gas-phase CO chemisorption

<u>Pt utilisation</u>:

40wt% Pt/Sibunit 1562P	60-80%
40wt% Pt/Vulcan XC 72R (Hispec 4000, JM)	35-60%

Transport properties

Proton transport:

Proton resistance – 0.100 -0.120 Ohm·cm^2 for 40wt%Pt/Sibunit 1562P

0.100 -0.130 Ohm·cm^2 for 40wt%Pt/Vulcan XC 72R (Hispec 4000, JM)

Oxygen and water:

Oxygen gain @ 1 A/cm^2 – 180 - 260 mV for 40wt%Pt/Sibunit 1562P

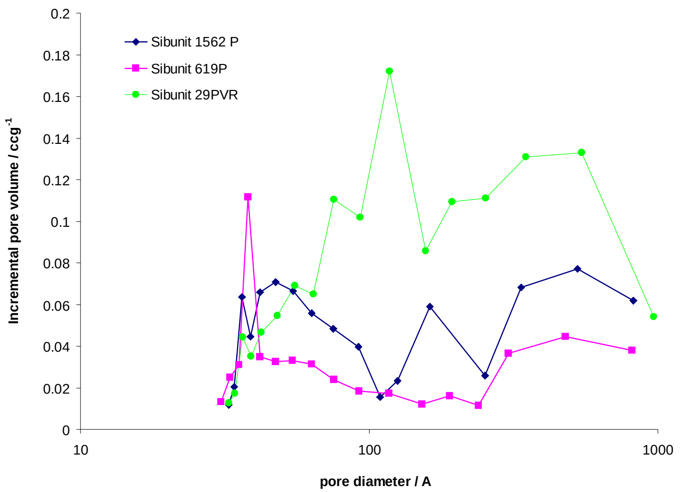
200 - 260 mV for 40wt%Pt/Vulcan XC 72R (Hispec 4000, JM)

N.P. Lebedeva, A.S. Booij, I.N. Voropaev, P.A. Simonov, A.V. Romanenko, Fuel Cells, ***2009****, in press*

Catalyst porous structure

- Novel Sibunit-supported catalyst shows
  - 2x increased mass activity compared to a commercial benchmark Hispec 4000 (JM) material due to higher Pt utilization and its better dispersion

- Offers a unique possibility to tune porous structure without changing other textural parameters (for example, microstructure at the surface), therefore, enabling fundamental studies of the structure – performance relationship

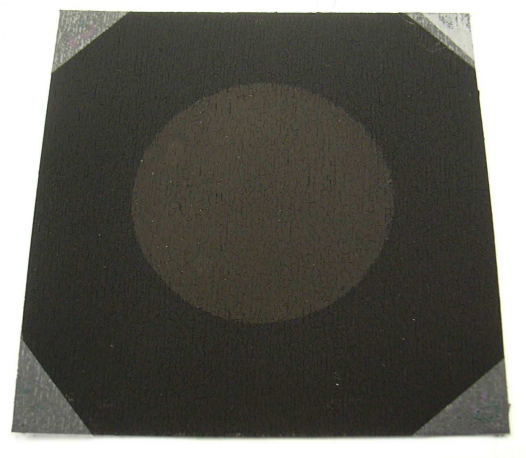


- Kinetics
- Transport
- Electron transport

Approach #2

• *Electrode - Catalytic layer*

Thin catalytic layer – reduced transport losses



Application method:

