Electrochemical Technologies For A Hydrogen Economy

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Newcastle University, UK

SUPERGEN Fuel Cells
powering a greener future

CONTENT

- Overview of UK Hydrogen Scene and Funding
- EPSRC SUPERGEN
- Fuel Cell Consortium Activities
- Newcastle University Fuel Cell Activities
- Hydrogen Funding in the EU

Sponsors and Players in the UK

- United Kingdom Hydrogen Association (UKHA)
- EPSRC
- Technology Strategy Board (TSB) [previously DTI]
- CARBON TRUST
- UKERC

Who is the UKHA?

UKHA
UNITED KINGDOM HYDROGEN ASSOCIATION

- Formed in May 2006
- Diverse Membership
- Industry association whose mission is to foster the development and use of hydrogen technologies and to promote the use of hydrogen as an energy carrier in the United Kingdom
- Key activities
  - Policy
  - Regulations and Standards
  - Education
  - Collaboration
  - Desire to lead effort to develop UK hydrogen roadmap/commercialisation plan

Air Products & Chemicals
AMEC
BOC / Linde
Bryte Energy
Cenex
The Centre for Process Innovation
E.ON UK
Glamorgan University
H2 Logic
ITM Power
Johnson-Matthey
Logan Energy
MMI
Newcastle University
Renew Tees Valley
S&TFC RAL
Voller Energy
Wind Hydrogen

UK Hydrogen Sites

UKHA
UNITED KINGDOM HYDROGEN ASSOCIATION

- BOC H2 production facility
- Other H2 production
- Refineries & other additional H2 locations
- Centres of H2 activities

Key Areas

Teesside
Existing hydrogen infrastructure and storage

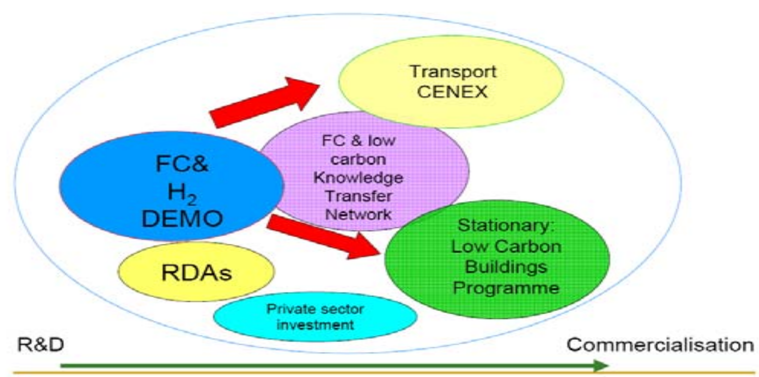
Midlands
Hydrogen production and academic research

London
Political will, transport focus

South Wales
Existing infrastructure and Academic excellence

Recent UK developments

UKHA



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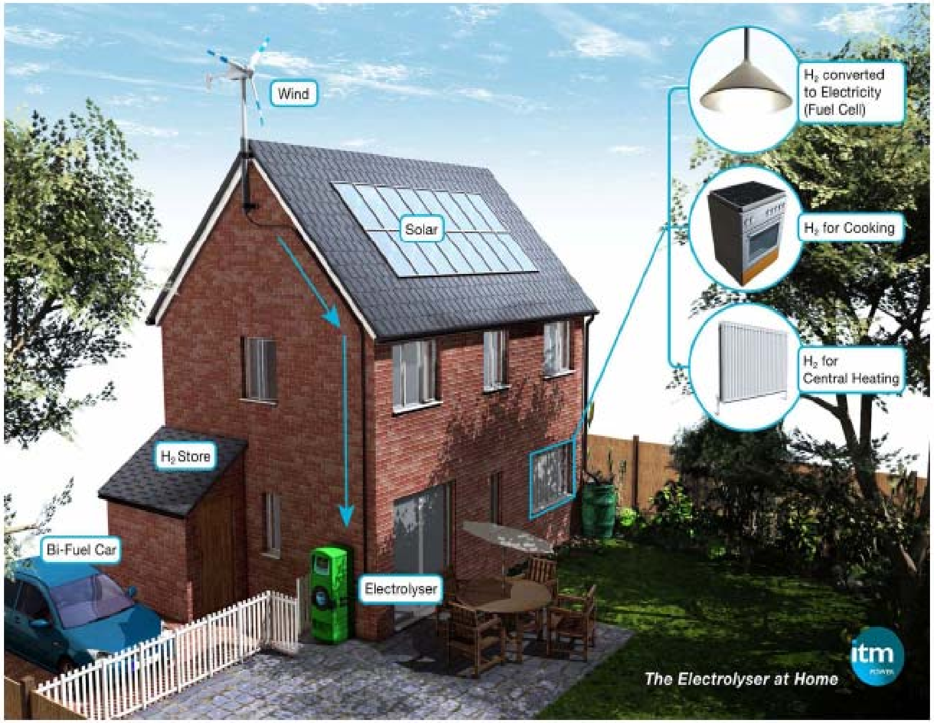
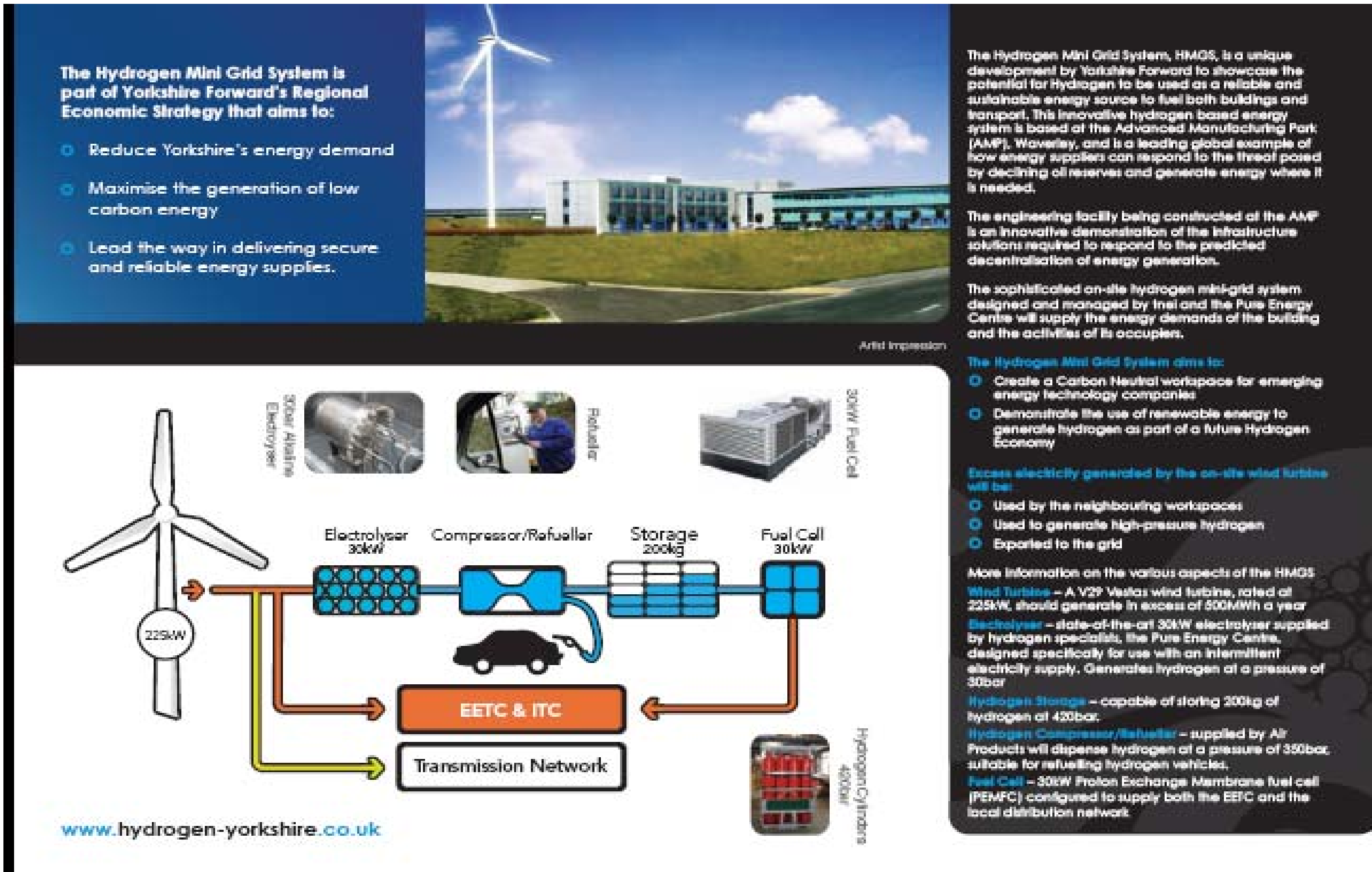
Opportunities – micro generation

- UK firm ITM Power is developing a low cost 10kW electrolyser for refuelling hydrogen cars, at home, with renewable hydrogen. The electrolyser can also make carbon free hydrogen for application in zero carbon housing developments.

  ITM's electrolyser is due to start field trials and production during 2008 .



