Oxidation catalyst for direct ethanol fuel cell: A target technology for on site power generation

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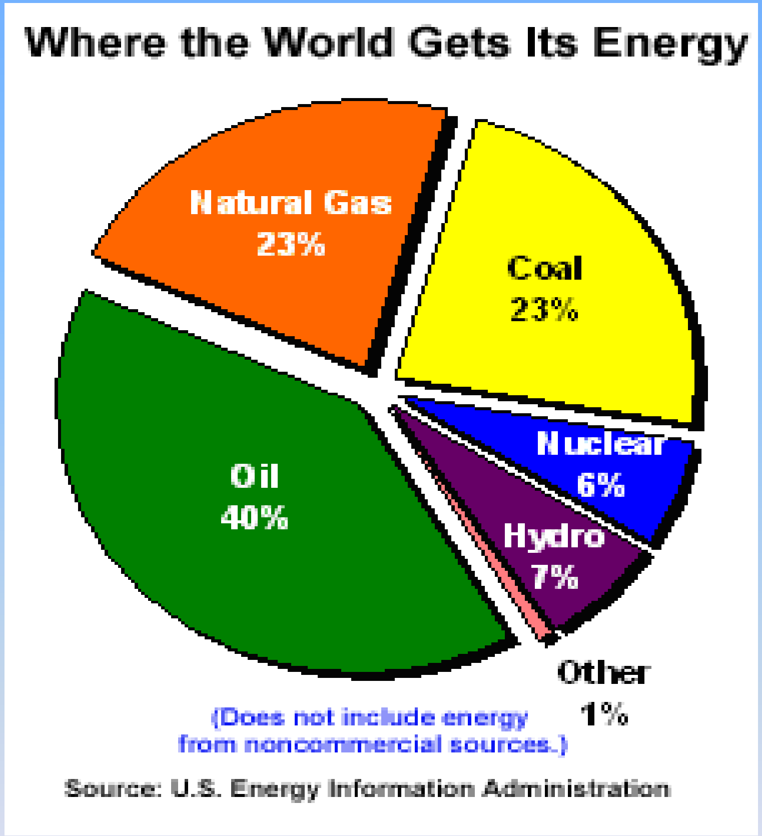
Global Energy Scenario

“A serious threat to further progress of human civilization”

- **Advancement in civilization is measured according to per capita consumption of power in a country.**
- **Modern society is sustained so far by fossil fuels (coal, oil & natural gas), without any replenishment.**
- **Burning of fossil fuel leads to emission of pollutants CO_2, CH_4, CO, NO_x, SO_x, CFC, etc.**

Thus, distorted climatic and associated eco-imbalance has led to the emergence of global consciousness for exploring the alternate / non-conventional energy sources.

World's major sources of energy today



Where the World Gets Its Energy

(Does not include energy from noncommercial sources.)

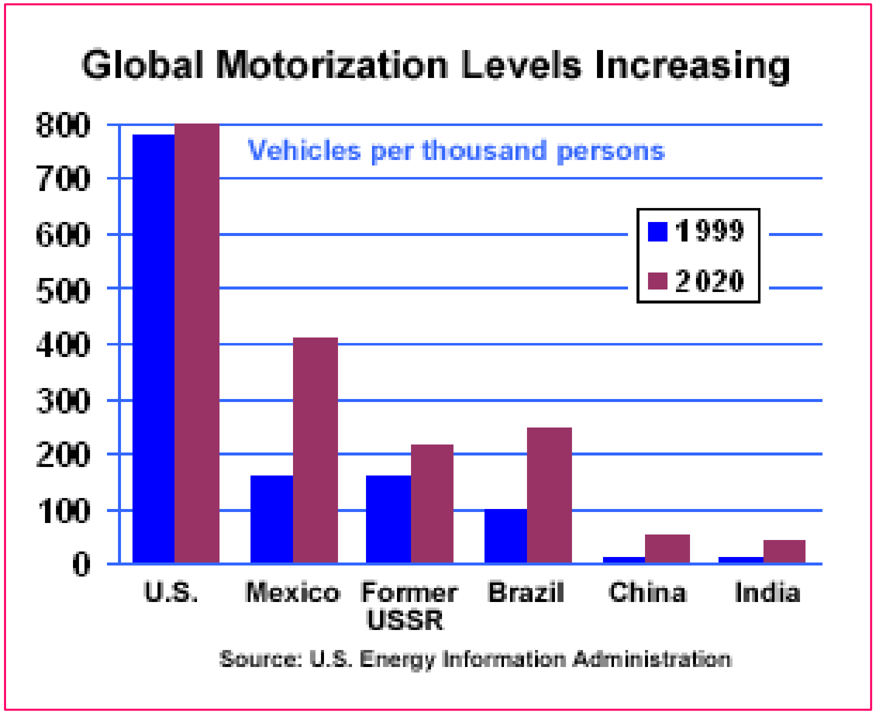
Source: U.S. Energy Information Administration

A negligible, but growing, portion of power generation is being furnished by renewable resources.

Energy Consumption for Transportation

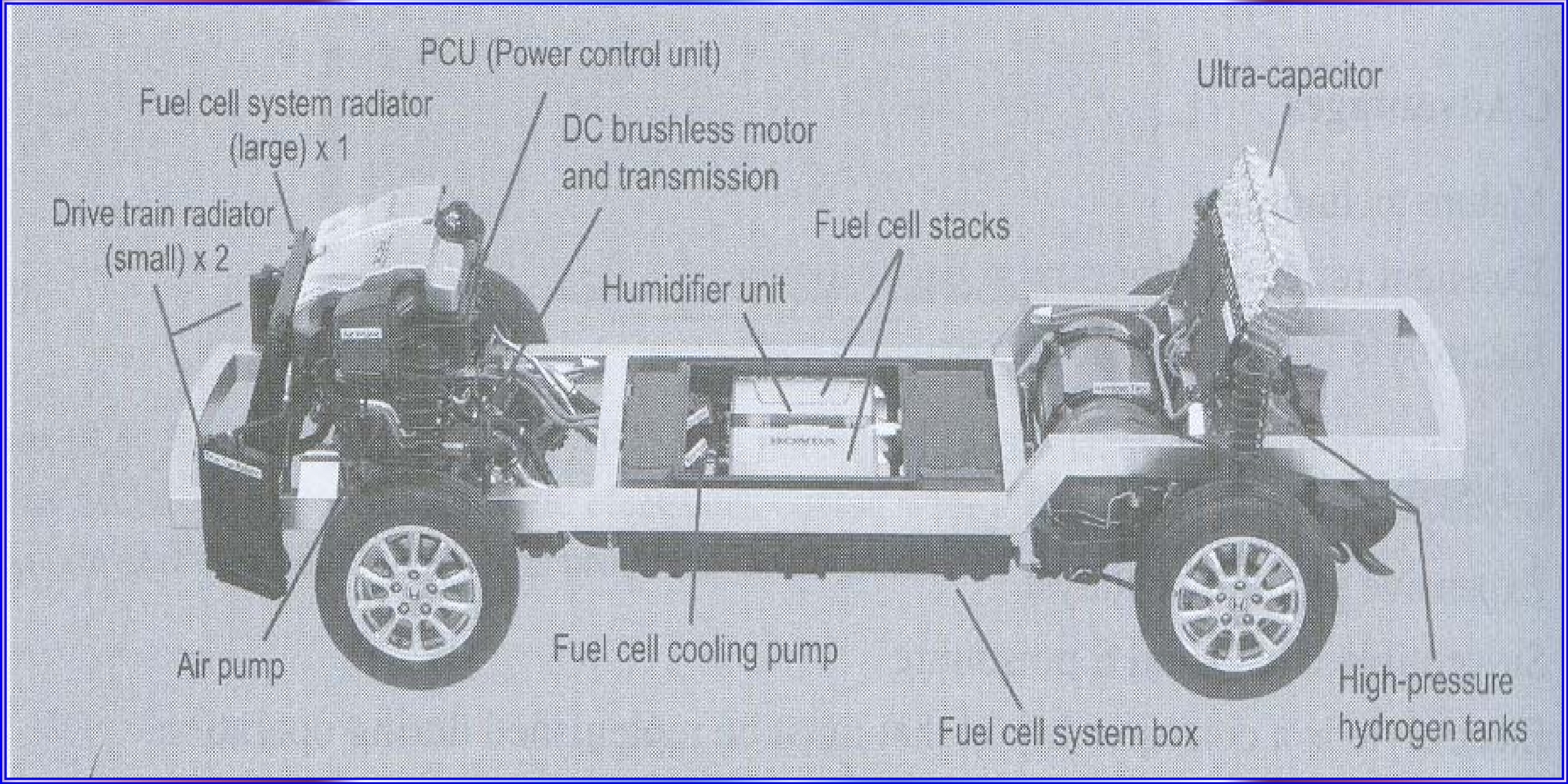
About 60 percent of all crude oil goes to make **transportation fuels**

- Motor vehicle ownership is increasing throughout the world.
- Trend is accelerating demand for oil-based transportation fuels, especially for the developing countries.



Source: U.S. Energy Information Administration

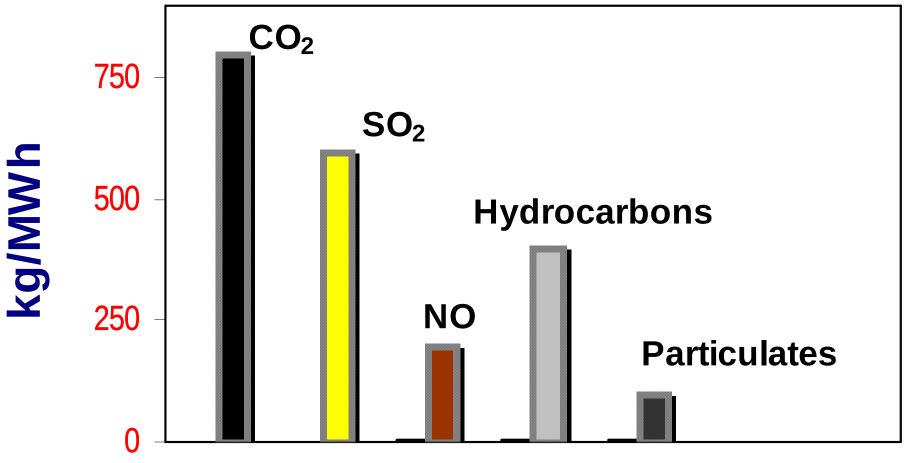
A Dream that may come true !



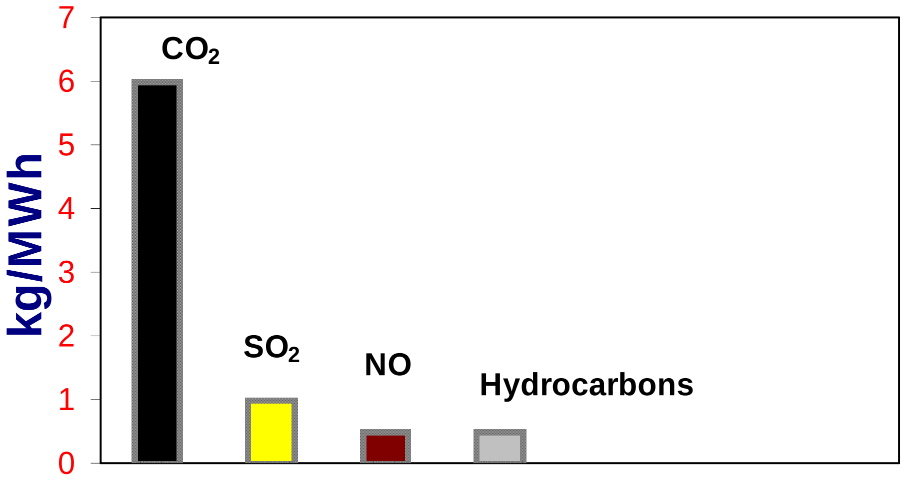
Honda FCX Fuel Cell Power car.

2 PEMFC Stacks Generate 86 KW of Electricity

Comparison of GHG emissions from the power plants of today & Fuel Cells

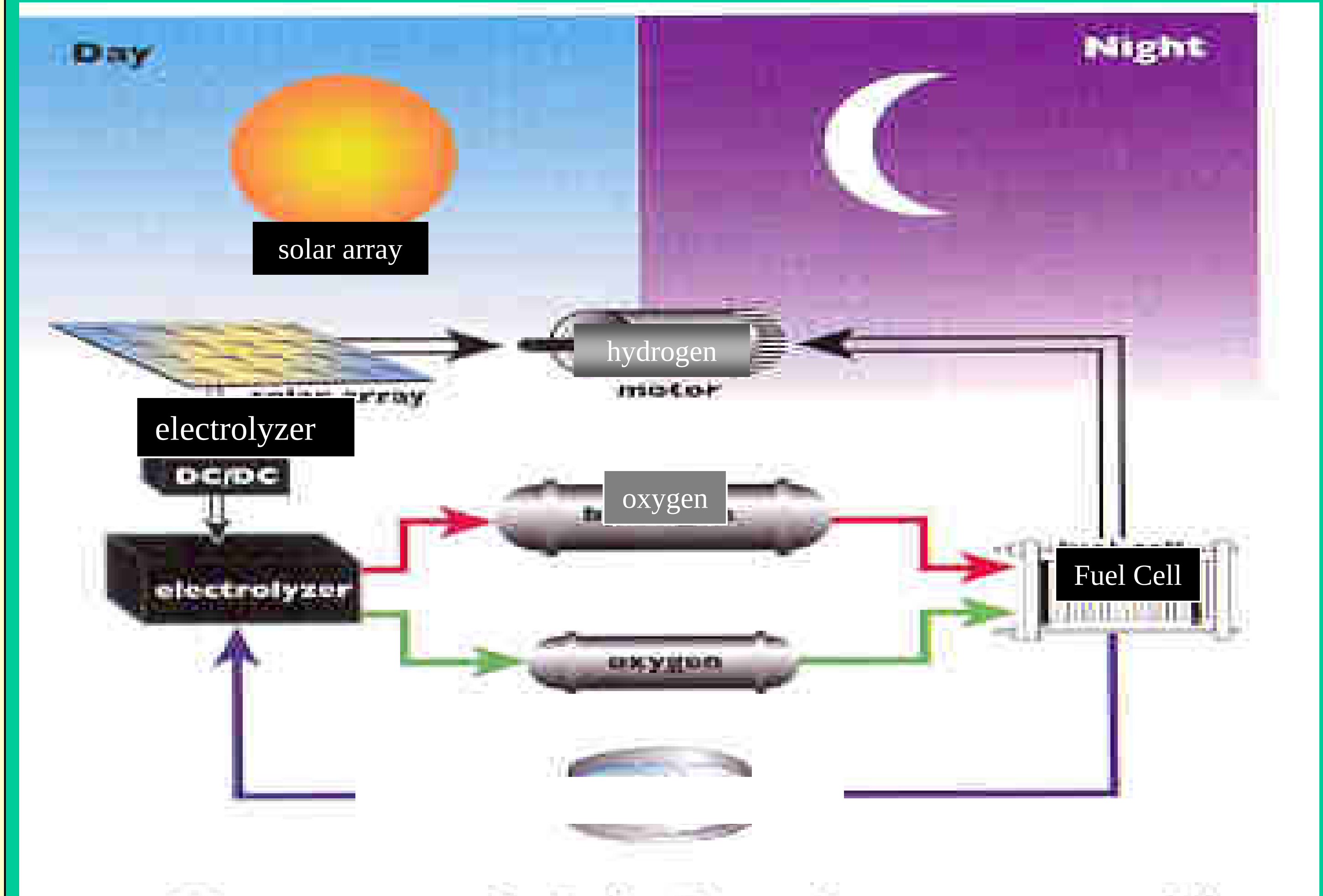


Thermal power plants
(Coal based)



Emission data from fuel cell
(NG based)

“Hydrogen Economy”

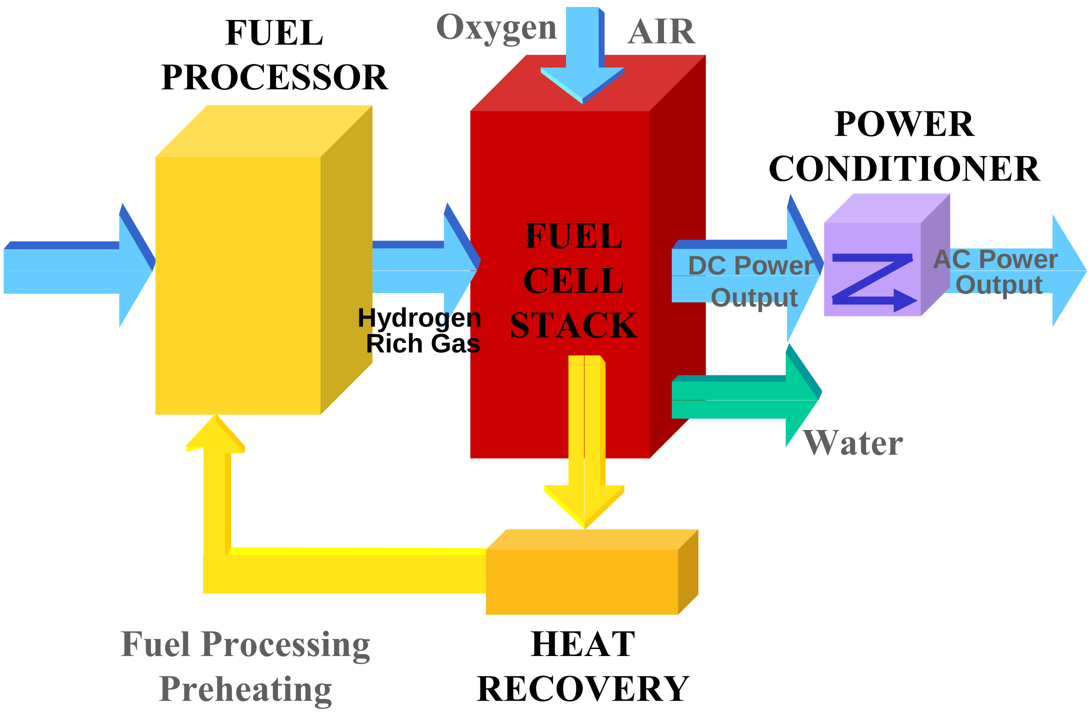


Renewable regenerative fuel cell utilizing the energy source of the sun to produce power (Courtesy: Aerovironment)

WHY HYDROGEN ?

- Potentially an inexhaustible supply of energy
- Can be produced from several primary energy sources
- Reduced dependence on fossil fuels if produced from renewable sources
- Potential environmental benefits
- High energy conversion efficiency by use of H_2 in Fuel Cells(UPTO 90%) in place of I.C. engines (30-35%)

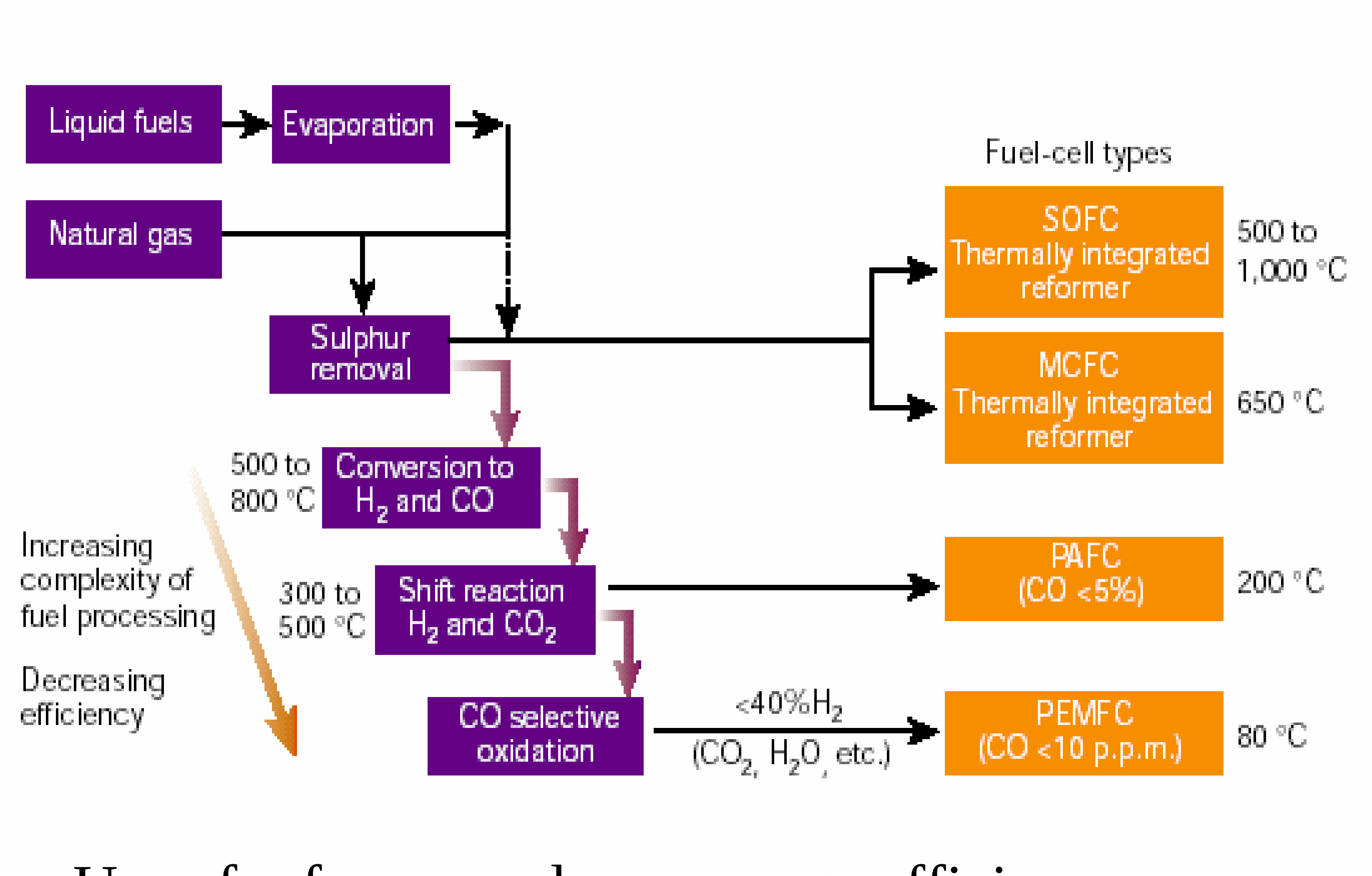
Fuel cell power pack



Main Components

- **Fuel Processor** : Fuel processor is an integrated unit used for the conversion of raw fuel to hydrogen rich gas suitable for the fuel cell
- **Fuel Cell Stack** :The hydrogen rich gas and oxygen (air) are fed to fuel cell stack to generate DC power
- **Power Conditioner:** The DC power output is converted into useful AC power

