Education Department
教育署

Fuel Cell Workshop: Part I

Education Department, HKSAR &

Department of Chemistry
The University of Hong Kong

September/October 2003

Sir William Grove 1839

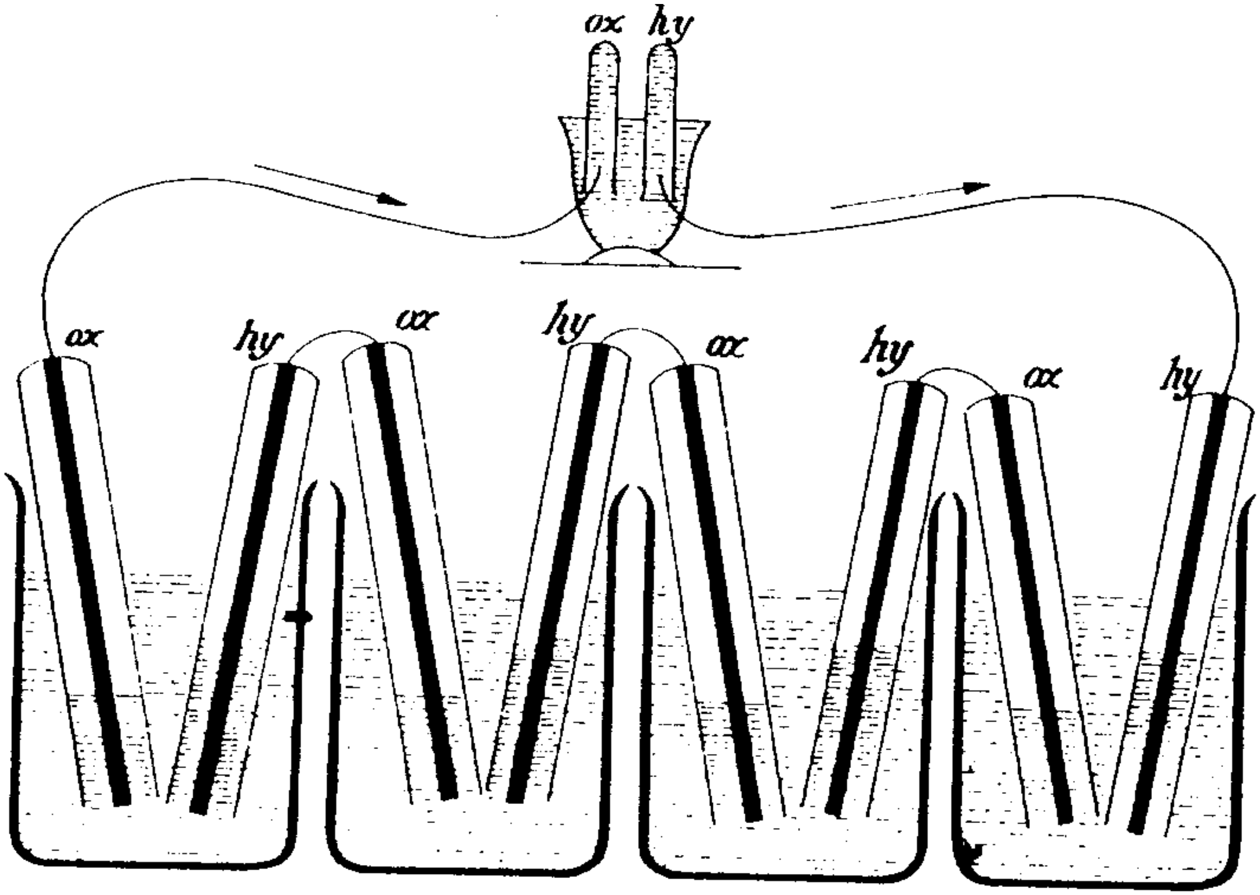


Fig. 1.5 *Four cells of Groves H_2/O_2 battery, used, in Grove's words, 'to effect the decomposition of water by means of its composition'*

Batteries Vs Fuel Cells

Batteries

- Recharge
- Intermittent
- Closed system
- Mostly solid
- High power density

Fuel Cells

- ReFuel
- Continuous
- Open system
- Mostly Gas/Liquid Fuel
- High energy density
- Micro to Mega Watts

Types of Fuel Cells

Classification according to electrolyte

- Alkaline Fuel Cells (AFC)
- Proton Exchange Membrane (PEM)
- Phosphoric Acid (PAFC)
- Molten Carbonate (MCFC)
- Solid Oxide Electrolyte (SOFC)

Classification according to fuel-oxidant

- Hydrogen-oxygen
- Direct methanol (DMFC)
- Hydrogen-bromine

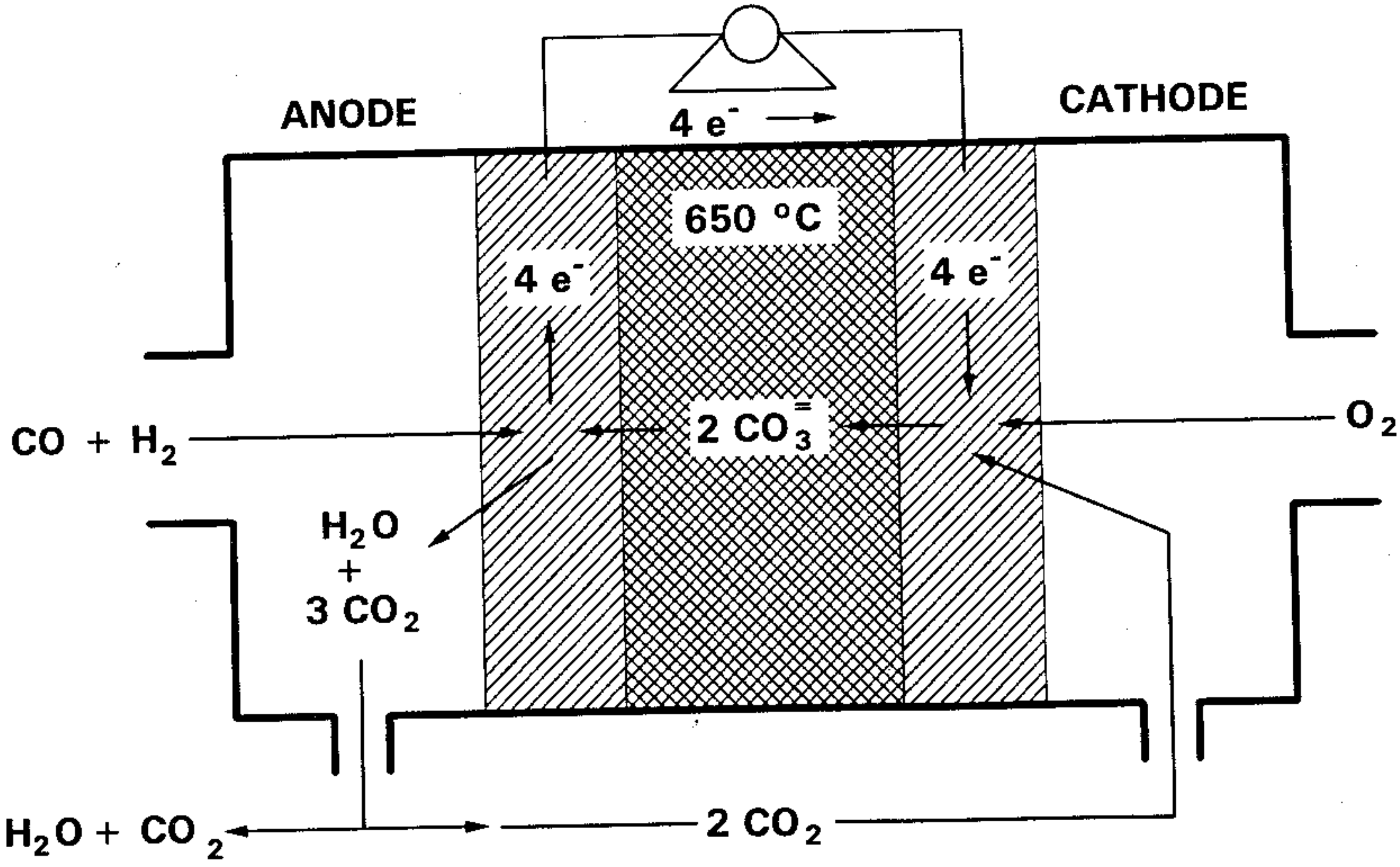
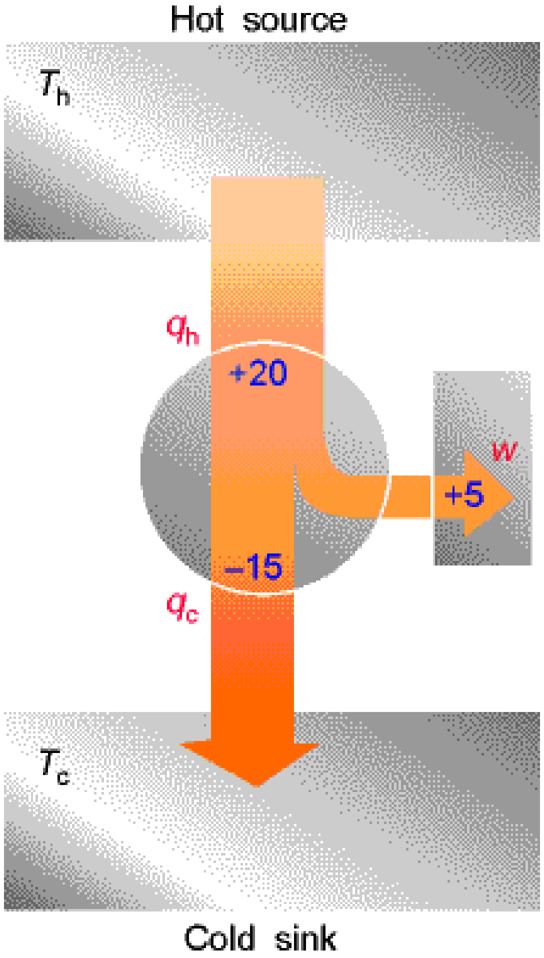


Figure 2.8. Schematic of a molten carbonate fuel cell.