Yorkshire Forward UK 300kW wind turbine



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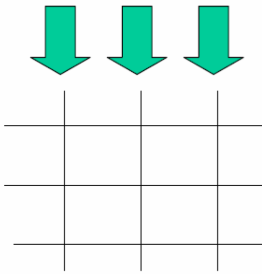
UKERC www.ukerc.ac.uk

- United Kingdom Energy Research Centre UKERC
  - Headquartered at Imperial
  - Imperial, Oxford, Edinburgh, Manchester, Lancaster, Policy Studies Institute

- UKERC aims to take a whole systems view.
  - Multidisciplinary team mix of scientist, engineers, social scientists, economists.
  - Three vertical themes
  - Three cross cutting themes

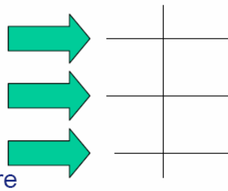
UKERC THREE VERTICAL THEMES

- Demand Reduction
  - Brenda Boardman, Environmental Change Institute, Oxford
- Future Sources of Energy
  - Robin Wallace, Edinburgh
- Infrastructure and Supply
  - Nick Jenkins, UMIST



UKERC THREE X-CUTTING THEMES

- Energy Systems and Modelling
  - Paul Ekins, Policy Studies Institute
- Environmental Sustainability
  - David Howard, Lancaster Environment Centre
- Material for Advanced Energy Systems
  - John Kilner, Imperial College



SUPERGEN

EPSRC’s flagship initiative in Sustainable Power Generation and Supply.

SUPERGEN

energy

Led by EPSRC in partnership with BBSRC, ESRC, NERC and the Carbon Trust. The initiative aims to help the UK meet its environmental emissions targets through a radical improvement in the sustainability of power generation and supply.

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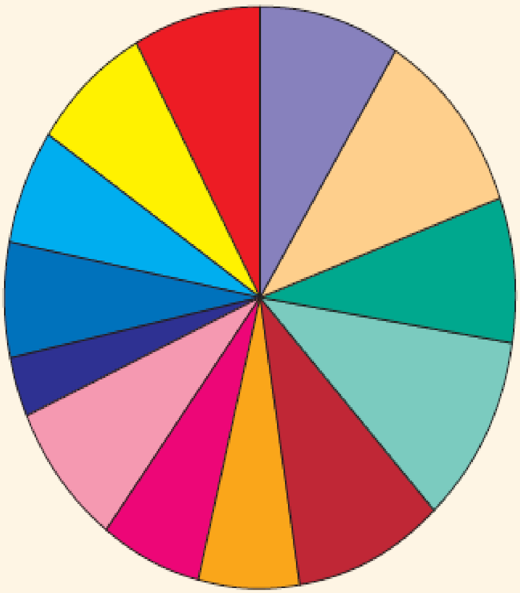
CeresPower JM [dstl] Imperial College London

Supergen Consortia

A recent Hydrogen generation Consortia Announced (Newcastle and St. Andrews lead) £5M



- Bioenergy Consortium, £2.9m
- UK Sustainable Hydrogen Energy Consortium (UK-SHEC), £3.48m
- Marine Energy Research Consortium, £2.61m
- Future Network Technologies Consortium, £3.42m
- Photovoltaic Materials for the 21st Century Consortium 'PV-21', £3.09m
- Conventional Power Plant Lifetime Extension (PLE) Consortium, £2.11m
- Fuel Cells Consortium, £2.08m
- Highly Distributed Power Systems Consortium, £2.57m
- Excitonic Solar Cell Consortium, £1.1m
- Energy Storage Consortium, £2.16m
- Biological Fuel Cells Consortium, £2.02m
- Asset Management and Performance of Energy System – AMPerES, £2.49m
- Wind Energy Technologies, £2.55m

EPSRC Supergen Fuel Cells Consortium.
Powering A Greener Future [Sept 2006-2010]

Partners

Industry

- Rolls-Royce Fuel Cell Systems Ltd
  - High temperature “large” SOFC-GT
- Ceres Power Ltd
  - Intermediate temperature “small” SOFC
- Johnson Matthey
  - PEM
- Defence Science and Technology Laboratory

Universities

- Imperial College
- Newcastle
- Nottingham
- St Andrews

www.supergenfuelcells.co.uk

SUPERGEN Fuel Cells powering a greener future

Consortium aims

- Multidisciplinary UK team across the academic and industrial sectors to address key technical barriers facing the UK fuel cell industry.
- To exploit synergies addressing three (traditionally distinct) fuel cell technologies;
  - High-Temperature Polymer Electrolyte Membrane Fuel Cells (HT-PEMFCs),
  - High-Temperature Solid Oxide Fuel Cells (HT-SOFCs)
  - Intermediate-Temperature Solid Oxide Fuel Cells (IT-SOFCs)
- To develop high quality researchers trained in fuel cell technology
- To communicate our research to the academic, industrial and general communities.

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Supergen consortium activities (1)

•WP1 Zero Leakage SOFC

To reduce ceramic electrolyte leakage to equivalent of <1% efficiency loss

green layer processing and characterisation,
constrained sintering,
novel processing, nano-powders
process optimisation, lower sintering temperature, co-sintering
mechanical properties.

•WP2 Significantly Improved Fuel Cell Durability

Improve durability from state-of-the-art by a factor of >2

durable SOFC anodes, resistance to coking and sulphur
ageing tests, phase analysis, electron microscopy
thermal and redox cycling (particularly SOFCs)
cell and stack modelling, stack design tools
control strategies to improve durability
lifetime prediction.

Supergen consortium activities (2)

- WP3 Significantly Improved Fuel Cell Performance
  - extend PEM to 130 C (automotive) and 200 C (stationary)
  - reduce SOFC to 500 C
    - MEAs for HT-PEMFCs,
    - cathodes for HT-PEMFCs (resistant to deactivation) and IT-SOFCs,
    - electrode modelling,
    - novel routes to powders and components.
- WP4 Enhanced Fuel Flexibility
  - Liquid hydrocarbons, alcohols, biofuels
    - direct hydrocarbons in SOFC, reforming
    - resistance to sulphur and other impurities
    - less clean fuels, biogas
    - ethanol in SOFC and PEM.
- WP5 Dissemination, Outreach and Training
  - Workshops and seminars, website, UK and overseas links, UKERC.

U K Main Industrial Organisations

Solid Oxide

- Ceres Power
- Fuel Cells Scotland Ltd
- Quinetic
- Rolls Royce Fuel Cell Systems
- St Andrews Fuel Cells Ltd

- ***Alkaline***

- Alternative Fuel Systems Ltd.
- Eneco ltd
- AFC Energy

fuel cells UK

PEM

- CMR Fuel Cells Ltd
- Dart Sensors Ltd.
- Intelligent Energy
- ITM Power PLC
- JM Fuel Cells
- Quinetic
- Voller Energy
- CMR

Govt. Labs

- Defence Science and technology Laboratory [DSTL
- National Physical Laboratory (NPL)

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UK PEMFC RESEARCH at Newcastle

Intermediate Temperature Polymer Electrolyte Fuel Cell
Alkaline Membrane Fuel cells
Direct Alcohol fuel cells
Composite membranes for electrolysers and fuel cells
Mixed Reactant Fuel Cell
Non Pt oxygen reduction catalysts
DMFC stack with new anodes
Methanol tolerant catalysts
Intermediate temperature proton conducting membranes
Sodium borohydride fuel cells
Direct propane and DME fuel cell
Two-dimensional modelling of hydrogen and direct methanol fuel cell
Thermal and stress Modelling of fuel cells
Microbial fuel cells
Enzymatic implantable fuel cells

Next- A selection of activities

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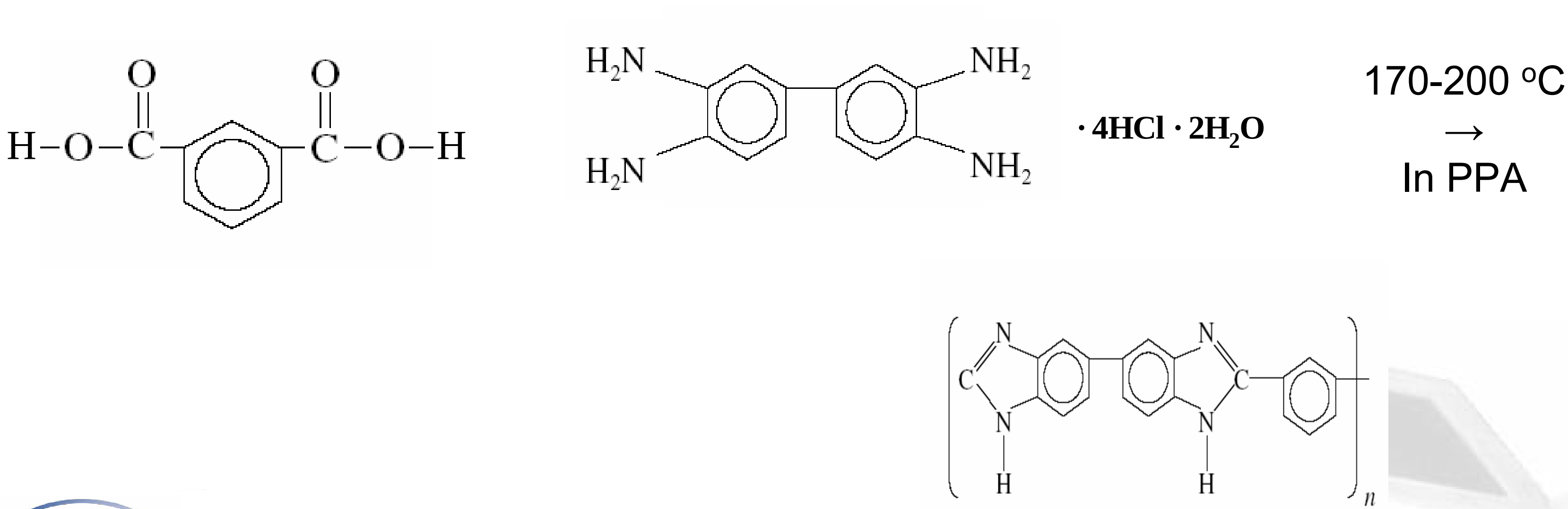
PBI Proton Conducting Membranes for HT-PEMFC.