Fuel Processing

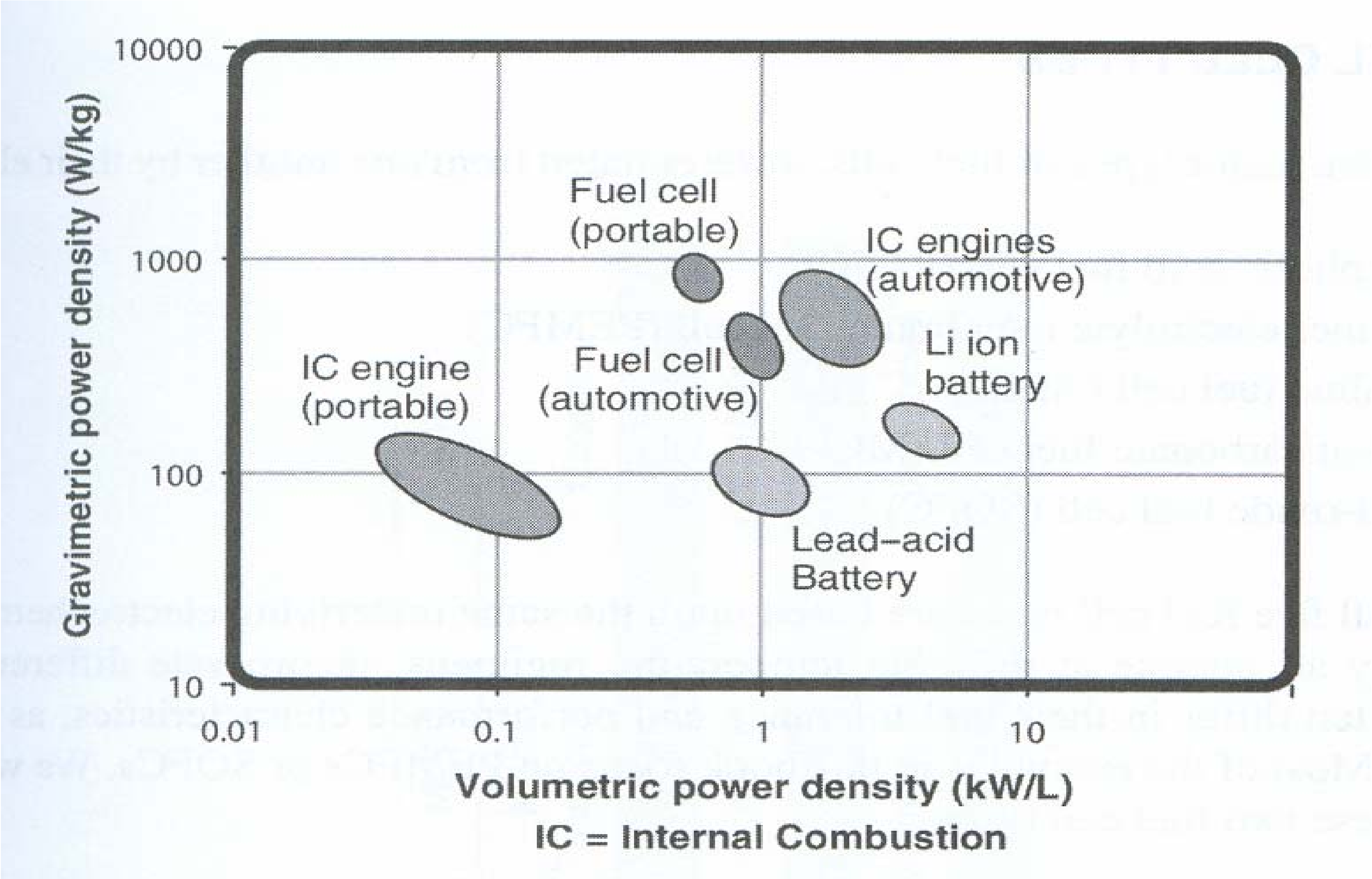


Use of reformer reduces energy efficiency

Fuel Cells are silent

Virtually zero emission

Independent scaling between power and capacity



IC = Internal Combustion

Power Density Comparison of Selected Technologies

Suitability of Direct Alcohol Fuel Cell (DAFC) in the Indian Scenario

- **Does not require infrastructure for H_2 storage**
- **No need of reformer**
- **Liquid fuel is compatible to existing storage & delivery infrastructure**
- **Zero Green House contribution to the environment**
- **Non-toxic (ethanol)**
- **Naturally available & renewable**
- **High energy density of the fuel**

Feasibility of alcohol as fuels

- Electrochemical oxidation of some alcohols: Thermodynamic data

Fuel	ΔG^o (kJ/mol)	E_{cell} (V)	W_e (kWh/kg)
CH_3OH	-702	1.213	6.09
C_2H_5OH	-1325	1.145	8.00
C_3H_7OH	-1853	1.067	8.58

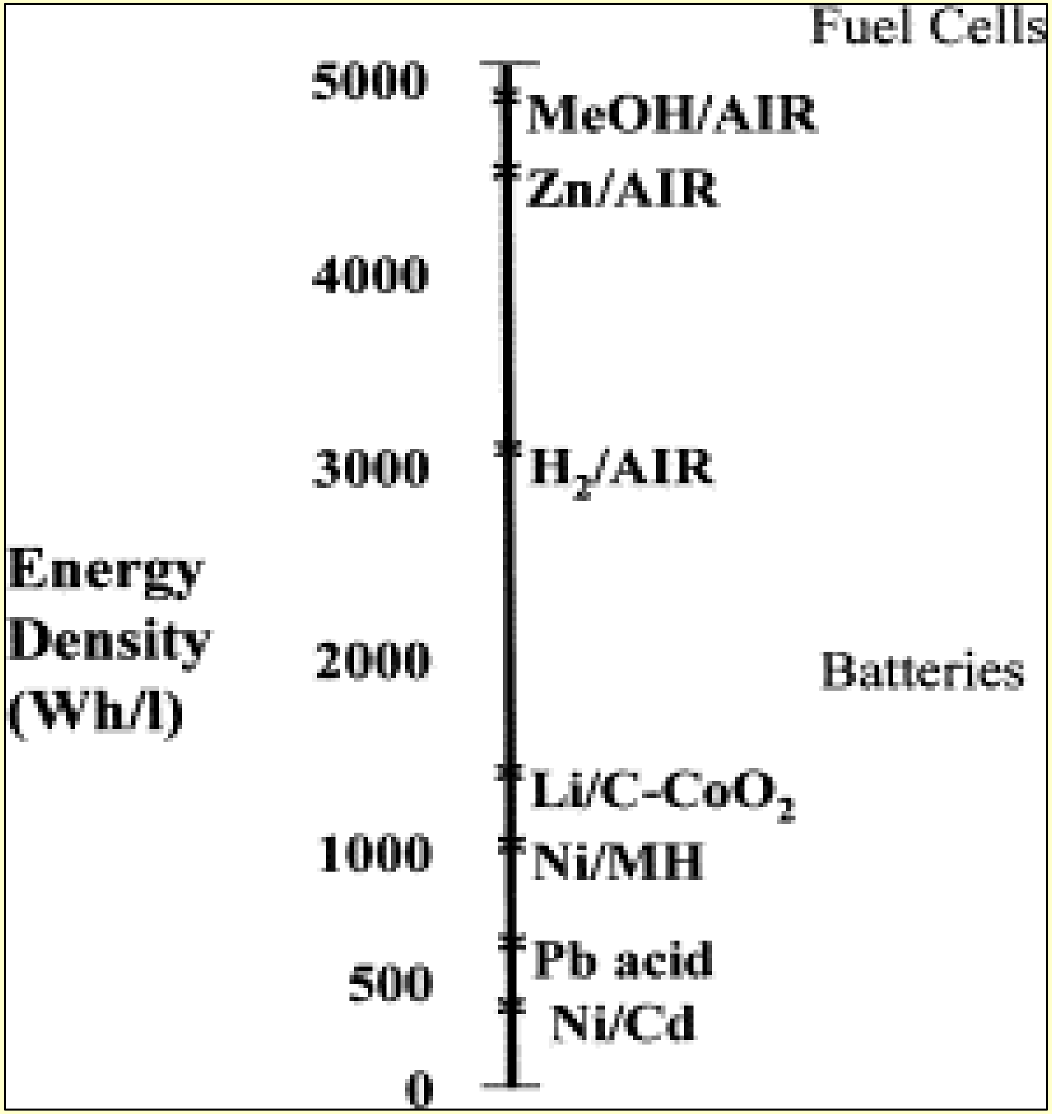
- Number of electrons exchanged increases with higher alcohols:

$$CH_3OH + H_2O \rightarrow CO_2 + 6\,H^+ + 6\,e^-$$

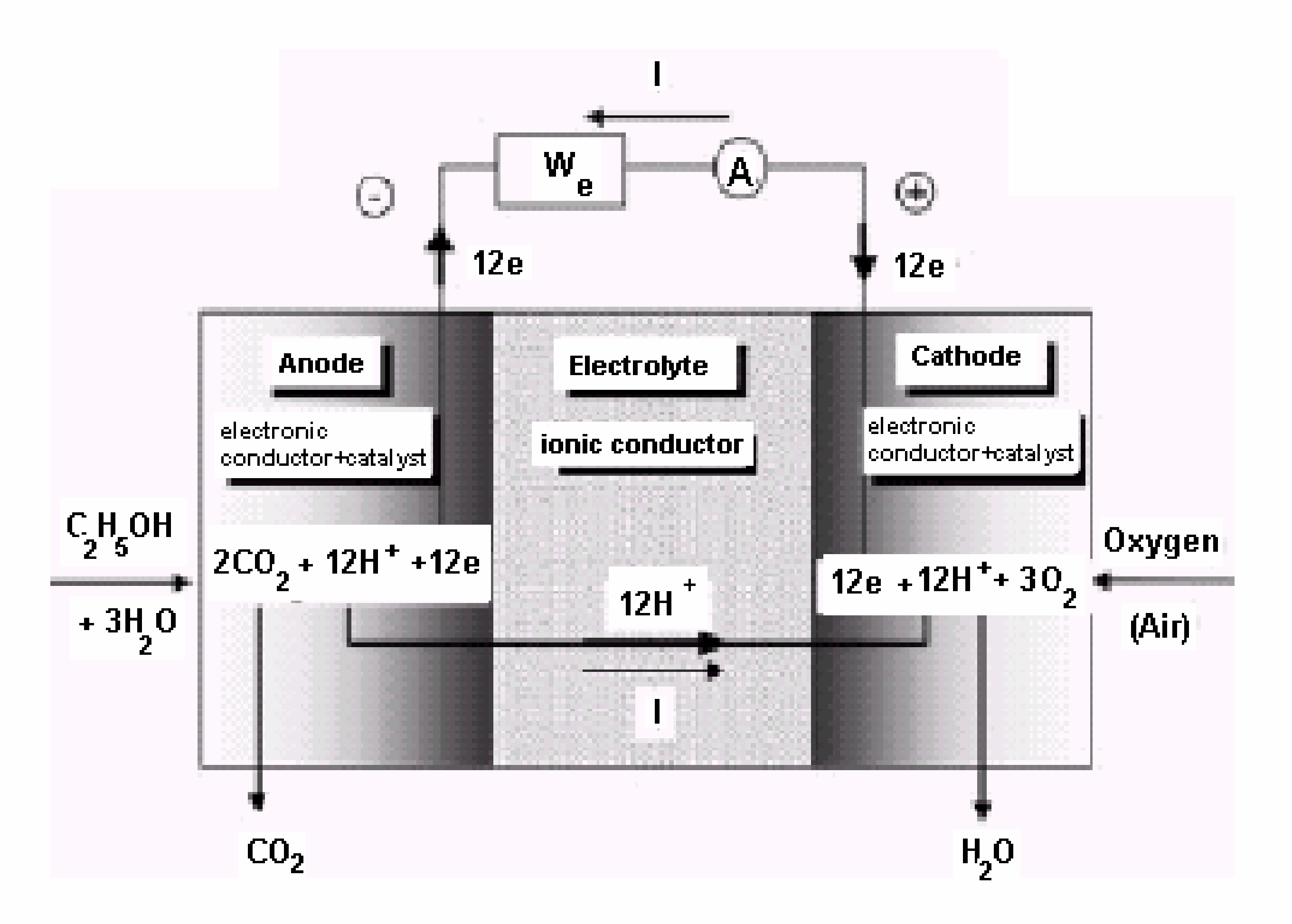
$$C_2H_5OH + 3\,H_2O \rightarrow 2\,CO_2 + 12\,H^+ + 12\,e^-$$

$$C_3H_7OH + 5\,H_2O \rightarrow 3\,CO_2 + 18\,H^+ + 18\,e^-$$

Comparison of energy densities of batteries & fuel cells



Schematic principle of a direct ethanol fuel cell



Ethanol Electro-oxidation

Major issue for C_2 compounds

- Choice of electrode material depends on substrate, catalysts, method of preparation, modifications
- Mechanism of electro-oxidation.
- Requirement of CO-tolerant catalysts.
- Complete oxidation hindered due to electrode poisoning.
- Influence of Second or third additives to provoke scission of C-C bond.
- Interaction between catalysts and support (Carbon Nano tube / Vulcan XC-72/metals & alloys).

Possible pathways of ethanol electro-oxidation

$$M + CH_3\text{-}CH_2OH \rightarrow M\text{-}CHOH\text{-}CH_3 + H^+ + e^- \qquad (1a)$$

$$M\text{-}CHOH\text{-}CH_3 \rightarrow M\text{-}CHO\text{-}CH_3 + H^+ + e^- \qquad (1b)$$

$$M\text{-}CHO\text{-}CH_3 \rightarrow M\text{-}CO\text{-}CH_3 + H^+ + e^- \qquad (1c)$$

$$M\text{-}CO\text{-}CH_3 + M \rightarrow M\text{-}CO + M\text{-}CH_3 \qquad (2)$$

$$M + H_2O \rightarrow M\text{-}OH + H^+ + e^- \qquad (3)$$

$$M\text{-}CO + M\text{-}OH \rightarrow 2M + CO_2 + H^+ + e^- \qquad (4)$$

Ethanol can also react with adsorbed hydroxyl species directly to produce acetate via a four-electron oxidation pathway:

$$C_2H_5OH + M\text{-}OH \rightarrow M\text{-}CH_3COO + 4H^+ + 4e^- \qquad (5)$$

An efficient electrocatalyst should facilitate each of the processes:

1) **dehydrogenation**
2) **C-C bond cleavage**
3) **CO_{ads} oxidation**

for complete conversion of ethanol to CO_2.

In addition

4) **water activation** at low electrode potential is important for the subsequent CO_{ads} oxidation step

Pt

- **Platinum is the best-known catalyst for the dissociative adsorption of small organic molecules, including ethanol.**
- **However, it has limited catalytic activity for breaking the C-C bond.**

Oxophilic metals….. Ru, Sn, Mo

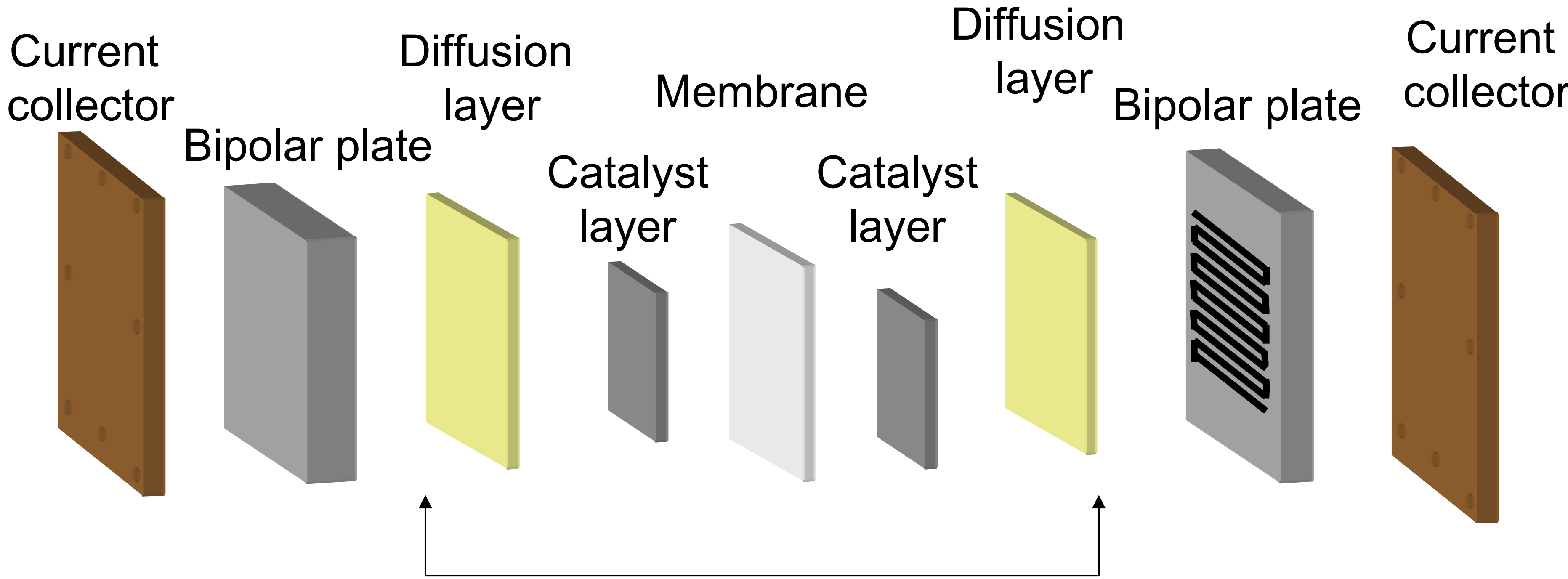
- The most studied binary catalysts for methanol oxidation, PtRu, PtSn, PtMo operate through a so-called bi-functional mechanism.
- The dissociative adsorption of methanol occurs on Pt. Ru, Sn or Mo is able to adsorb water dissociatively forming OH species at less anodic potential than Pt, with the result that CO_{ads} can be oxidized at a lower potential.

$$M + H_2O \rightarrow M\text{-}OH + H^+ + e^-$$

$$Pt\text{-}CO + M\text{-}OH \rightarrow Pt + M + CO_2 + H^+ + e^-$$

- However no evidence of Ru, Sn or Mo facilitating C-C bond cleavage has yet come to light.

Schematic illustration of DE-PEMFC Components



Current collector

Bipolar plate

Diffusion layer

Catalyst layer

Membrane

Catalyst layer

Diffusion layer

Bipolar plate

Current collector

Membrane Electrode Assembly
(MEA)

HEART OF THE CELL

Designing & Fabrication of MEA

I.

A) Catalysts ink with PTFE or Nafion spread on to diffusion layer to form electrode.

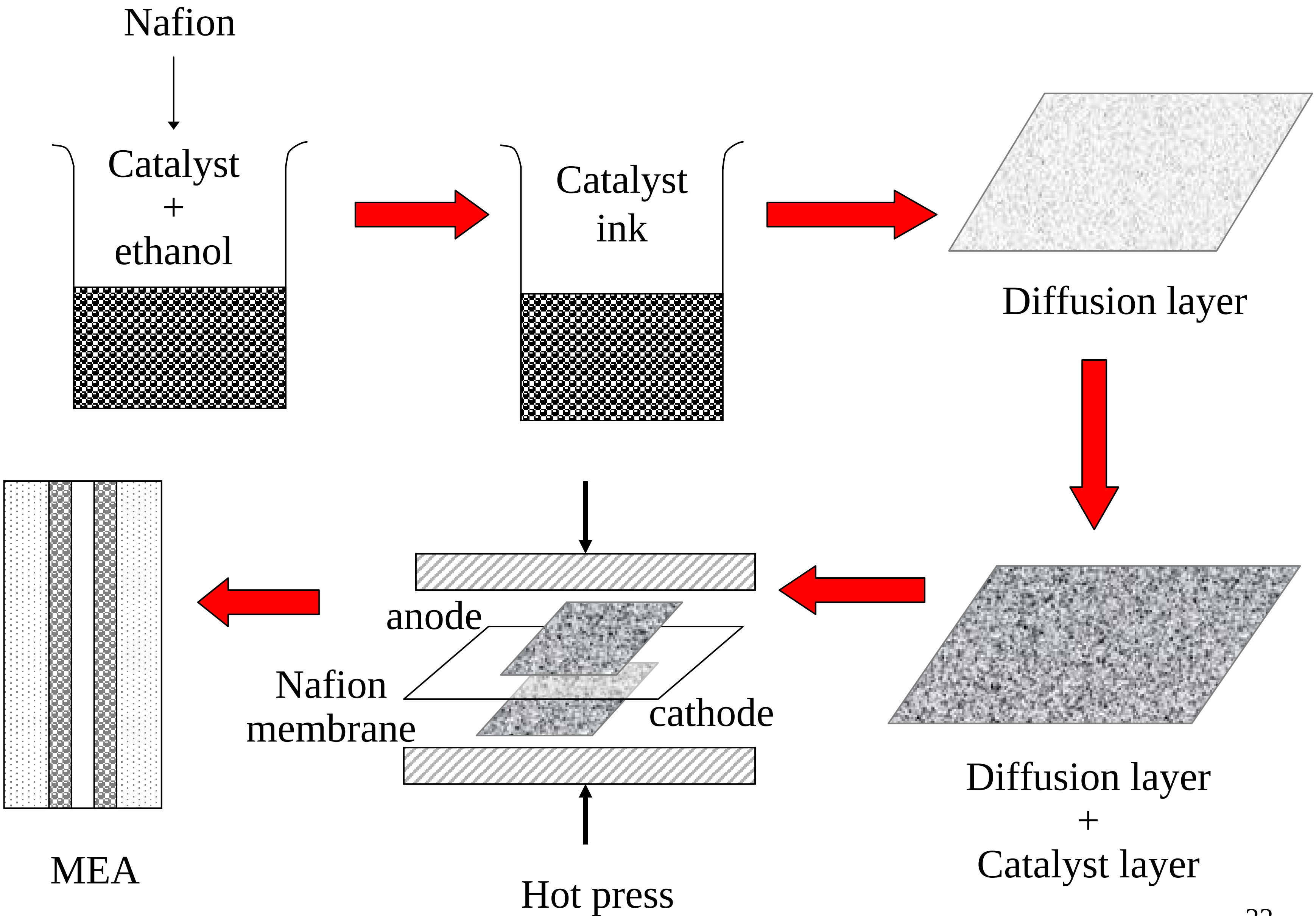
B) Electrode fixed to each side of the membrane & hot pressed.