Advantages of Fuel Cells

- Efficient conversion of Chemical Energy to useful energy (without losing to heat, mechanical linkages)
- Environmentally friendly
- Flexible: from micro to mega
- Continuous or Rapid refueling for portable use
- Quiet: for military applications



Carnot's Theorem

Efficiency of Heat Engine

$$\eta_{\text{thermal}} = \frac{\text{Work}}{\text{Heat}} = 1 - \frac{T_c}{T_h}$$

Fuel Cells

Chemical Energy → Electrical Energy

$$\eta_{\text{thermal}} = \frac{\text{Work}}{\text{Heat}} = \frac{\Delta G}{\Delta H} = \frac{\Delta H - T\Delta S}{\Delta H}$$

Thermodynamics

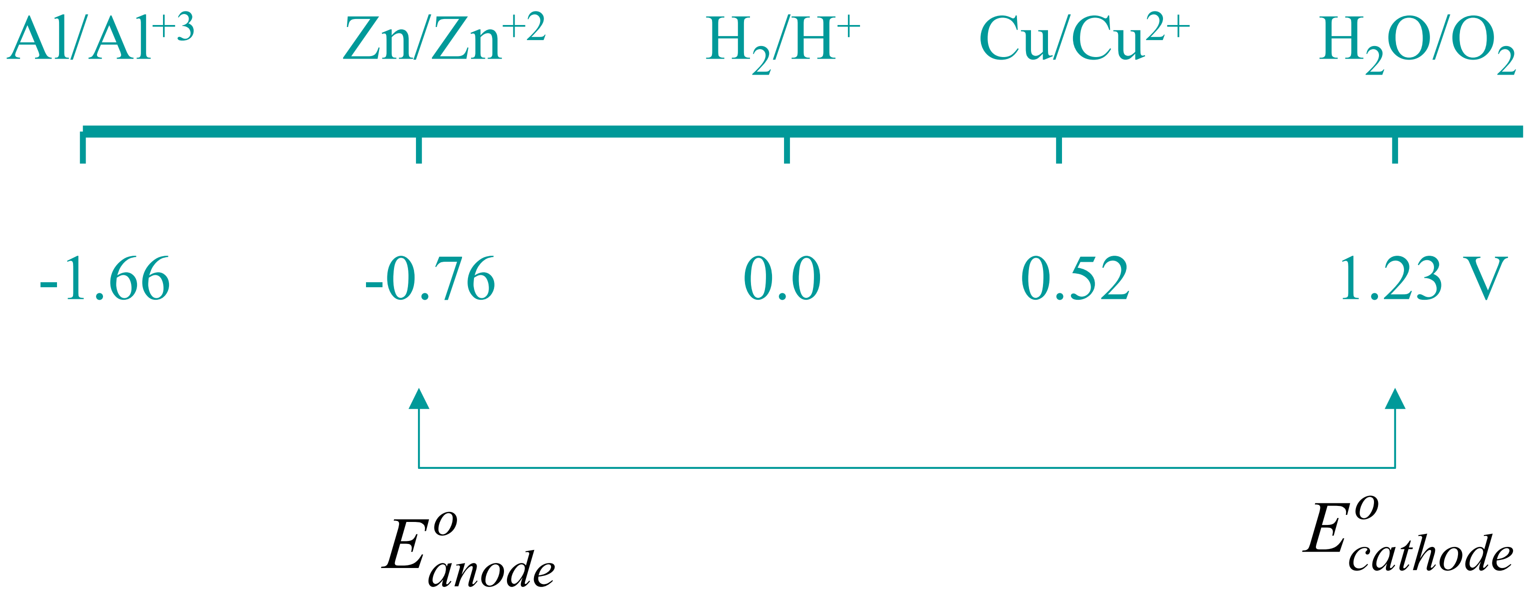
- Relate Reactivity to **Electrode Potential**
- **Nernst Equation** accounts for concentration(activity) effects

$$E - E^o = -\frac{RT}{nF}\ln\left[\frac{a_C^c a_D^d}{a_A^a a_B^b}\right] \approx \frac{-0.0591}{n}\log\frac{[\mathrm{Re}]}{[Ox]}$$

- Calculate Electrode Potential from **Free Energy**

$$E^o_{cathode} - E^o_{anode} = E^o_{cell} = -\frac{\Delta G^o}{nF}$$

Electrochemical Activity Series



Al/Al^{+3} Zn/Zn^{+2} H_2/H^+ Cu/Cu^{2+} H_2O/O_2

-1.66 -0.76 0.0 0.52 1.23 V

E^o_{anode} $E^o_{cathode}$

$$E^o_{cathode} - E^o_{anode} = E^o_{cell} = -\frac{\Delta G}{nF}$$

HYDROGEN + OXYGEN ⟶ WATER + ENERGY

Alkaline

Anode: $H_2 + 2\ OH^- \longrightarrow 2H_2O + 2e^-$

Cathode: $\frac{1}{2}\ O_2 + 2e- + H_2O \longrightarrow 2\ OH^-$

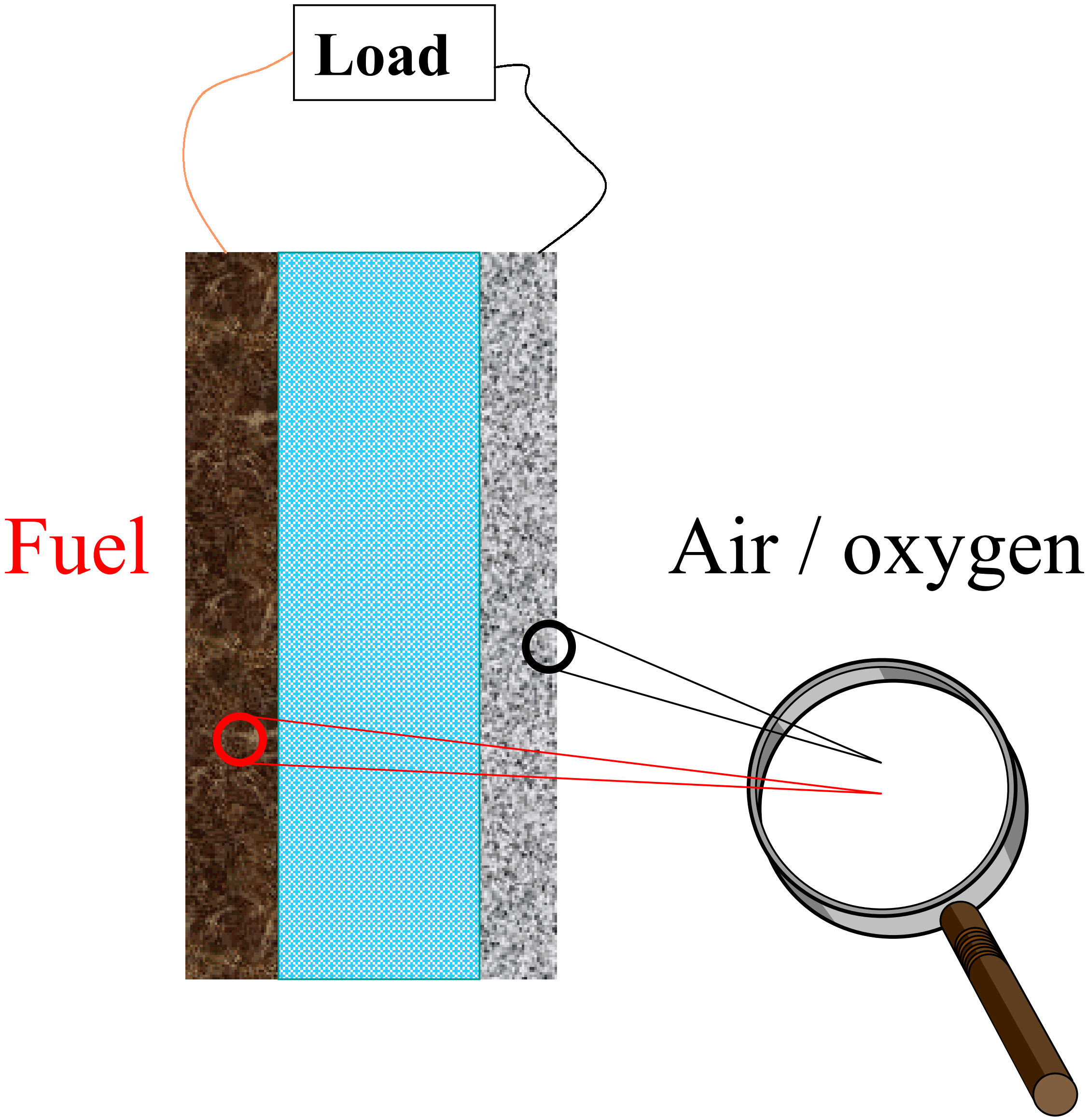
Acidic

Anode: $H_2 \longrightarrow 2H^+ + 2e^-$

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

Thermochemistry

	$\Delta_c H°$ (kJmol^{-1})	$\Delta_c G°$ (kJmol^{-1})	n	E°	kJ/kg	kJ/cm^3
Hydrogen	- 285	- 237	2	1.23	118500	10.65
Carbon	- 395	- 394				
Methane	- 890	- 818	8	1.06	51125	
Ethane	-1560	-1467				
Methanol	- 726	- 702	6	1.21	21938	17.37
Glucose	-2808	-2865	24	1.23	15916	24.57
Octane	-5471				47907	


