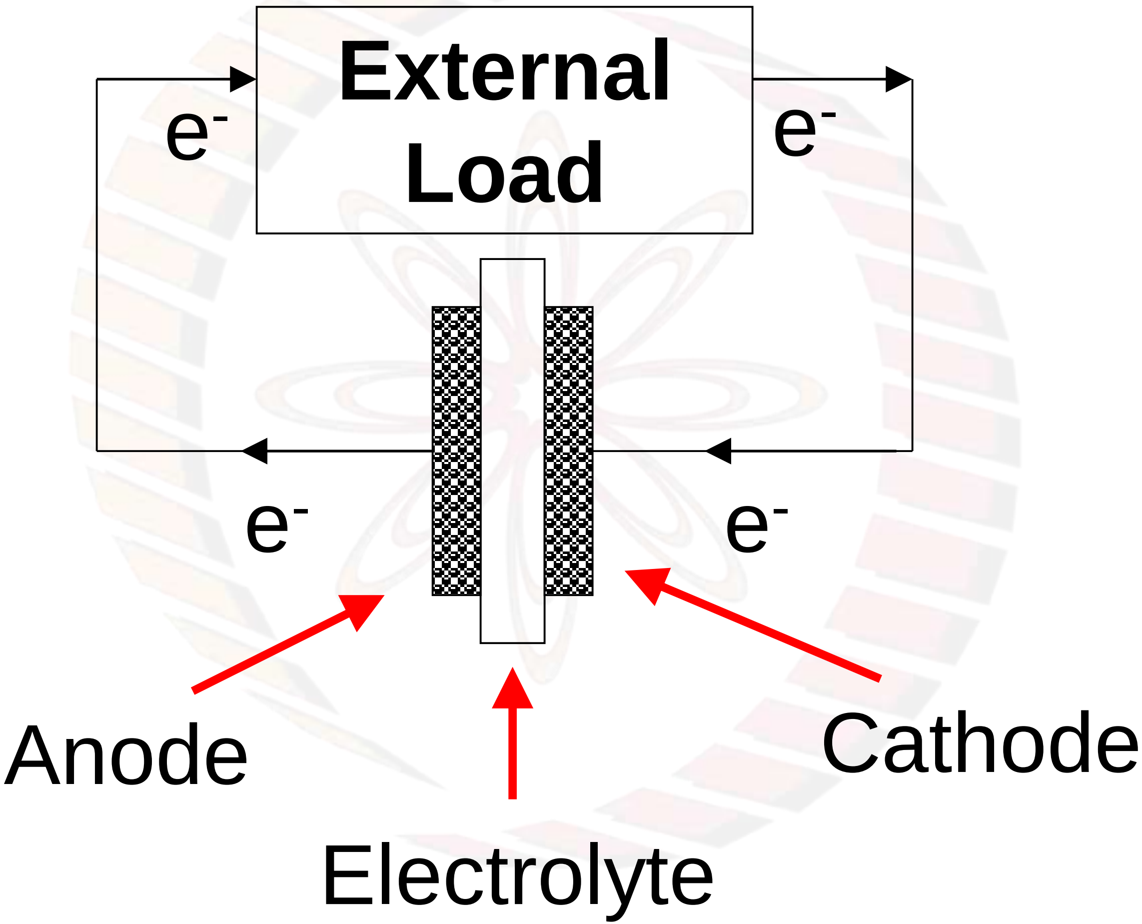
Types of Fuel Cells

Learning Objectives:

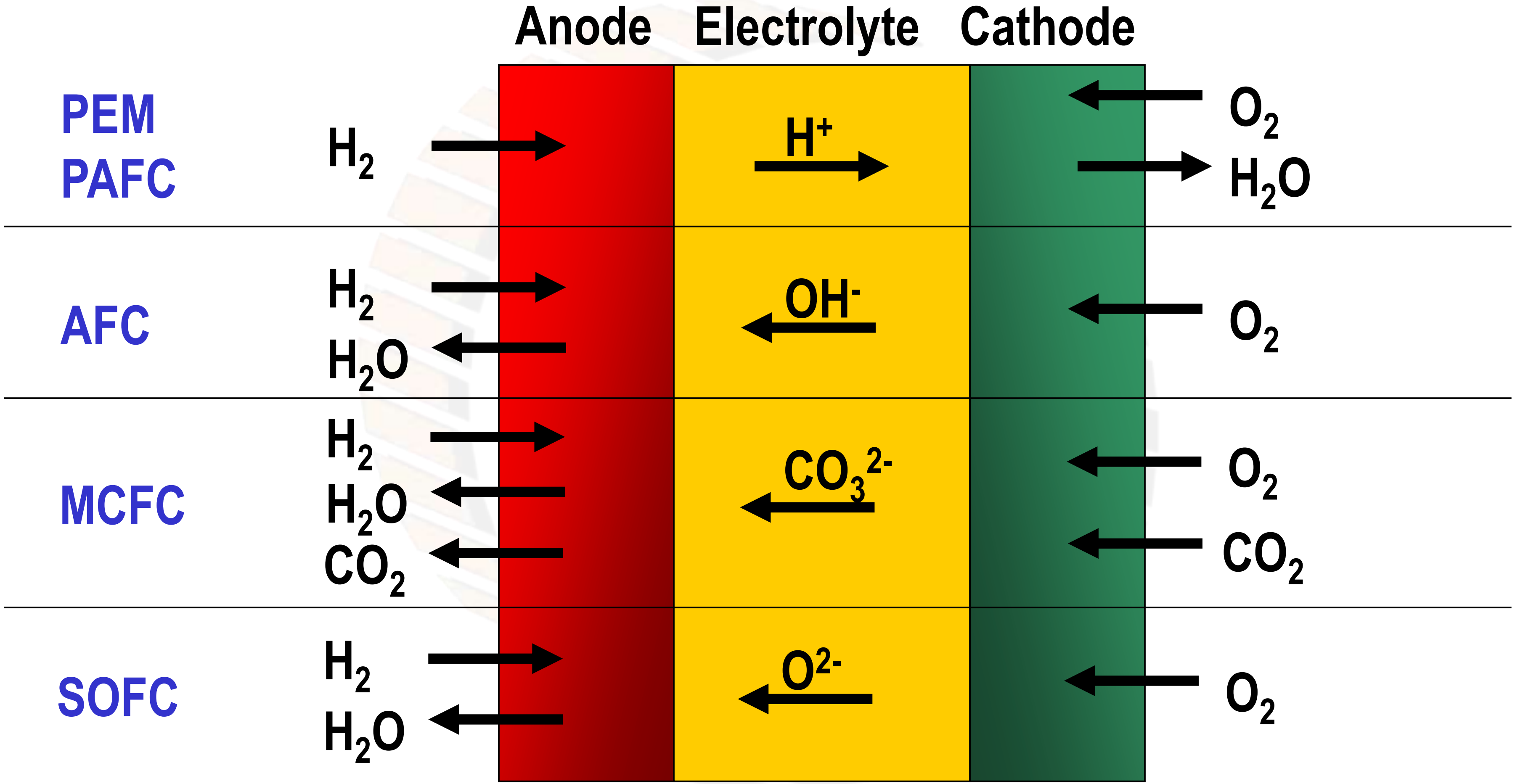
1) What are the different types of Fuel Cells
2) What differentiates them from each other
3) What are their relative advantages and disadvantages