II.

A) Catalysts fixed directly onto electrolyte membrane to form catalysts coated membrane.

B) Hot pressing the CCM with diffusion layers.

Schematic of the MEA preparation technique



Nafion

Catalyst
+
ethanol

Catalyst
ink

Diffusion layer

Diffusion layer
+
Catalyst layer

anode

Nafion
membrane

cathode

Hot press

MEA

Important criteria for enhancing potentiality of MEA

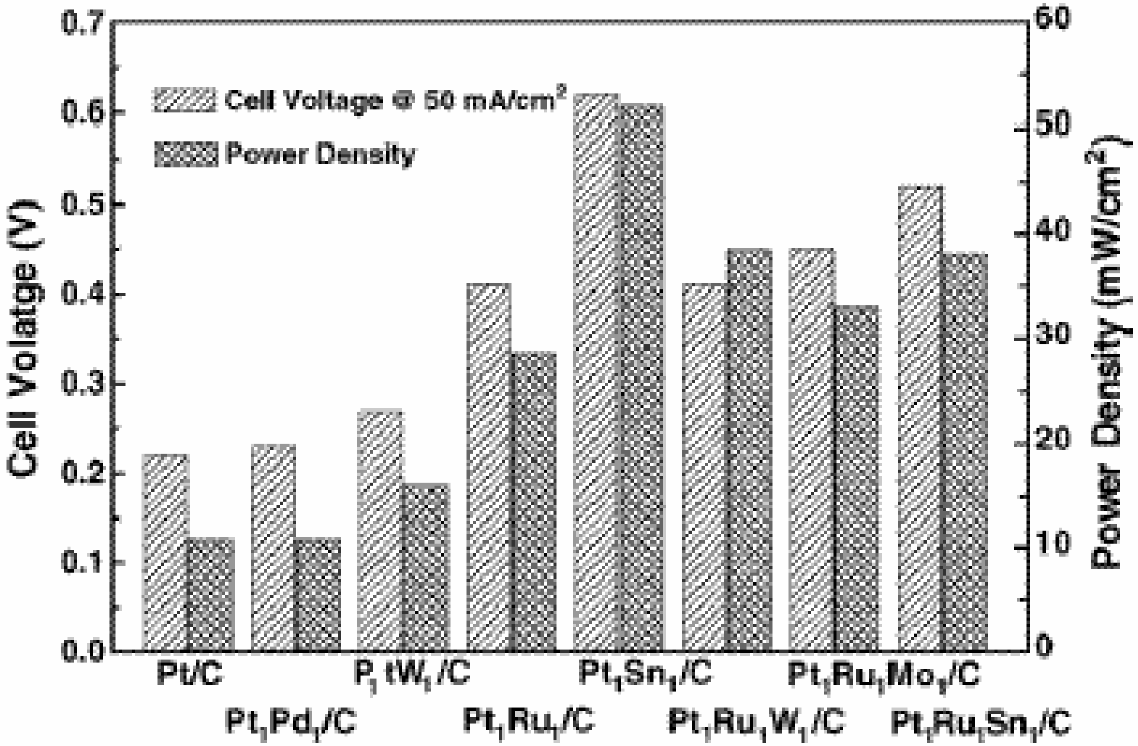
- **Increase surface area to improve electrode kinetics.**
- **Agglomeration of electro-catalysts.**
- **Extended three phase boundary (TPB) involving reactant, electrolyte and electrode.**
- **Effective release of CO_2 for alcoholic fuels.**
- **Swelling degree of the membrane.**
- **Scaling off / delamination of catalysts creating discontinuity in electronic/ ionic conductivity.**
- **Control of ethanol crossover through membrane.**

Recent Progress

in

DEFC/DE-PEMFC

Activity of different binary and ternary electrocatalysts toward ethanol electro-oxidation in single direct ethanol PEMFCs under the same operation conditions



T_{cell} = 90 ^{0}C

Anode: PtM/C, 1.3 mg Pt/cm^2

$C_{ethanol}$ = 1.0 mol/L

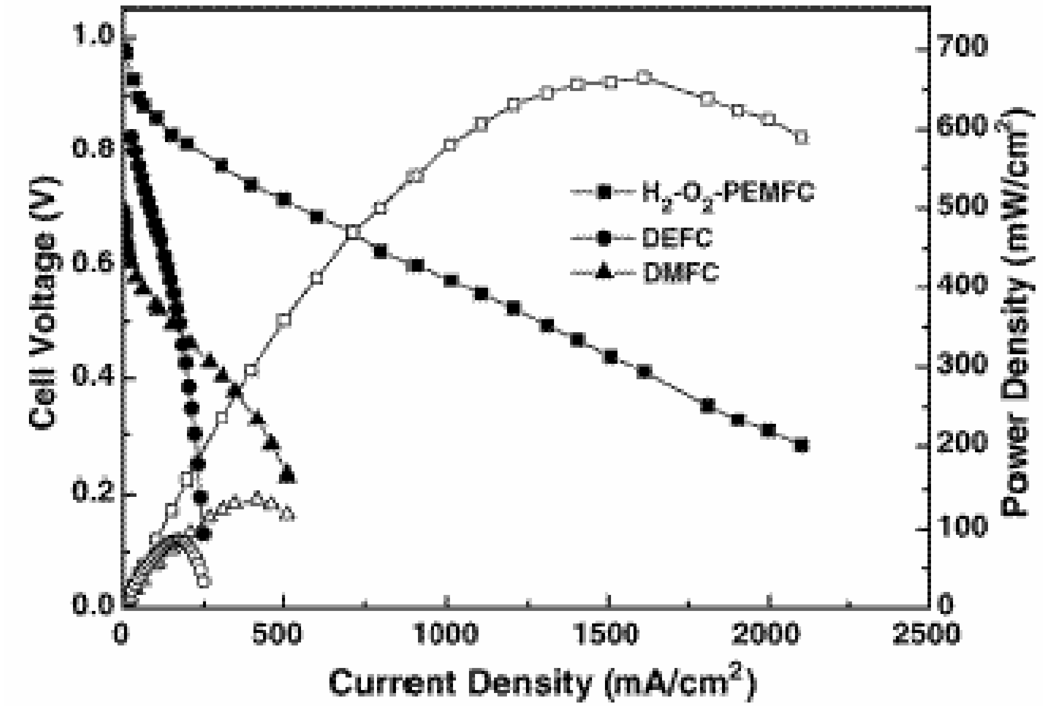
flow rate: 1.0 mL/min

Cathode: Pt/C (20%, JM Corp.), 1.0 mg/cm^2

P_{O2} = 2.0 atm

Electrolyte: Nafion1-115 membrane

Single Cell Performance



Materials	Catalyst (Loading, mg/cm^2) (Feeding Conditions)		T_{cell} (°C)	Electrolyte
	Anode	Cathode		
H_2-O_2 PEMFC	Pt/C (0.3), (H_2,2.0atm)	Pt/C (--), (O_2,2.0atm)	80	Nafion®-112
DMFC	PtRu/C (2.0), (1.0M MeOH)	Pt/C (1.0), (O_2,2.0atm)	90	Nafion®-115
DEFC	PtSn/C (2.0), (1.0M EtOH)	Pt/C (1.0), (O_2,2.0atm)	90	Nafion®-115

Excerpts

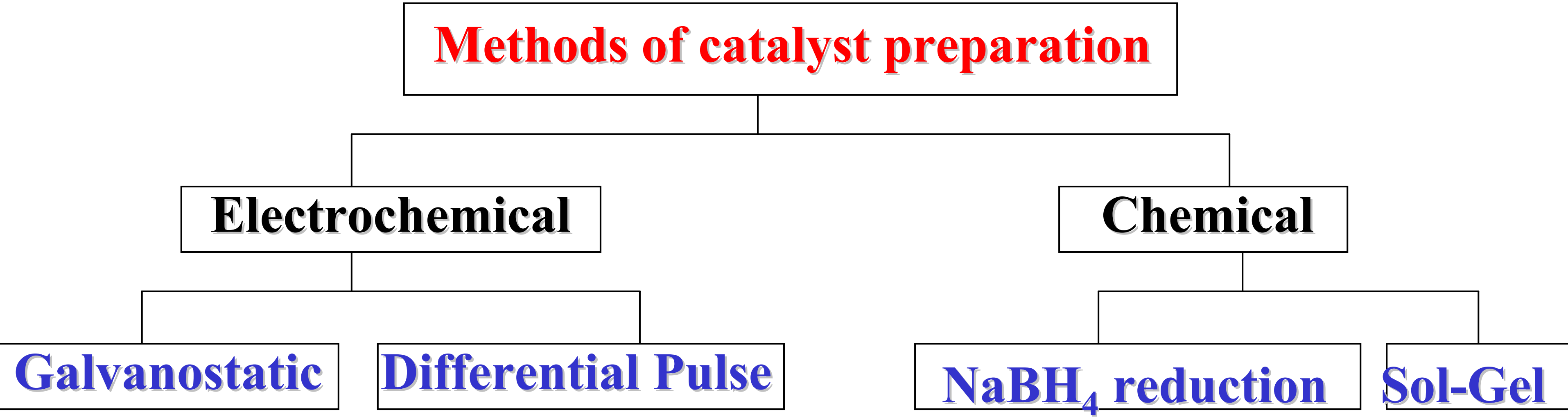
from our comprehensive work

on the development of electrode catalysts

for DEFC anode

OBJECTIVE

Fabricate novel binary and ternary electrocatalysts as MEA components tailored for Direct Ethanol Fuel Cell



Methods of catalyst preparation

Electrochemical

Chemical

Galvanostatic

Differential Pulse

$NaBH_4$ reduction

Sol-Gel

Synthesized Catalysts:
(Carbon /
70:30 CuNi Alloy Substrate)

Single	*Binary*	*Ternary*
Pt	PtRu	PtRuMo
Pd	PtSn	
	PtRh	
	PtMo	

Surface Characterization & Composition

- Scanning Electron Microscopy
- Transmission Electron Microscopy
- Energy Dispersive X-ray Analysis
- X-ray Diffraction
- X-ray Photoelectron Spectroscopy

Electrochemical Measurements

- Cyclic Voltammetry
- Steady state polarization
- Potentiodynamic polarization
- Chronoamperometry
- Electrochemical impedance spectroscopy

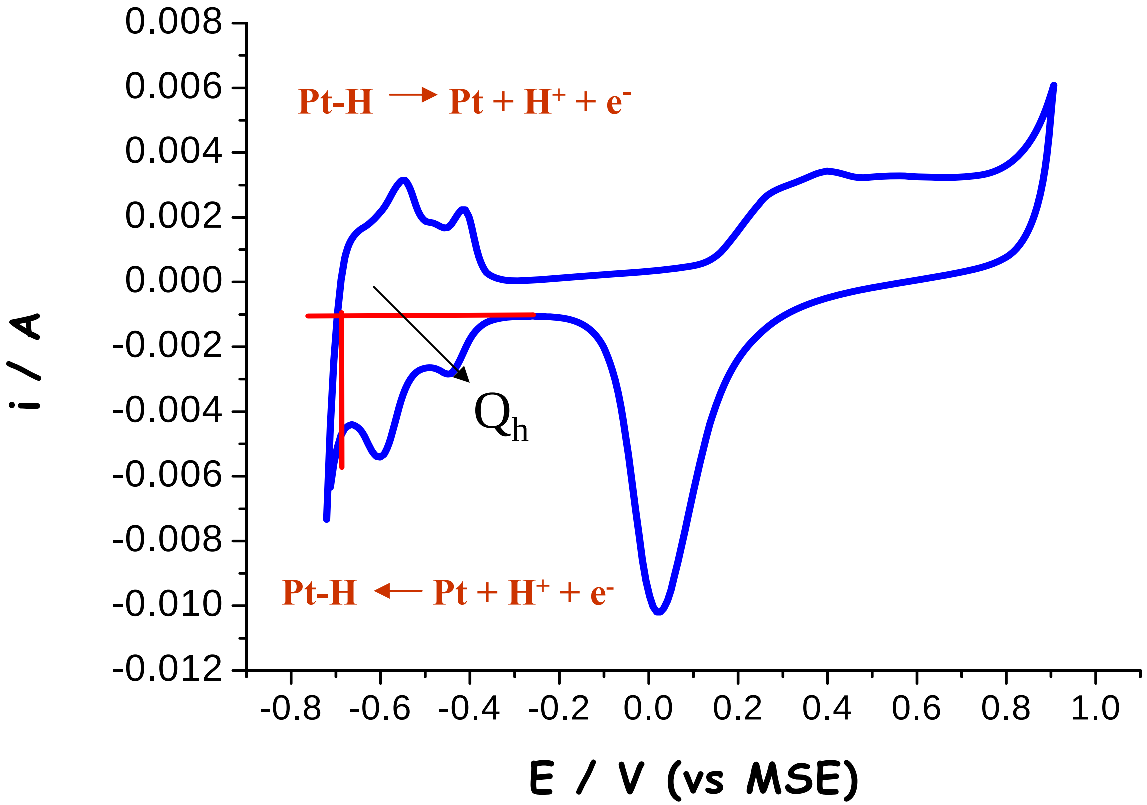
Development of MEA & Single Cell Testing

Unit Cell of the Proposed Fuel Cell Stack

Power : 0.65 Volt x 0.5 amp/25cm^2

Target : 100 mW/Cm^2

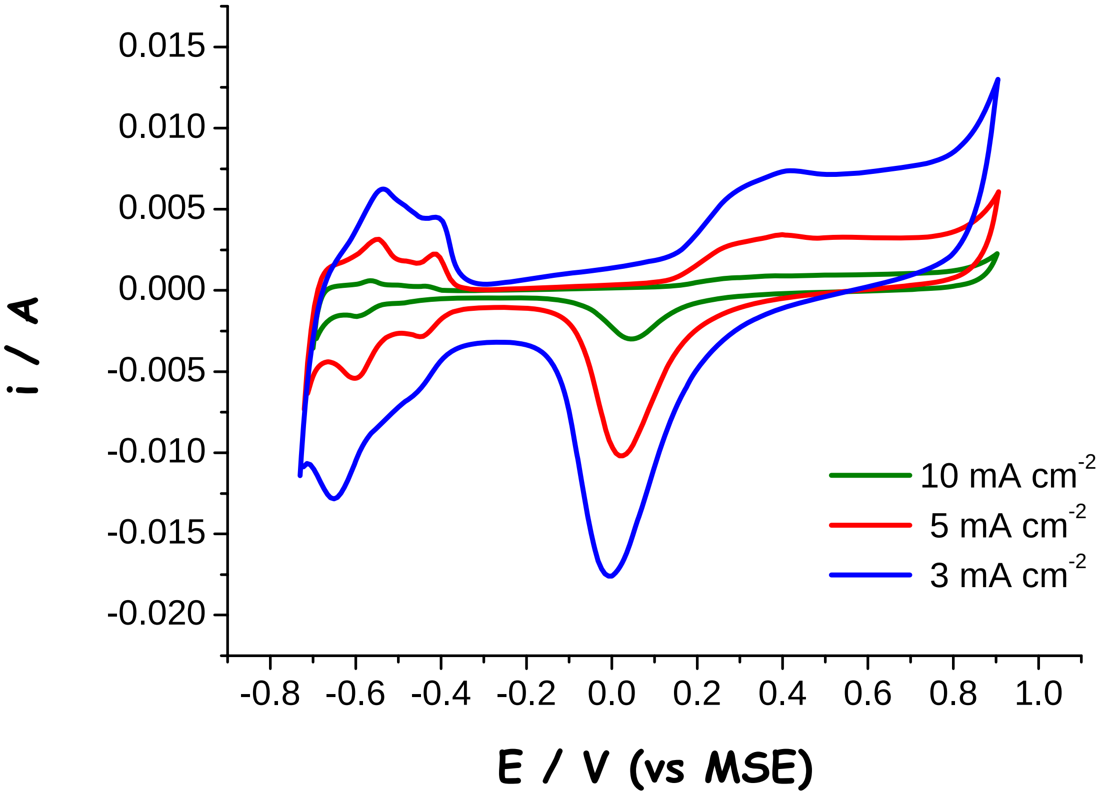
The real electrochemical surface area of the Pt deposits is determined using the hydrogen adsorption charge as obtained from cyclic voltammograms in 0.5 M H_2SO_4.



$$A_r = Q_h / Q_m$$

where Q_h = charge for saturated hydrogen coverage on the electrode (μC), and

Q_m= charge associated with monolayer adsorption of hydrogen (210 μC cm^{-2} Pt)



- Pt layers deposited at 3 mA cm^{-2} show a pronounced increase in surface roughness compared to those platinized at higher current densities

Model assumption:

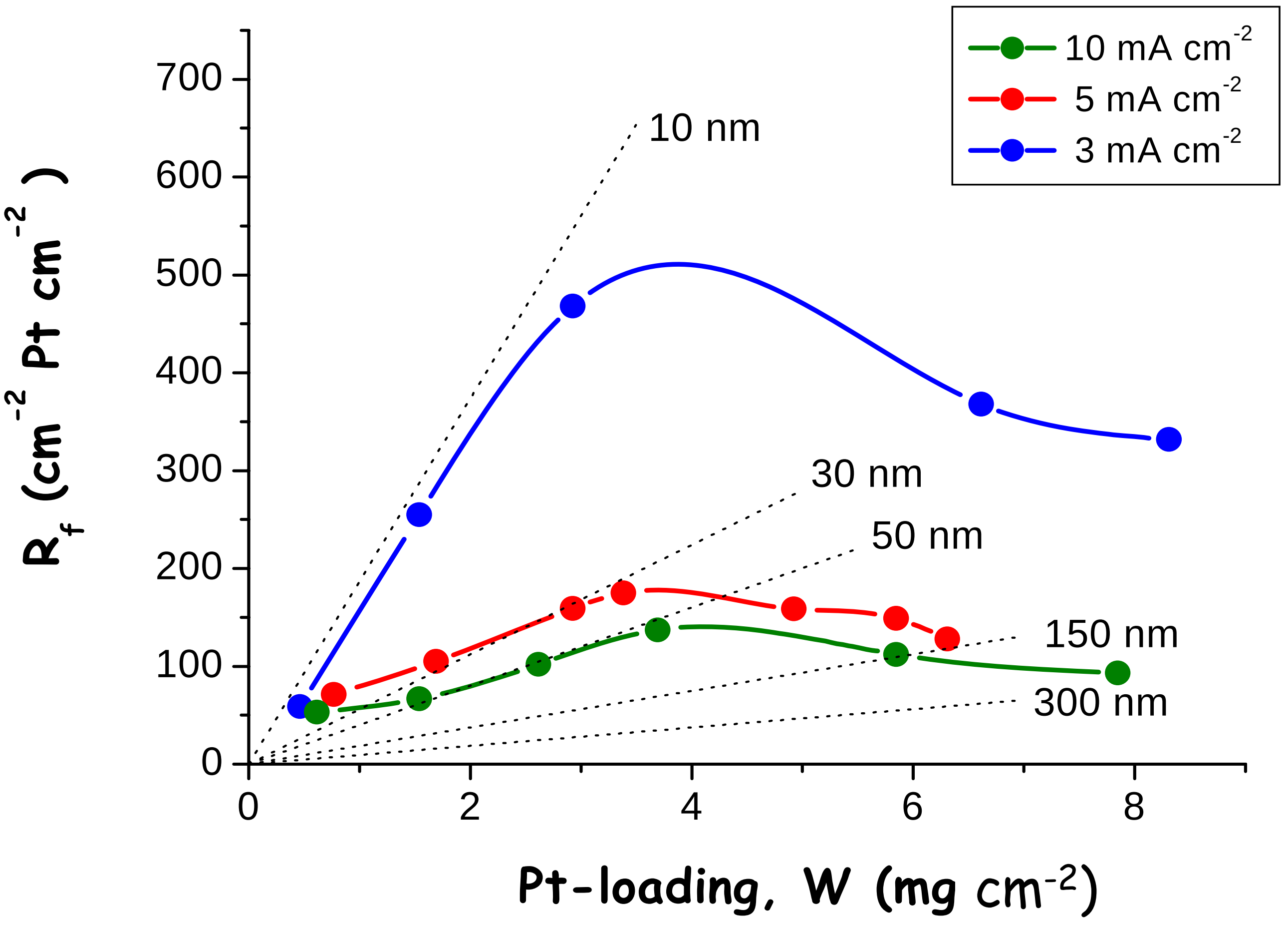
The Pt deposit has been considered as a homogeneous distribution of smooth, spherical particles each of a diameter d (cm)

Specific surface area, S ($cm^2\ g^{-1}$ Pt) :

$S = 6/\rho d$, ρ = density of platinum(21.4 g cm^{-3})

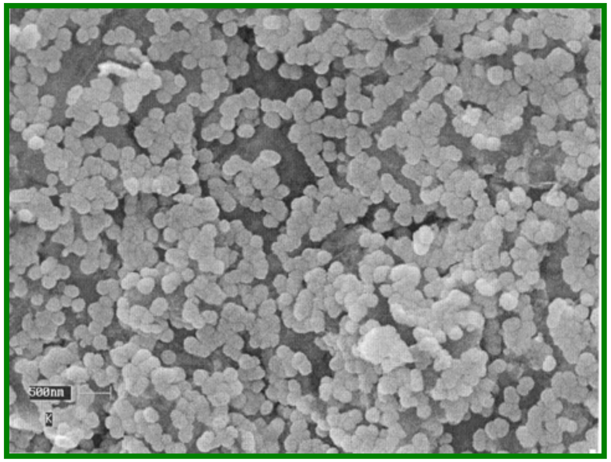
Roughness factor : $R_f = SW$, W = Pt-loading (mg cm^{-2})

Experimental observation vs. Model prediction

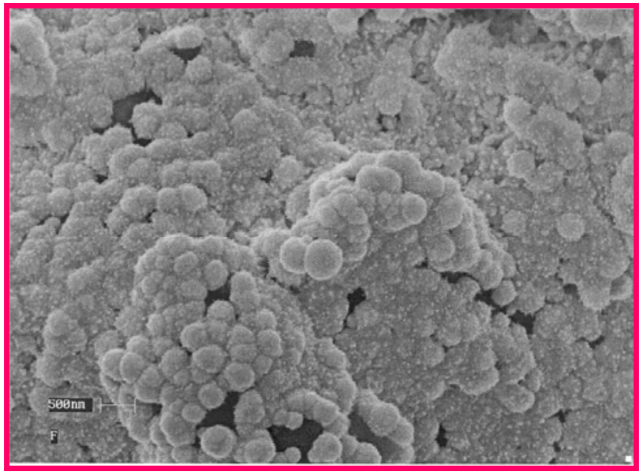


- The dashed lines show the model predictions for a range of Pt particle diameters.