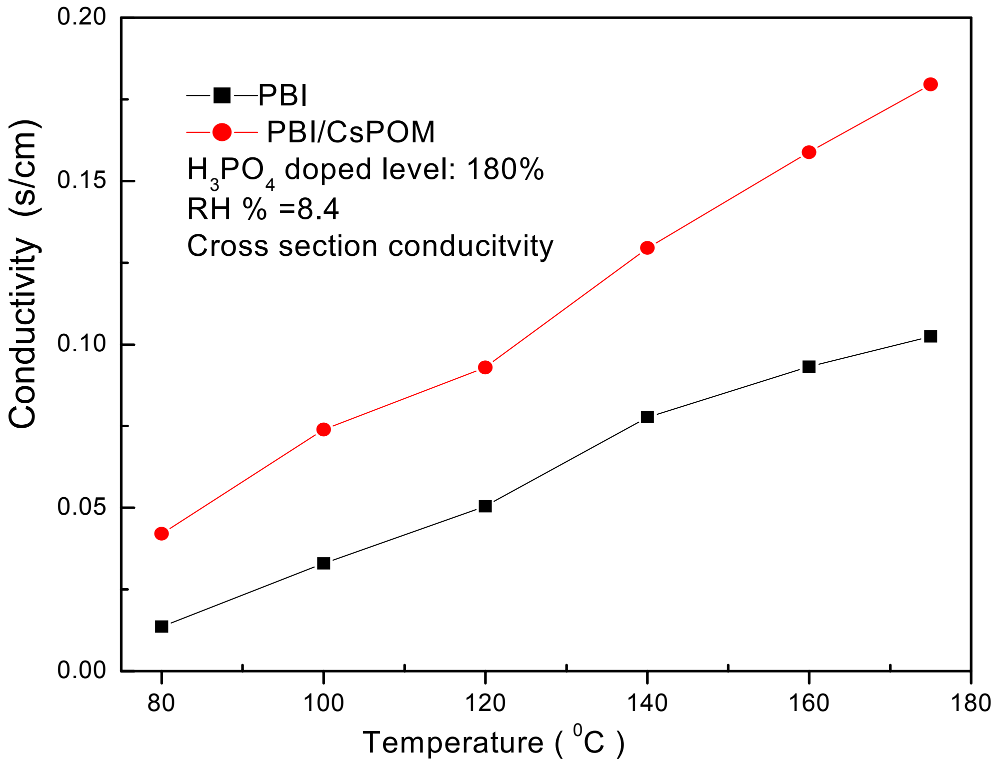
PBI High Temperature Membrane- Low Cost Option

- Polybenzimidazole synthesized from 3,3'-diaminobenzidine tetrahydrochloride and isophthalic acid by a polycondensation process in polyphosphoric acid
  Iwakura et al. (1964)



Composite membranes

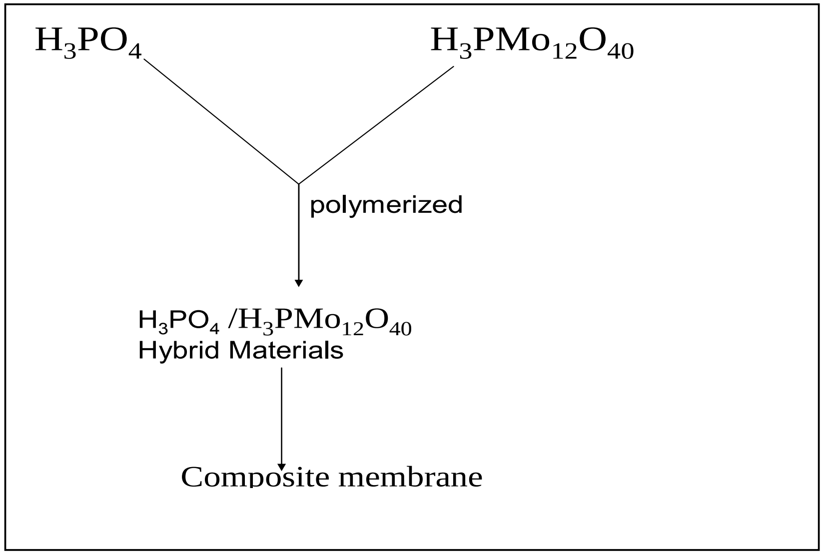
(CsPOM)/ PBI membrane doped on H_3PO_4

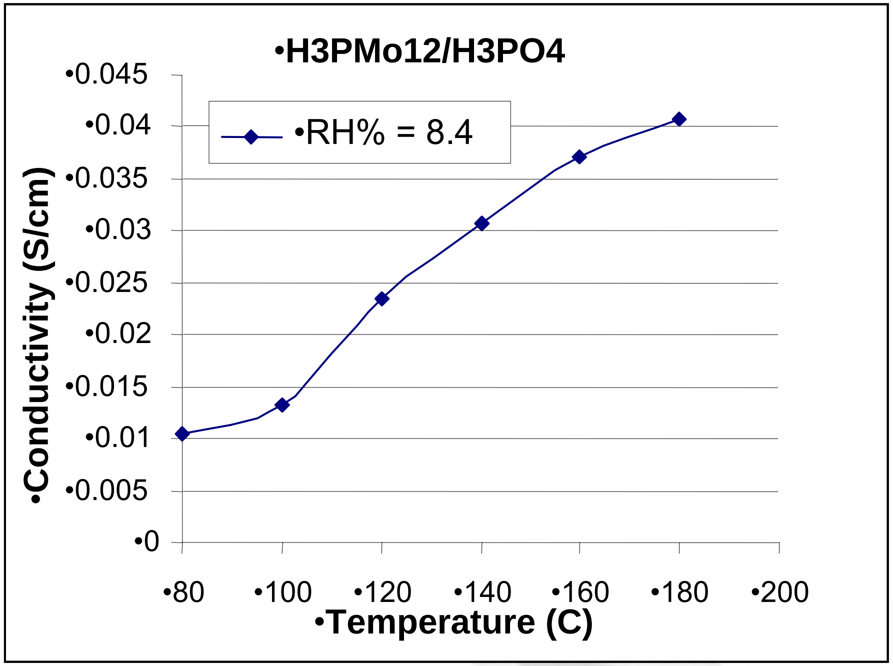


Conductivity of $Cs_{2.5}H_{0.5}PMo_{12}O_{40}$ (CsPOM)/ PBI membrane doped in H_3PO_4 compared to PBI doped in H_3PO_4

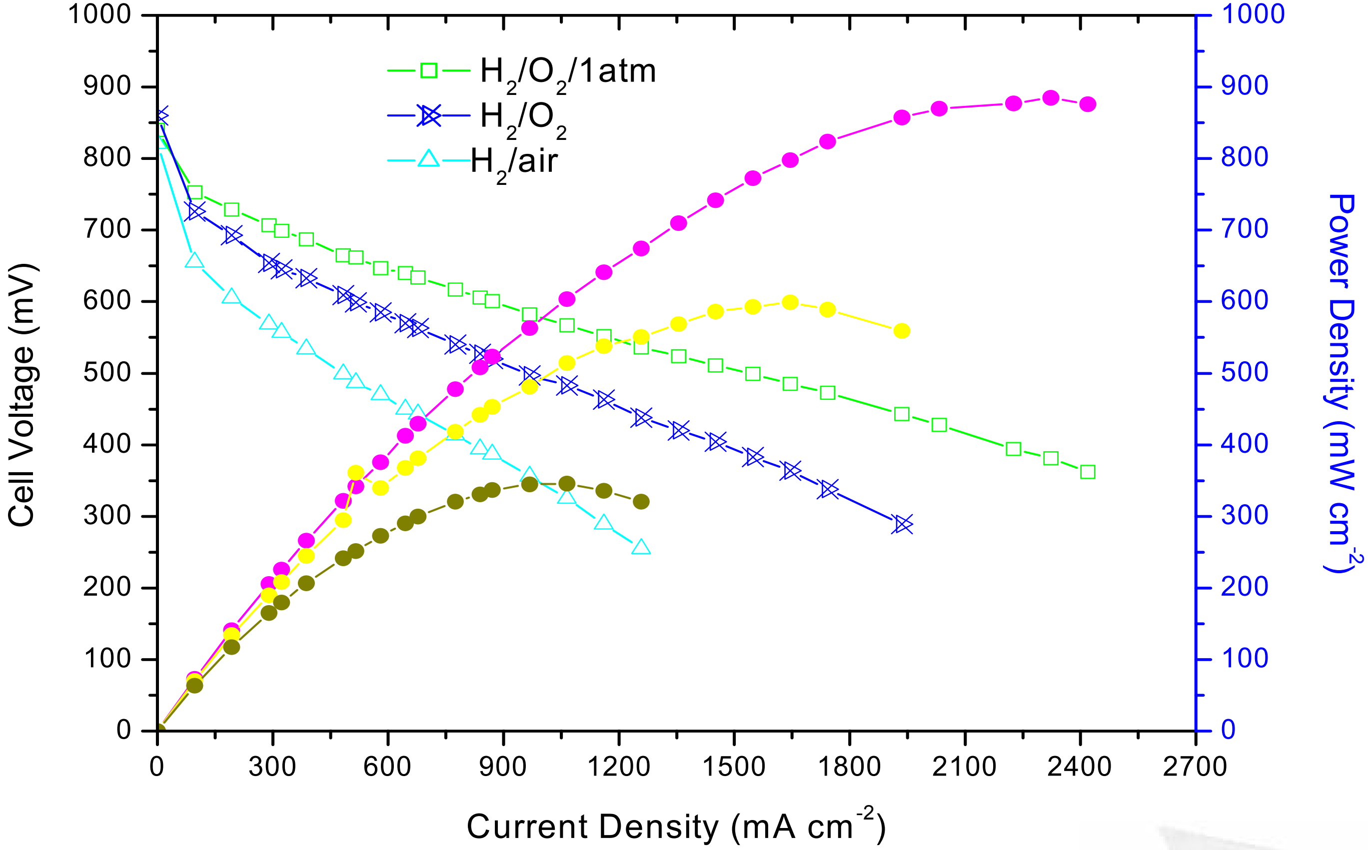
Other Composite Higher temperature PEM electrolytes