Load
Fuel
Air / oxygen

Fuels: Hydrogen
- Metals
- Natural Gas
- Small Hydrocarbons (methanol, glucose)

Oxidant: air
- oxygen
- halides
- oxides

Catalysts: platinum
- metals
- metal oxides
- macrocycles

Catalyst Support:
- Porous Carbon
- Ceramic Matrix
- Metal Foam
- PTFE

Bipolar Plate, Frame, container.

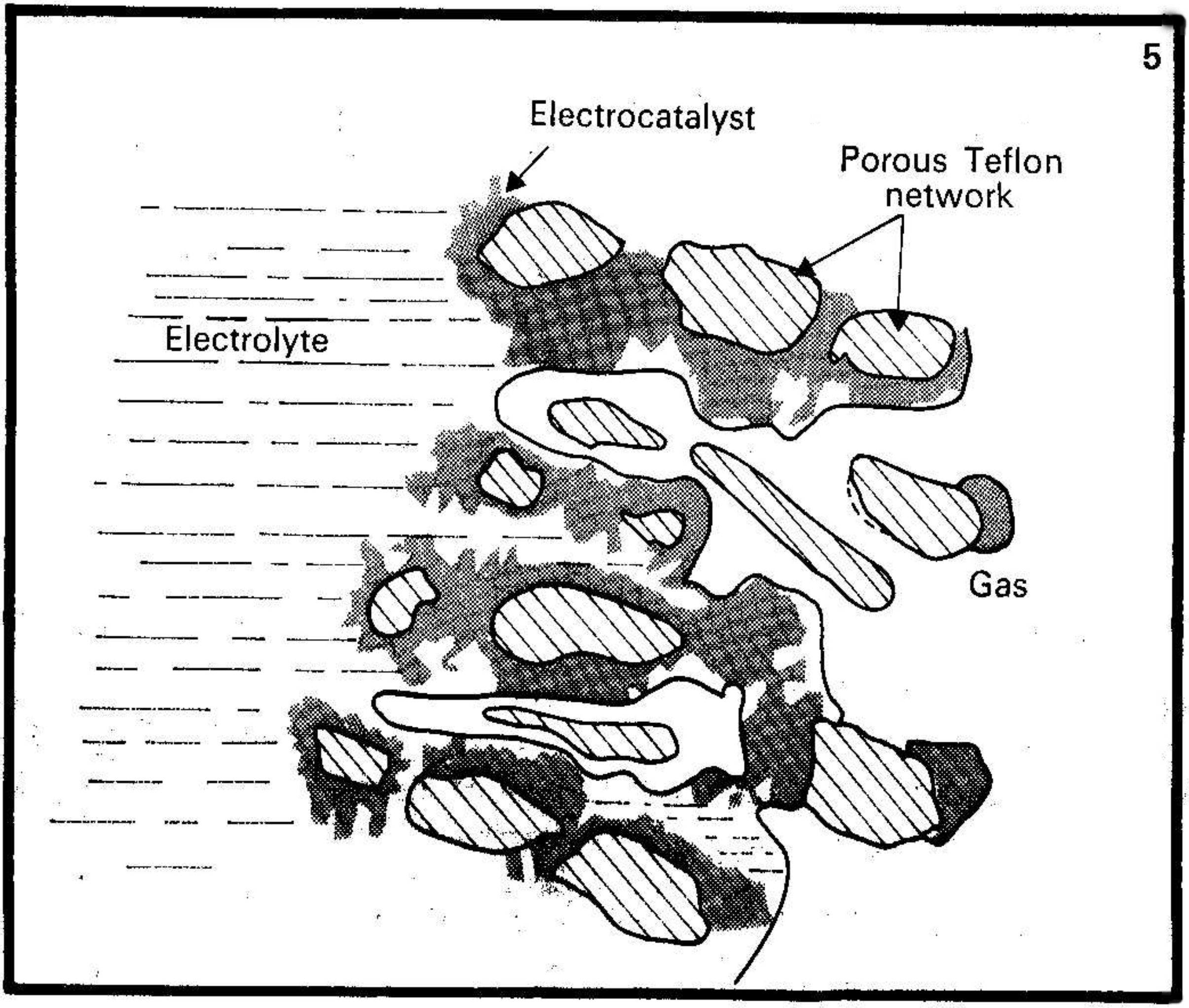
Electrolyte:
- Porous Matrix
- Proton Exchange Membranes
- Yttrium stabilized Zirconia

Storage: Metal Hydride

Electrodes:

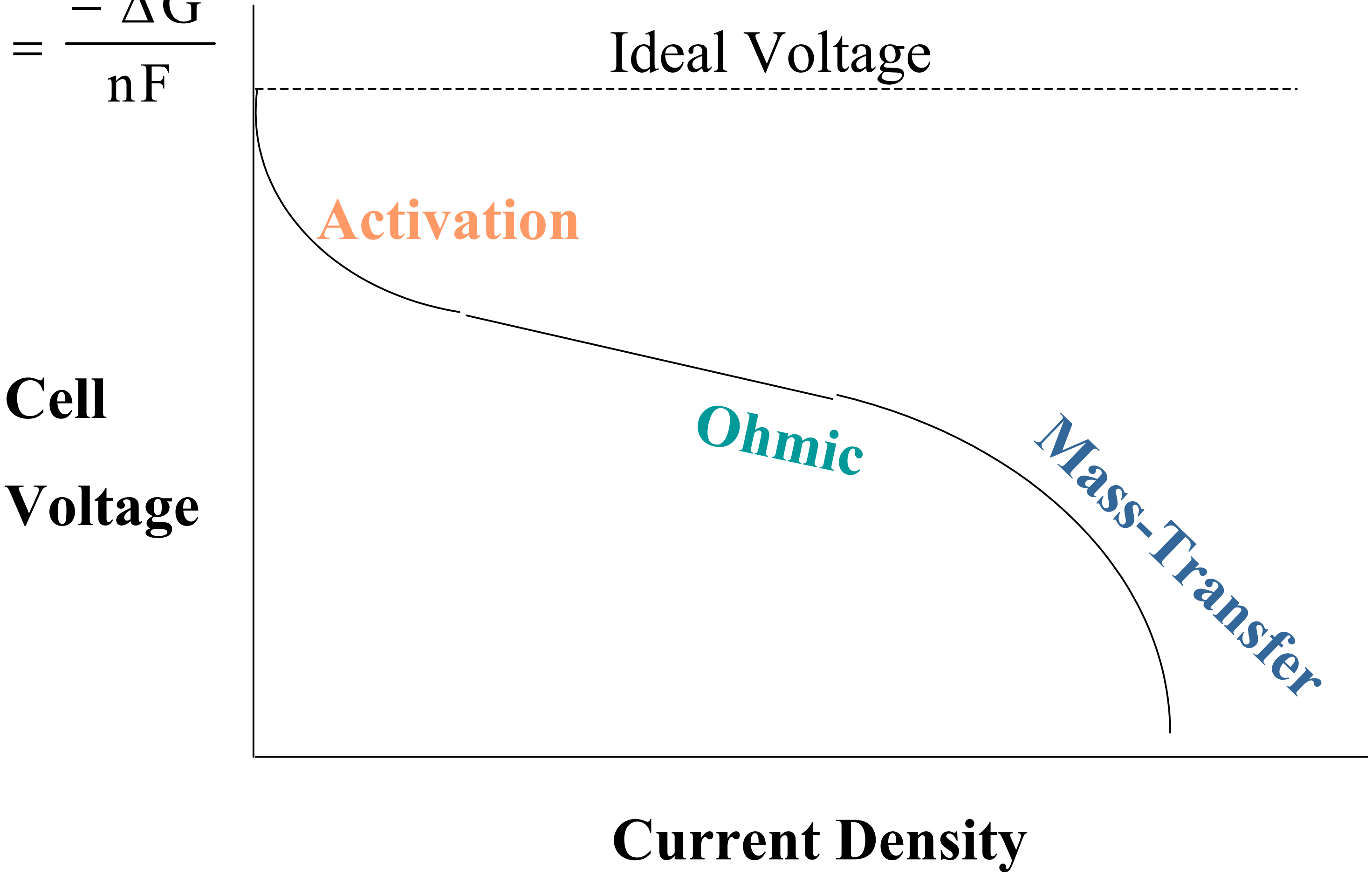
- Catalyst Support: High Surface Carbon
- Size Effects of Catalysts
- Controlled Porosity
- Controlled Wetting
- Maximum Gas-Liquid-Solid Interface
- Minimize ohmic resistance
- Minimize ionic resistance