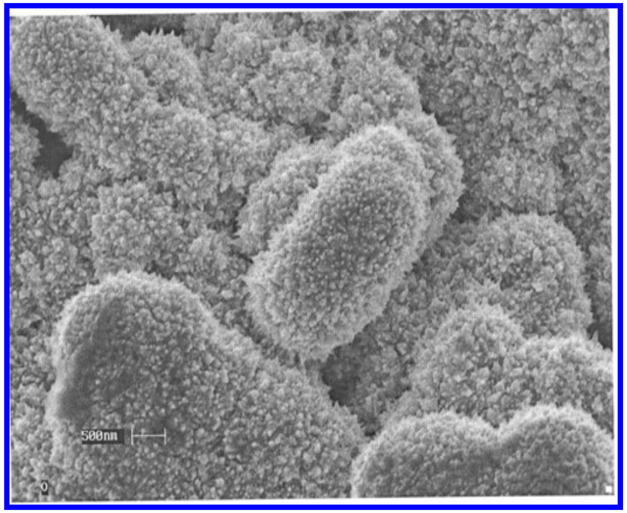
SEM images of C/Pt catalysts (Pt loading ~3.0 mg cm^{-2})



3mA cm^{-2}



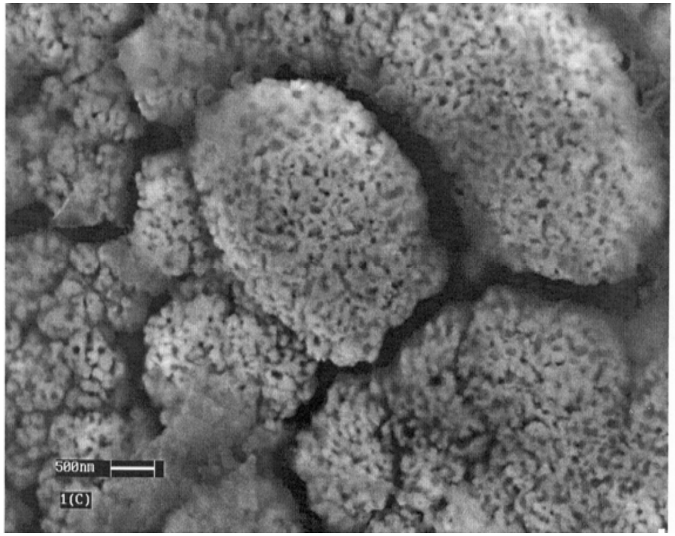
5mA cm^{-2}



10 mA cm^{-2}

- Carbon supported Pt deposited at a controlled current density of 3 mA cm^{-2} yielded well-dispersed particles of 100-150 nm diameter, which translated to a pronounced increase in surface roughness compared to those platinized at higher current densities

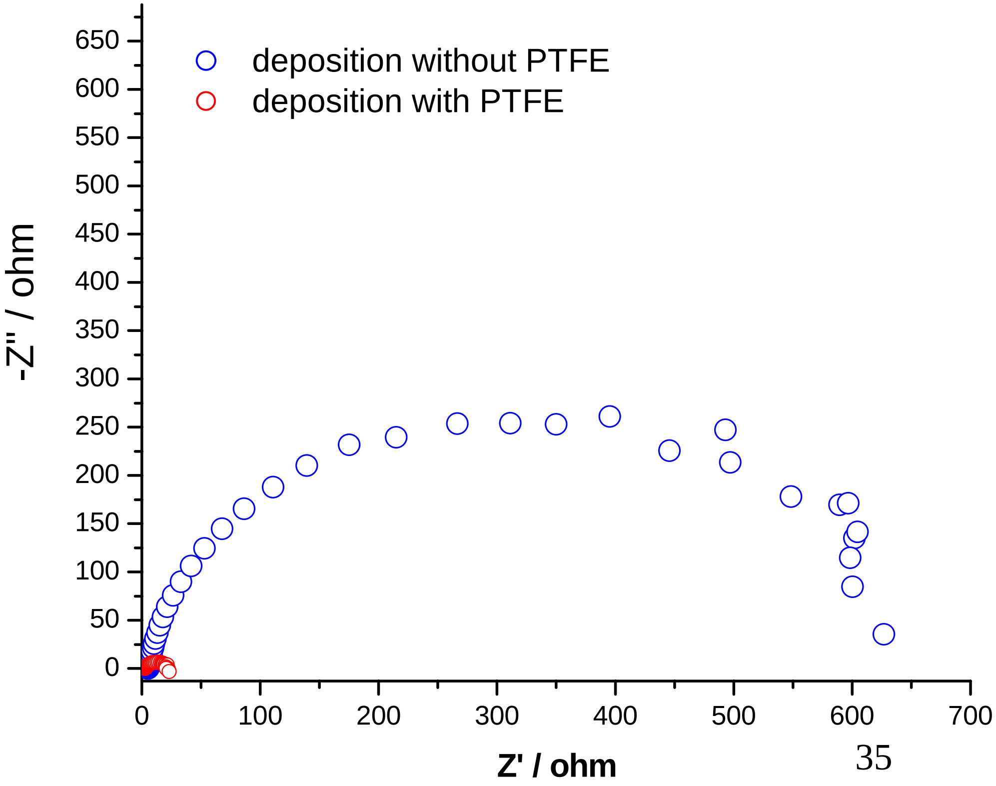
SEM image of C/Pt/PTFE electrodeposited at 3 mA cm^{-2}



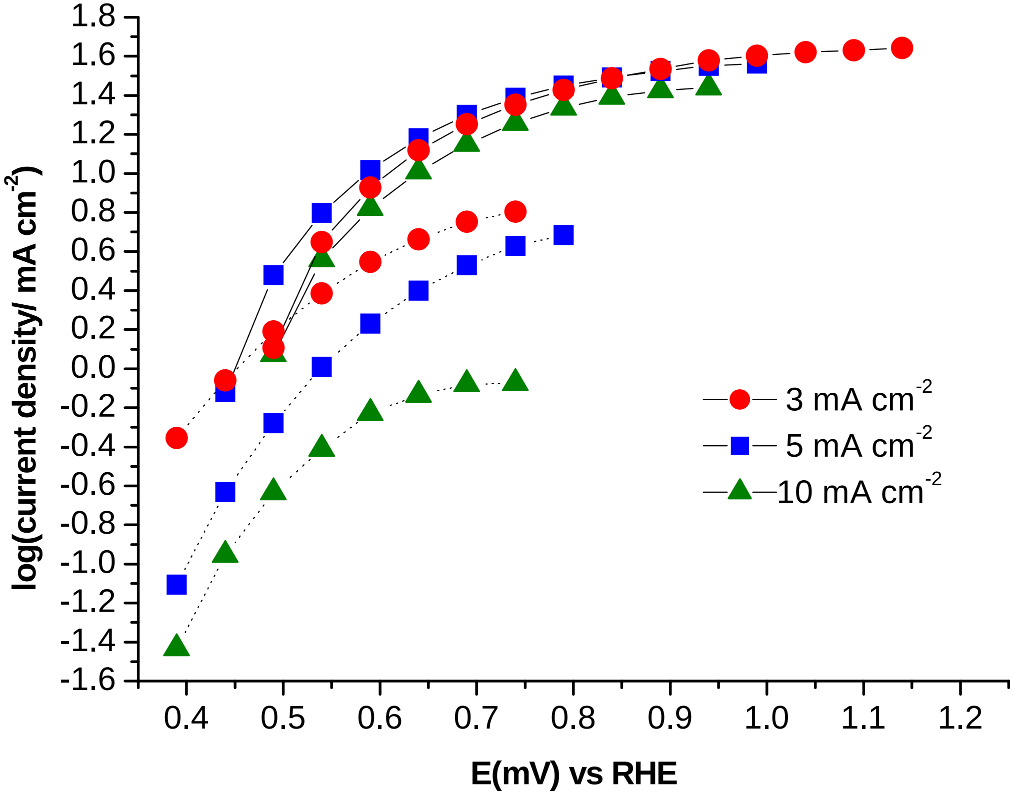
EDX analysis confirmed the presence of indicating the incorporation of PTFE in the deposited layer

EIS shows a considerable decrease in the charge transfer resistance at the PTFE incorporated catalyst surface

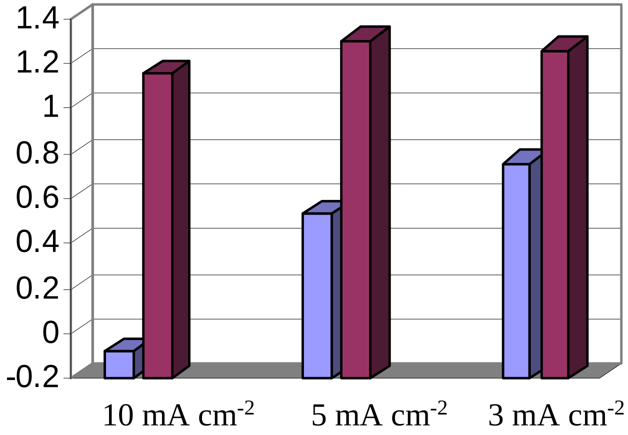
The highly porous nature of the dispersed Pt provides a novel route of synthesizing active catalysts involving PTFE



Steady-state polarisation curves in 1.0 M EtOH + 0.5 M H_2SO_4



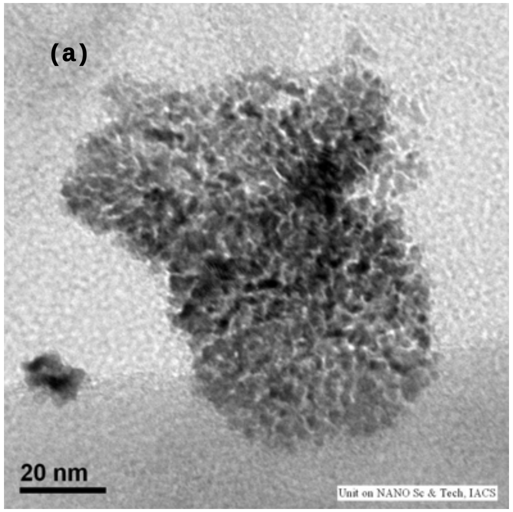
Comparison of the log of current density at a potential of 0.7 V vs RHE



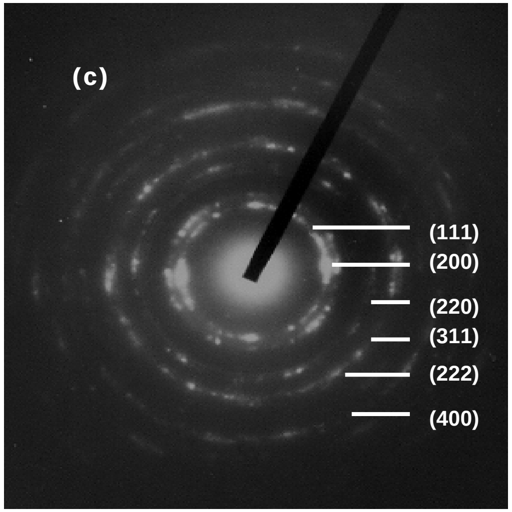
……. deposition without PTFE 🟦

_____ deposition with PTFE 🟥

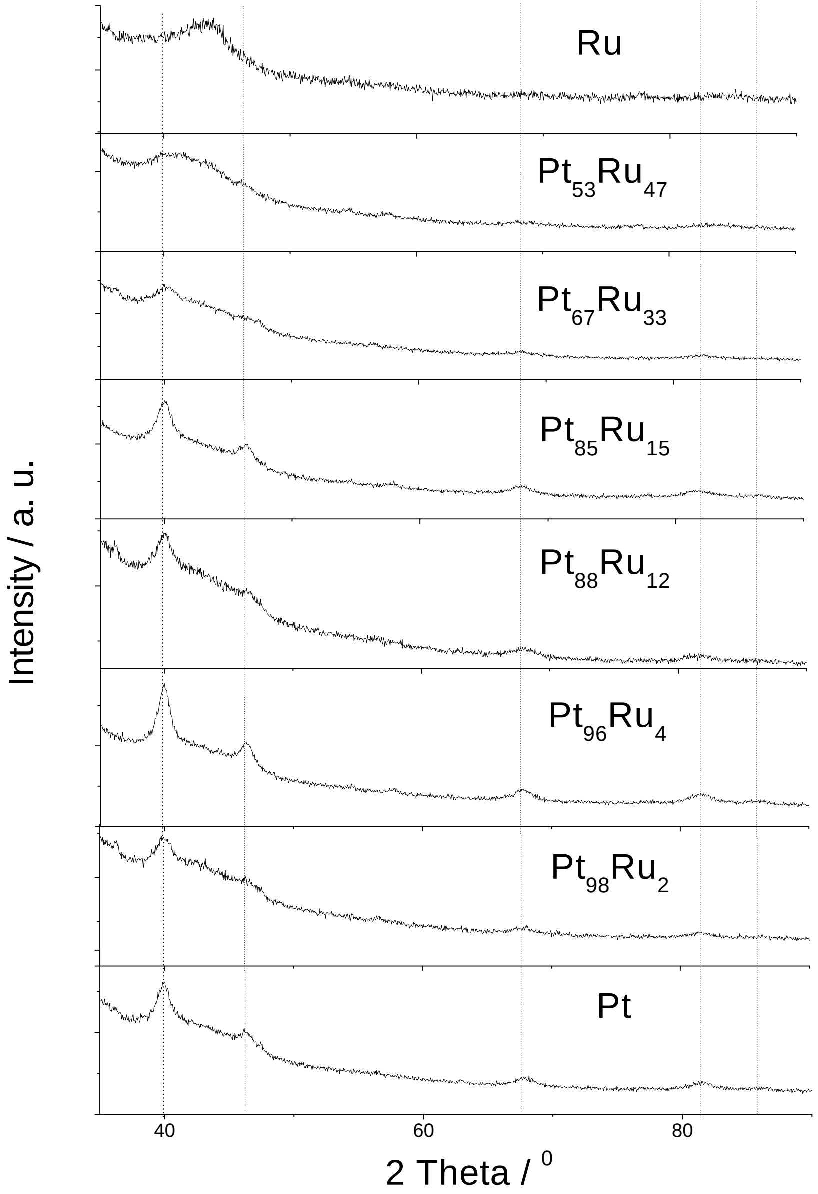
PtRu Binary Catalysts: Search for optimum Ruthenium contents



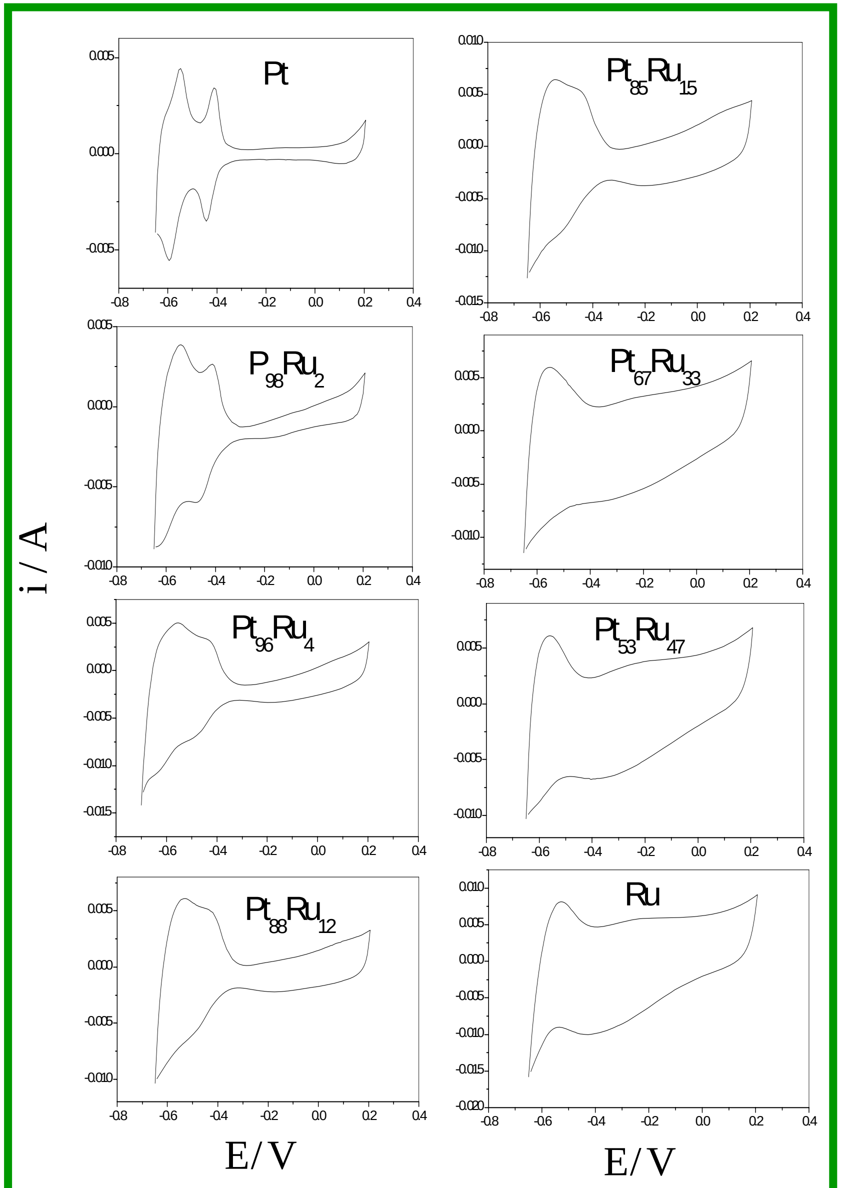
HRTEM images of electro-deposited $Pt_{88}Ru_{12}$



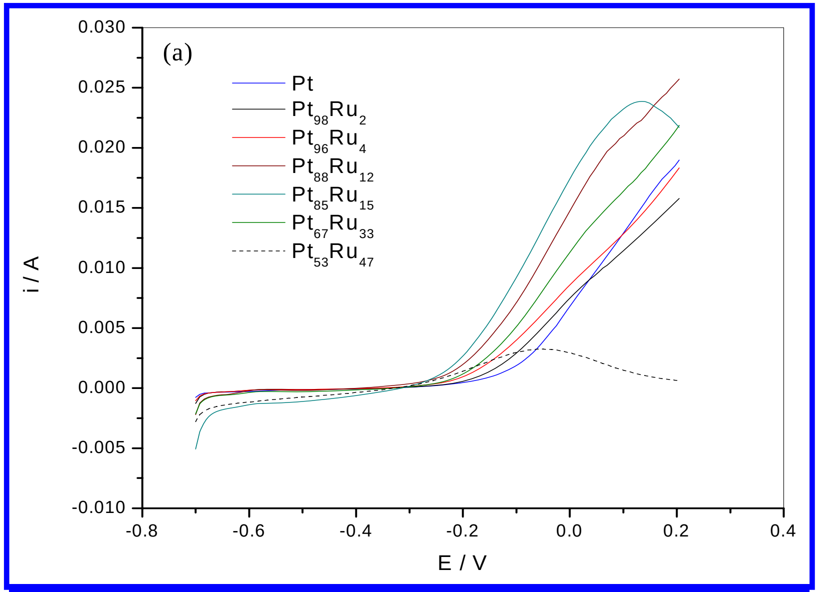
SADP (Rings are indexed for FCC crystal structure)