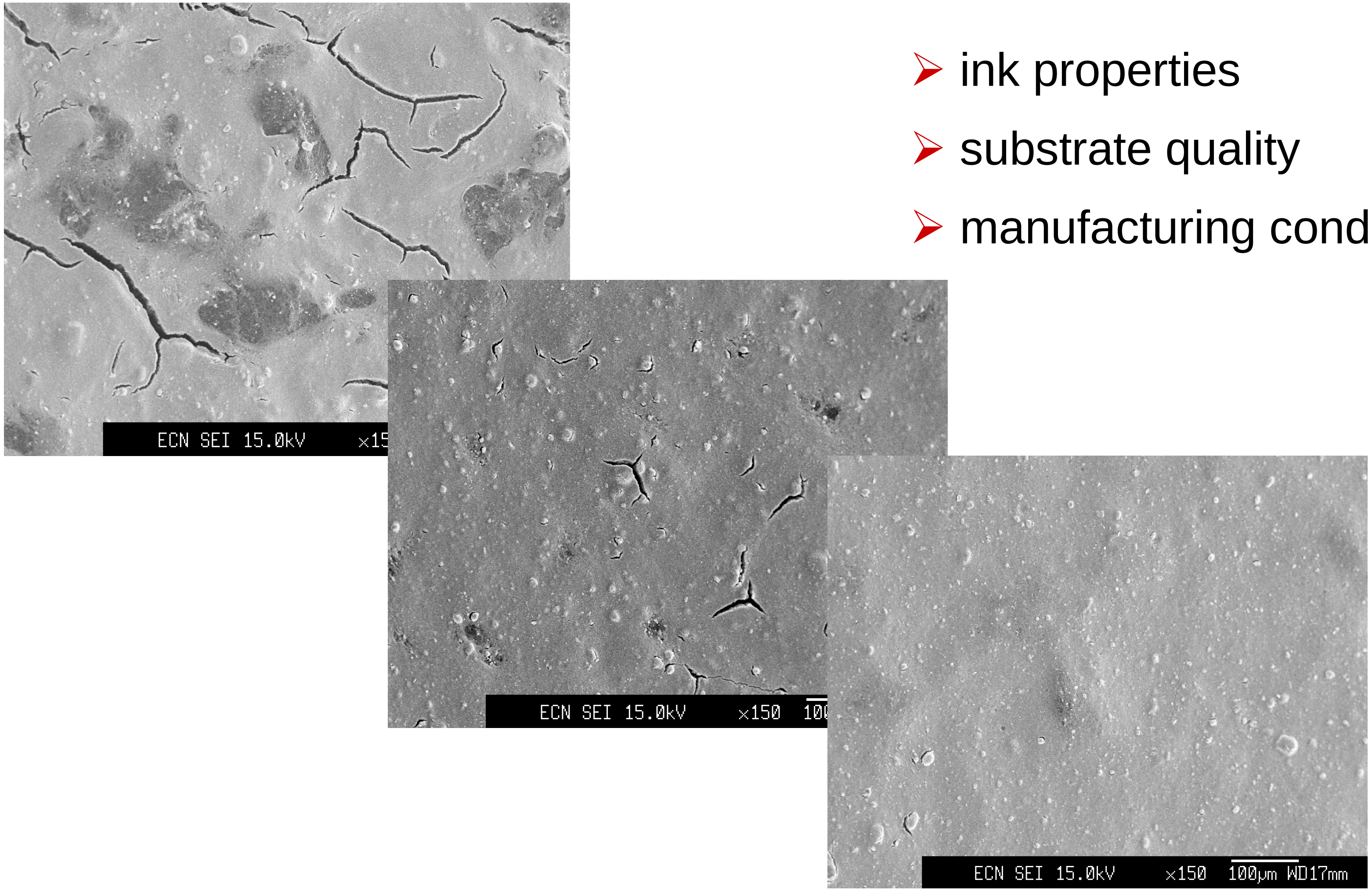
- screen-printing on GDL

Characterisation:

- thickness & quality of the catalytic layer – SEM
- statistics: average ± standard deviation
  - 15 point measurements on each electrode;
  - 5 electrodes of each thickness per production run;
  - 3 production runs