Gas Diffusion Electrode: PTFE bonded electrode



Performance of a Fuel Cell

$$E = \frac{-\Delta G}{nF}$$



$E^o_{cell} = -\Delta G/(nF)$

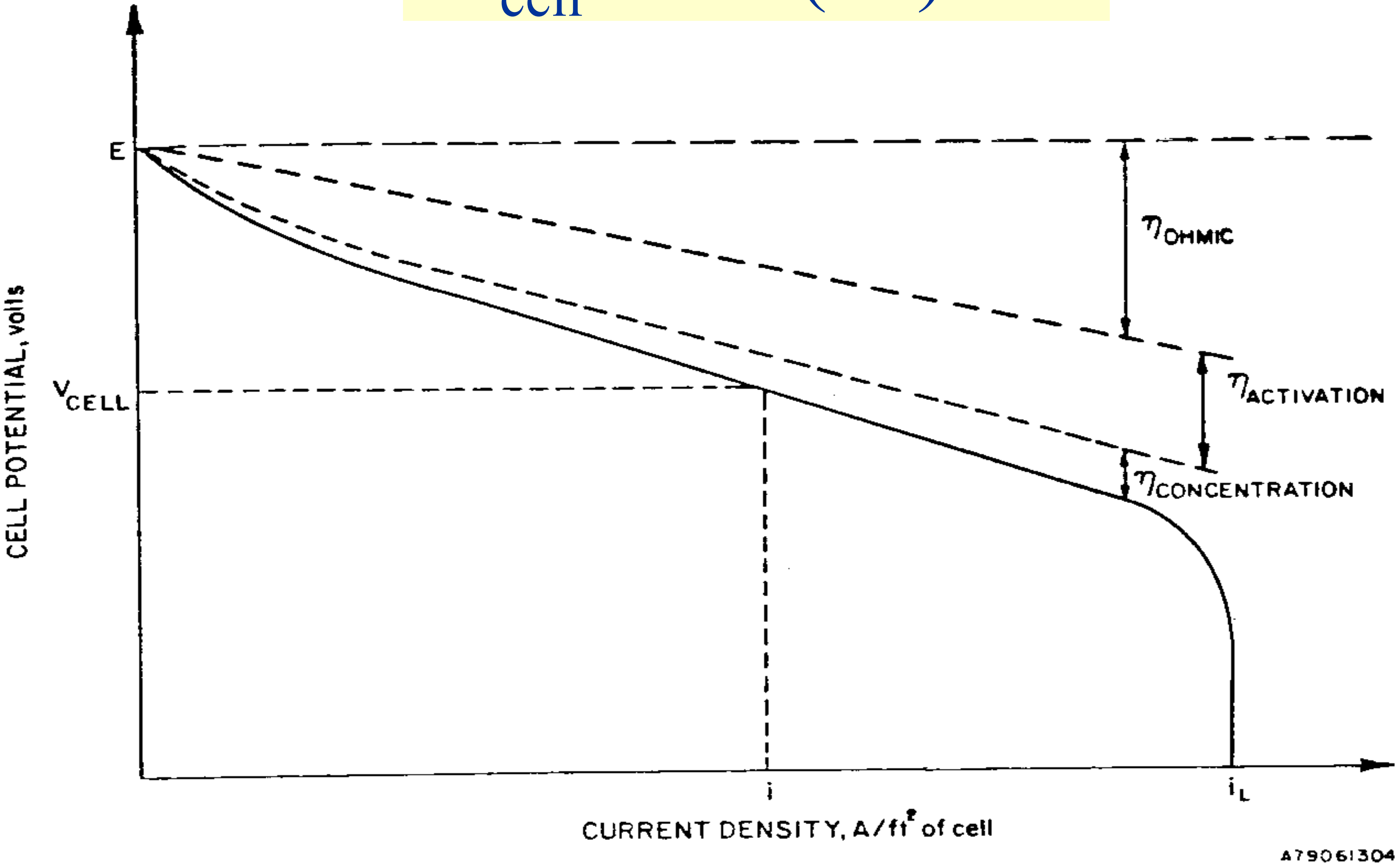


Figure 2.1. SCHEMATIC FUEL CELL POLARIZATION CURVE

Electrode Kinetics

- Current ∝ Rate of reaction (Faraday's law)
- Rate (current) described by **Tafel Equation**

$$E - E^{eq} = \frac{RT}{\alpha nF} \ln i + const._o$$

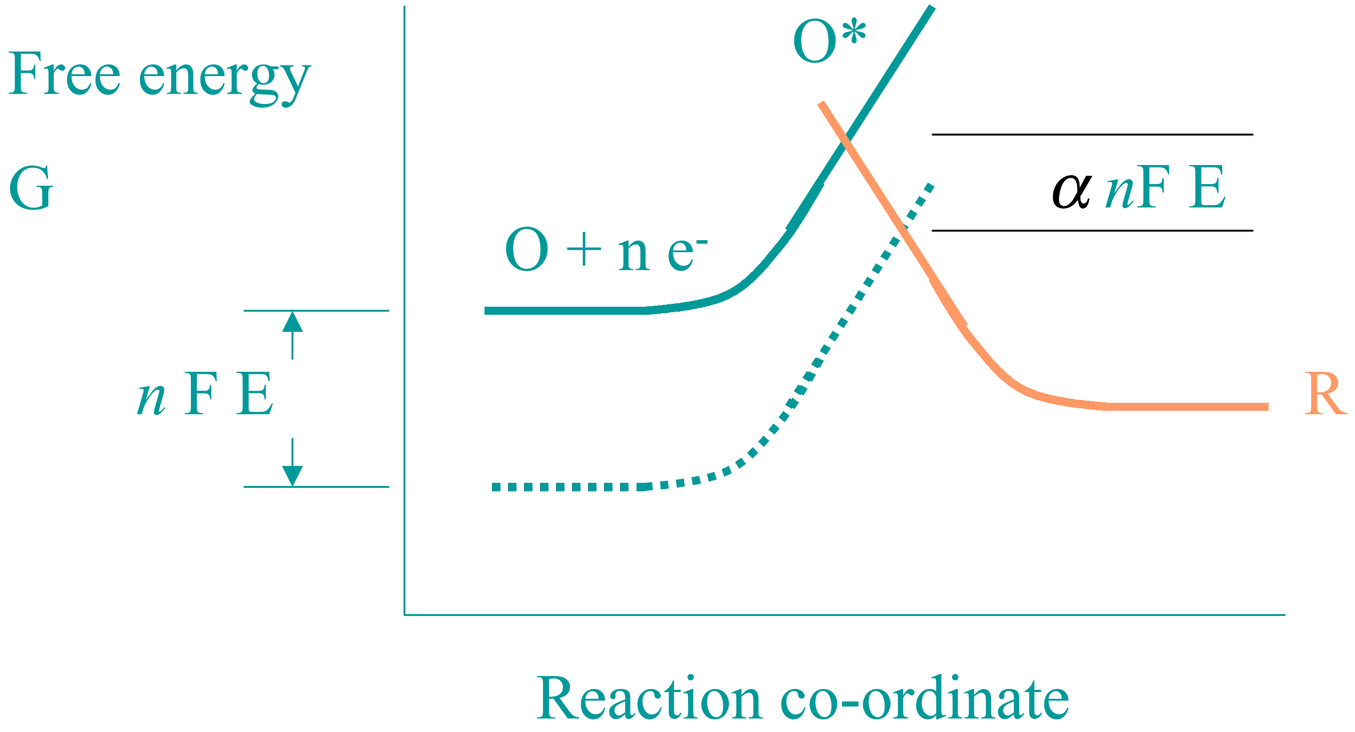
or Butler-Volmer Equation (Bard and Faulkner, Wiley 2001)