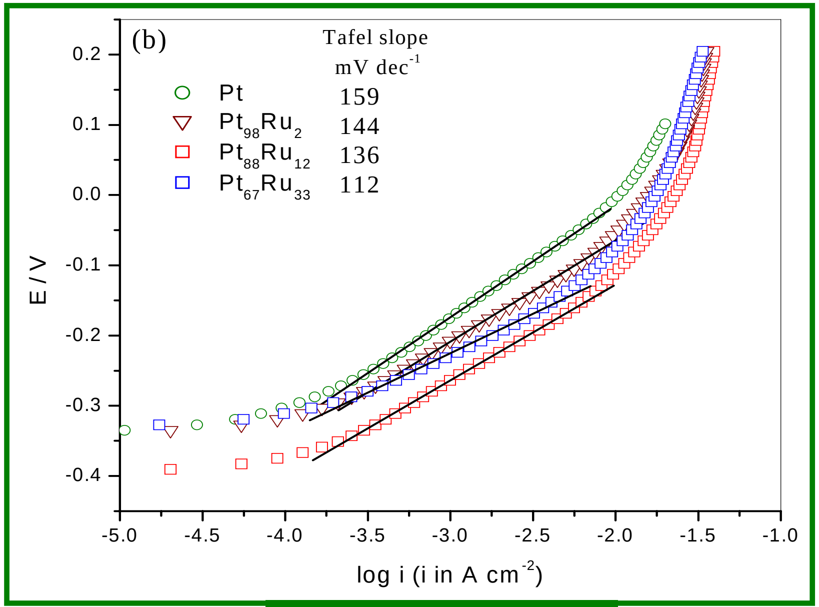
XRD Studies of Pt, Ru & Pt-Ru



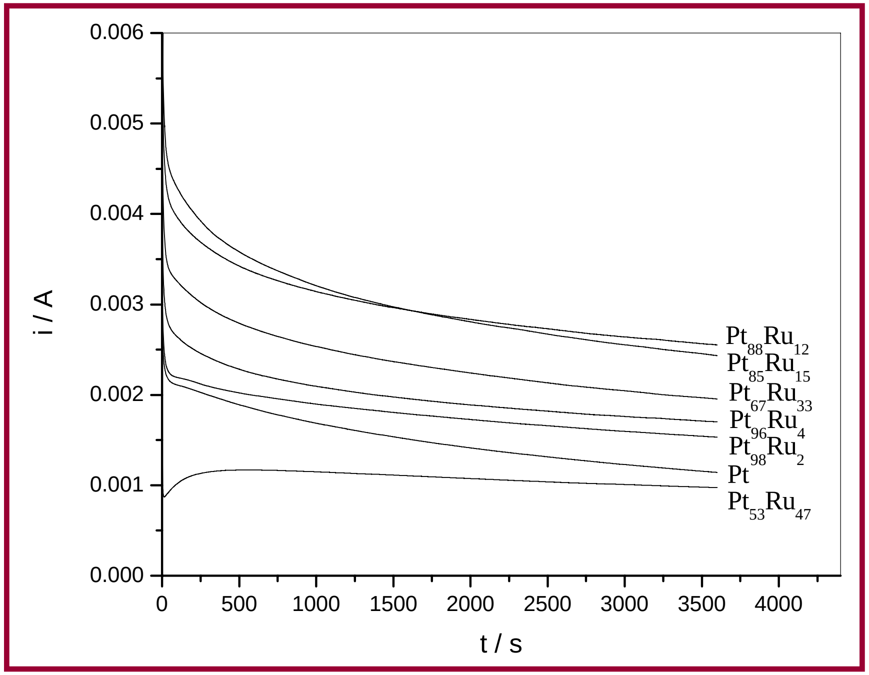
Cyclic Voltamogram of Ethanol Oxidation



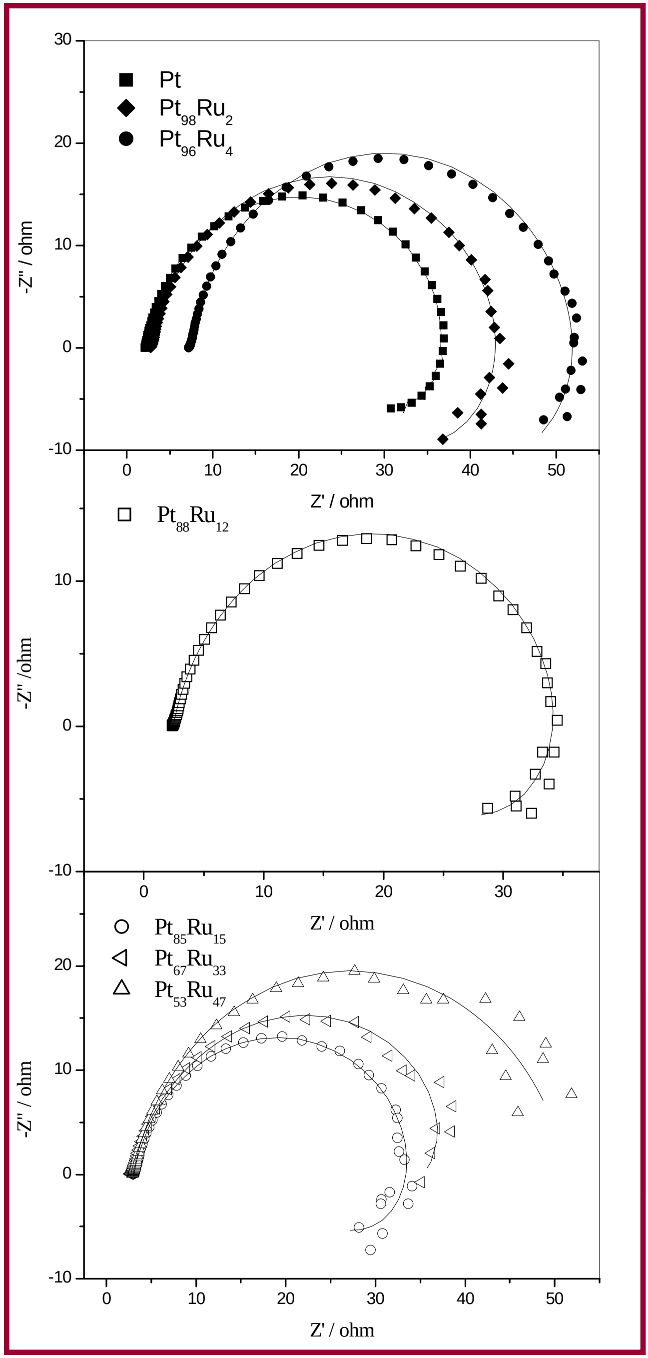
Linear Sweep Voltammetry

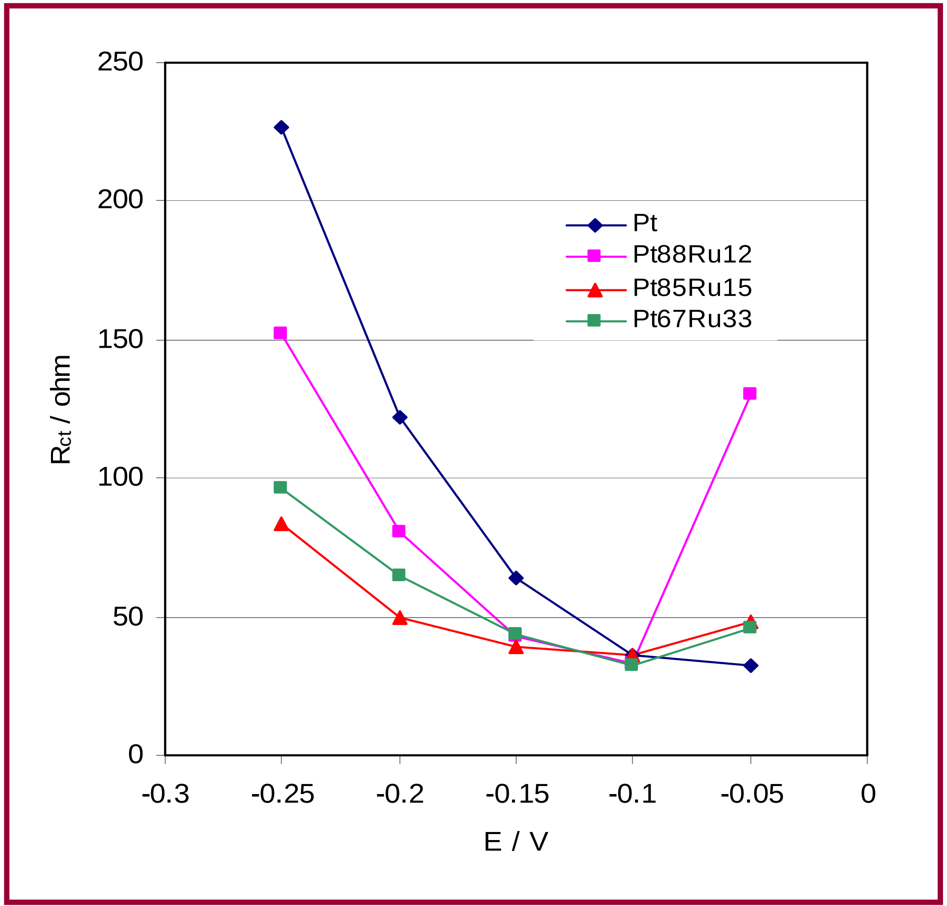


Tafel Plots



Chronoamperometry





Electro-chemical Impedance Spectroscopy

Pt-Rh alloys : Possible facilitation in C-C bond cleavage

Ratio of Pt to Rh in the deposition bath and on the carbon supported PtRh electrode surfaces.

Pt/M	Rh/M	% Pt	% Rh	Pt/Rh (solution)	Pt/Rh (surface)
0.05	0.005	90.4	9.6	10	9.4
0.025	0.025	73.7	26.3	1	2.8
0.005	0.05	35.1	64.9	0.1	0.5

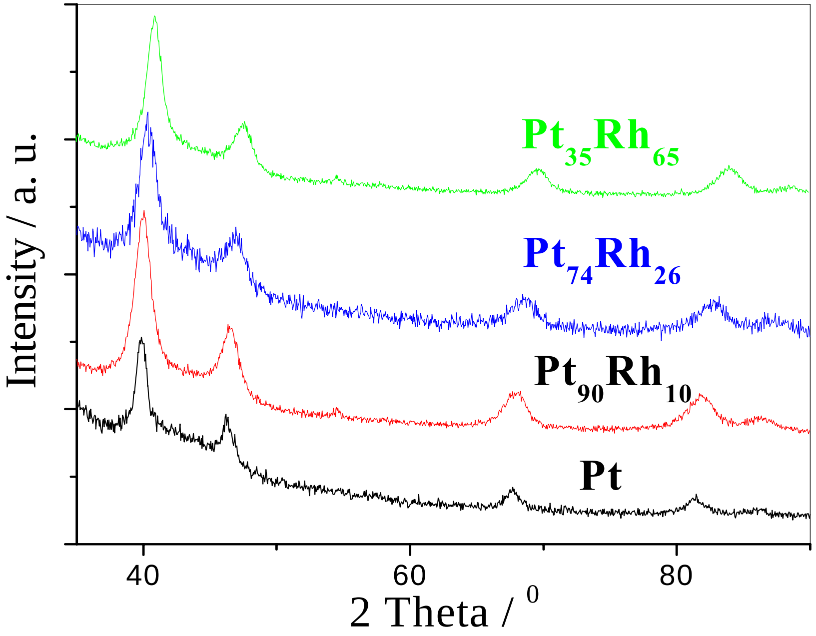
The substantial lowering of the reduction potential on complexation explains the weaker tendency of Rh deposition at higher concentrations of $RhCl_3$.

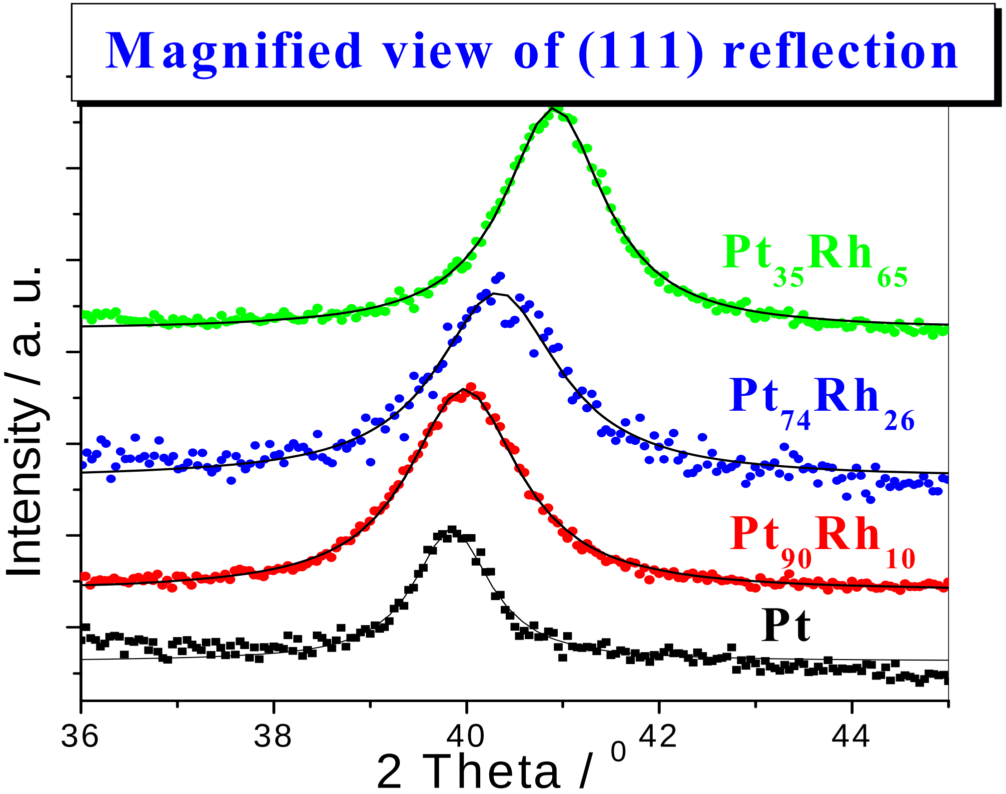
$RhCl_3 + 3Cl^- = [RhCl_6]^{3-}$

since the standard reduction potential of the species involved are in the order:

Rh^{3+}/Rh (0.76 V) >> $[RhCl_6]^{3-}/Rh$ (0.43 V) (vs. SHE)

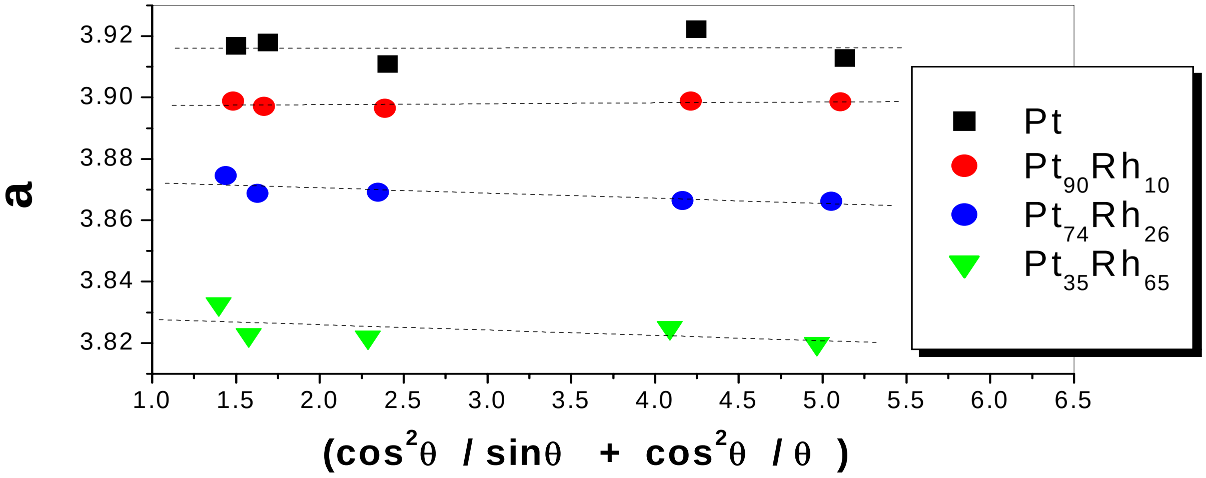
X-ray diffraction patterns of carbon-supported Pt and Pt-Rh catalysts



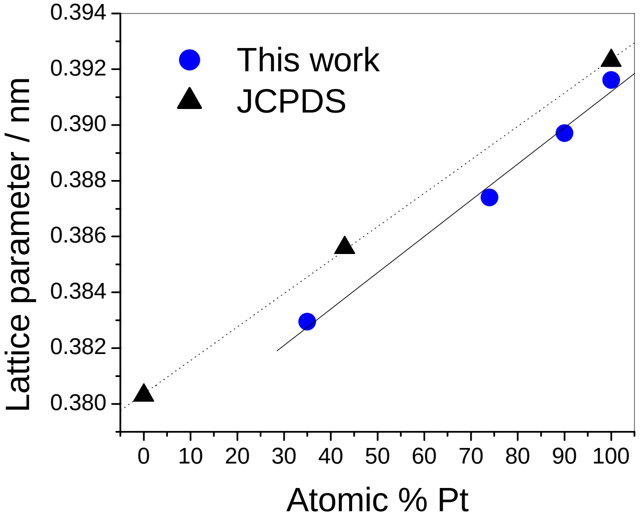


- The diffraction peaks related to PtRh catalysts shift towards higher 2θ values w.r.t the corresponding reflections of Pt.
- Formation of PtRh alloys in the coelectrodeposited catalysts.

- A more precise value of the lattice parameter can be obtained by extrapolation of the measured lattice parameters against the Nelson Relay parameter:

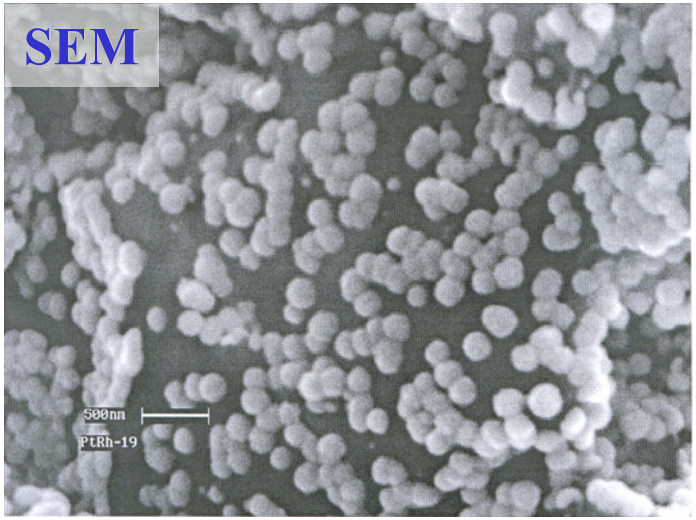


The lattice parametrs for all the PtRh alloy catalysts are smaller than that for Pt and decrease with the increase of Rh content, indicating lattice contraction after alloying due to the incorporation of the smaller sized Rh atoms in the Pt crystal lattice.

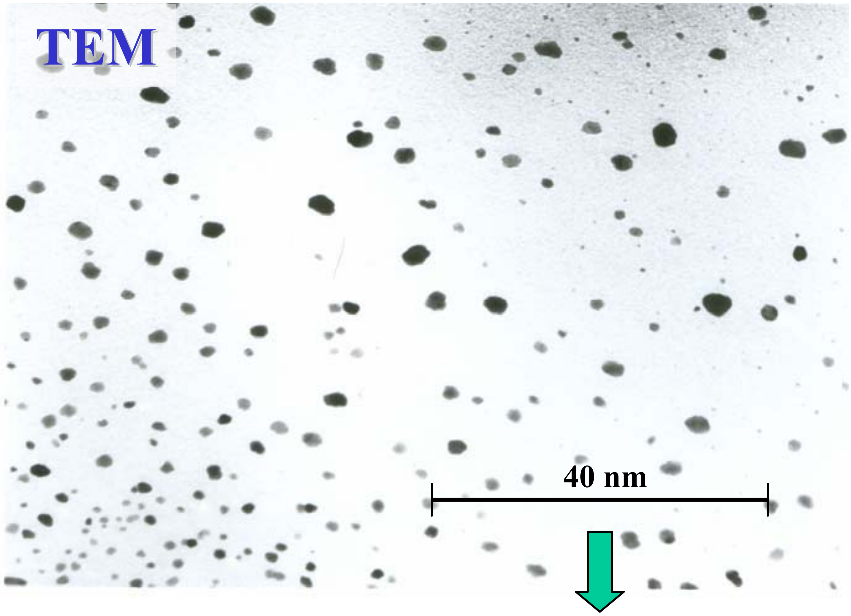


- The lattice parameter corresponding to the compositions of the deposited alloys deviates negatively over the entire composition range from that obtained by Vegard's law, possibly due to metal-support interaction

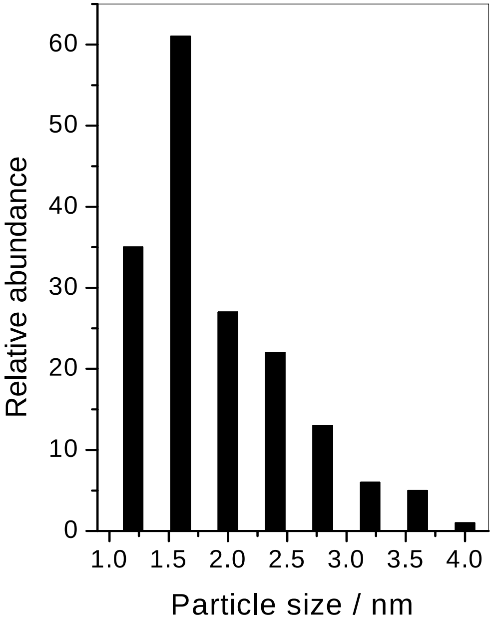
Electron Microscopy of the Pt$_{74}$Rh$_{26}$ alloy catalyst



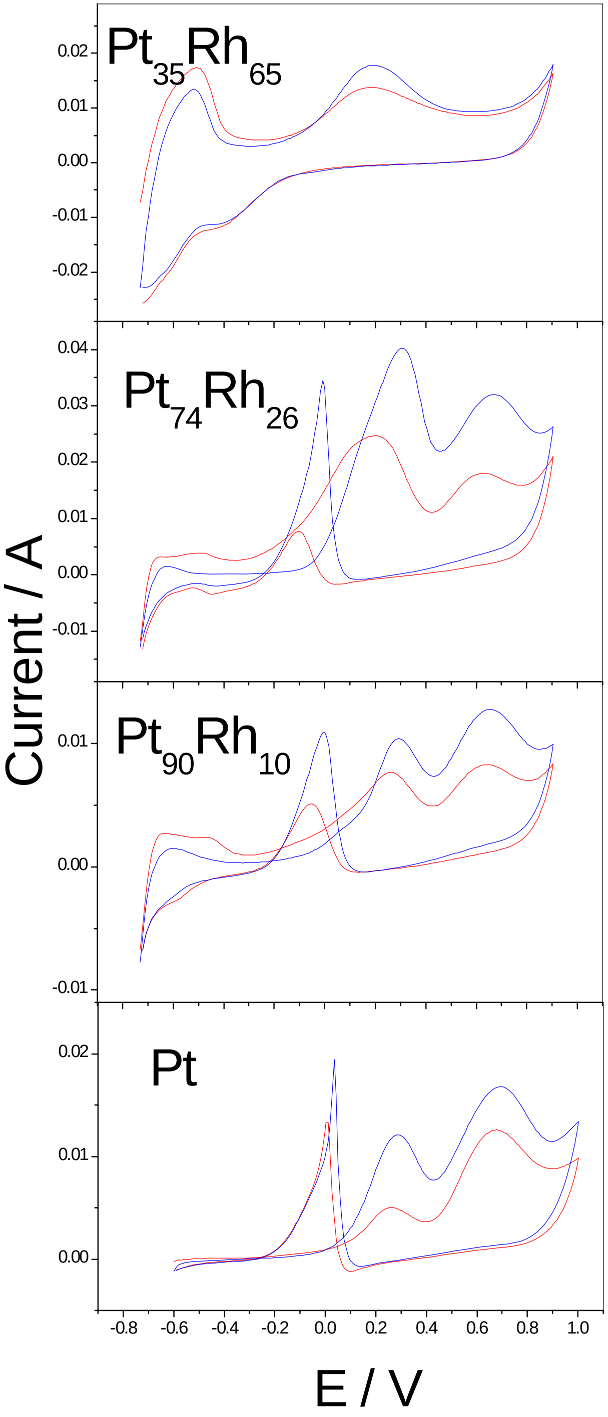
SEM reveals homogenous dispersion of catalyst particles on the graphite support (200 and 250 nm)



Particle size distribution



This clearly demonstrates that the particles observed in SEM are truly agglomerates of many smaller crystallites.