External Load
e-
e-
e-
e-
Anode
Electrolyte
Cathode

Ionic conductivity
Vs
Electronic conductivity

Type of fuel cell	Temperature
PEFC / PEM ***Polymer electrolyte fuel cell***	**< 100 ^{o}C**
AFC ***Alkaline fuel cell***	**100 - 250 ^{o}C**
PAFC ***Phosphoric acid fuel cell***	**160 - 220 ^{o}C**
MCFC ***Molten carbonate fuel cell***	**600 - 700 ^{o}C**
SOFC ***Solid oxide fuel cell***	**~ 1000 ^{o}C**



Anode
Electrolyte
Cathode
PEM
PAFC
H_2
H^+
O_2
H_2O
AFC
H_2
H_2O
OH^-
O_2
MCFC
H_2
H_2O
CO_2
CO_3^{2-}
O_2
CO_2
SOFC
H_2
H_2O
O^{2-}
O_2

PEM **PAFC**	H_2	$\rightarrow$	$2H^+ + 2e^-$
	$\frac{1}{2} O_2 + 2H^+ + 2e^-$	$\rightarrow$	H_2O
AFC	$H_2 + 2\ OH^-$	$\rightarrow$	$2H_2O + 2e^-$
	$\frac{1}{2} O_2 + H_2O + 2e^-$	$\rightarrow$	$2\ OH^-$
MCFC	$H_2 + CO_3^{2-}$	$\rightarrow$	$2H_2O + CO_2 + 2e^-$
	$CO + CO_3^{2-}$	$\rightarrow$	$2CO_2 + 2e^-$
	$\frac{1}{2} O_2 + CO_2 + 2e^-$	$\rightarrow$	CO_3^{2-}
SOFC	$H_2 + O^{2-}$	$\rightarrow$	$2H_2O + 2e^-$
	$CO + O^{2-}$	$\rightarrow$	$CO_2 + 2e^-$
	$\frac{1}{2} O_2 + 2e^-$	$\rightarrow$	O^{2-}

	Anode	Electrolyte	Cathode
PEM	Pt	Perflourinated sulfonic acid	Pt
PAFC	Pt	Phosphoric acid in SiC	Pt
AFC	Ni/Ag	KOH in Asbestos	Metal Oxides
MCFC	Ni	Alkali Carbonate in $LiAlO_3$	NiO
SOFC	$Co\text{-}ZrO_2$ $Ni\text{-}ZrO_2$ Cermet	Y_2O_3 stabilized ZrO_2	Sr doped $LaMnO_3$

PEM	Quick startup; easily available auxiliaries; Water management; susceptible to impurities
AFC	Reliable Handles CO_2 poorly
MCFC	Can operate with a wide range of fuels High temperature, corrosion, thermal fatigue
SOFC	Can operate with a wide range of fuels Expensive auxiliary parts; slow startup

Focus of most international efforts:

PEM

SOFC

They represent two extremes of the issues faced and are ideally suited for distinctly different applications

Fuel Processing

Why ‘Fuel Processing’ ?

Type of fuel cell / availability of fuel

Hydrogen Vs other fuels

Infrastructure

Steam Reforming

Fuel ($C_nH_mO_p$) + Steam $\longrightarrow$ Carbon Oxides + Hydrogen

$\Delta H > 0$

Strongly endothermic
Reactor design limited by heat transfer
Reactors tend to be large and heavy
Typically catalyst required, usually Ni

Partial Oxidation

$$\text{Fuel } (C_nH_mO_p) + \text{Air} \longrightarrow \text{Carbon Oxides} + \text{Hydrogen} + \text{Nitrogen}$$

$$\Delta H < 0$$

Temperature can climb over 1000 °C

May not require a catalyst

Auto Thermal Reforming

Fuel ($C_nH_mO_p$) + Air + Steam $\longrightarrow$ Carbon Oxides + Hydrogen + Nitrogen

$\Delta H < 0$

Extent of steam reforming limits the maximum temperature attained

Issues with Reforming

System complexity

Presence of carbon monoxide

Response time

Start up and shut down in case of automotive use

Water Gas Shift Reaction

$$CO + H_2O \longrightarrow CO_2 + H_2$$

$$\Delta H^o = -41.2 \text{ kJ mol}^{-1}$$

Catalysts: Fe_3O_4, CuO/ZnO

Selective Oxidation / Preferential Oxidation

$$2CO + O_2 \longrightarrow CO_2$$

Ruthenium and Rhodium, supported on Alumina, are usually used as catalyst. Cu and ZnO on Alumina also used