Mixed acid proton conductor immobilised in PTFE



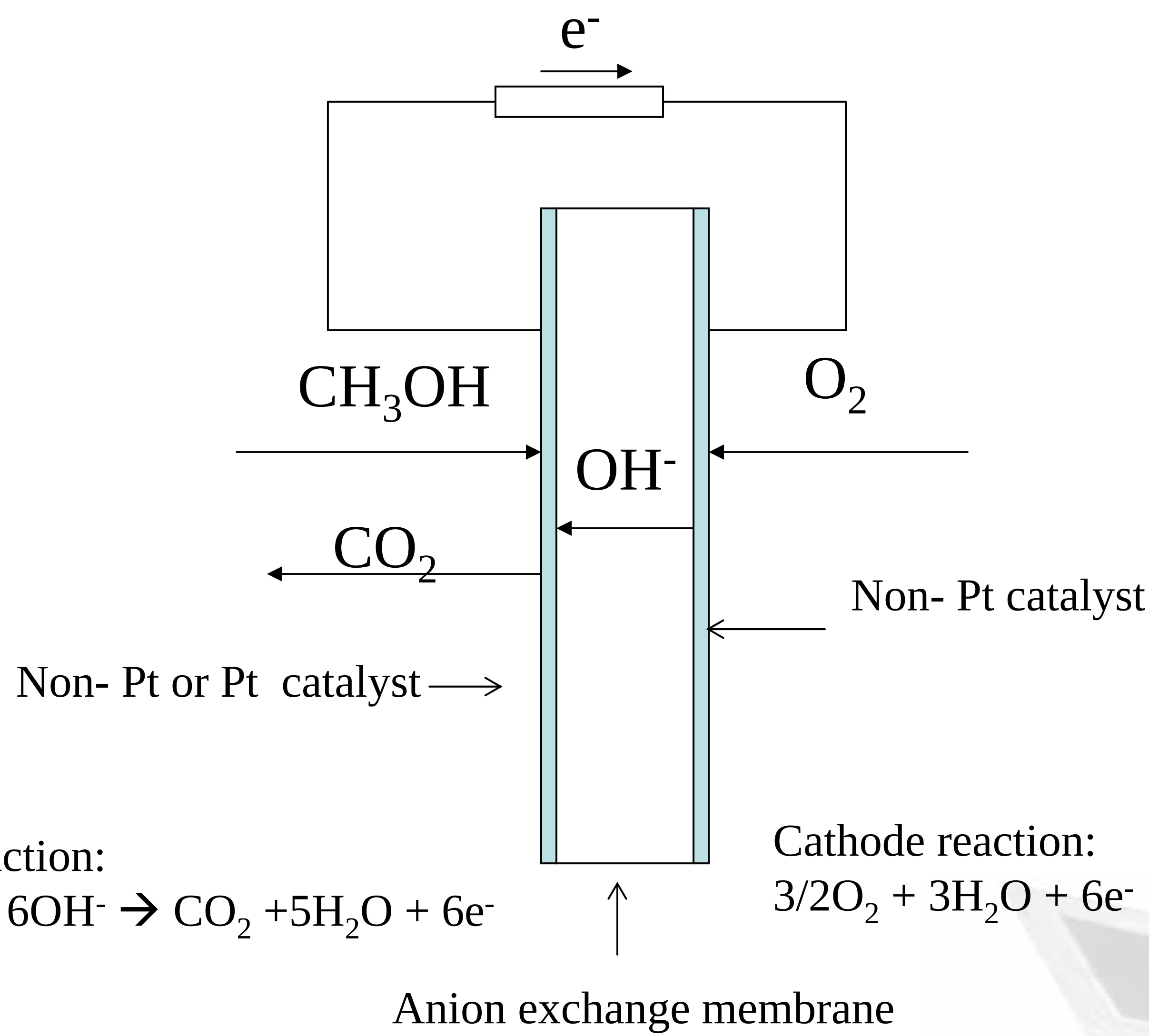


Polarization and power density of a PEMFC with PBI membrane



PBI membrane doped on H_3PO_4 . Temperature: 175 °C, Loading Pt: 0.95mg/ cm^2

Direct Methanol Alkaline Fuel Cell



Anode reaction:

$CH_3OH + 6OH^- \rightarrow CO_2 + 5H_2O + 6e^-$

Cathode reaction:

$3/2O_2 + 3H_2O + 6e^- \rightarrow 6OH^-$

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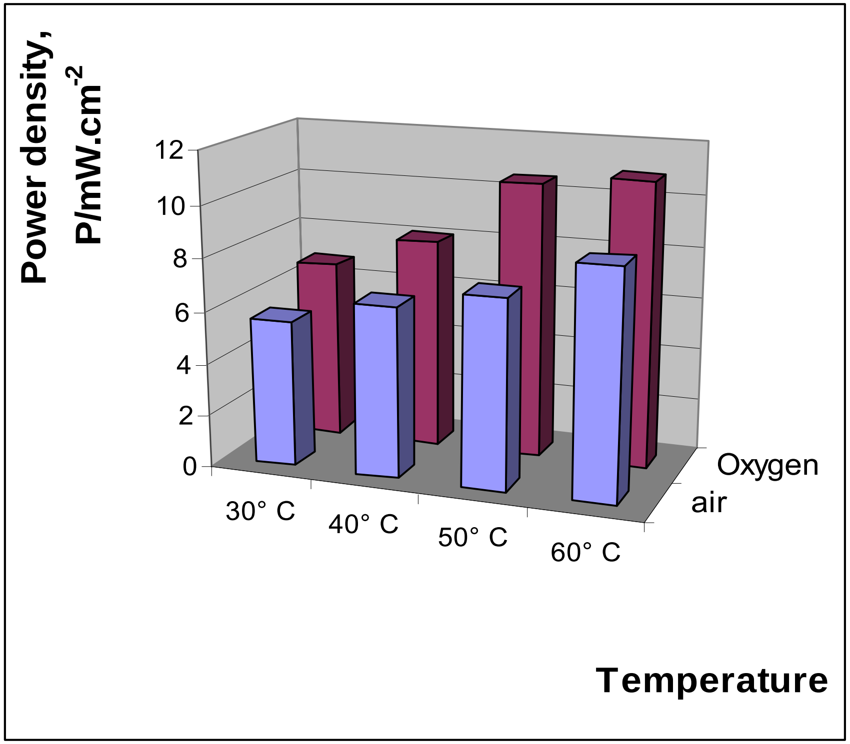
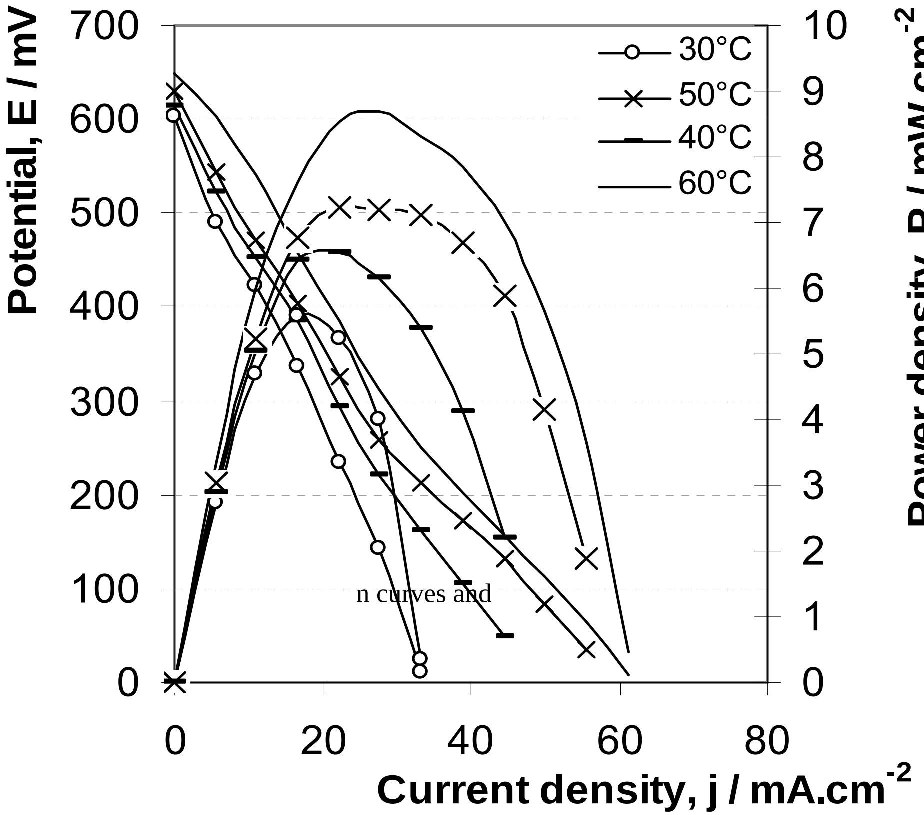
DMAFC