Cyclic voltammograms in 0.5 M H_2SO_4 +1.0 M EtOH. Scan rate 50 mV s^{-1}.

Red line: 1st scan, **Blue line**: 10th scan.

On Pt the two peaks on the anodic sweep can be ascribed to the oxidation of the fuel by two kinds of chemisorbed oxygen species

$$\mathrm{Pt + H_2O \rightarrow Pt\text{-}OH_{ads} + H^+ + e^-}$$

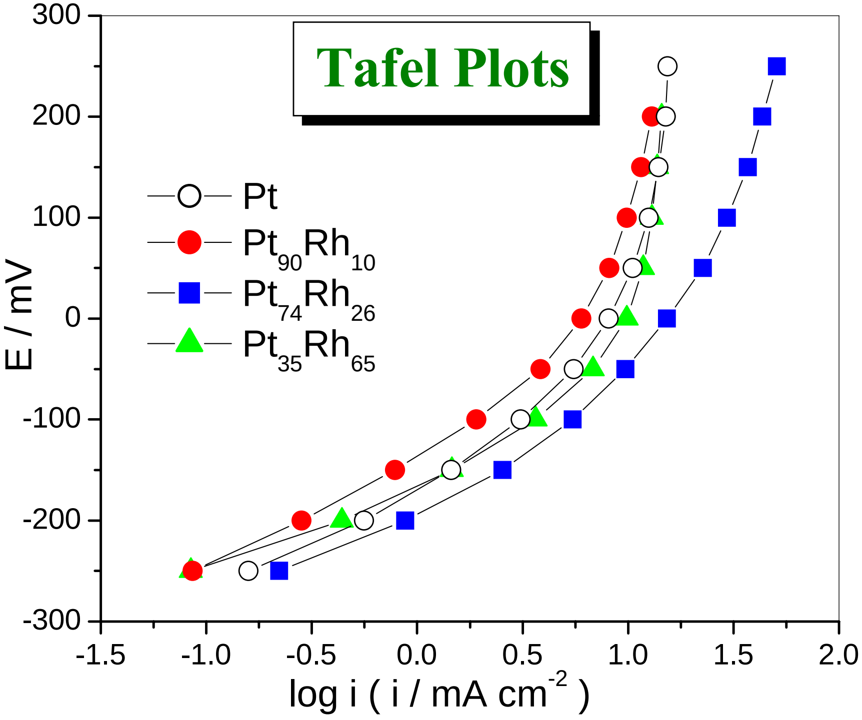
$$\mathrm{Pt\text{-}OH_{ads} \rightarrow Pt\text{-}O + H^+ + e^-}$$

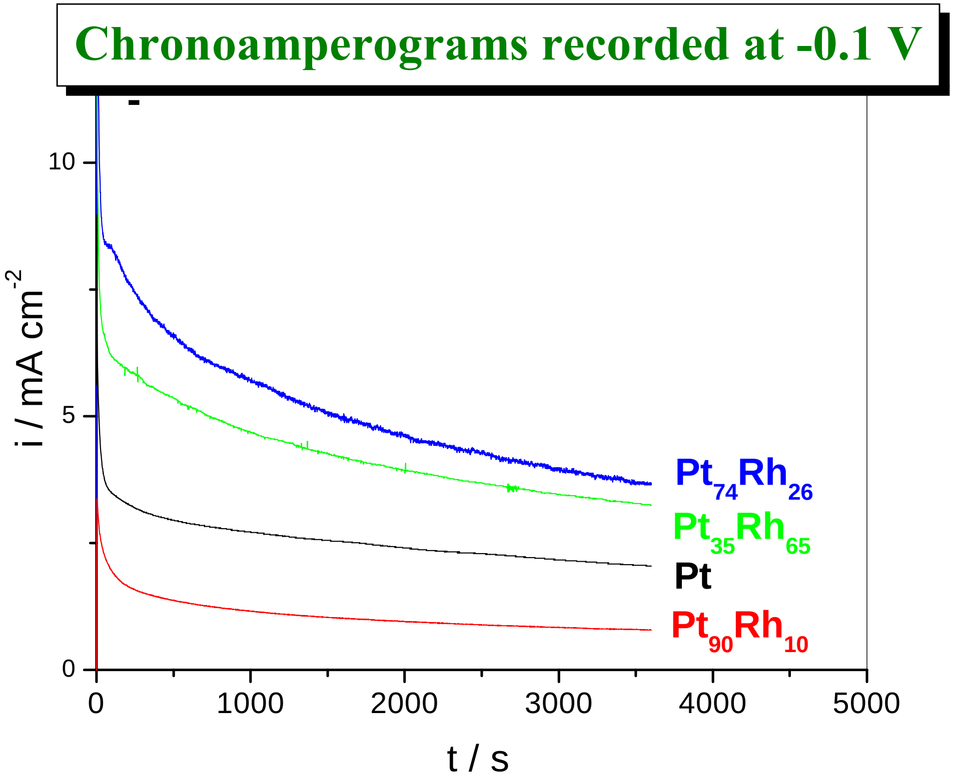
Rh — O = 293 kJ mol^{-1}

Pt — O = 167 kJ mol^{-1}

The strong Rh-O bond limits its utility as a source of oxygen. Consequently, with the increase in the amount of rhodium in the alloy catalysts, the ability to oxidize ethanol residues at high potential diminishes. This is probably manifested in the diminution of the second oxidation peak compared to the first for rhodium containing alloy electrodes.

Polatisation curves for ethanol oxidation in 0.5. M H_2SO_4 + 1.0 M EtOH

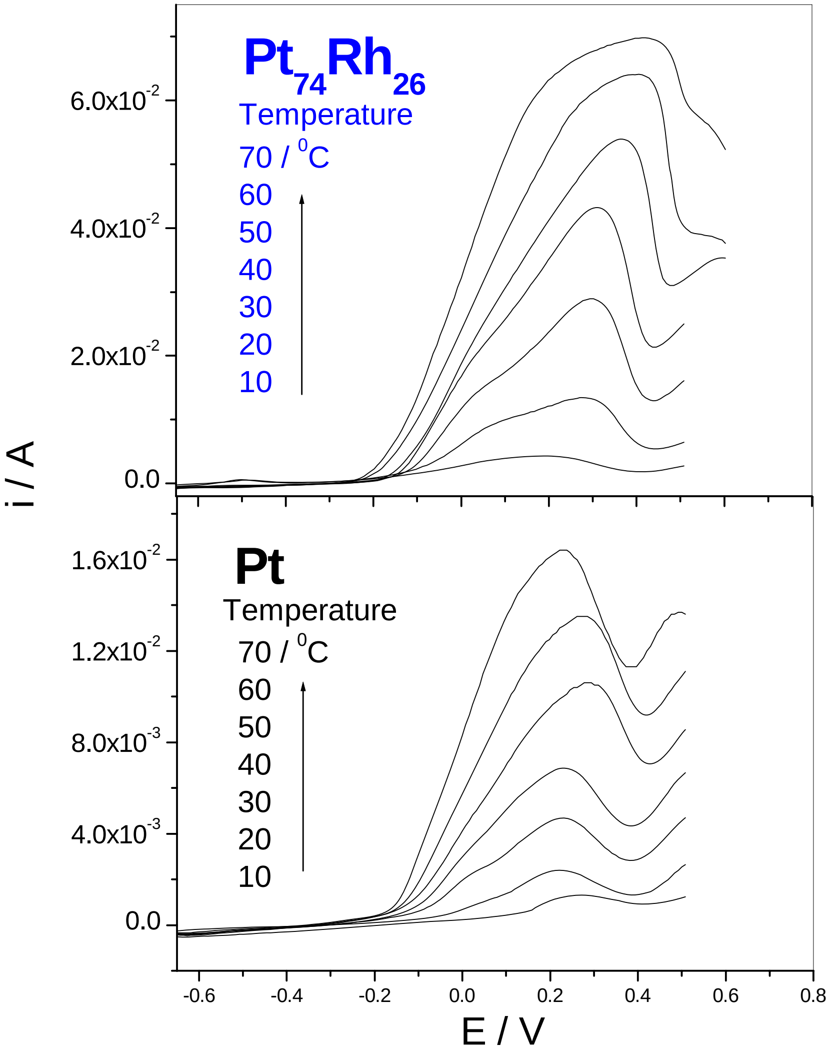


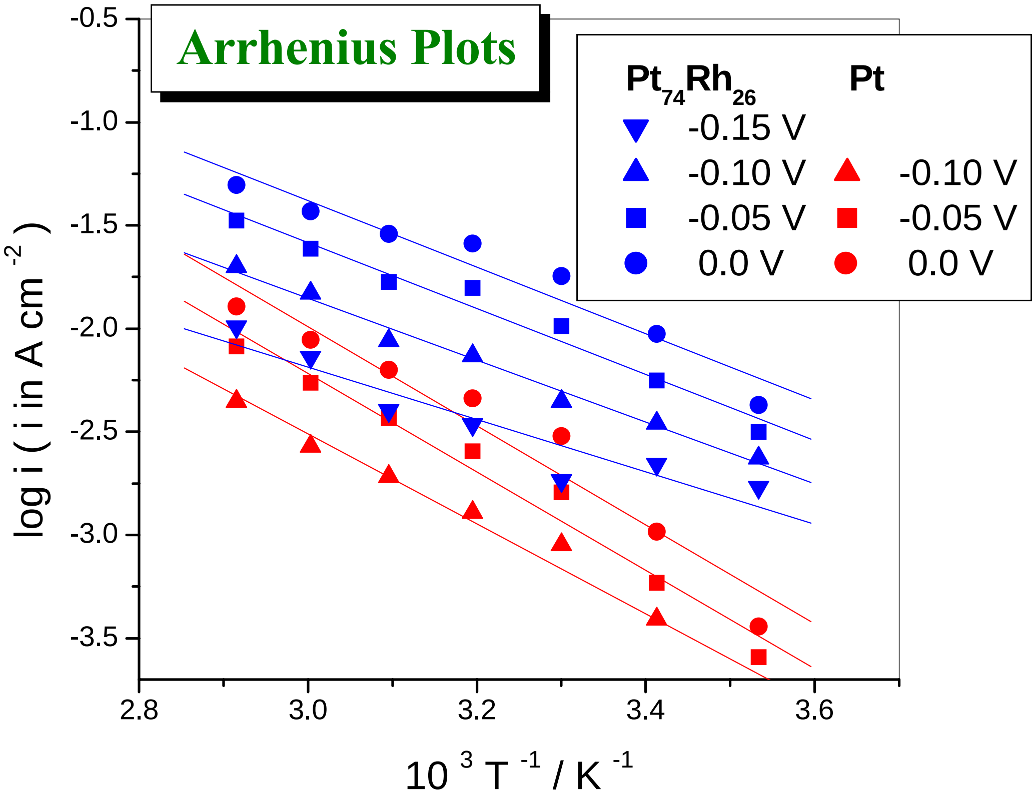


Order of activity in terms of polarisation current densities:

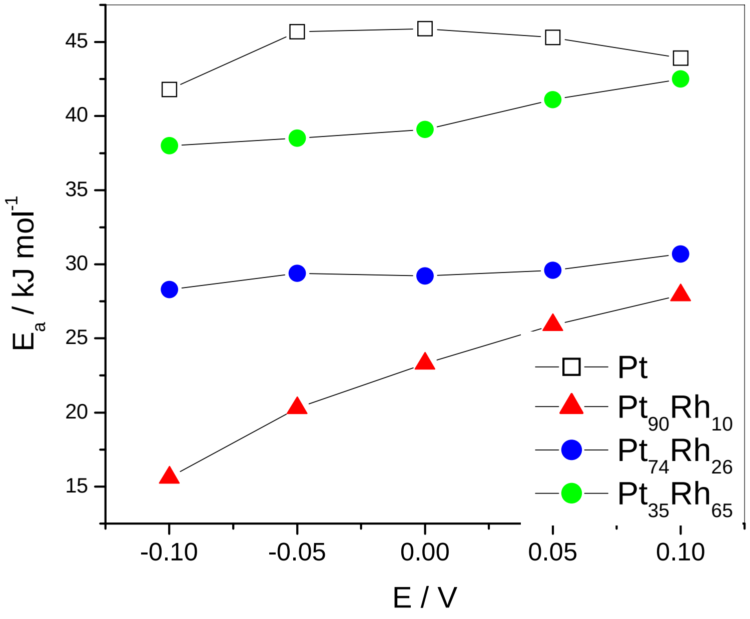
$Pt_{74}Rh_{26} > Pt_{35}Rh_{65} > Pt > Pt_{90}Rh_{10}$

Determination of activation energy for ethanol oxidation





LSVs in 0.5 M H_2SO_4 + 1.0 M EtOH at various temperatures. Scan rate 5 mV s^{-1}.



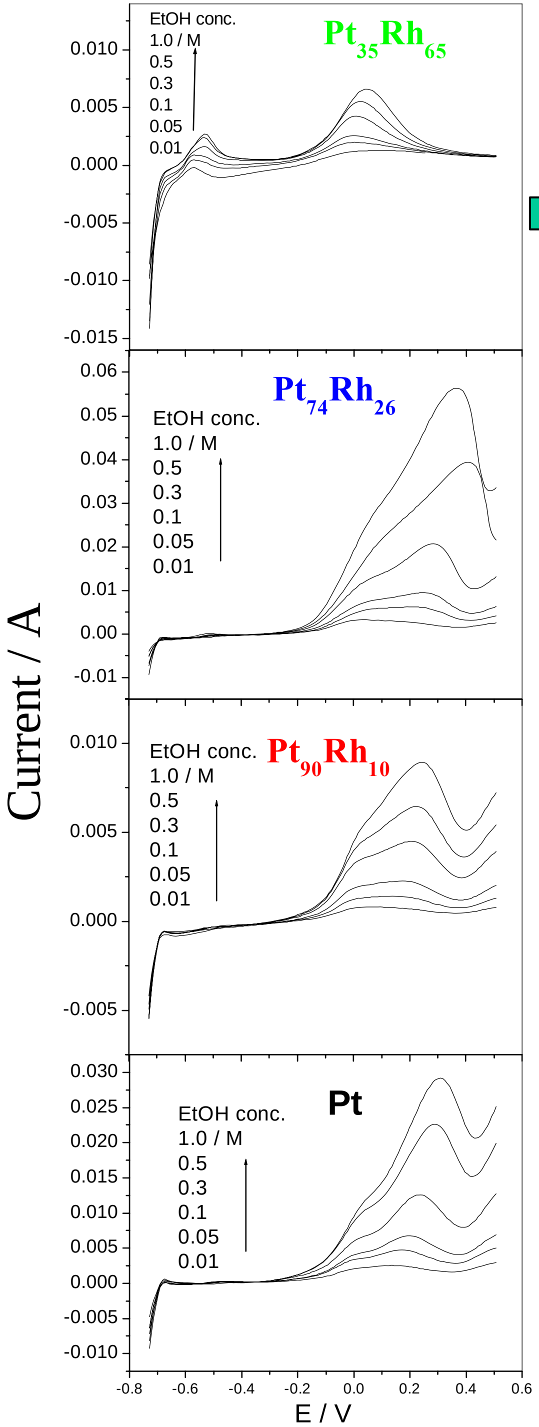
Variation in activation energy with potential for the ethanol oxidation reaction on carbon-supported Pt and PtRh electrodes.

Therefore, it can be said that alloying rhodium with platinum helps in lowering the activation energy for ethanol oxidation.

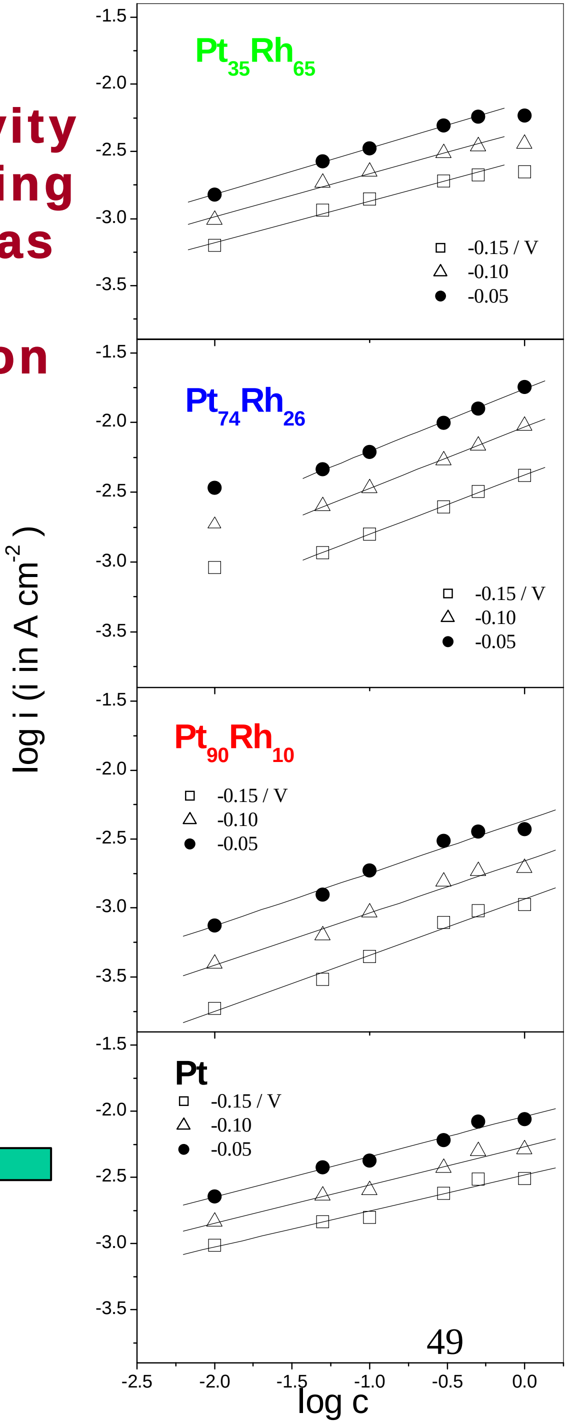
Electrode	Onset potential / V (vs. MMS)		
	30 ^{0}C	50 ^{0}C	70 ^{0}C
Pt	-0.109	-0.131	-0.151
$Pt_{90}Rh_{10}$	-0.115	-0.137	-0.159
$Pt_{74}Rh_{26}$	-0.161	-0.177	-0.203
$Pt_{35}Rh_{65}$	-0.177	-0.183	-0.192

Decrease of ~ 0.05 V was observed for the PtRh electrodes in comparison to Pt.

Bifunctional role of PtRh plays only a small part in its activity towards ethanol oxidation. The improvement in catalytic activity over Pt can be ascribed to an intrinsic character of the PtRh alloy system for efficient C-C bond scission ---- this requires product analysis.



In all the cases, it was observed that the activity increased with increasing ethanol concentration as evidenced from the increase in the oxidation currents and the lowering of the onset potentials.

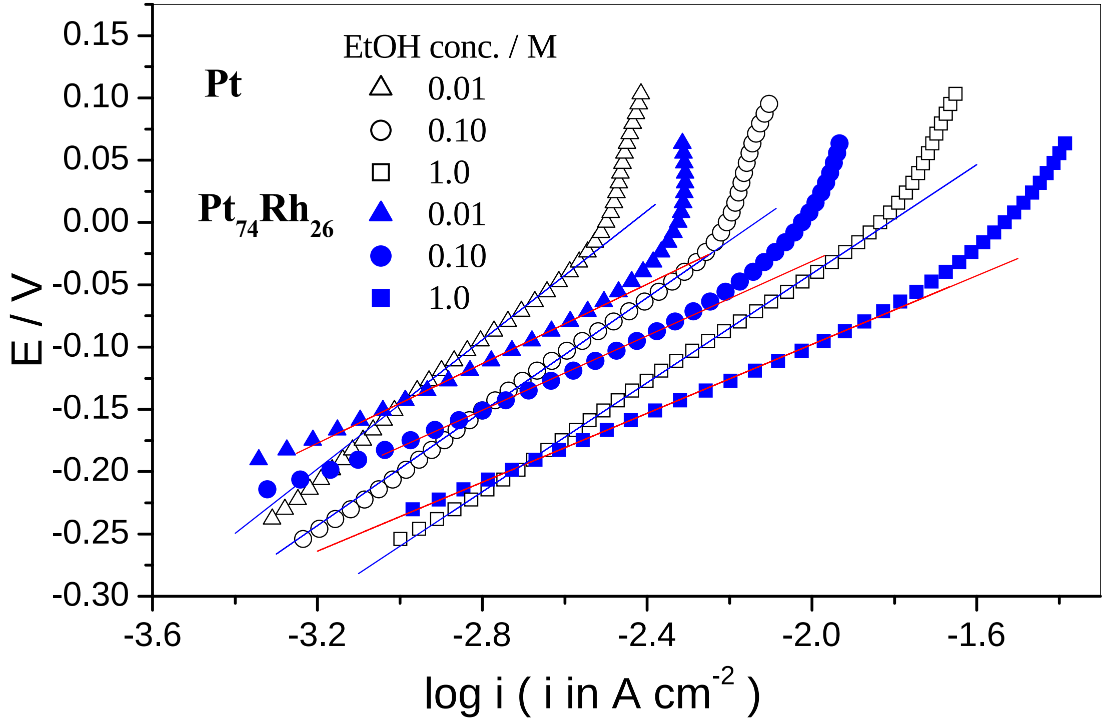


These log*i* vs log*c* plots allow the possibility to calculate apparent reaction orders β for ethanol.