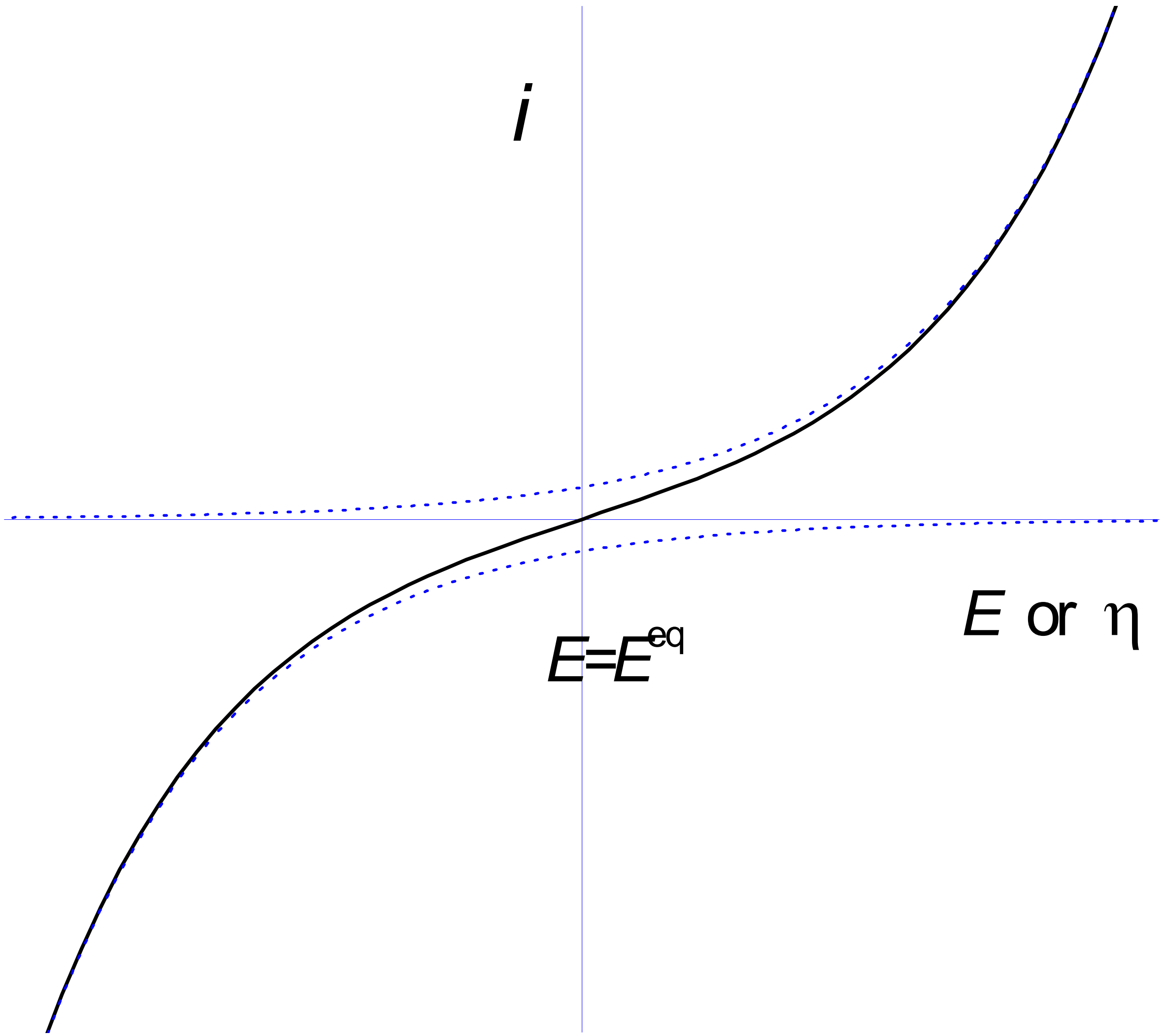
$$i = i_o \left\{ \frac{C_O}{C_O^*} \exp\left[\frac{-\alpha nF(E - E^{eq})}{RT} \right] - \frac{C_R}{C_R^*} \exp\left[\frac{(1-\alpha)nF(E - E^{eq})}{RT} \right] \right\}$$

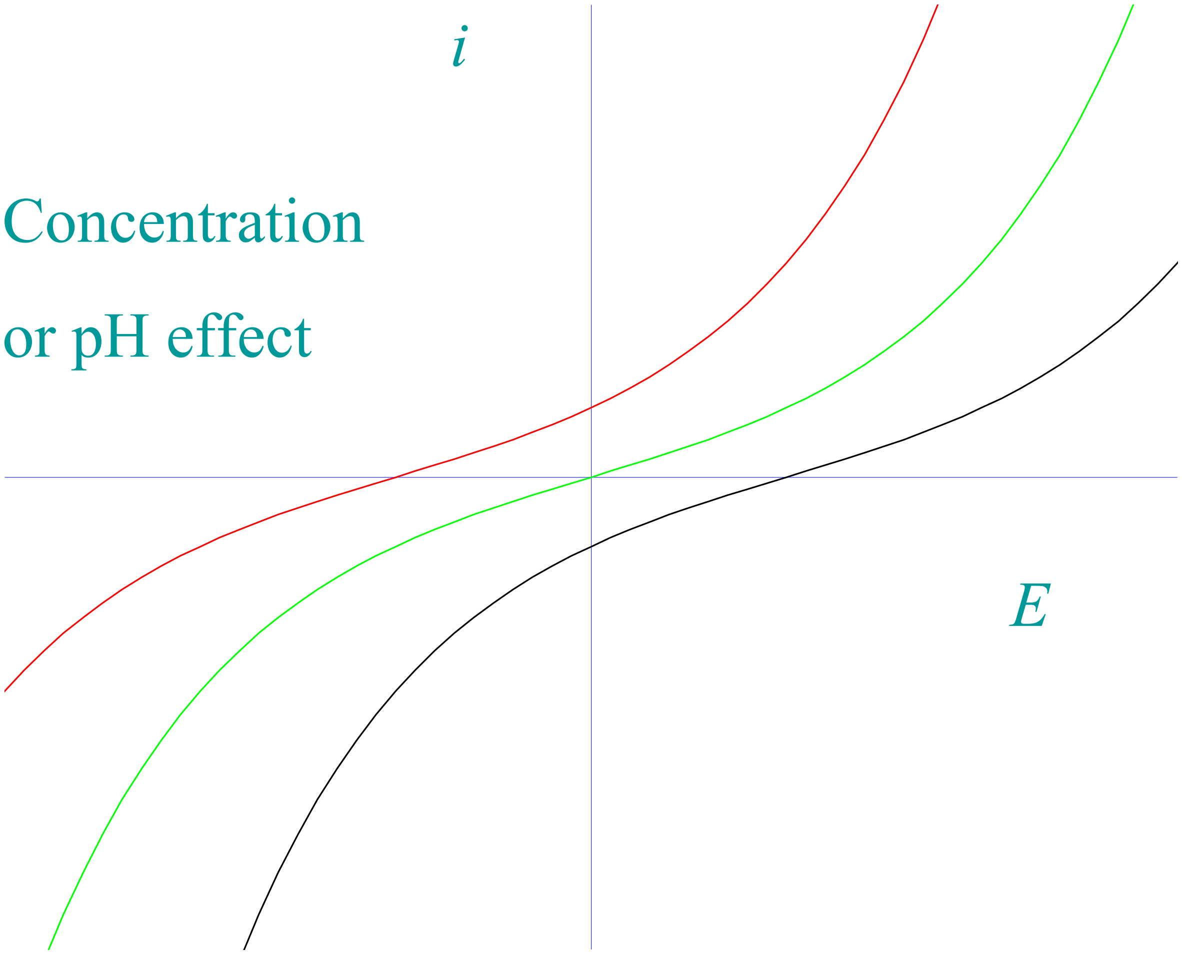
Electrode Kinetics

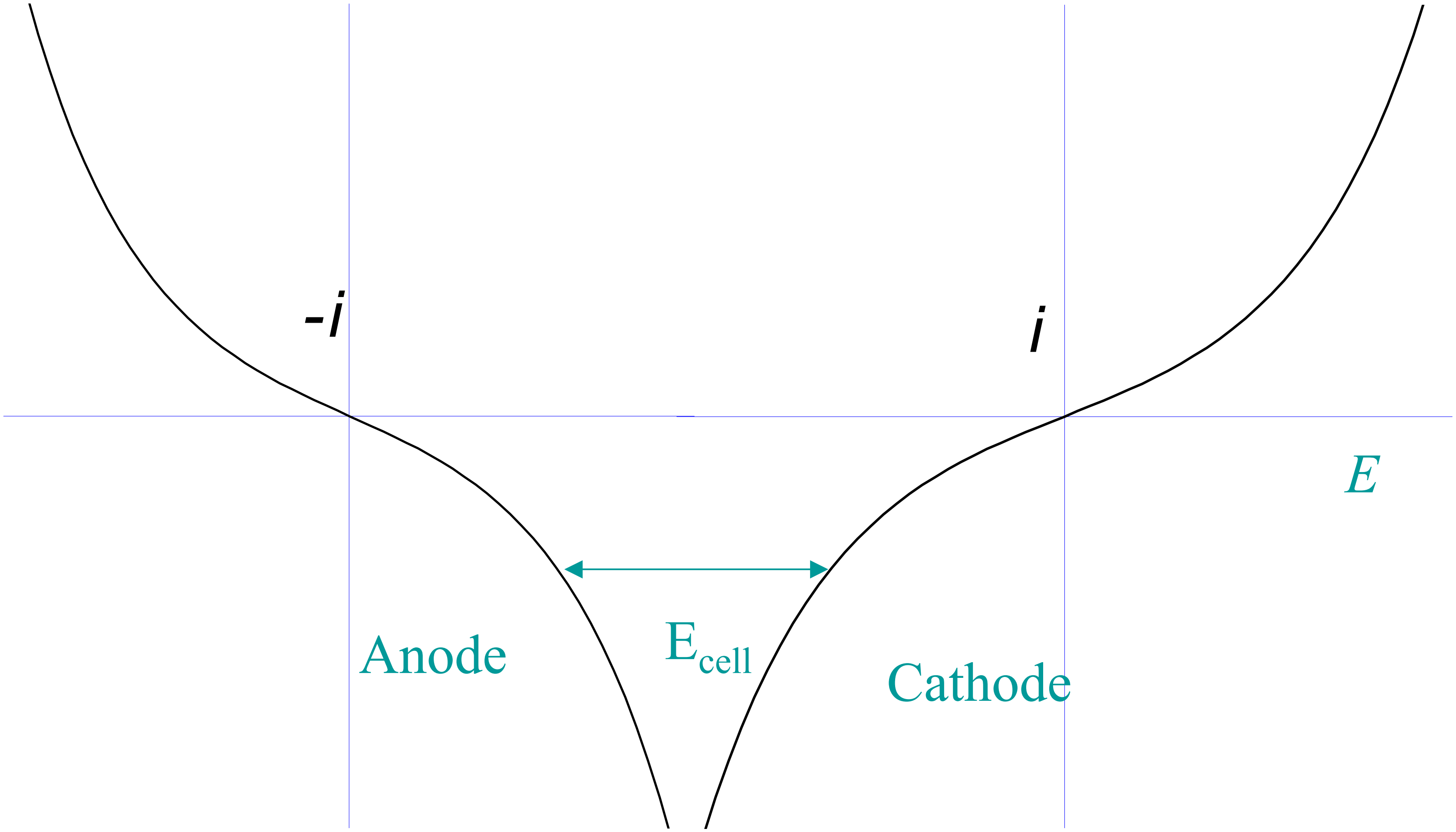
$$i = i_o \left\{ \frac{C_O}{C_O^*} \exp\left[\frac{-\alpha n F (E - E^{eq})}{RT} \right] - \frac{C_R}{C_R^*} \exp\left[\frac{(1-\alpha) n F (E - E^{eq})}{RT} \right] \right\}$$