Fuel

Steam Reforming/Partial Oxidation/
Auto Thermal Reforming

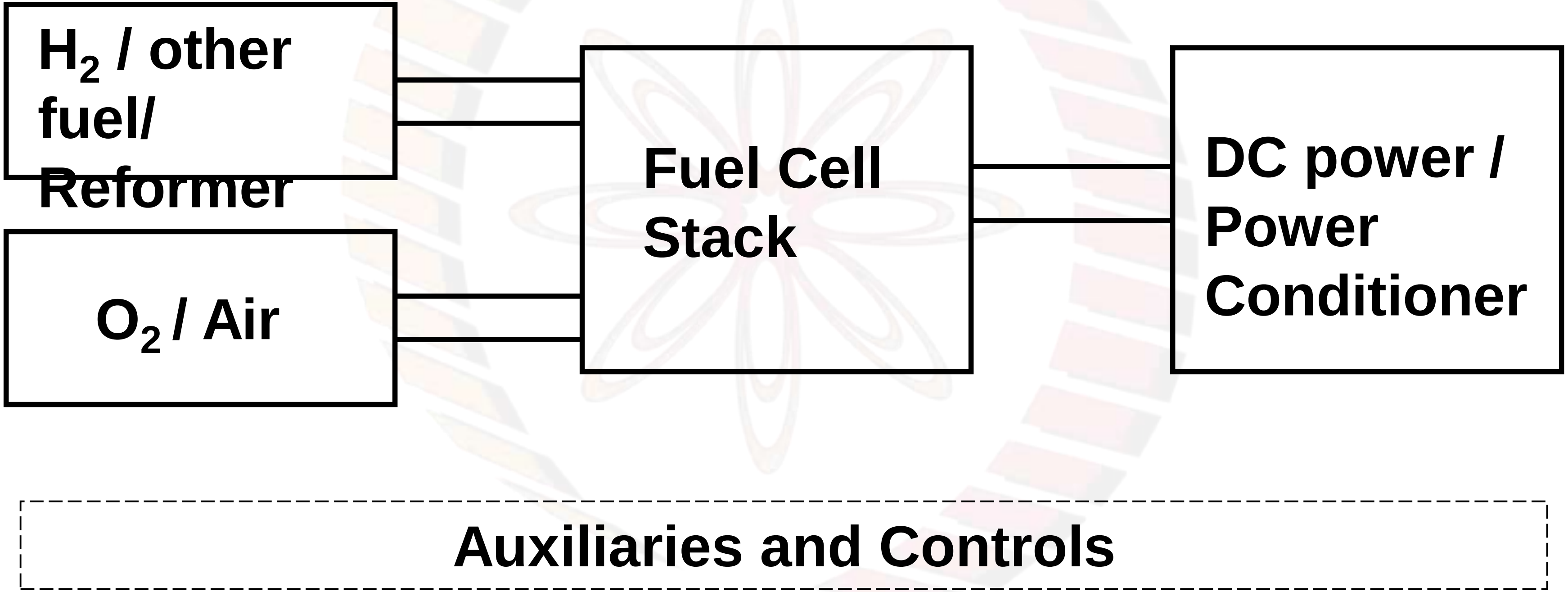
Water gas shift reaction

Selective Oxidation
Preferential Oxidation

Fuel Cell Anode

System Integration Case Studies

Schematic of typical Fuel Cell systems



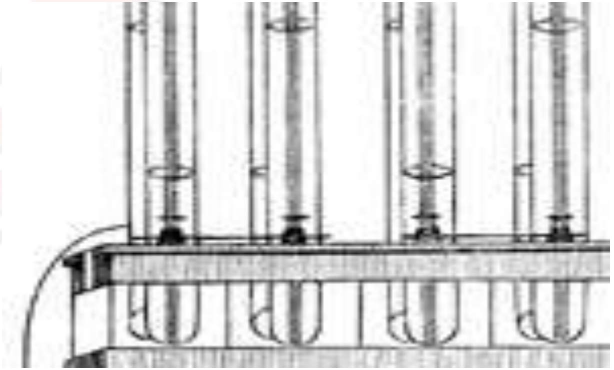
Timeline:

1800 **Alessandro Volta**

Prof. Of Physics

Univ. of Pavia, Italy

Volta Pile



1839 **Sir William Grove**

English lawyer turned scientist

“Gas Battery”