-Low power densities due to un-optimised ptfe bonded electrodes





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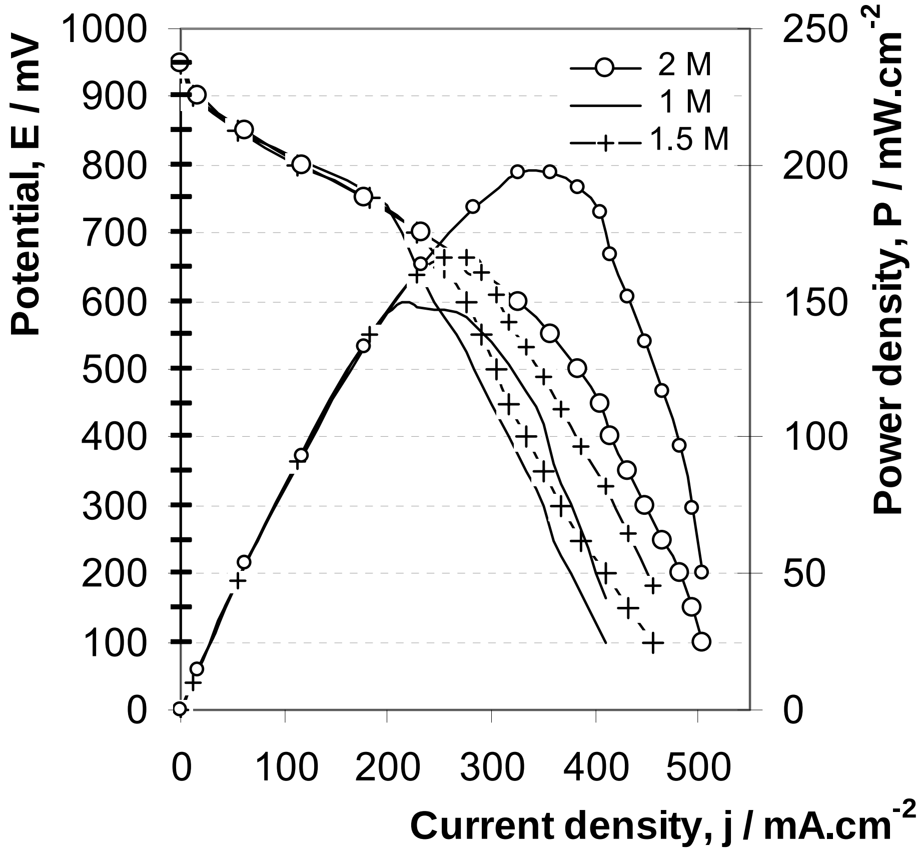
Sodium Borohydride Fuel Cell

Pt/Ru anode, Pt cathode, anion exchange membrane. Power Densities > 0.12 W/cm2 air

Attractions of the DBFC:

- High theoretical open circuit voltage of 1.64 V
- High energy density of 9285 W h (kg NaBH4)$^{-1}$; **cf** 3200 Wh (kg methanol)$^{-1}$



- Anode: $BH^{4-} + 8OH^{-} = BO^{2-} + 6\ H_2O + 8\ e^-$ $\quad E_0 = -\ 1.24$ V
- Cathode: $2\ O_2 + 4\ H_2O + 8\ e^- = 8\ OH^-$ $\quad E_0 = 0.4$ V
- Overall: $BH^{4+} + 2\ O_2 = BO^{2-} + 2\ H_2O$ $\quad E_0 = 1.64$ V

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Flexible Fuel Cells

Aim to produce a portable fuel cell design that offers flexibility in application, and can use several liquid based fuels.

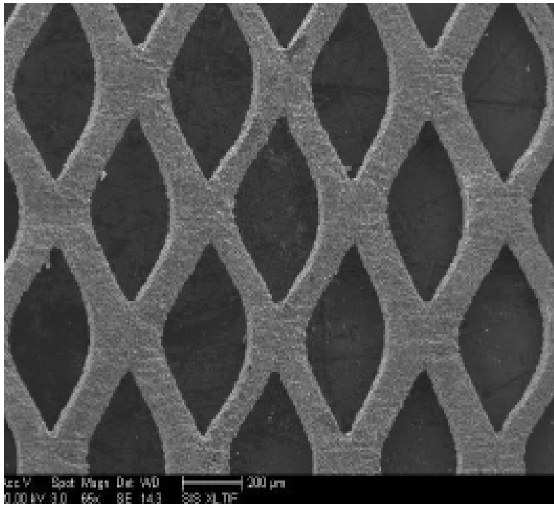
Optimisation of electrocatalysts

Examination of oxidation of organic fuels

***e.g.* ethanol, formic acid, isopropanol, dimethyl ether, ethylene glycol, etc**

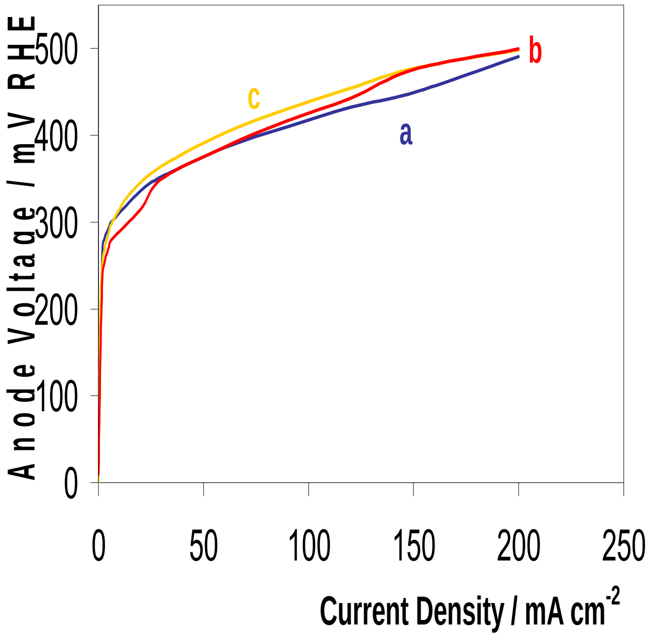
To operate at 30-60ºC with air at near atmospheric pressure.

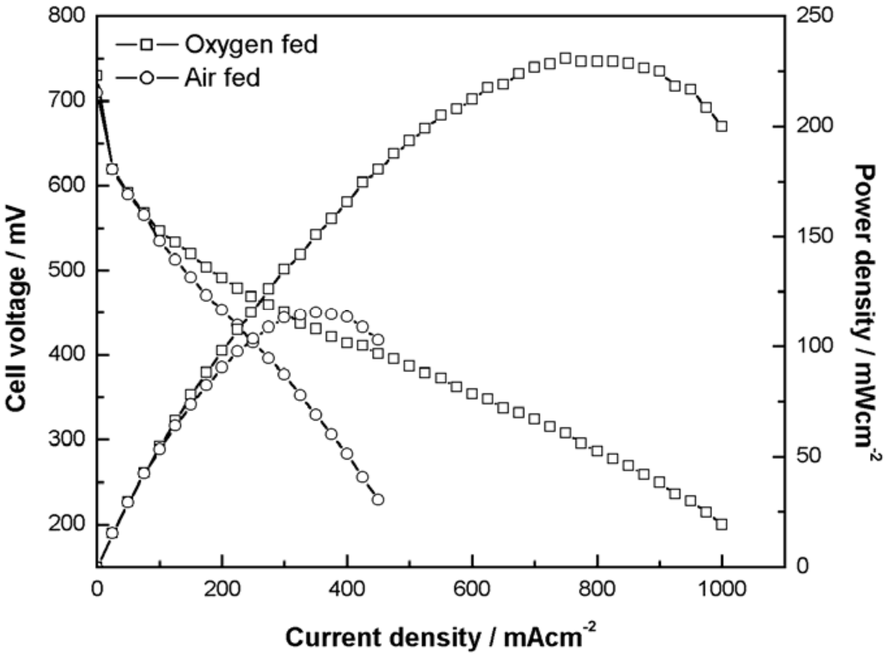
The portable fuel cell will produce 5 W power (1.2 to 2 V) using 4-6 cells.