from Absolute Rate Theory




i
E or η
E=E^eq


i
Concentration
or pH effect
E

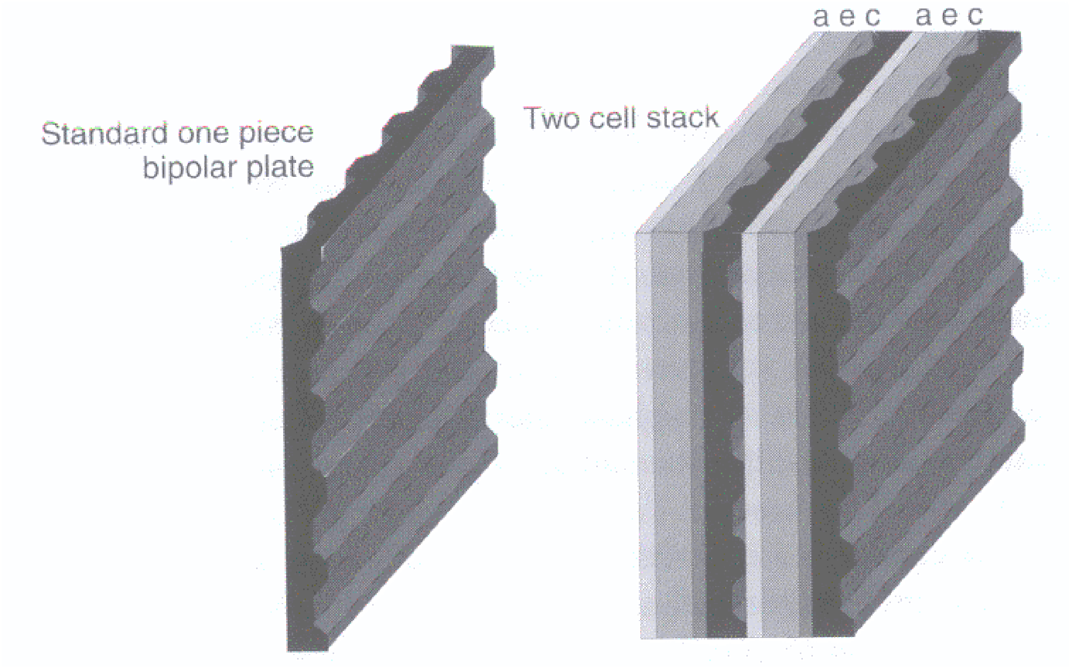

-*i*
i
E
Anode
E_{cell}
Cathode

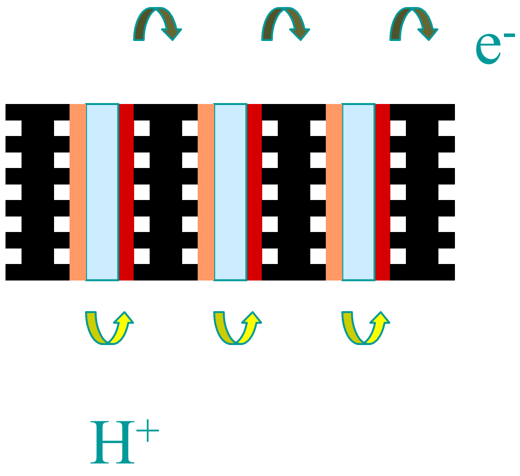
Tests Other than Polarization Curve:

- Half Cell Study (3 Electrode set up)
- Chronopotentiommetry
- Chronoampereometry

Stack Design

- Manifold for fuel feed
- Manifold for oxidant feed
- Electronic circuit
- Ionic circuit
- Water transport
- Temperature, humidity control


Standard one piece bipolar plate
Two cell stack
a e c a e c


e-
H+

Stationery Power Utilities

10~100 kW

100~500 kWhr

ONSY (IFC), Fiji

SOFC (Westing House, Honey Well)

Load Levelling

Power Distribution

Life


ONSI
非工作人員
禁止入內

Portable Power Sources

10~100 kW

100~500 kWhr

Battery vs Fuel Cells

Safety (H_2 , MeOH, caustic electrolyte), Open vs Closed System

Volume vs Weight

Refueling Vs Recharging

Electric Vehicles

10~100 kW

100~500 kWhr

Battery vs Fuel Cells

Hybrid with ICE and capacitor

Costs: 7 times normal costs

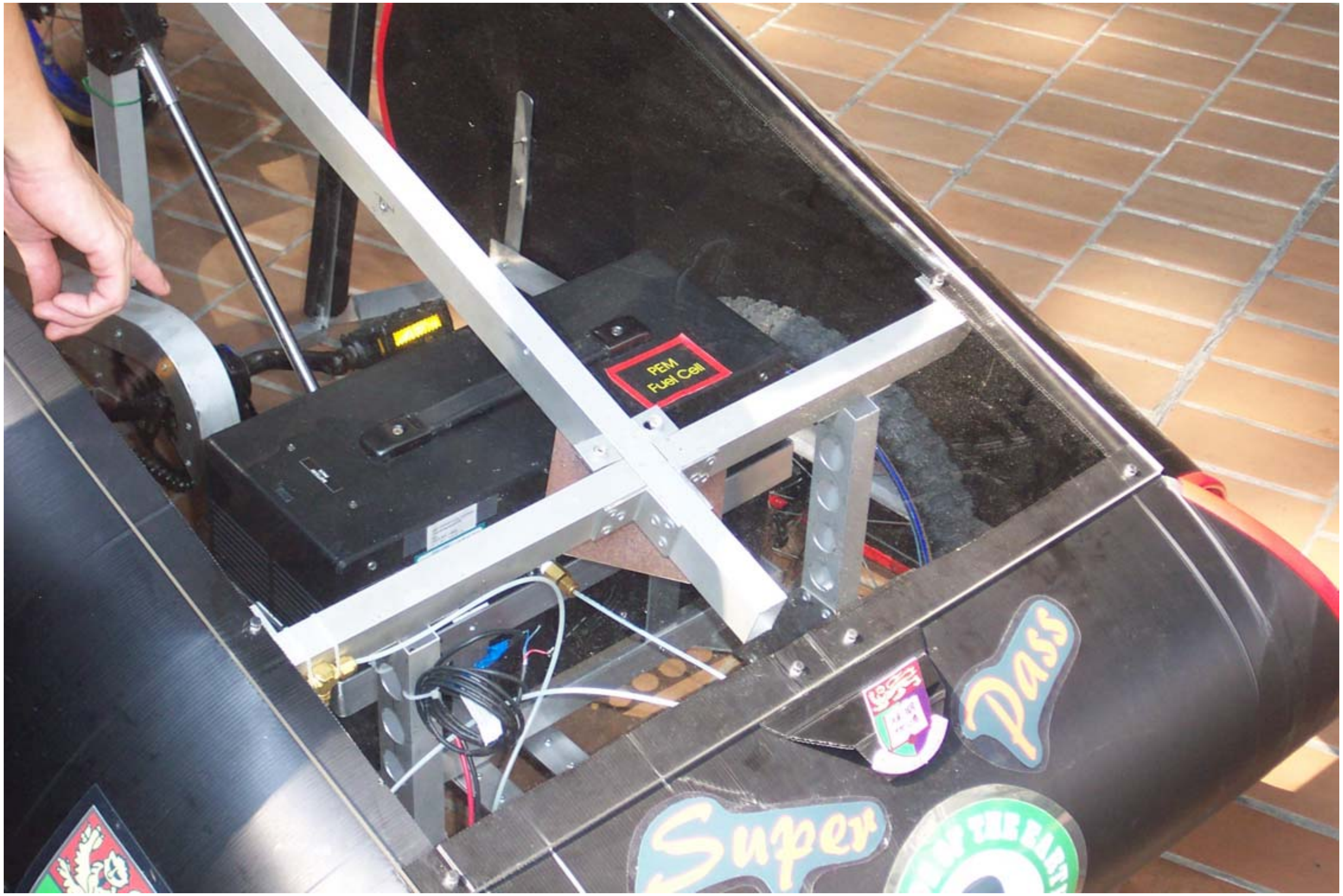
Startup time

Direct/Reformer

Fueling Station Infrastructure


The University of Hong Kong
Department of Mechanical Engineering
Fuel Cell Car
O2me
Super Pass
Department of Mechanical Engineering
FRIENDS OF THE EARTH
6
SAPIENTIA ET VIRTUS
HISTORY SOCIETY