1930s to 1940s

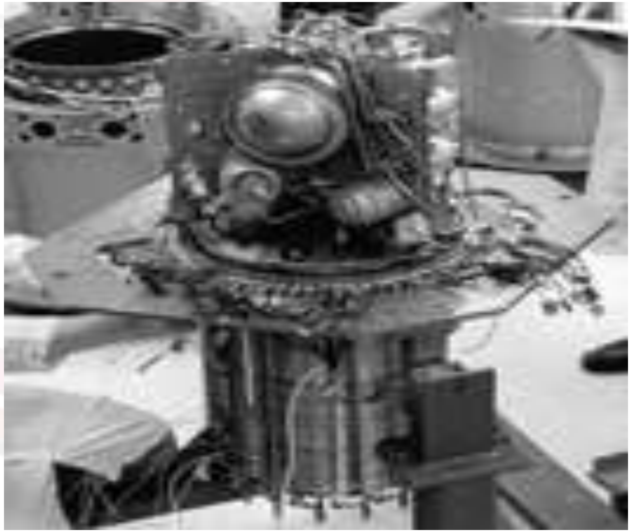
Francis T. Bacon

Alkali Fuel Cells for Royal Navy Submarines

1960s

Pratt & Whitney

licensed Bacon's cell for use in Apollo Spacecraft



1990s

Los Alamos National Laboratory

Dramatic reduction in need for Pt catalyst

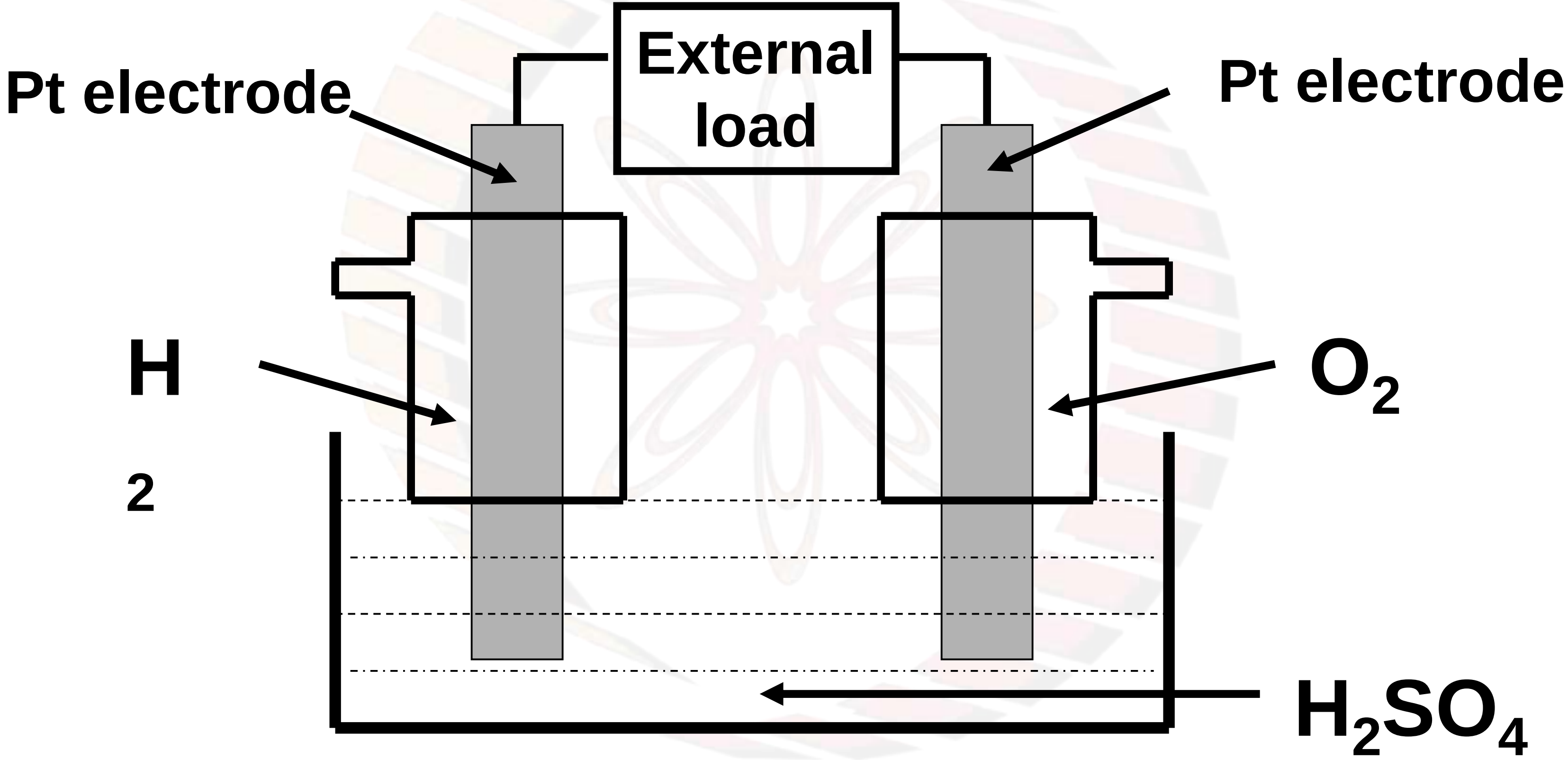
Late 1990s till today

Several demonstrations of “commercial” fuel cells

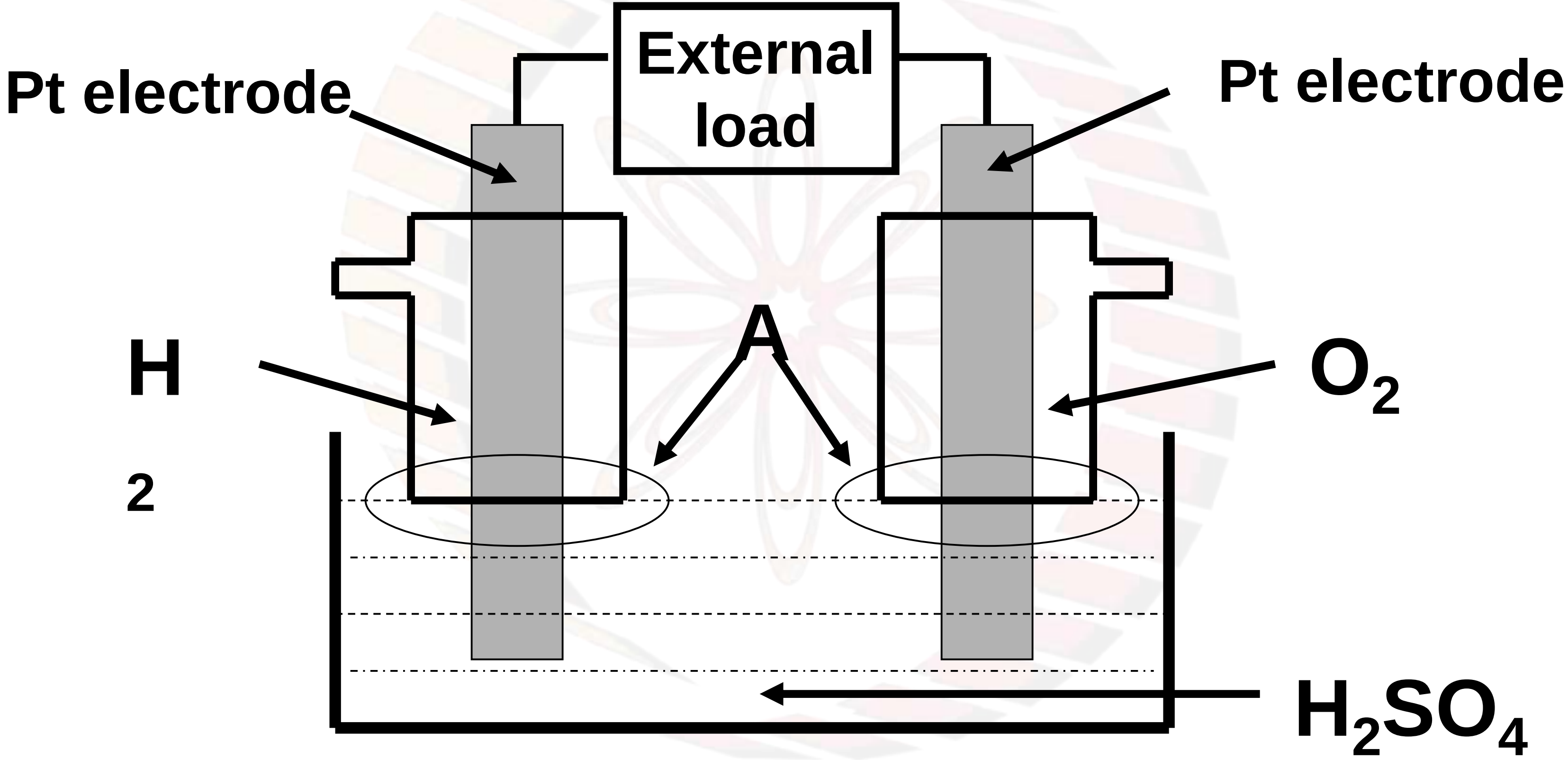
Homes:
Plug Power, Latham, NY, USA

Automobiles:

Schematic of early design of fuel cell

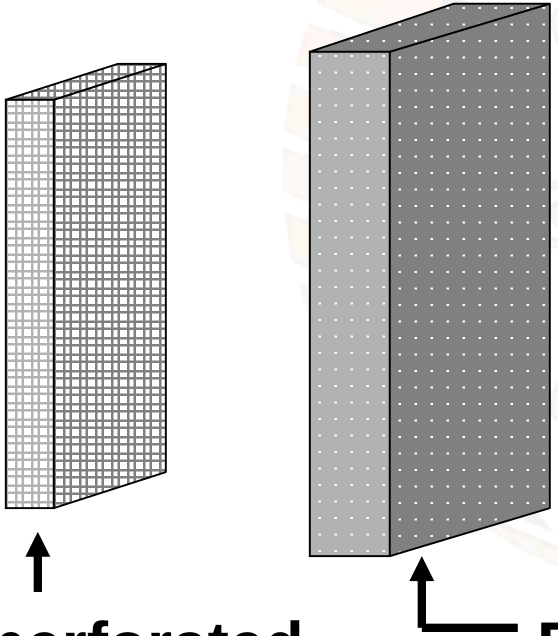


Schematic of early design of fuel cell



Improvements in design of fuel cell

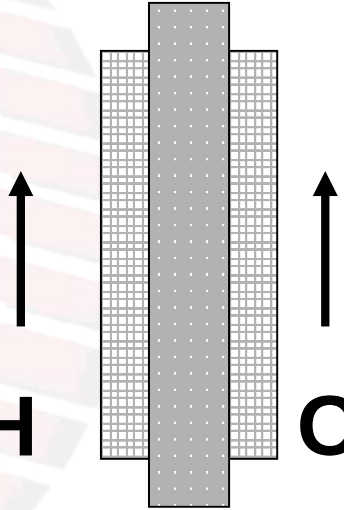
<u>"Exploded" view</u>



Thin, perforated Pt electrode

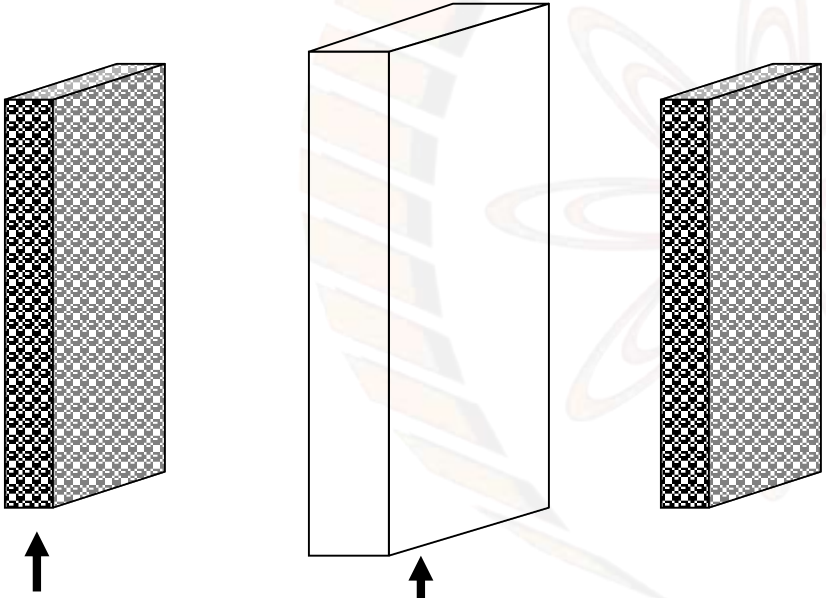
Porous material soaked in H_2SO_4

<u>"Assembled" Side view</u>



Improvements in design of fuel cell

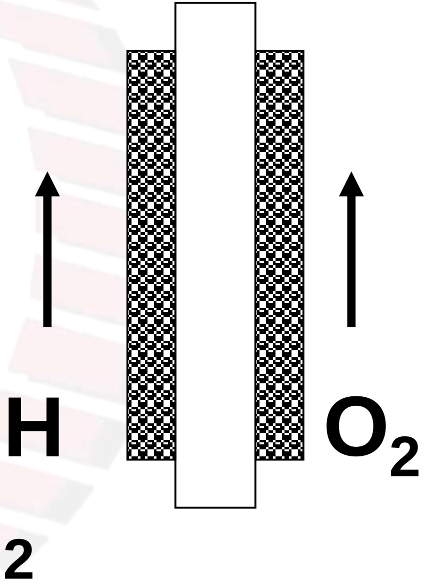
"Exploded" view

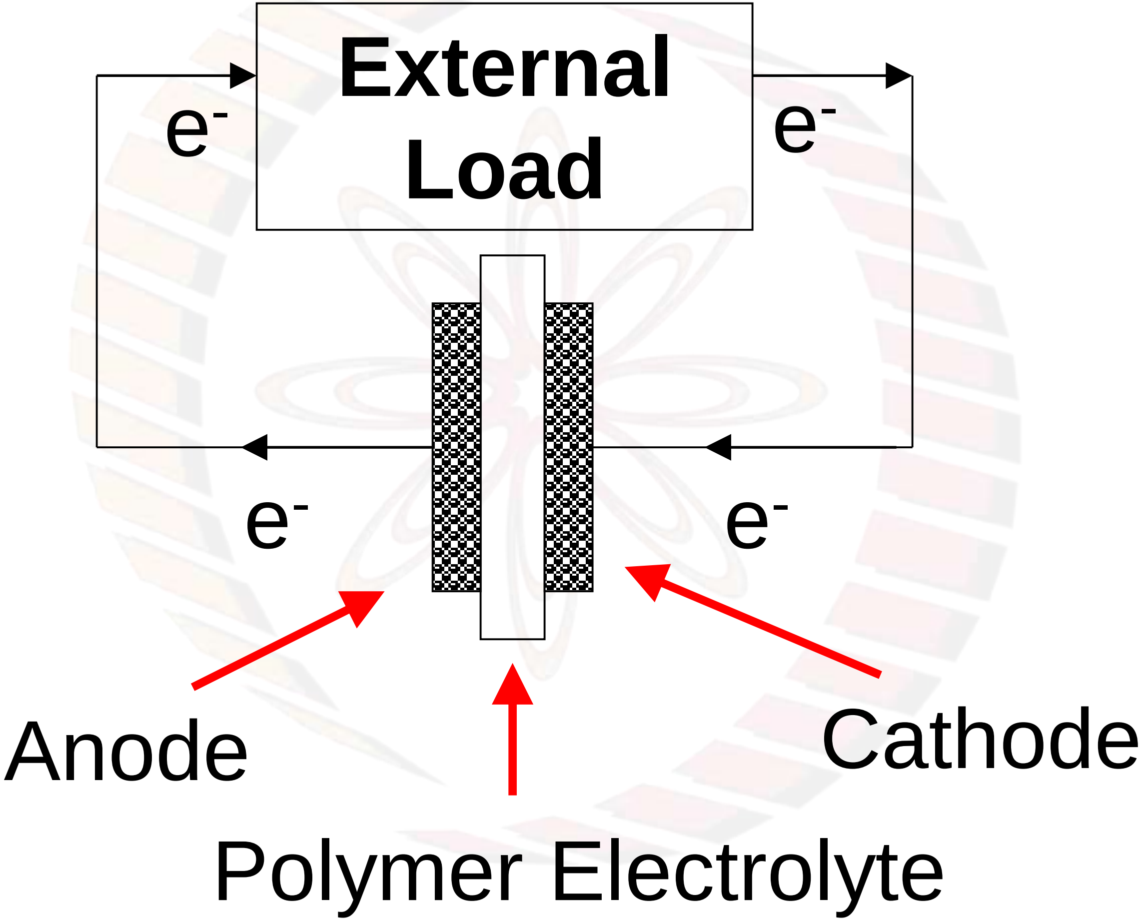


Catalyst based Pt electrode

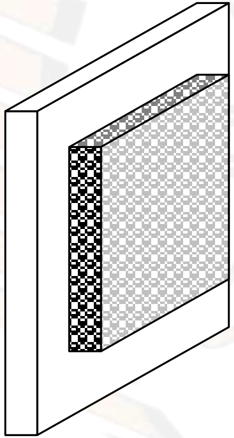
Polymer electrolyte material capable of H^+