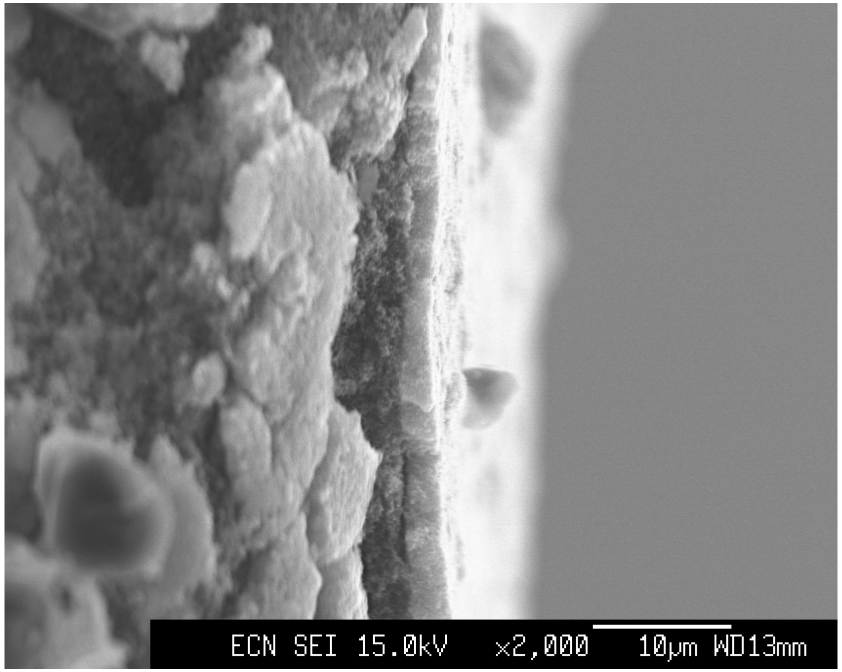
EU FP6 projects
“IPHE-GENIE” & “AUTOBRANE”

Catalytic Layer - quality



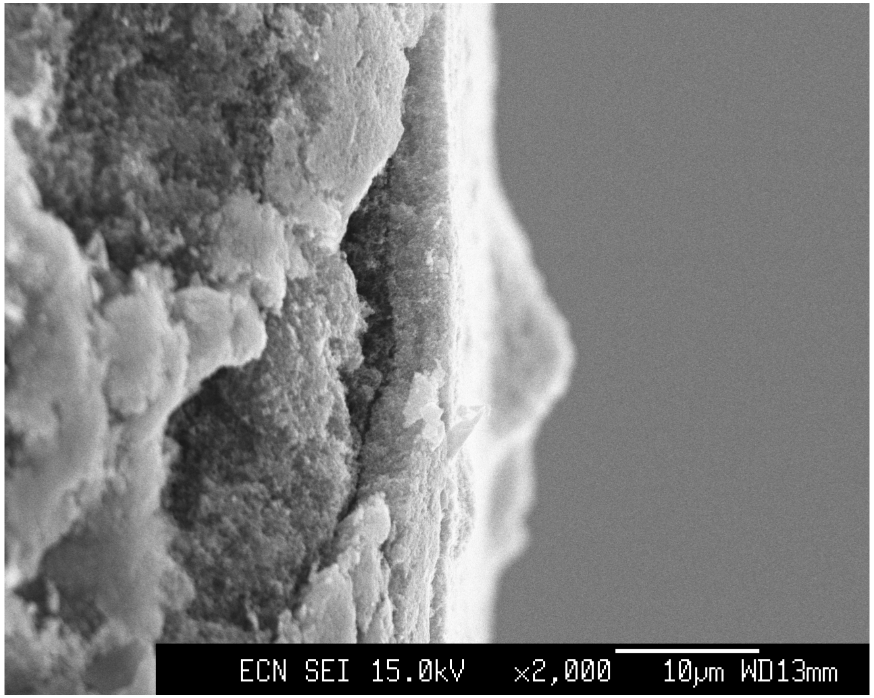
- ink properties
- substrate quality
- manufacturing conditions