200 μm

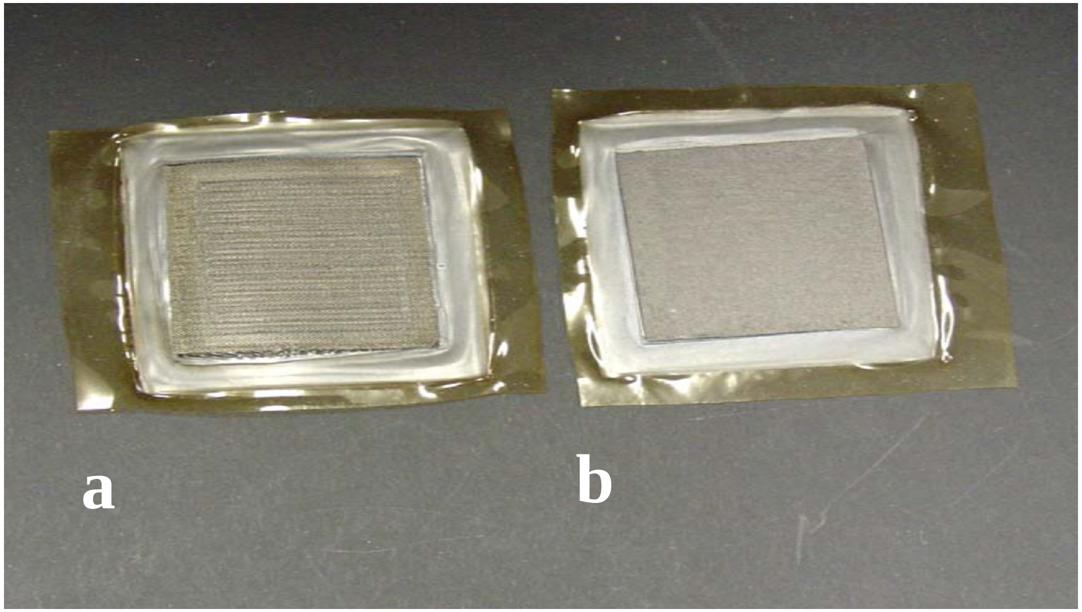
Comparison of Methanol Oxidation in 2M MeOH a. Conventional, b. Thermally Decomposed and c. Electrodeposited Pt-Ru catalysts





MEA constructions

a. Mesh based and b. regular



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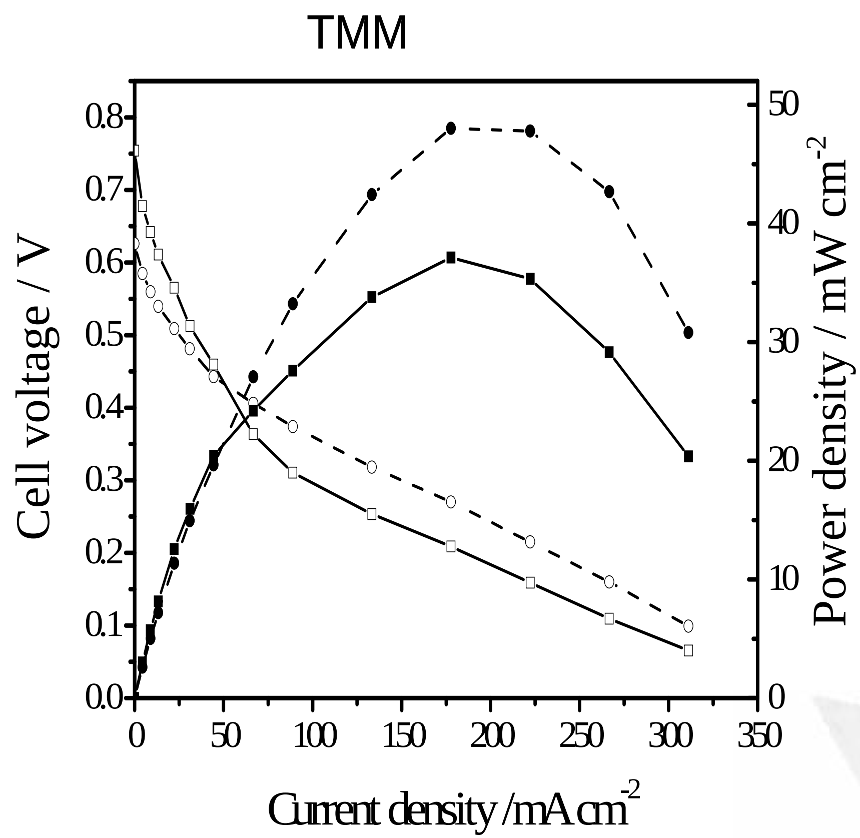
Fuel cell data- Trimethoxy methane

thermally decomposed PtRu/Ti (dotted line) and PtSn/Ti (solid line) anodes. 60oC. Anode catalyst

loading 2 mg cm-2 and cathode catalyst: 2 mg cm-2, 60 wt.% Pt/C (E-Tek).

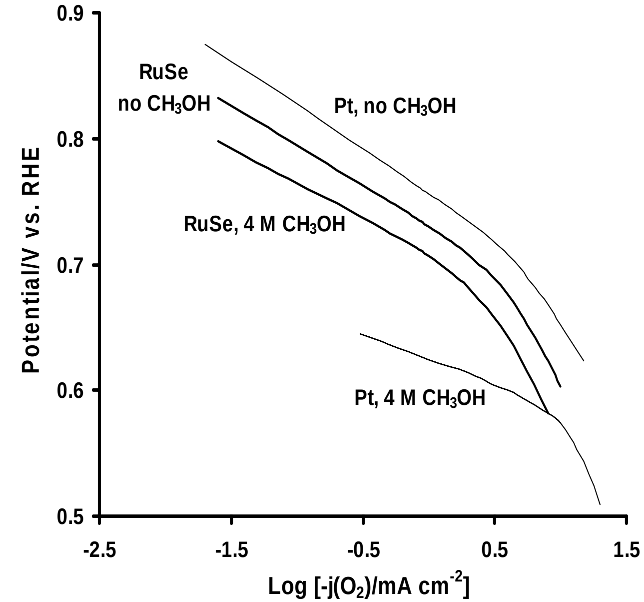


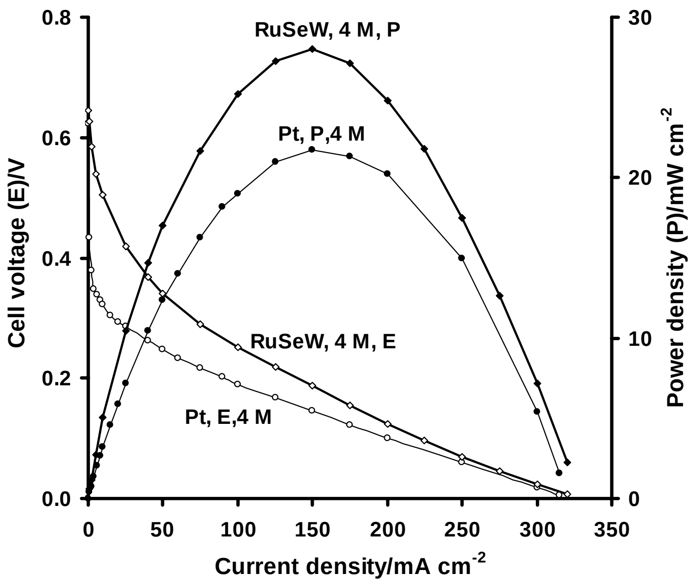
METHANOL TOLERANT CATHODES

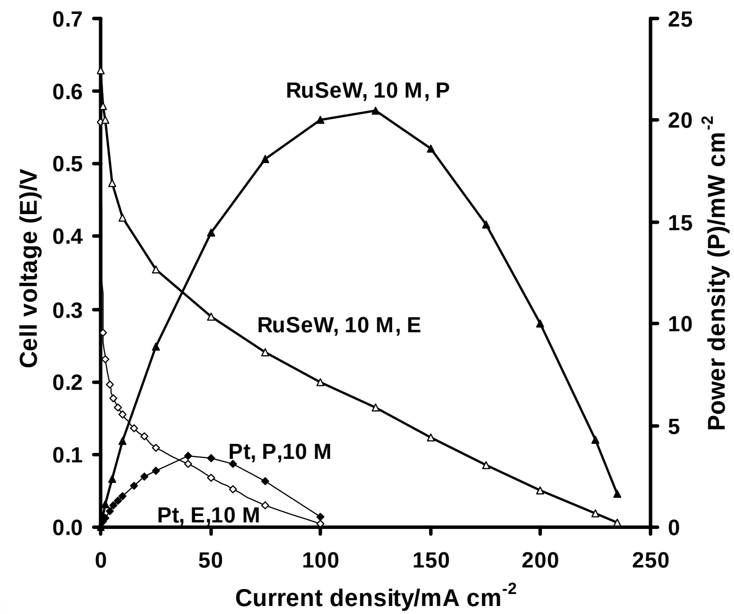
- **TETRAMETHOXYPHENYLPORPHYRIN**
  FeTMPP-Cl and CoTMPP-Cl
- **Platinum based Binary catalysts**
  Pt-Co, Pt-Cr, Pt-FeO_x
- **Ruthenium based binary and ternary catalysts**
  Ru-Se-Mo, Ru -Se , Ru-S-Mo
- **Rhodium based catalysts**