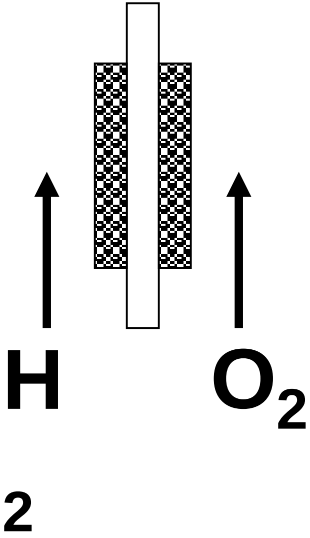
"Assembled" Side view

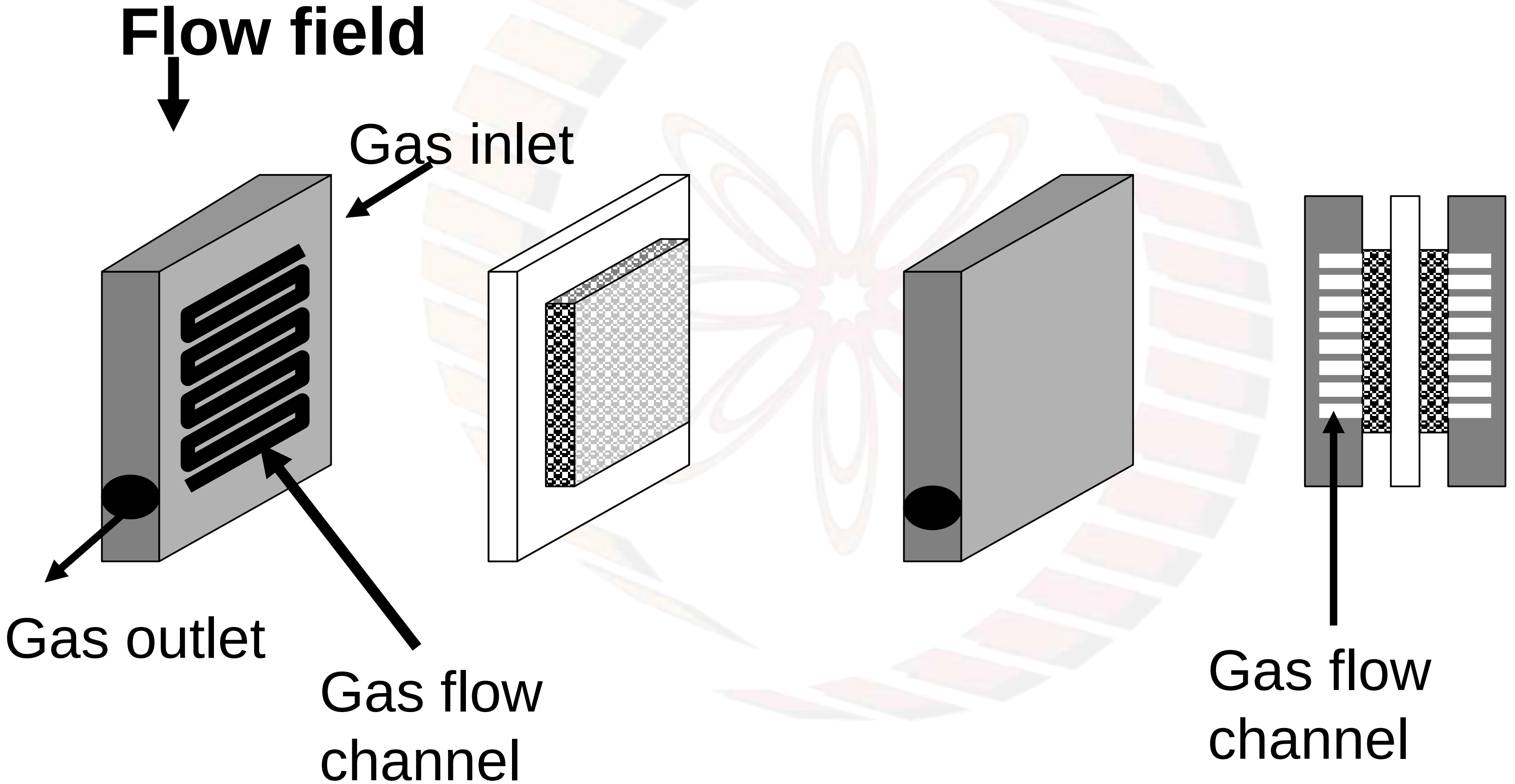


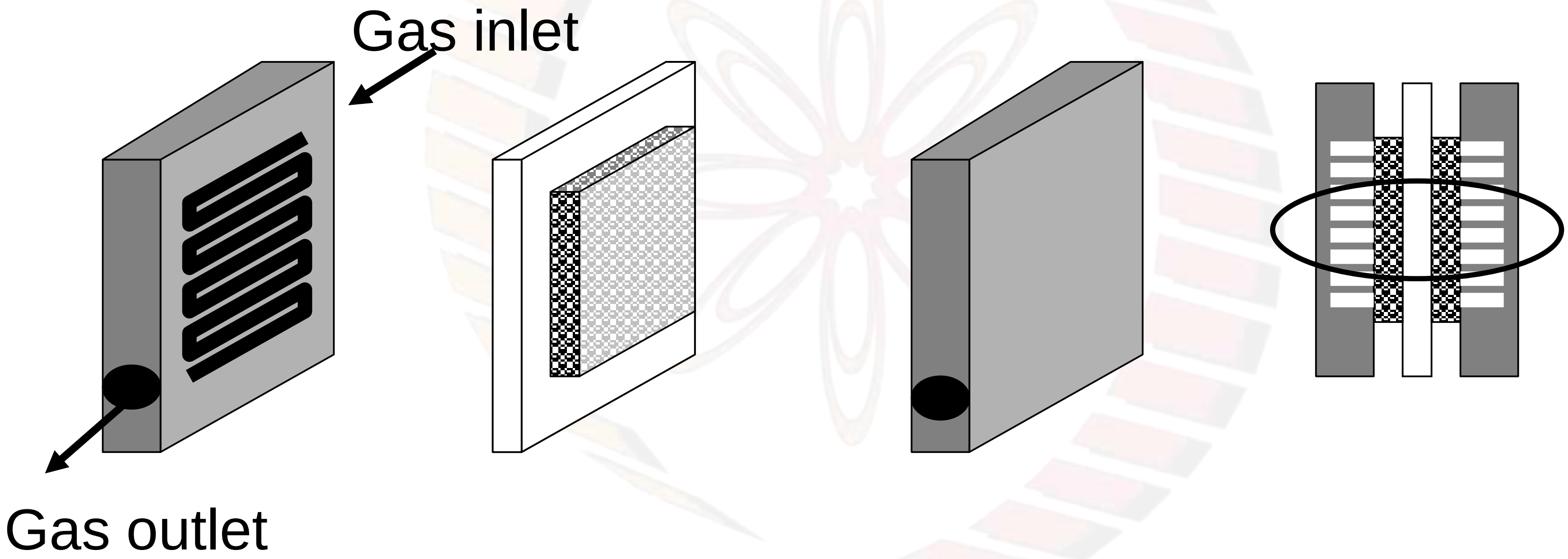