Catalytic layer: thickness

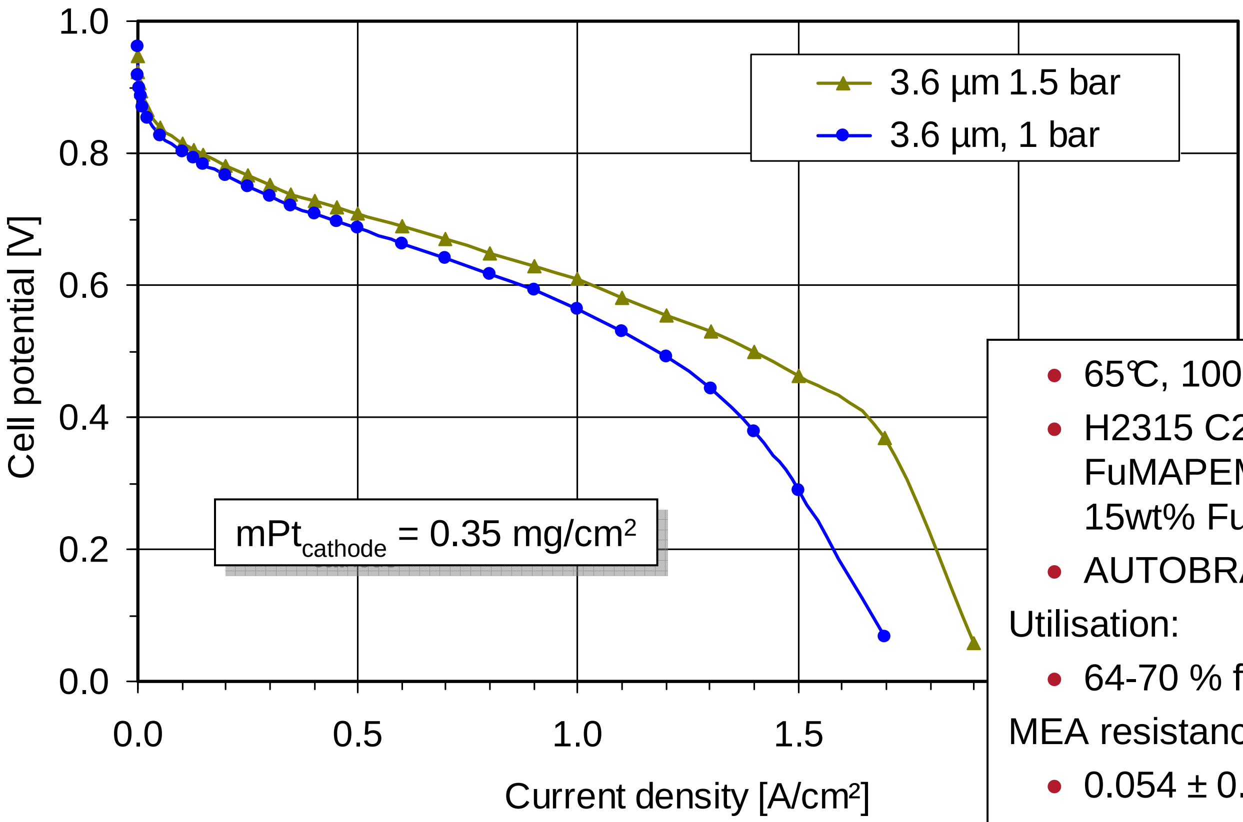


Catalytic layer thickness
2.2 ± 0.7 μm

Catalytic layer thickness
3.6 ± 1.3 μm



Catalytic layer - performance



- 65℃, 100% RH, λ_{H2}=1.5, λ_{air}=2.0
- H2315 C2 GDL, Hispec 13100, FuMAPEM 950 membrane, 15wt% Fumion 910 ionomer
- AUTOBRANE test protocol