DMFC with Ru-Se Cathodes- Effect of Methanol

Concentration

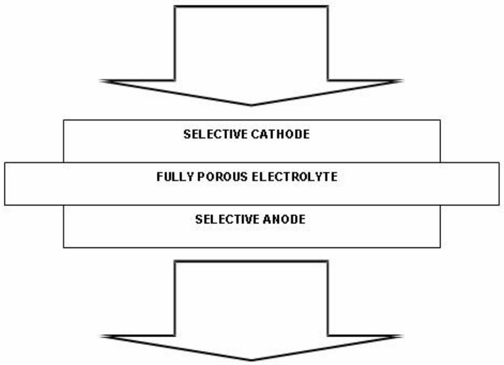






MIXED REACTANT FUEL CELL (MRFC) IS POSSIBLE

- No need for gas-tight structure within the stack- providing relaxation of sealing the reactant/products delivery structures.
- Minimum membrane thickness possible- reduced Ohmic voltage losses
- Simplified manifolding.
- No bipolar plate needed.
- Much Cheaper than conventional fuel cells.
- No fuel oxidation at cathode



Issues

- Selective electrocatalysts mandatory.
- Reduced cathode voltage
- High Ohmic resistance between neighboring cells, when a strip-electrode configuration is used.
- Increased Fuel and Oxidant Dilution.
- Crossover inevitable.
- Safety with explosive gas mixtures

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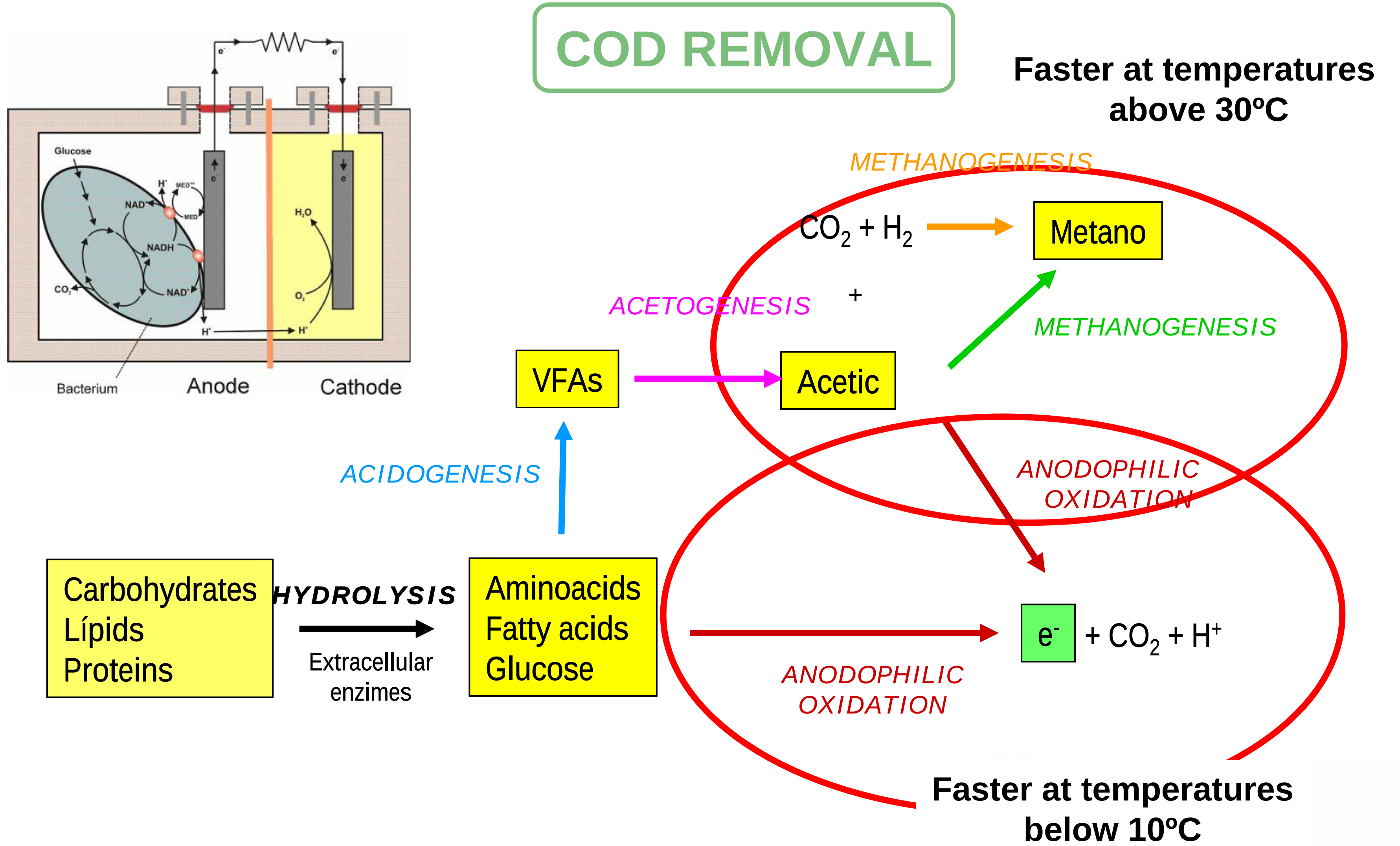
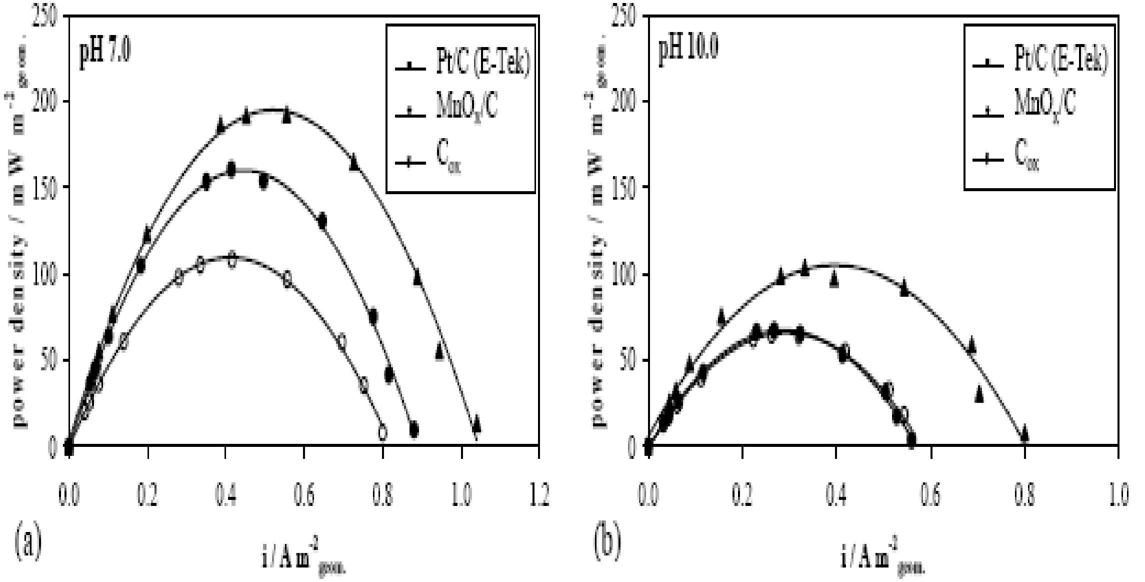
Microbial Fuel Cells



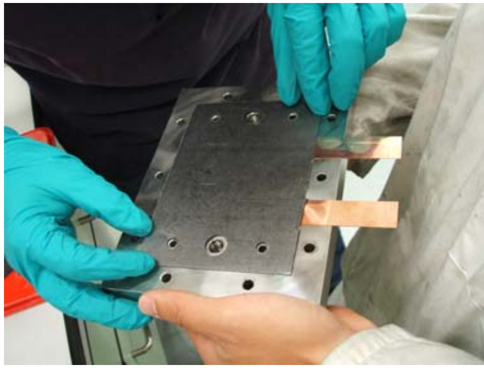
Microbial Fuel cell Power from Wastewater

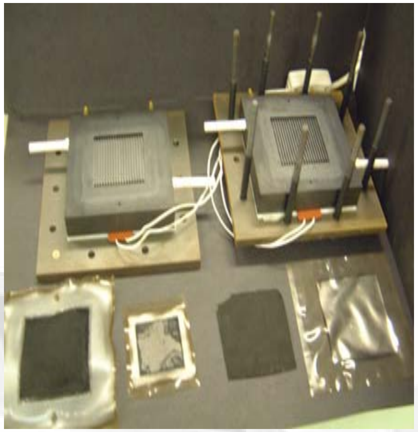


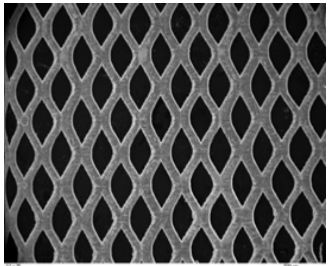
. MFC power densities curves, Pt/Vulcan XC72 (E-Tek), MnO_x/Monarch 1000

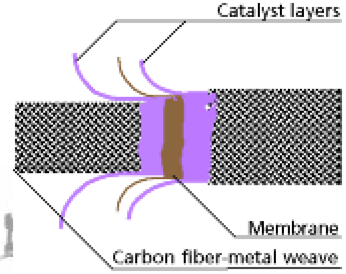
Newcastle Achievements Include

- First UK DMFC (PEM) 0.5 kW Stack in 1999
- First to demonstrate alkaline membrane in DMFC
- Titanium mini-mesh supports for anode (and cathode catalysts)
- Fabrication of tubular capillary MEA
- DMFC with methanol tolerant non-platinum catalysts
- First to demonstrate mixed reactant DMFC with PEM
- 50 W DMFC with mesh based flow fields
- Room temperature borohydride fuel cells