External Load
e-
e-
e-
e-
Anode
Cathode
Polymer Electrolyte

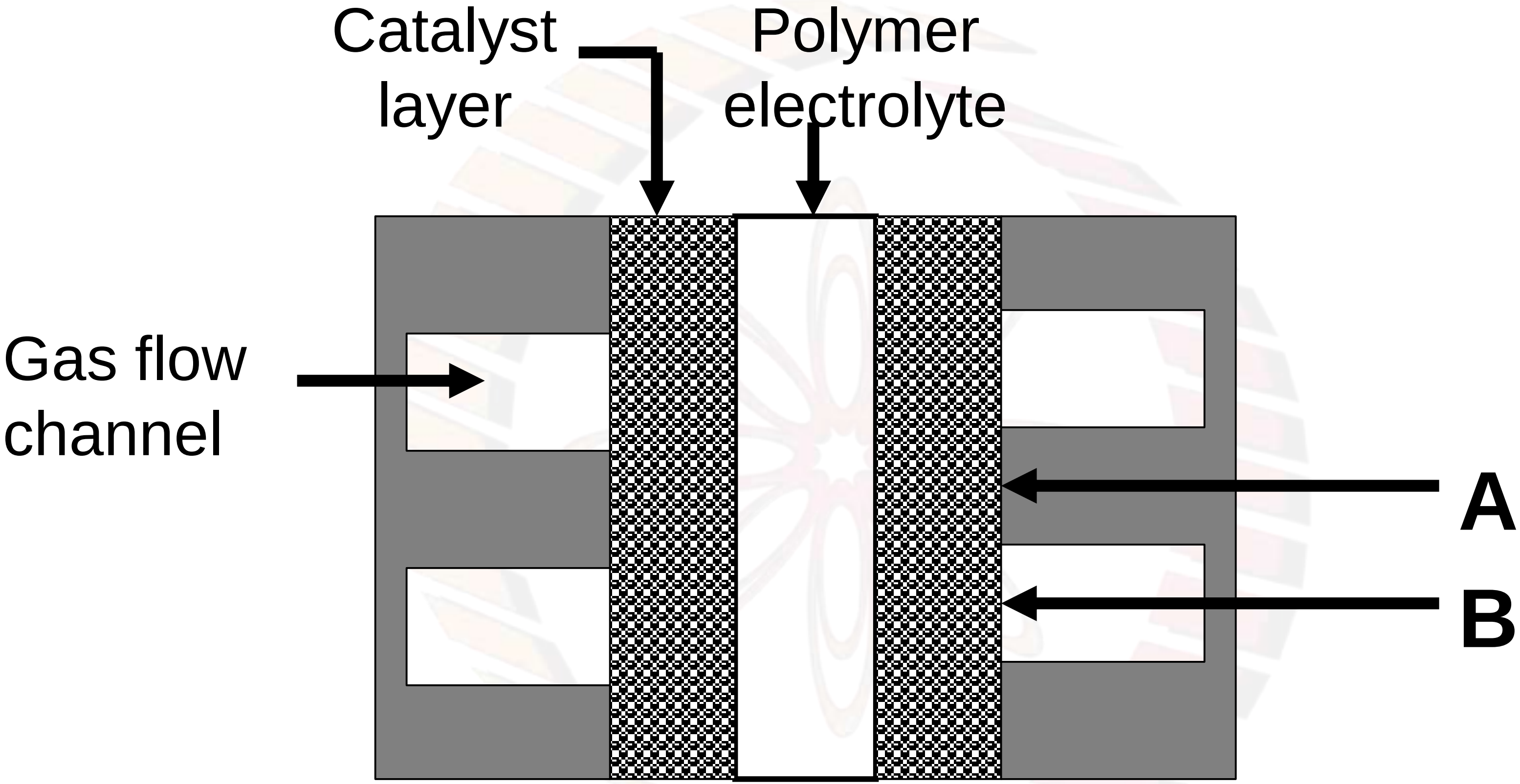
Polymer electrolyte with catalyst layer on either side