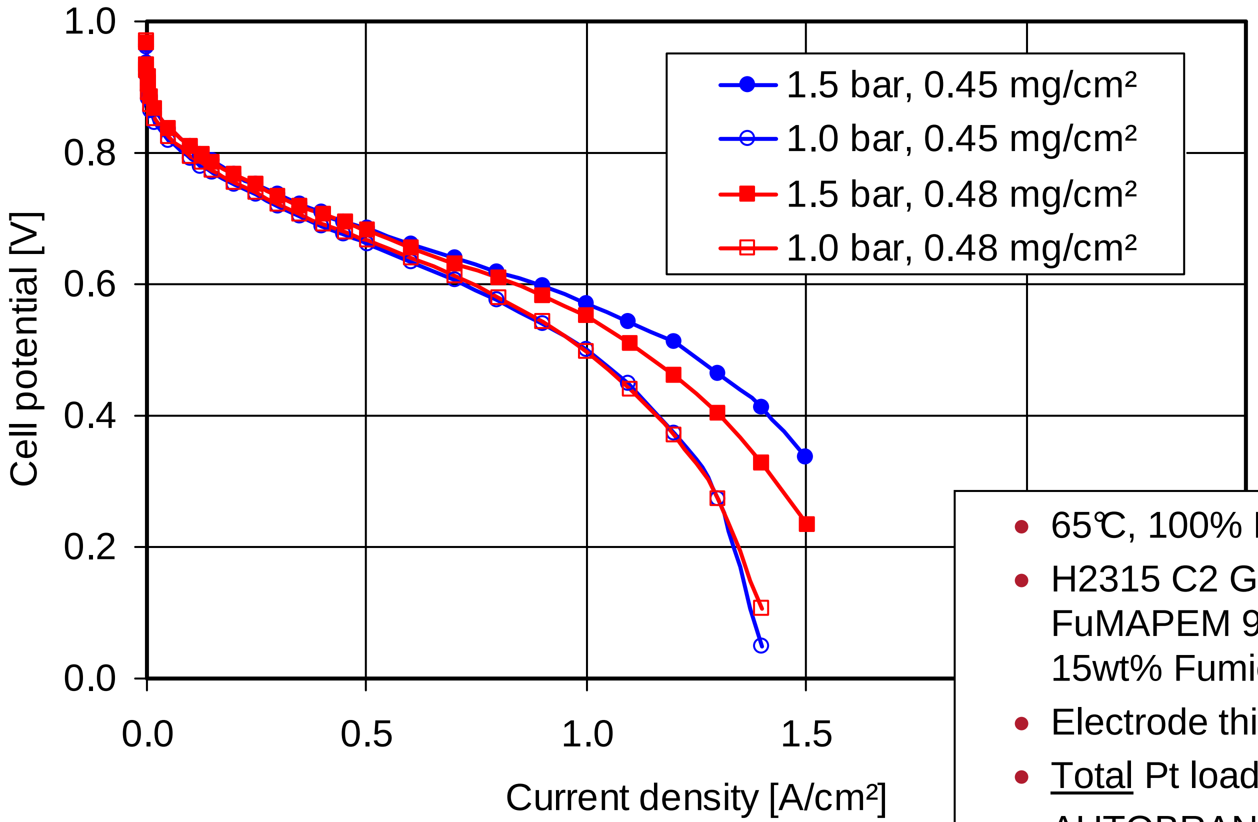
Utilisation:

- 64-70 % for 3.6 µm-thick

MEA resistance:

- 0.054 ± 0.02 Ohm cm^2

Catalytic layer - performance



- 65℃, 100% RH, λ_{H2}=1.5, λ_{air}=2.0
- H2315 C2 GDL, Hispec 13100, FuMAPEM 950 membrane, 15wt% Fumion 910 ionomer
- Electrode thickness: 3.6 µm
- Total Pt loading numbers given
- AUTOBRANE test protocol