The University of Hong Kong
Department of Mechanical Engineering
Fuel Cell Cart
Department
Mechanical
Engineering
Super Pass
FRIENDS OF THE EARTH
6
History Society
Chess and Boardgames Club


PEM
Fuel Cell
Super
Pass

Special Applications

Defence

Communication

Energy Storage for Solar, Wind

Energy Vector

Biomedical

Enery Recovery from Waste

Marine and Remote Power Sources

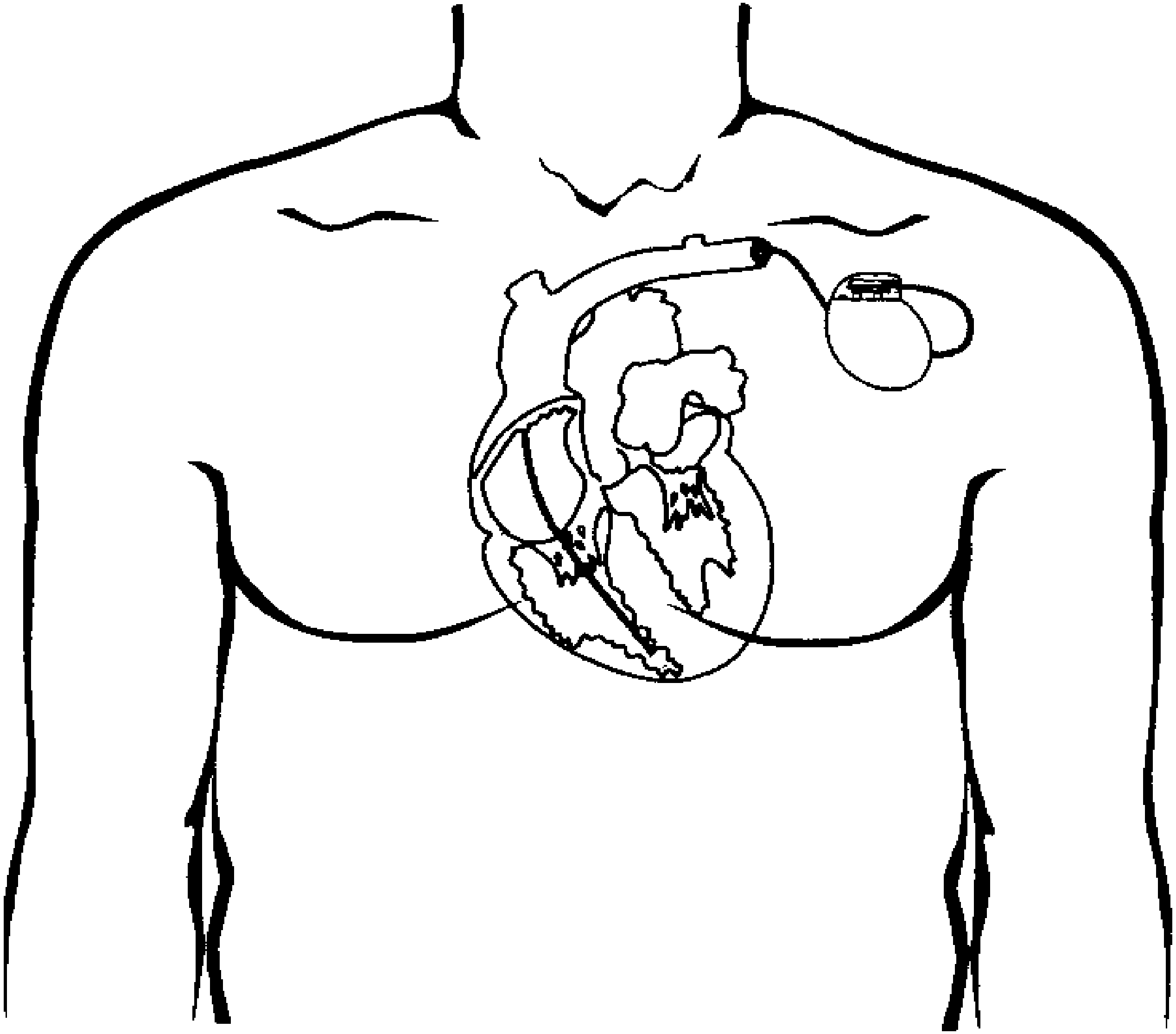


Figure 1. Implanted cardiac pacemaker

Demo Fuel Cells

0.02 ~ 10 W

H_2 , MeOH, Glucose, alcohols

PEM, Alkaline

$NaBH_4$ Fuel Cell

Features:

1)Leak Proof

2)Compact Design

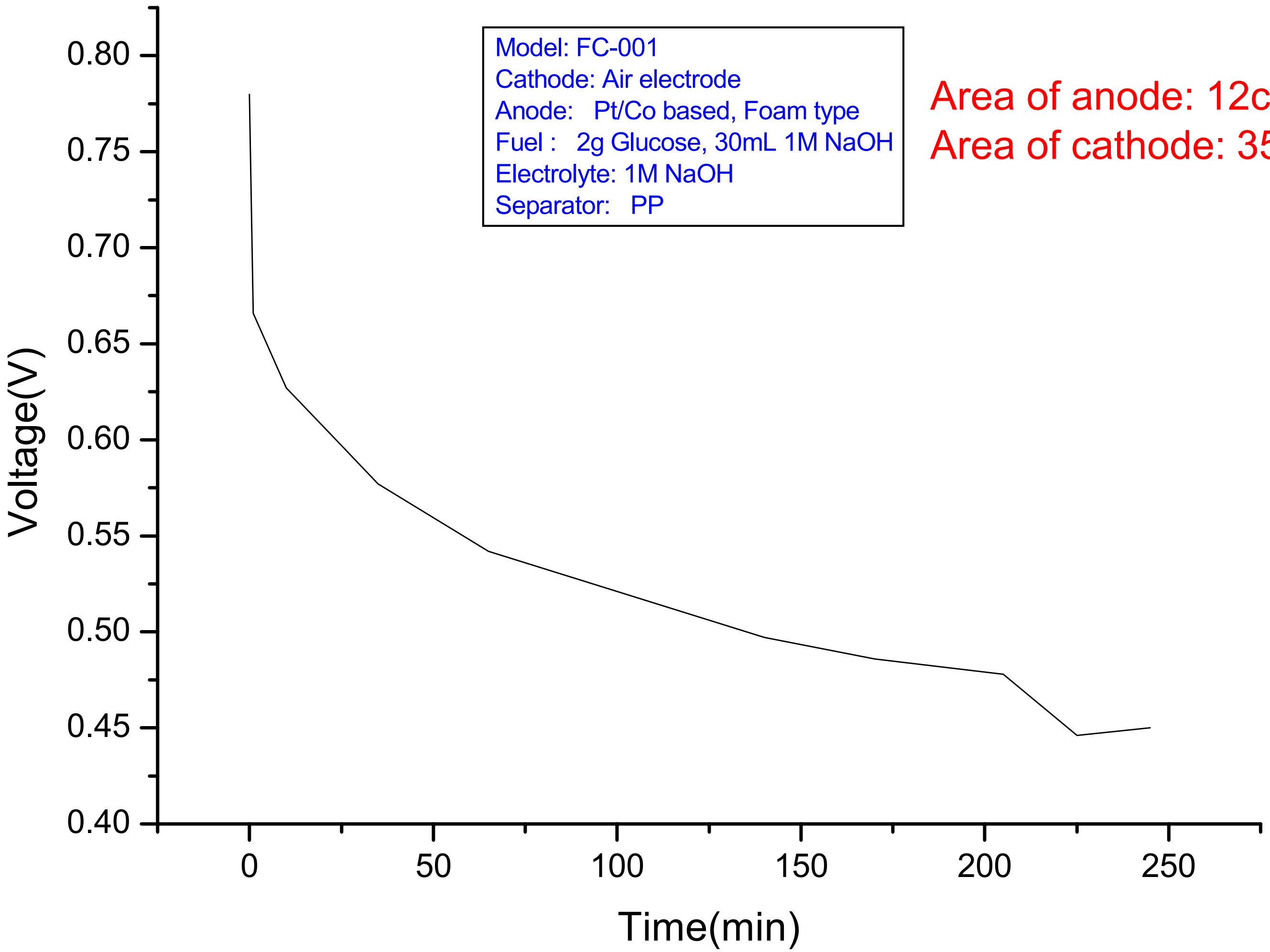
3)Sandwich Type “MEA”