Potentials (mV) (vs MMS)	Reaction order with respect to ethanol concentration			
	Pt	**$Pt_{90}Rh_{10}$**	**$Pt_{74}Rh_{26}$**	**$Pt_{35}Rh_{65}$**
-150	0.27	0.41	0.43	0.23
-100	0.29	0.38	0.44	0.23
-50	0.30	0.38	0.45	0.28

- The higher apparent reaction order clearly demonstrates the better performance of Rh incorporated Pt alloys over Pt.
- The Rh-rich catalyst formulation creates high barrier to the dehydrogenetion can hinder the C-C bond breaking process leading to CO, thus weakening the overall catalytic activity of an electrode. There are fewer sites for ethanol absorption on a Rh-rich surface. This is manifested in a lower reaction order for the Rh-rich catalyst.

Tafel plots for EtOH oxidation in 0.5 M H_2SO_4 at various ethanol concentrations

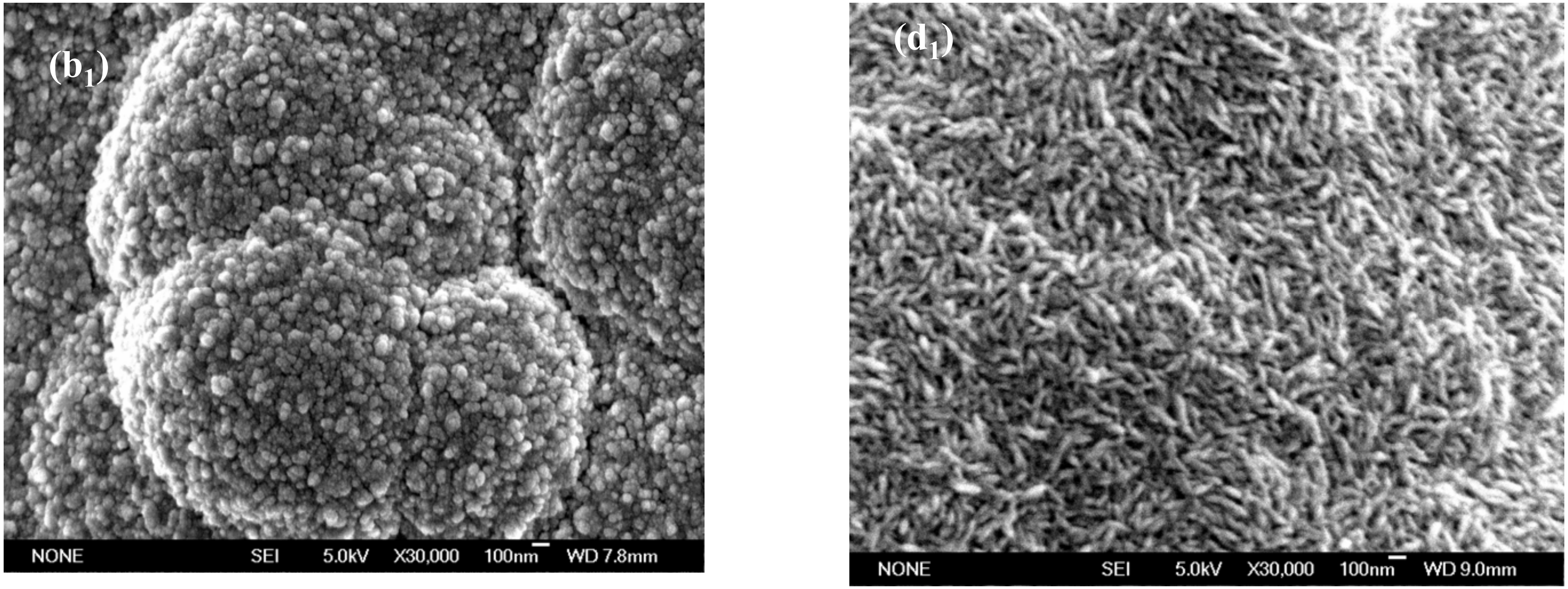


The linear region of the Tafel slope was better expressed when the ethanol concentration was higher

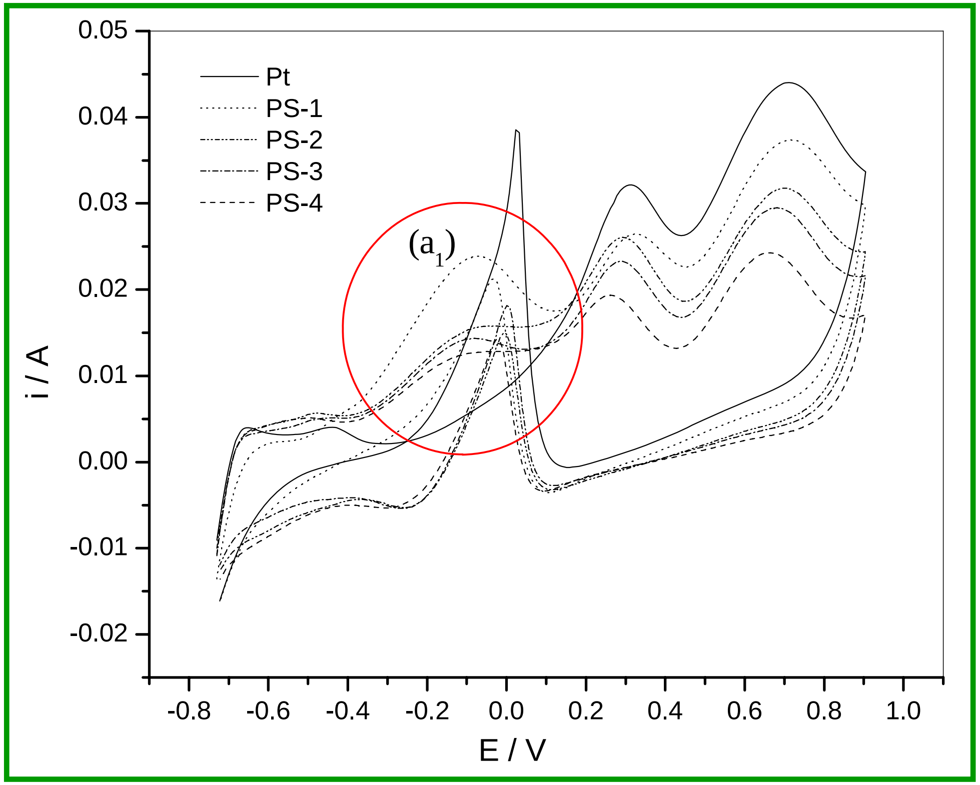
The observed values of the Tafel slope implies that for a 10-fold increase in current density, the overpotential for the $Pt_{74}Rh_{26}$ electrocatalyst ~ 90 mV lower than that for Pt itself.

Electrodes	Tafel slopes, b / mV dec $^{-1}$		
	0.01 M	0.10 M	1.0 M
Pt	258	228	219
$Pt_{74}Rh_{26}$	159	150	138

Promoting Role of Sn in the bi-functional mechanism



FESEM images of as synthesized Pt-Sn catalysts



Cyclic Voltammetry

XRD & EDX Studies indicate presence of SnO2 which facilitates water activation

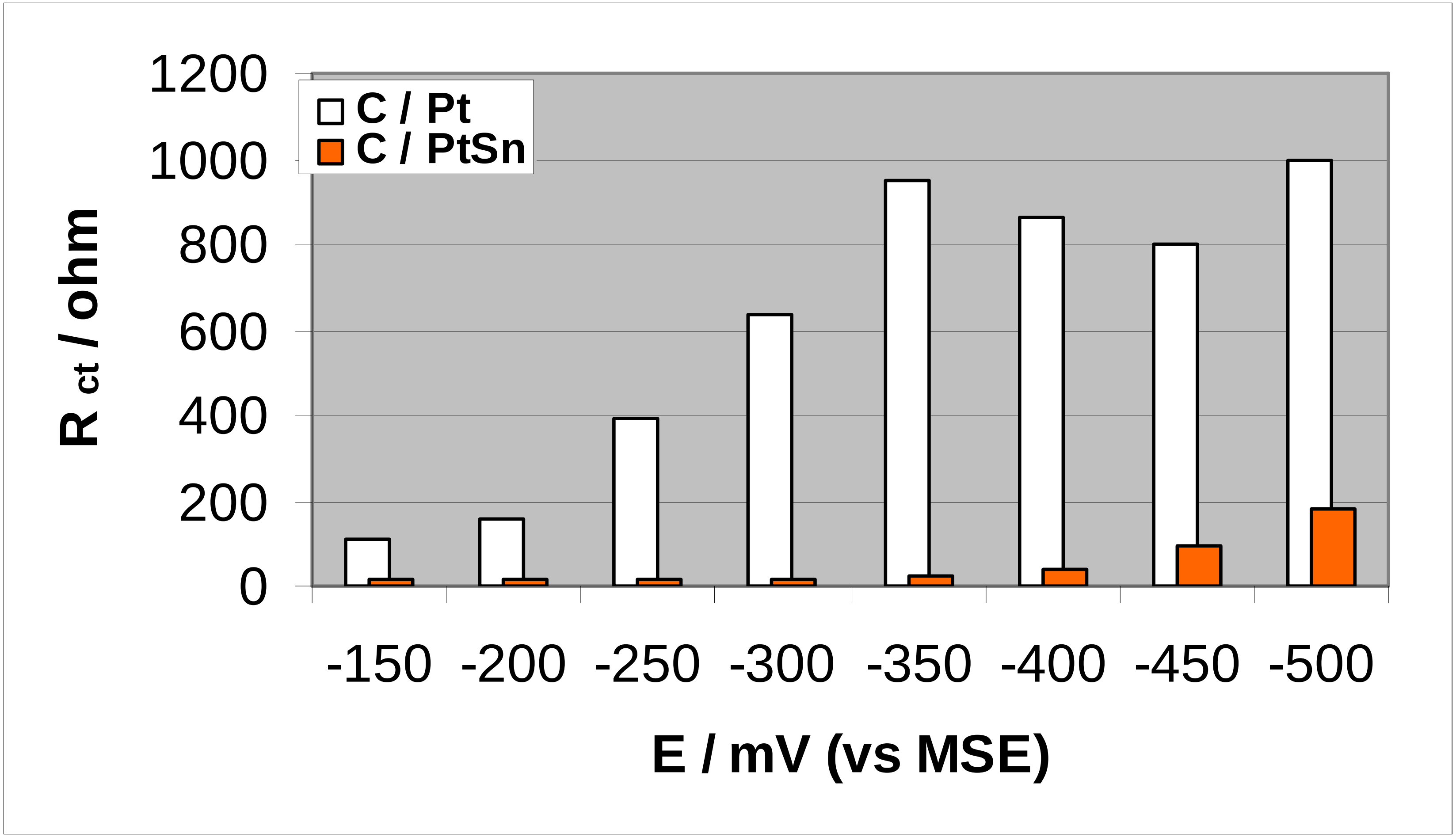
$SnO_2 + H_2O \rightarrow SnO_2\text{-}OH_{ads} + H^+ + e^-$

$Sn + H_2O \rightarrow Sn\text{-}OH_{ads} + H^+ + e^-$

$Pt\text{-}CO_{ads} + SnO_2\text{-}OH_{ads} \rightarrow CO_2 + H^+ + e^-$

$Pt\text{-}CO_{ads} + Sn\text{-}OH_{ads} \rightarrow CO_2 + H^+ + e^-$

Comparison of charge transfer resistance at C/Pt and C/PtSn electrodes



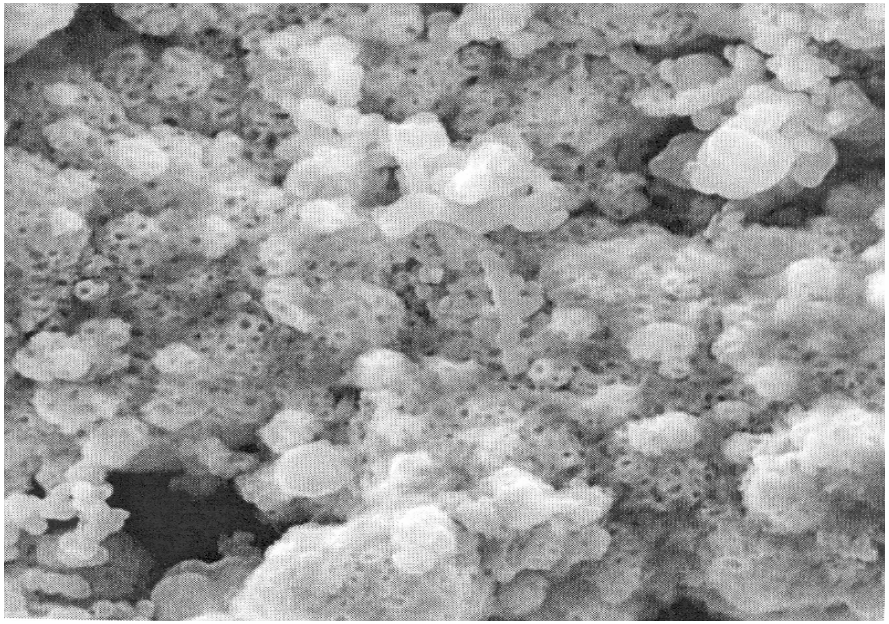
A Novel Electrocatalyst on Metallic Support

Specific objective:

Use of substrate that not only offers enhanced surface area but also assist in the catalytic activity of the noble metal deposits during electro-oxidation of the fuel

- We selected 70:30 copper-nickel alloy as a potential substrate for fabricating the anode catalyst of DAFC

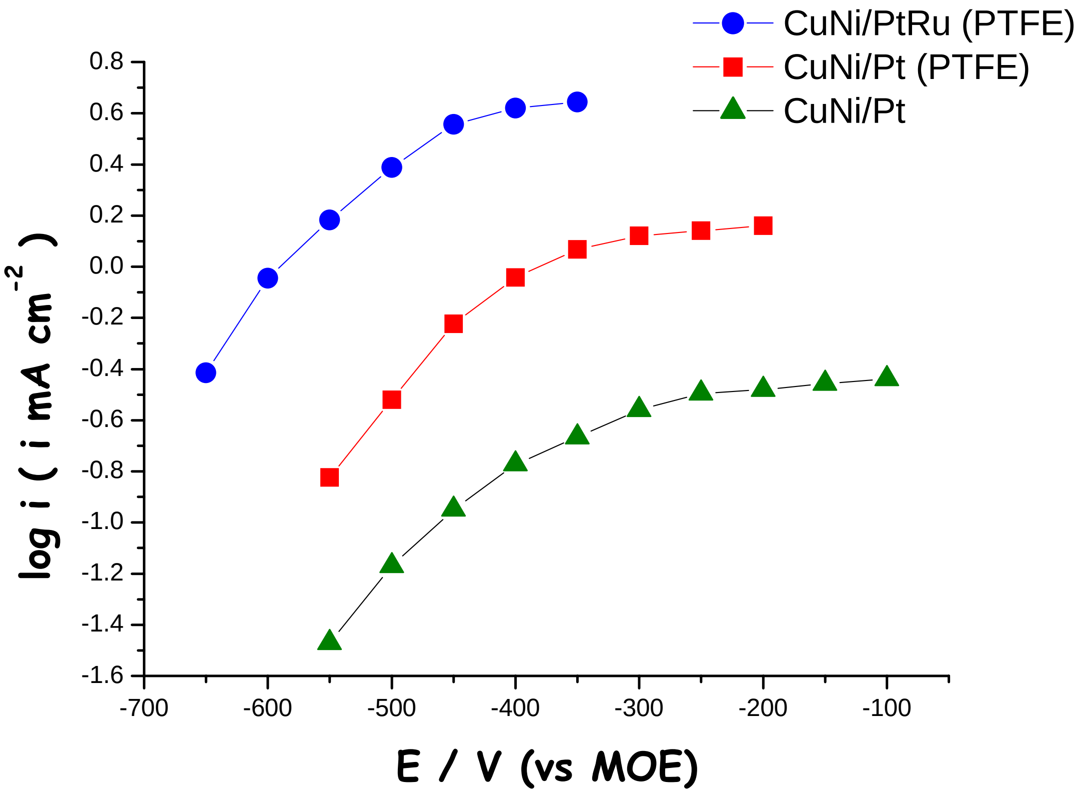
- Catalysts were prepared via electrodeposition from HCl medium & a dilute suspension of PTFE emulsion containing the respective metal chlorides



CuNi/PtRu (PTFE)

- The SEM image show homogeneously distributed small dark particles of about 50nm in diameter which we attribute to Ru deposits on the platinum layers.

Steady-state polarisation curves (1 M EtOH + 0.5 M NaOH)

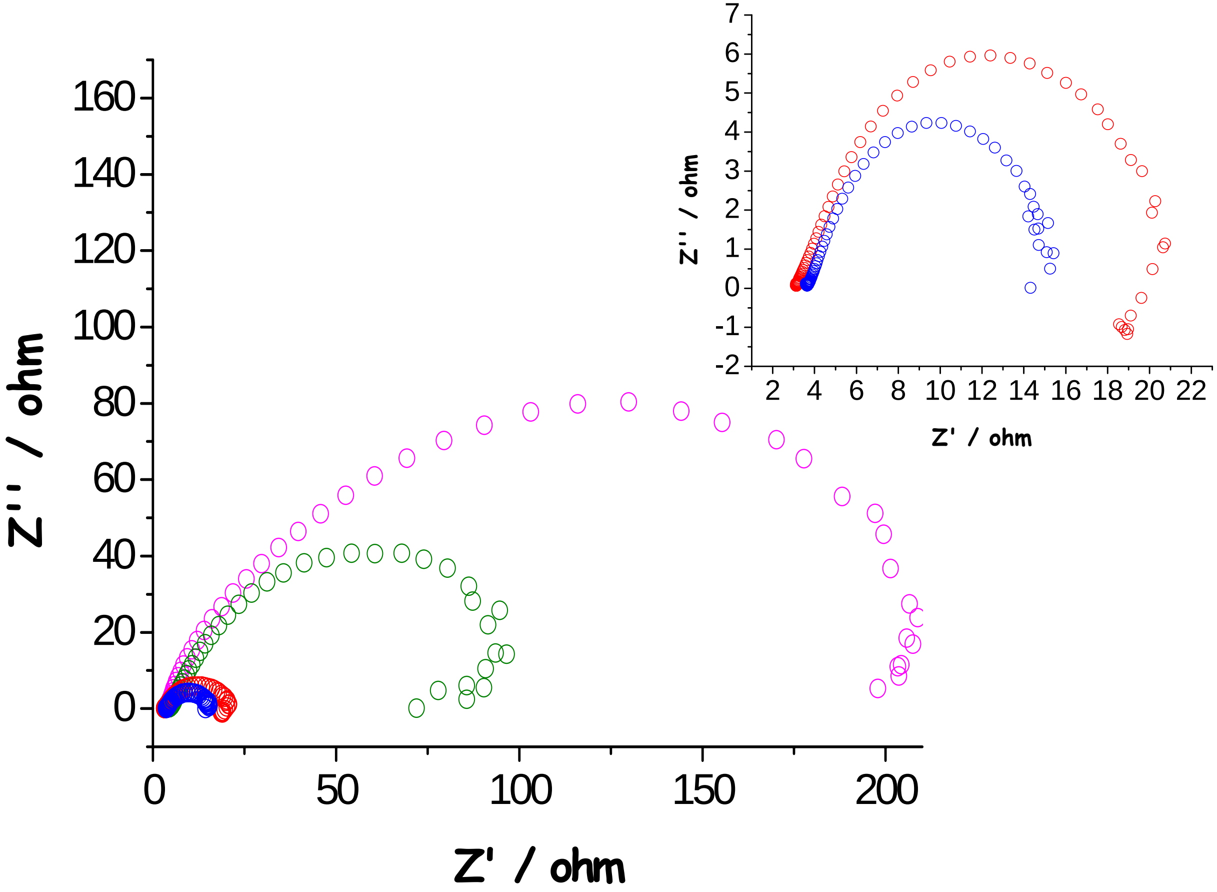


- At -500 mV CuNi/Pt : i_{ox}
  CuNi/Pt(PTFE) : ~ 5 i_{ox}
  CuNi/PtRu(PTFE) : ~ 40 i_{ox}

- The higher electrocatalytic activity for the binary PtRu deposits is explained on the basis of the promoting effect of Ru for the electro-oxidation of alcohols