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EU

FURIM

Further Improvement and System Integration of High Temperature Polymer Electrolyte Membrane Fuel Cells

EUROPEAN COMMISSION
Community Research

Project partnership

Research/Industry/tasks

- **1-Technical Univ. of Denmark (DK) (coord, membranes, electrodes)**
- **2-Volvo Technology Corp. (SE) (enduse, test, model., simul., safety)**
- **3-Norwegian Univ. of Science and Technology (NO) (cat. electr.)**
- **4-Univ. of Newcastle upon Tyne (UK) (training, electr., DMFC)**
- **5-Elsam A/S (DK) (Finished task 2006) (utility application)**
- **6-Danish Power Systems ApS (DK) (MEA manufacturing)**
- **7-Case West Reserve University (USA) ("consultancy")**
- **8-University of Stuttgart (DE) (membranes)**
- **9-HyGear B.V. (NL) (reformer, system)**
- **10-Freudenberg FCCT (DE) (GDL, sealing)**
- **11-IRD Fuel Cell A/S (DK) (stacking)**
- **12-Foundation of Research and Technology (GR) (reformer cat. etc.)**
- **13-Between Lizenz GmbH (DE) (membranes, MEA)**

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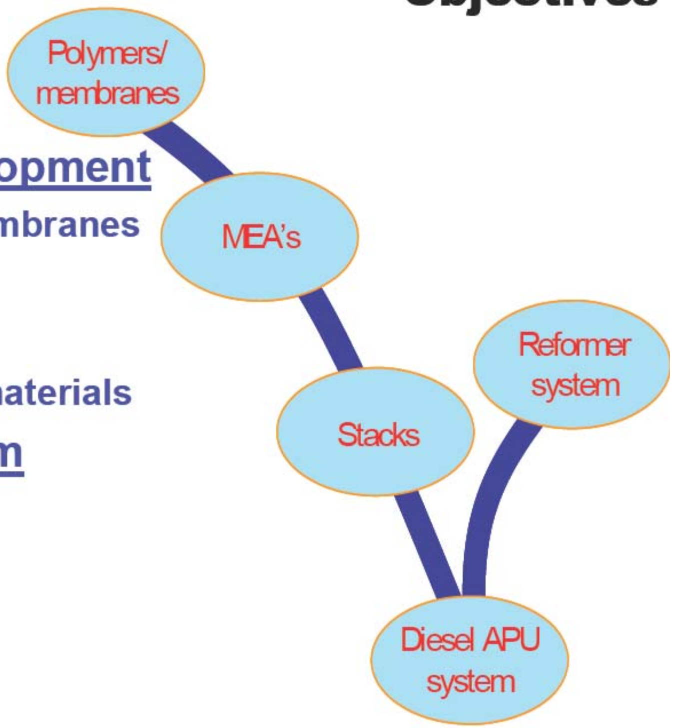
Objectives

WB0 Membrane/MEA development
- PBI modification and new membranes
- Electrodes and MEA's

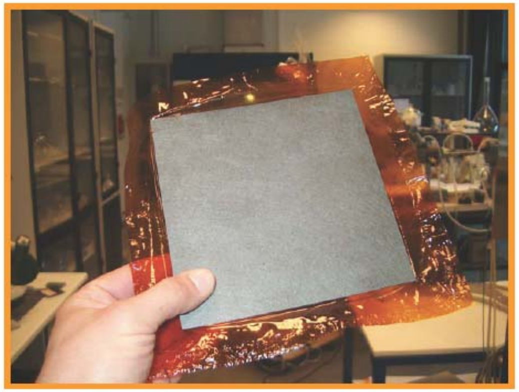
- **WB1 Stacking**
  - Updating LT to HT with new materials
- **WB2 Diesel reformer system**
  - For APU
- **WB3 Modelling/simulation**
  - Of cells and system
  - System control and safety
- **WB4 Training**
  - Workshop/symposium/summer school
  - University courses



EUROPEAN COMMISSION
Community Research

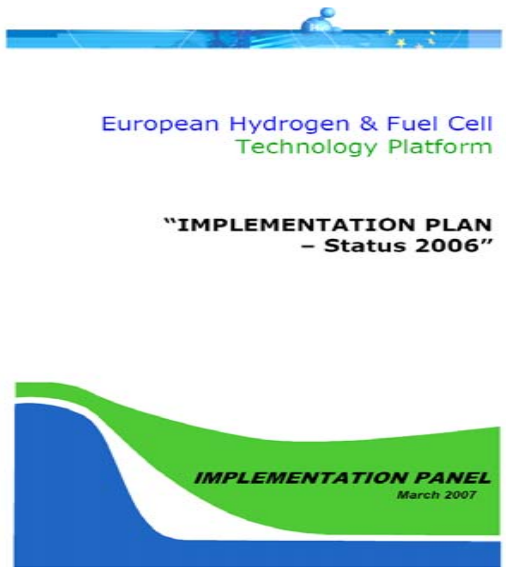
Project Achievements

- WP0 Membranes and MEA's
- Target: 0.6V - 0.7mA/cm^2

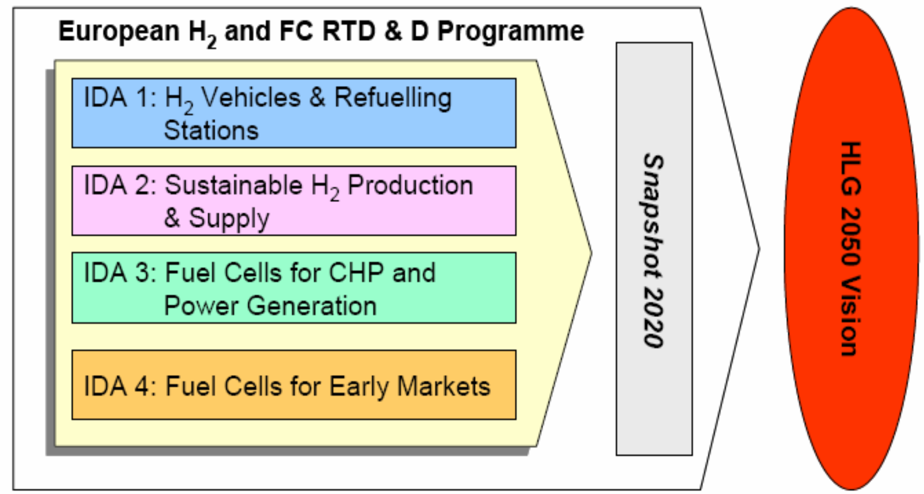


- Blend membrane
  - (DTU/DPS + U. Stuttgart/BTW)
  - PBI/SFS
  - Paper under way: Li/Kerres et al. *J. Membr. Sci.*
- Cross linking PBI (covalent)
  - Paper: Li et al. *Chemistry of Materials* (2007)
- GDL and sealing from Freudenberg
- Catalyst: Johnsson Matthey + DTU + NTNU
- Improved performance
  - 0.6V - 0.6 mA/cm^2 at 200^{o}C, H_2/air

5 kW Stack System with Diesel Reforming



Innovation and Development Actions



IDA 1 : Hydrogen Vehicles and Refuelling Stations

Goal: Improve and validate hydrogen vehicle and refuelling technologies to the level required for commercialisation decisions by 2015 and a mass market-rollout by 2020

IDA 2: Sustainable Hydrogen Production and Supply

Goal: 10-20% of the Hydrogen supplied for energy applications to be CO2 lean or free by 2015

IDA 3: Fuel Cells for CHP and Power Generation

Goal: Commercially competitive Fuel Cells for CHP and Power Generation; > 1 GW

IDA 4: Fuel Cells for Early Markets

Goal: X000 commercial early market FC products in the market by 2010.

The target for this IDA, on the way to reaching the "Snapshot 2020" milestone, is to achieve cumulative production of 200MW (circa 20,000 units) not later than 2012.

Water Electrolyser Research in the EU

- **Medium temperature PEMs are an important topic of the Strategic Research Agenda and of the scoping paper for collaborative R&D in the International Partnership for the Hydrogen Economy.**

  The European Community funded strategic research on hydrogen electrolysers and related PEMFC technology and materials includes:

- **Development of low temperature high pressure PEM electrolyser.**

  Under FP5 (1999-2002) HYSTRUC

- **Develop small scale low temperature PEM electrolysers.**

  GenHyPEM [http://www.genhypem.u-psud.fr; 2005-2008] 1.1 M euro 6 partner

- **Solid oxide electrolysers**

  Under FP6, Hi2H2, a STREP with 4 partners 1.1M euro

- **Lower temperature PEM electrolyser (120 oC).**

  In 2008 "small and medium scale focused research project" on "New material processes for advanced electrolysers" (WELTEMP) with 6 partners (2.38M euro).

Conclusions

Fuel Cell Applications Continue to Increase Rapidly

Hydrogen Fuelling Stations beginning to appear

Electrolyser Future Market Size Expanding

Year	2010	2020	2030	2040	2050
UK H_2 production potential from wind+marine+solar (TWh)	9.8	103	197	289	383

A report produced by Professor Marcus Newborough

SUPERGEN Fuel Cells powering a greener future

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