4) Transparent outlook

5)Easy to use

6)Low cost

Typical Performance of HKU-001



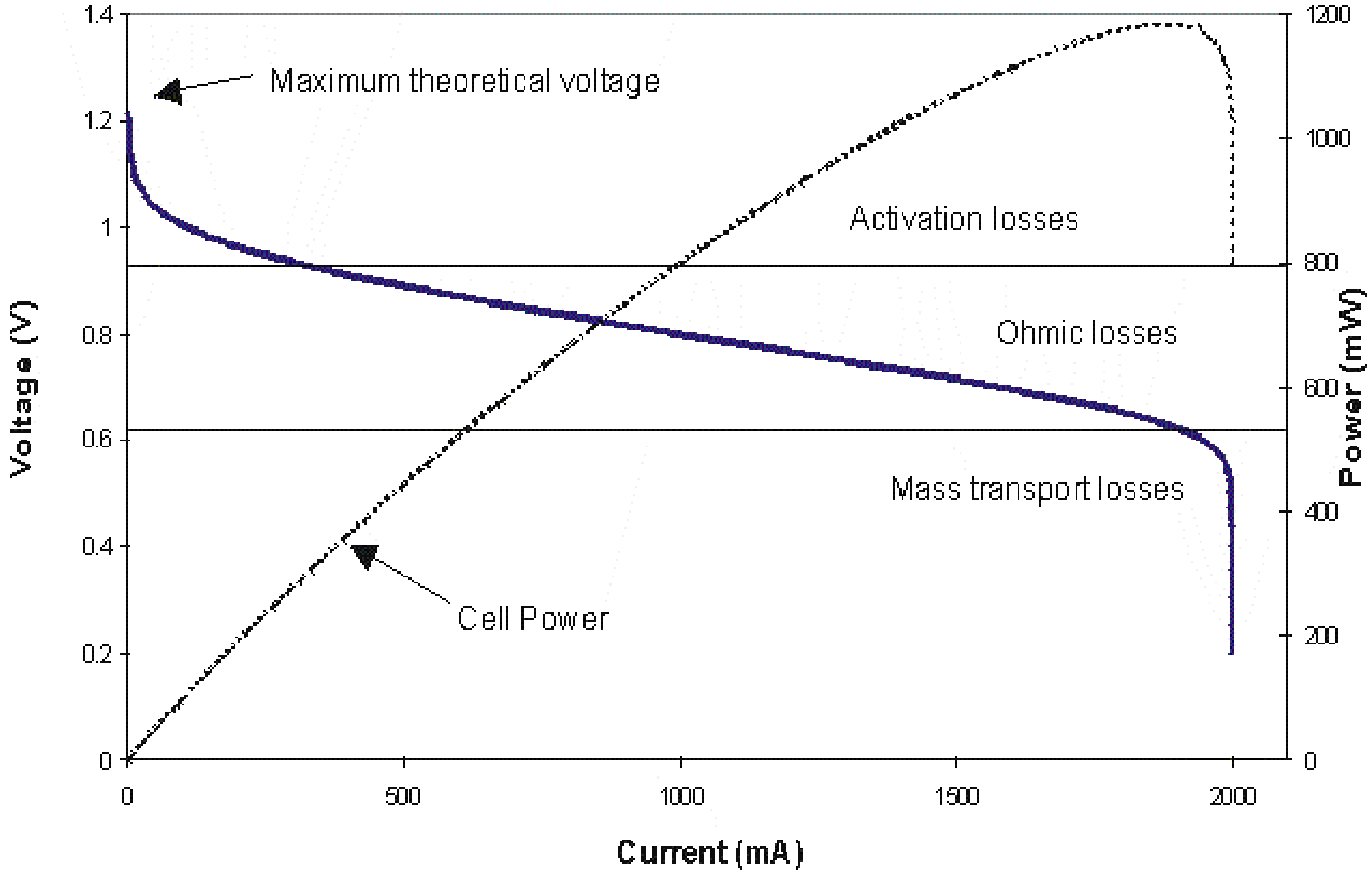
Model: FC-001
Cathode: Air electrode
Anode: Pt/Co based, Foam type
Fuel : 2g Glucose, 30mL 1M NaOH
Electrolyte: 1M NaOH
Separator: PP

Area of anode: 12cm2
Area of cathode: 35cm2

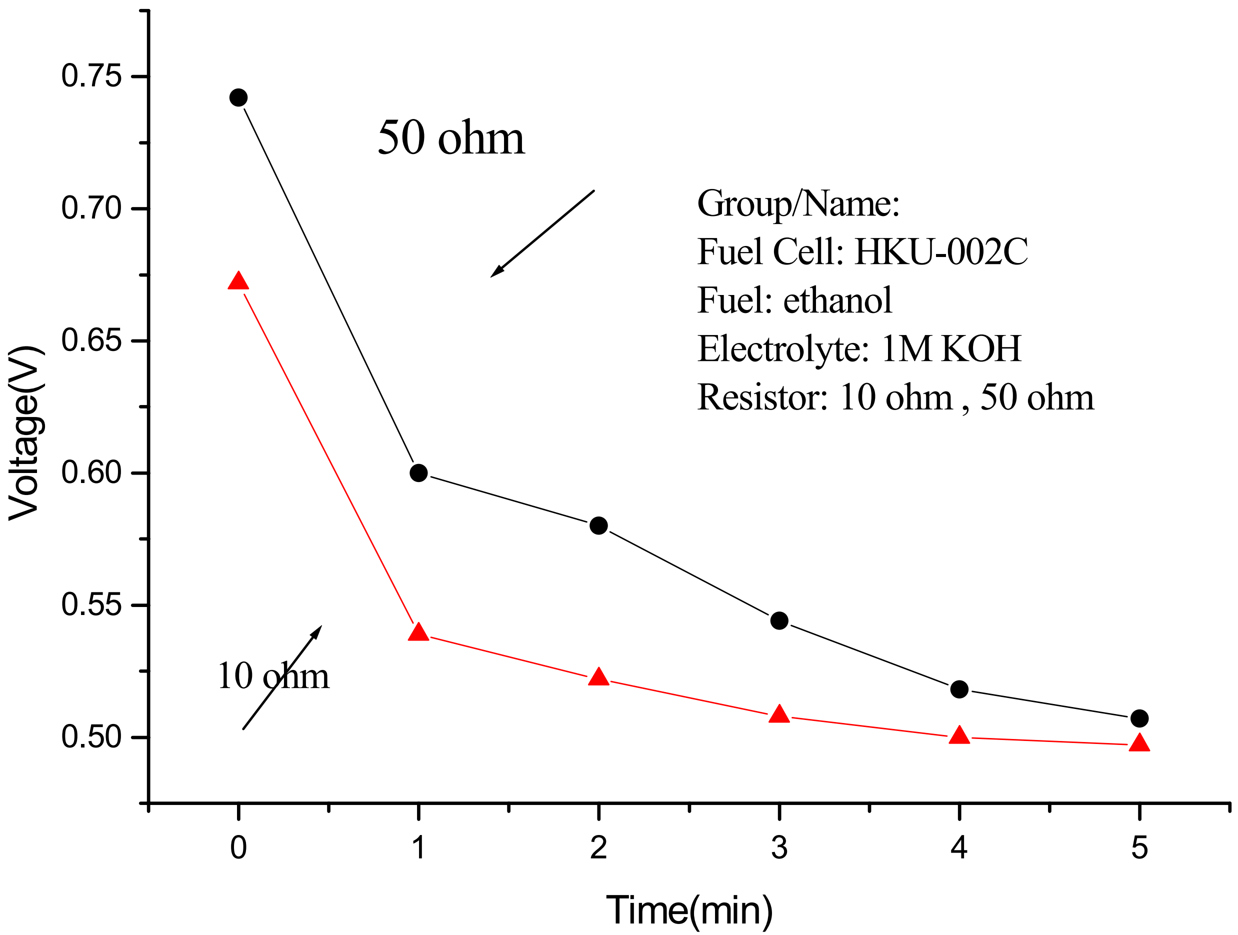
Toy R/C Market

Power by 4 AA
6.0V, 200—300mA

Powered by 1AA, 1.5V
100—200mA


Maximum theoretical voltage
Activation losses
Ohmic losses
Mass transport losses
Cell Power
Voltage (V)
Power (mW)
Current (mA)
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1200
1000
800
600
400
200
0
0
500
1000
1500
2000

Voltage Response to different loadings



Group/Name:
Fuel Cell: HKU-002C
Fuel: ethanol
Electrolyte: 1M KOH
Resistor: 10 ohm , 50 ohm

Electrolyte
:

Fuel Cell Used: HKU-002

Clock time	Time elapsed(min)	Voltage	Current(V/R: mA)
	0	OCV	
	1		
	2		
	3		
	4		
	5		