Electrochemical impedance spectroscopy(EIS): Nyquist plots

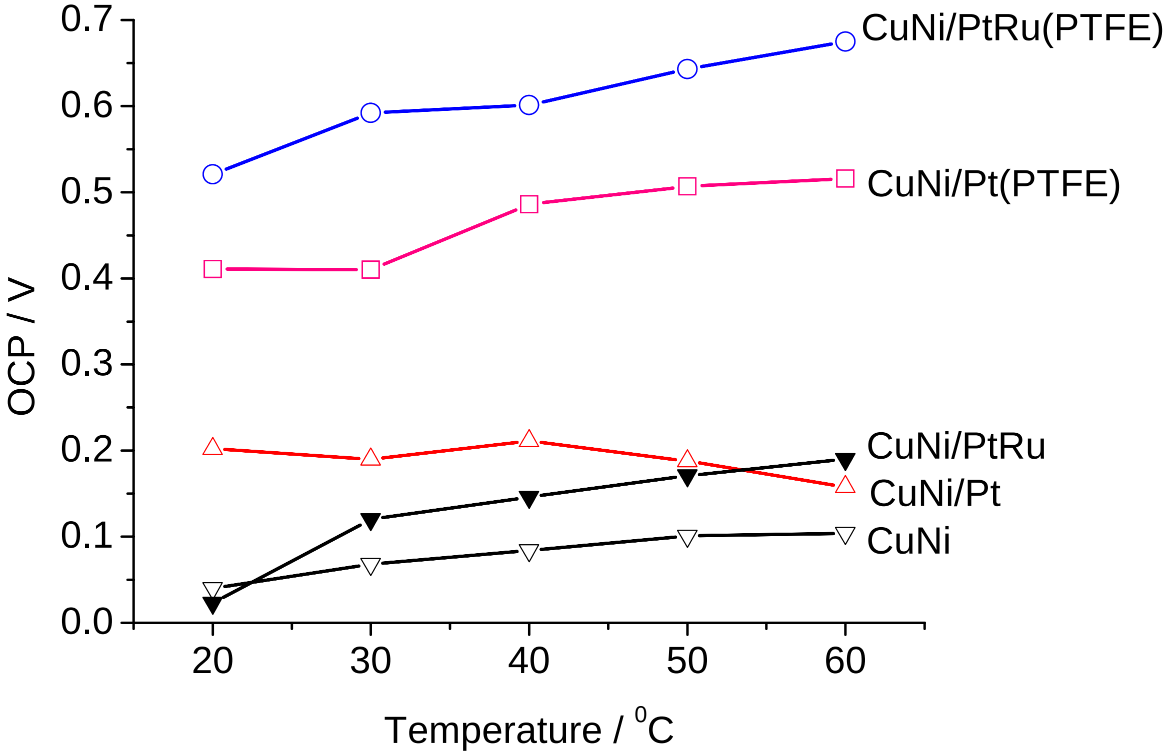
- Applied potential: 0.5 V (vs MOE)
- Frequency range: 65 kHz to 5 mHz



	Rct(ohm)
○ CuNi/Pt (PTFE)	217.5
○ CuNi/Pt	99.0
○ CuNi/PtRu	22.0
○ CuNi/PtRu(PTFE)	15.9

- *A significant decrease in the magnitude of R_{ct} for PtRu co-deposited surfaces indicating an increase in reaction kinetics*
- The highest charge transfer resistance was observed for the Pt deposited electrode indicating the greater poisoning effect on such surfaces

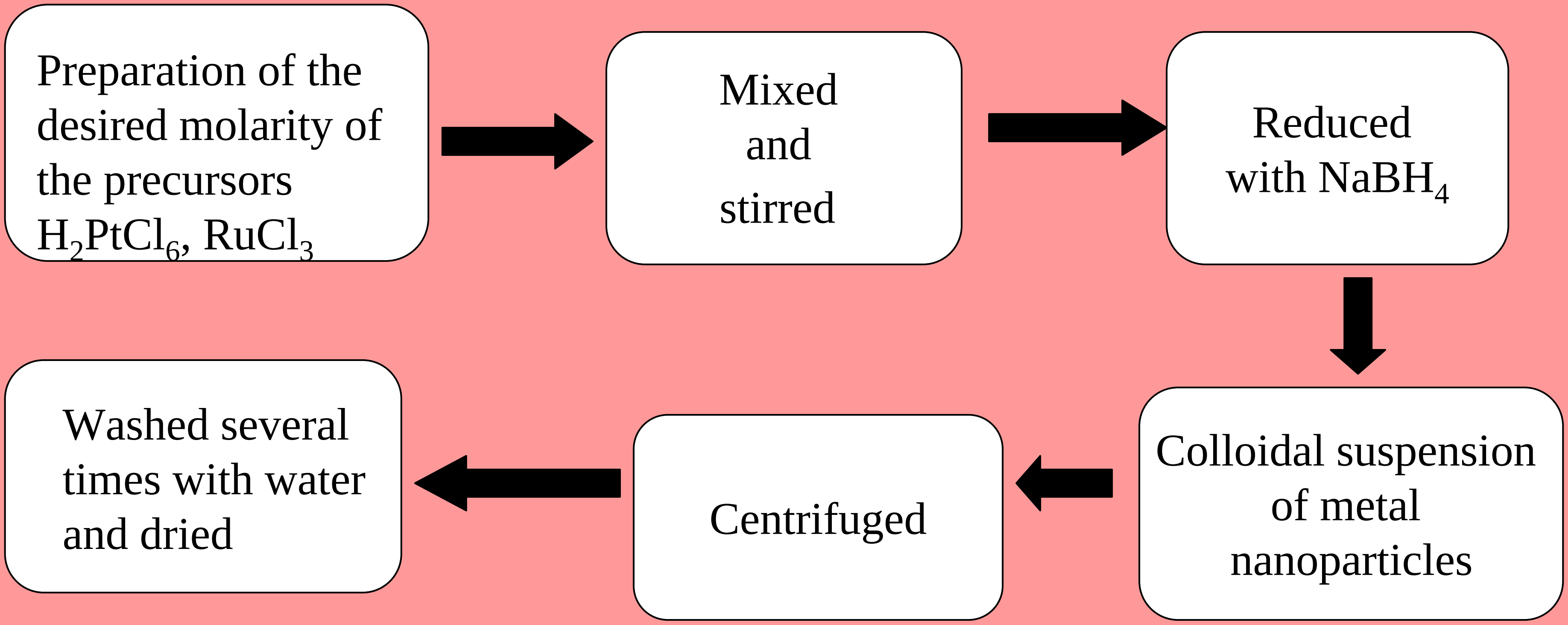
Variation of open circuit potential (OCP) with temperature



- The best performing electrodes are those prepared via electrodeposition from PTFE suspension as would be expected from the results of polarisation and EIS measurements.

FLOW DIAGRAM OF THE CATALYST PREPARATION TECHNIQUE

BOROHYDRIDE REDUCTION



Preparation of the desired molarity of the precursors H_2PtCl_6, $RuCl_3$

Mixed and stirred

Reduced with $NaBH_4$

Colloidal suspension of metal nanoparticles

Centrifuged

Washed several times with water and dried

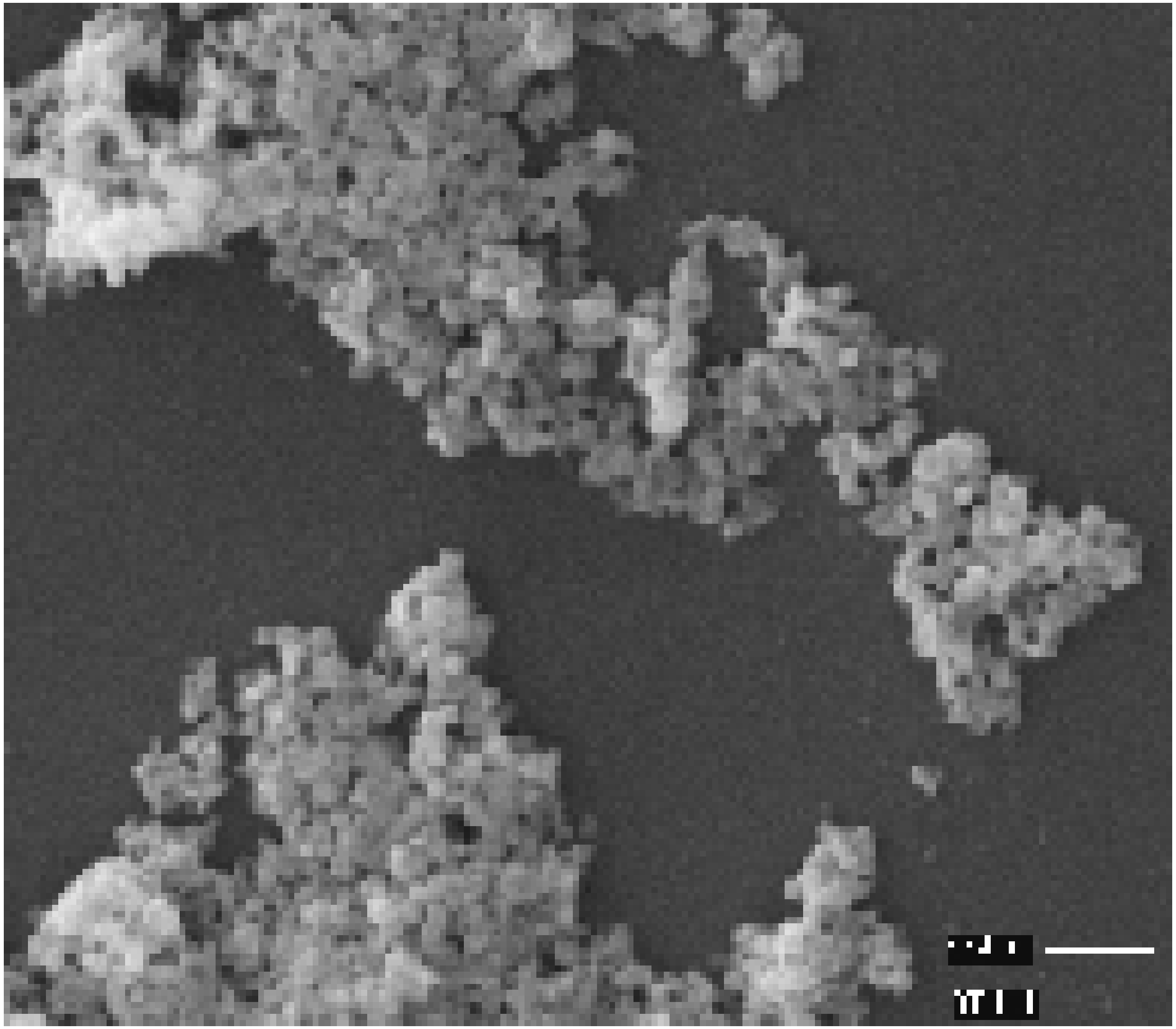
Proposed reaction sequence:

$$BH_4^- + 2H_2O \rightarrow BO_2^- + 4H_2\uparrow$$

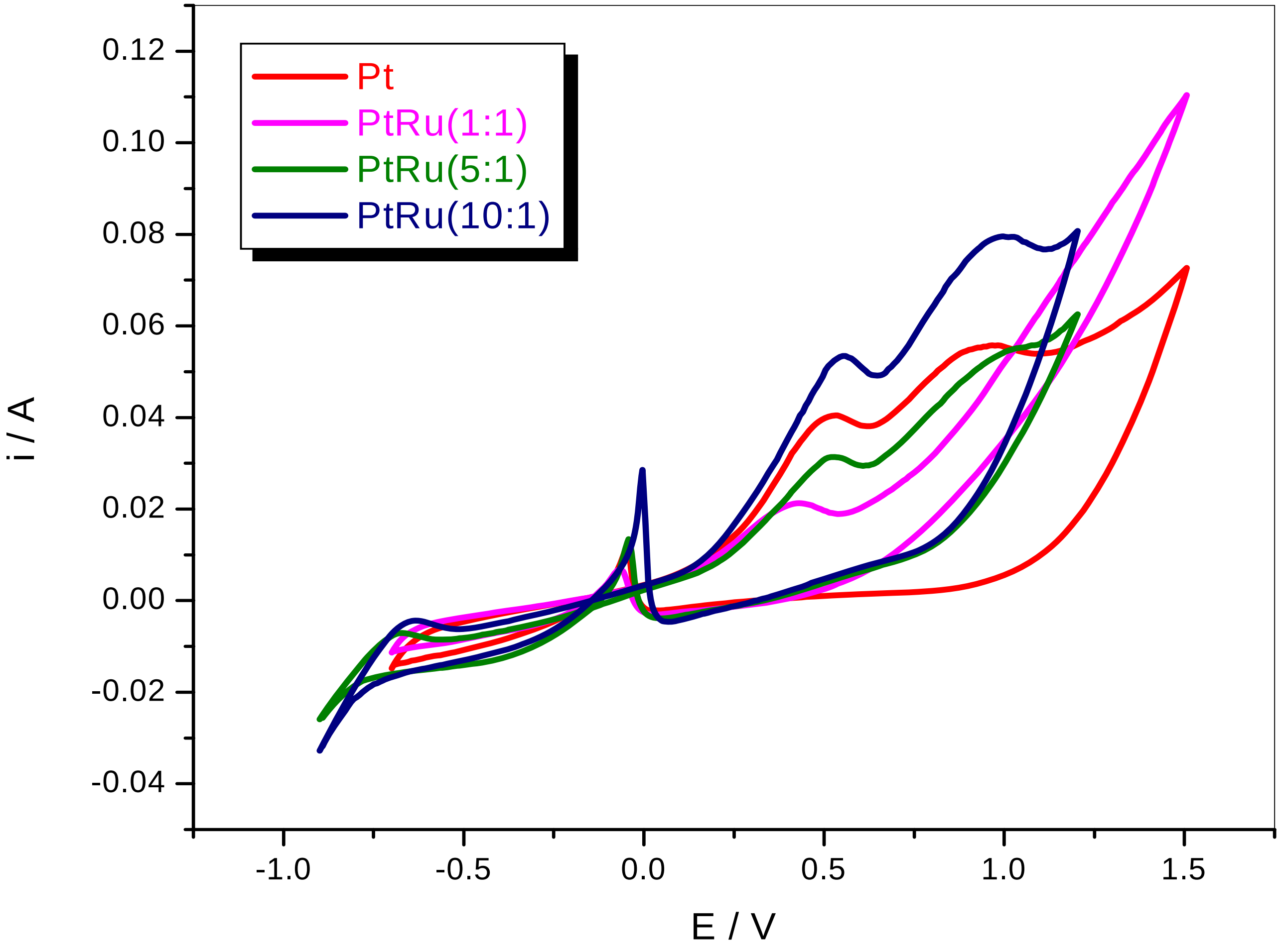
$$n\,BH_4^- + 4M^{n+} + 2nH_2O \rightarrow 4M\downarrow + n\,BO_2^- + 4nH^+ + 2nH_2\uparrow$$

$$(M = Pt, Ru)$$

SEM image of unsupported PtRu(10:1) electrocatalyst

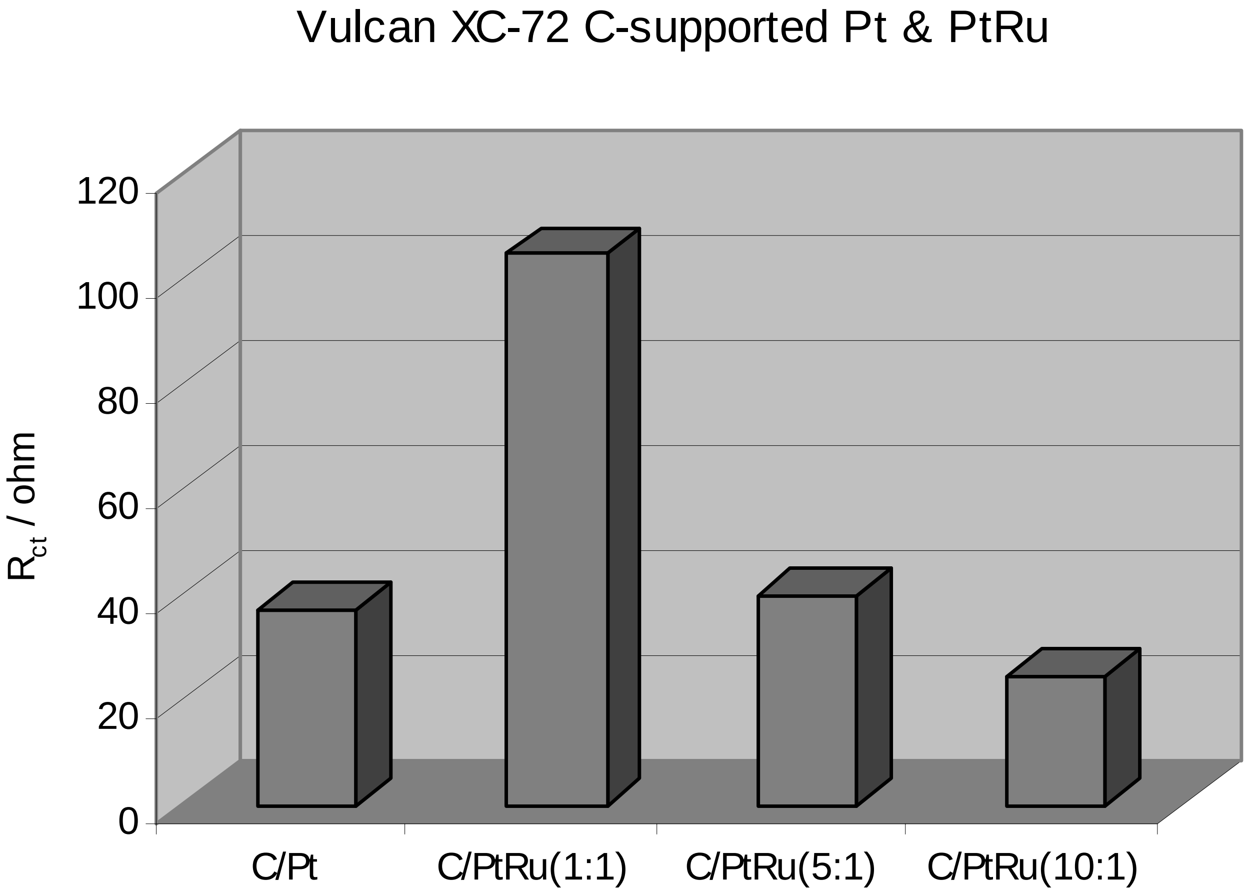


Cyclic voltammograms of ethanol oxidation on supported Pt and different PtRu alloy compositions. Scan rate = 50 mV s^{-1}.



The enhanced electrocatalytic activity of PtRu (10:1) is demonstrated through a lowering of the onset potential and higher electro-oxidation current

Bar chart showing the variation of resistance of Pt and different PtRu alloy compositions



Highest catalytic activity forEthanol Electro-oxidation with binary systems

PtRu: *low Ru content (12-15 at. %). XPS results indicates presence of substantial amount of RuO_4 species in these catalysts.*

Ru does not solely promote ethanol oxidation via the bifunctional mechanism but the dissociative adsorption of ethanol is also favoured by the presence of Ru.

PtRh: Our work has suggested that a suitable alloy composition of PtRh catalyst (relative atomic ratio Pt:Rh = 3:1) may be helpful in dissociating the C—C bond of the adsorbed ethanolic residues.

PtSn: Existence of Sn oxide particles closely associated with the Pt particles seems to excise a catalytically synergistic effect towards oxidation of adsorbed CO on Pt.

Remarks

DEPEMFC: *Incorporation of a third metal in the form of Ru or Sn to the PtRh alloy may lead to the ideal catalyst for complete oxidation of ethanol to* CO_2*.*

Alkaline DEFC: *Novel CuNi supported electrocatalysts synthesized from PTFE suspension of noble metal salts can be an alternative anode material for alkaline DEFC*

Borohydride reduction is a simple cost effective method of developing supported nano-catalysts for DAFC anode on a top-down approach.

Publication related to Fuel Cell Activity

Journals:

J. Datta* and S. Sengupta, *A comparative study on ethanol oxidation behavior at Pt and Pt-Rh electrodeposits*, **Journal of Electroanalytical Chemistry,** Vol. 594, **2006**, 65-72.

J. Datta*, N.R. Bandyopadhyay and S. Sen Gupta, *Carbon supported Pt catalyst for direct alcohol fuel cell anode*, **Journal of Materials & Manufacturing Processes**, Vol.21, **2006**, 703-709.

J. Datta*, and S. Sen Gupta, *Electrode kinetics of ethanol oxidation on novel CuNi alloy supported catalysts synthesized from PTFE suspension*, **Journal of Power Sources**, Vol. 145 **2005**, pp. 124 – 127.

J. Datta*, and S. Sen Gupta, *An invesigation in to the electro-oxidation of ethanol and 2-proanol for application in direct alcohol fuel cells (DAFCs)*, **Journal of Chemical Sciences,** Vol. 117, **2005** pp. 337 – 344.

S. Sengupta, S.S. Mahapatra and **J. Datta***, *A potential anode material for direct alcohol fuel cell*, **J. Power Sources**, vol. 131, **2004**, pp.169-174.

J. Datta*, S. Sinha, C. Bhattacharya and K.K. Kundu, *Solvent and electrode kinetic effects on anodic oxidation of* Br^- - Br_3^- - Br_2 *system on some bare and platinized electrode in some dipolar aprotic solvents found from cyclic volammetric measurements*, **Ind. J. Chem.**, Vol.42A, **2003**, pp.2509-2512.

J. Datta, S. Narayan and M.K. Banerjee Waste Recycling and Resource Management in the developing World, **Ecological Engineering Approach, Pub. University of Kalyani, India and International Ecological Engineering Society, Switzerland, © 2000**, Article - Eco-sustainable technology in India - its present and future, pp 631-637.

Proceedings :

S. Sengupta, S. Sur and **J. Datta**, *Electro-oxidation of ethanol on nano-structured Pt-Rh alloy catalysts*, **Proc. International symposium on Advances in Electrochemical Sciences and Technology (ISAEST-8),** Goa, India, **28–30 November 2006.**

S. Sengupta, S. Sur and **J. Datta**, *Ethanol electro-oxidation on PtRh nanoparticles synthesized by modified borohydride reduction method*, **Proc. International symposium on Advances in Electrochemical Sciences and Technology (ISAEST-8),** Goa, India, **28–30 November 2006.**

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J. Datta*, S. Sengupta and N.R. Bandyopadhyay, *Carbon supported platinum catalyst for direct alcohol fuel cell anode*, **Proc. International Conference on Nano-materials: Synthesis, Characterization and Application - 2004**, Hotel Taj Bengal, Kolkata, India, p.480, **4-6 November, 2004**.

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J. Datta*, S. Sengupta and S. S. Mahapatra, *Potential anode material for direct alcohol fuel cell*, **Proc. 8th Grove fuel cell symposium**, ExCeL, Docklands, London, UK, **24 – 26 Sept. 2003**, p.P2.12

J. Datta*, S. Sengupta, S.S. Mahapatra and M.K. Banerjee, *Search for electro-catalyst for oxidation of methanol and ethanol in alkaline fuel cells*, **Proc. All India Inter Science, Technology & Engineering College Academic Meet 2002**, B.E. College (D.U.), Howrah, India, **6 April 2002**, p.A19

S.S. Mahapatra, S. Sengupta and **J. Datta***, *Electrocatalysts for ethanol oxidation for alcohol-air fuel cells*, **Proc. Complete Cycle Characterization of Materials**, IGCAR, Kalpakkam, Tamil Nadu, **12-14 Sept. 2001**, p.70.

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&

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