Electrode – Catalytic Layer

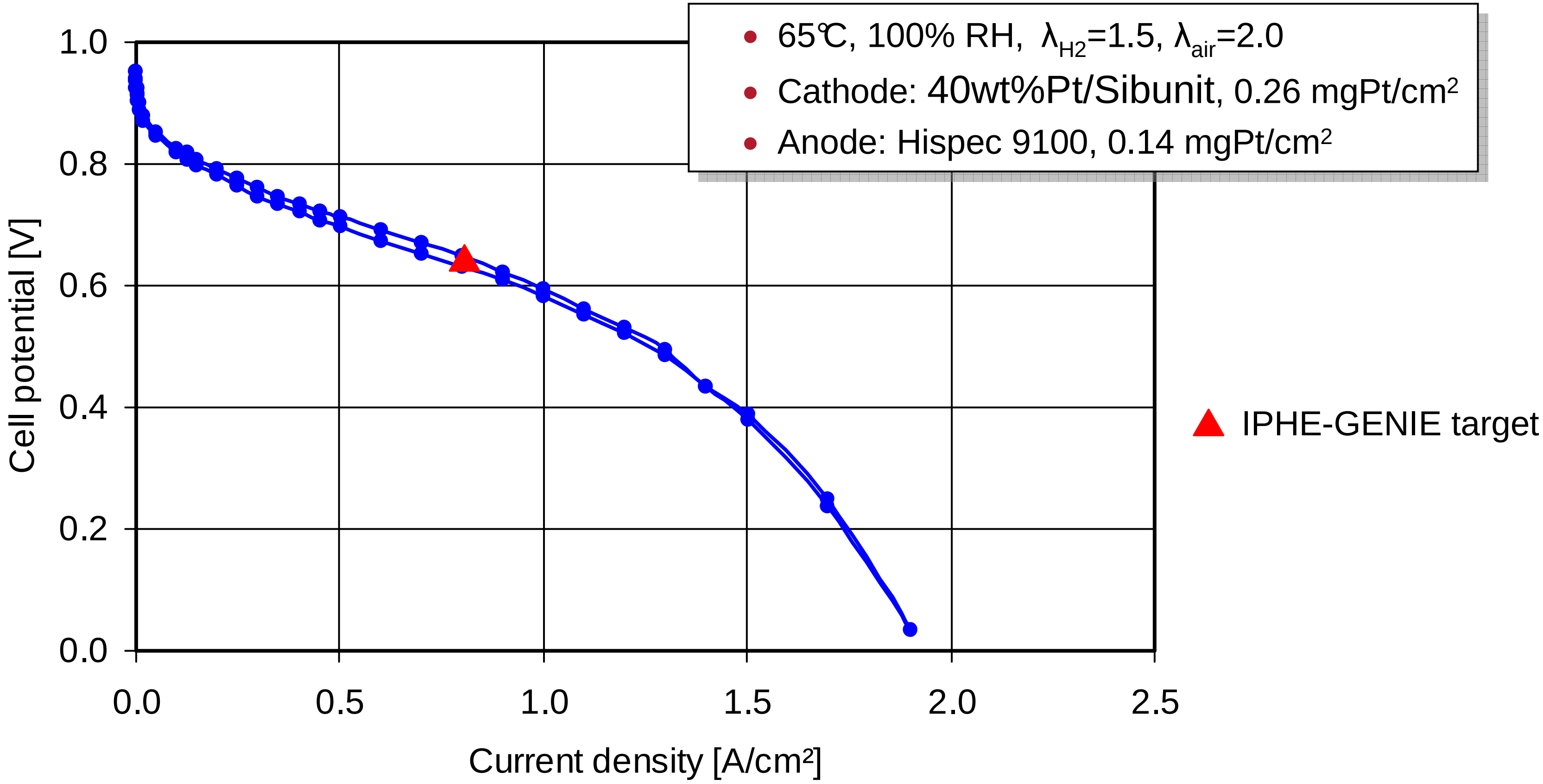
- Electrodes with thin (2-4 µm) catalytic layers can be manufactured by screen-printing

- Their quality is sensitive to:
  - ink properties
  - substrate quality
  - manufacturing conditions

- Performance of the electrodes with thin catalytic layers is characterized by:
  - improved mass transport
  - lower electric resistance

Combined approach

Thin catalytic layer + Pt/Sibunit catalyst



Conclusions

- **Optimization of the porous structure of the catalyst and of the catalytic layer has been proven to be efficient in the reduction of the amount of Pt and, therefore, cost of kW for PEMFCs.**
- **2x lower Pt loading (total of 0.4 mgPt/cm^2) has been achieved, while improvement of the MEA performance has been simultaneously realized.**

- Novel Sibunit-supported catalyst shows
  - 2x increased mass activity compared to a commercial benchmark Hispec 4000 (JM) material due to higher Pt utilization and its better dispersion
- Offers a unique possibility to tune porous structure without changing other textural parameters (for example, microstructure at the surface), therefore, enabling fundamental studies of the structure – performance relationship

- High quality, homogeneous electrodes with thin (2-4 µm) catalytic layers can be manufactured by screen-printing. Performance of these electrodes is characterized by improved mass transport

Acknowledgement

Arend Booij (ECN, Petten) – for technical support
Marijke Roos (ECN, Petten) – SEM imaging
Dr. Onne Wouters (NRG, Petten), Paul van den Idsert (NRG, Petten) – TEM imaging
Vera Smit-Groen (NRG, Petten) – XRD analysis

Ivan Voropaev, Dr. Pavel Simonov and Dr. Anatoly Romanenko (BIC, Novosibirsk, Russia) – for preparation and characterisation of the Pt/Sibunit catalysts

Dr. Bernd Bauer (FuMa-Tech GmbH, St.Ingbert, Germany) – for ionomer and membrane samples and useful discussions

Dr. Volker Banhardt (Freudenberg FCCT KG, Germany) - for samples of H2315 C2 GDL material

Financial support provided by the EU-FP6 projects “IPHE-GENIE”, contract #039016, and “AUTOBRANE”, contract # 020074