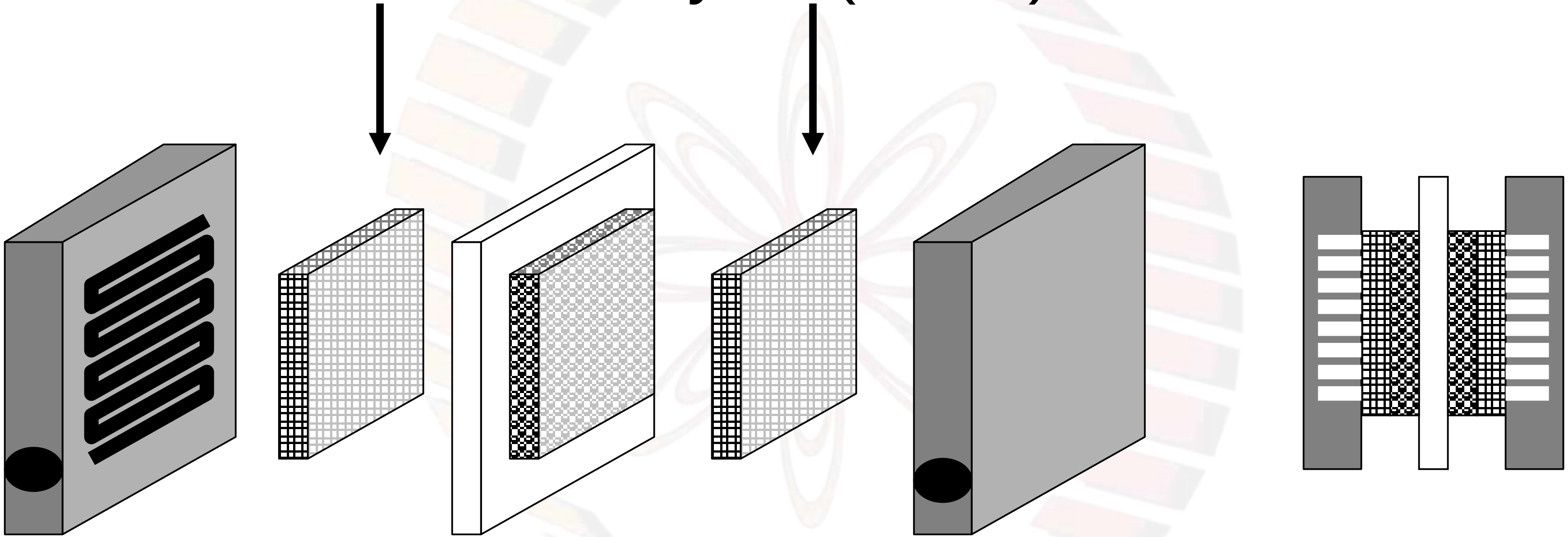


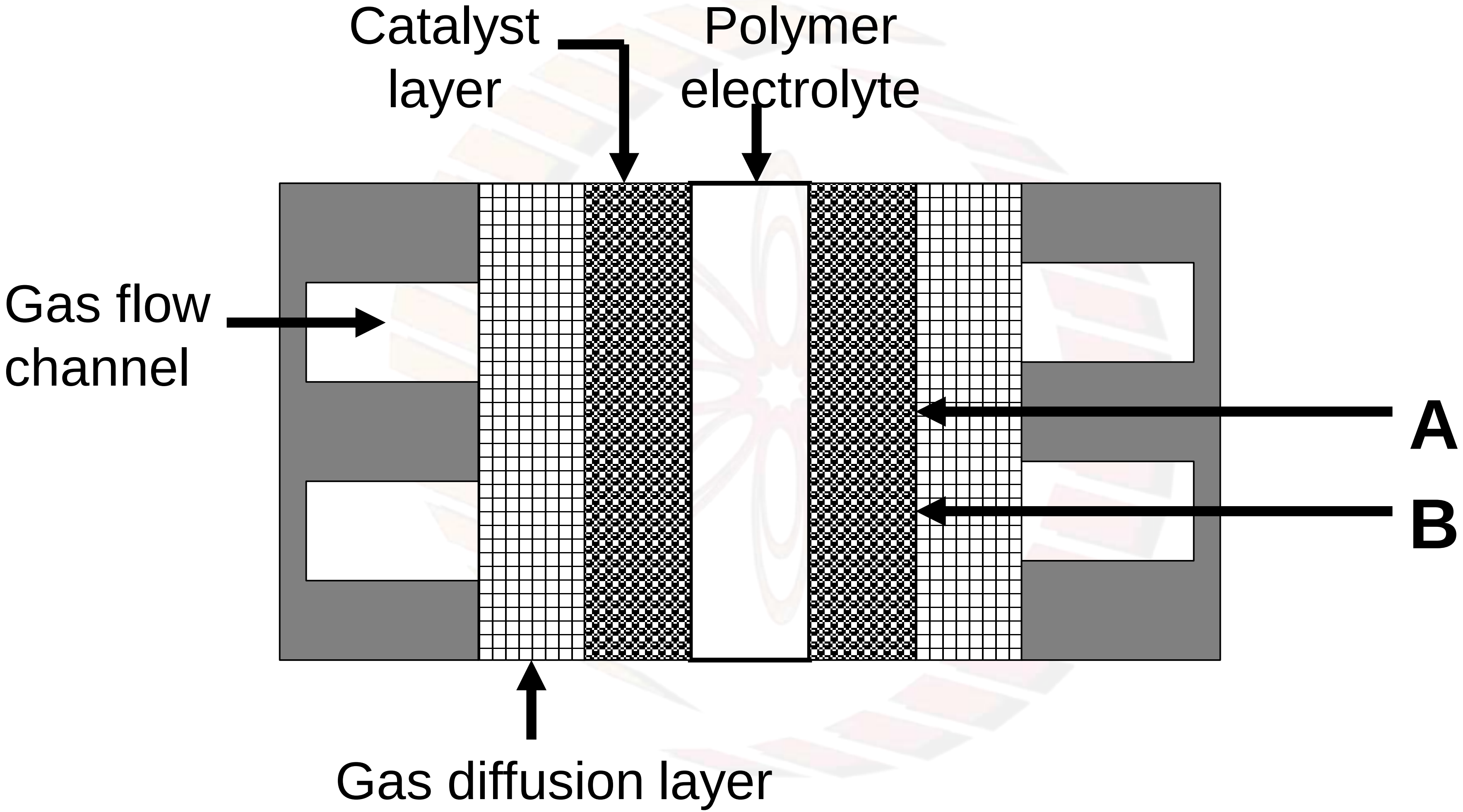

Flow field
Gas inlet
Gas outlet
Gas flow channel
Gas flow channel


Gas inlet
Gas outlet

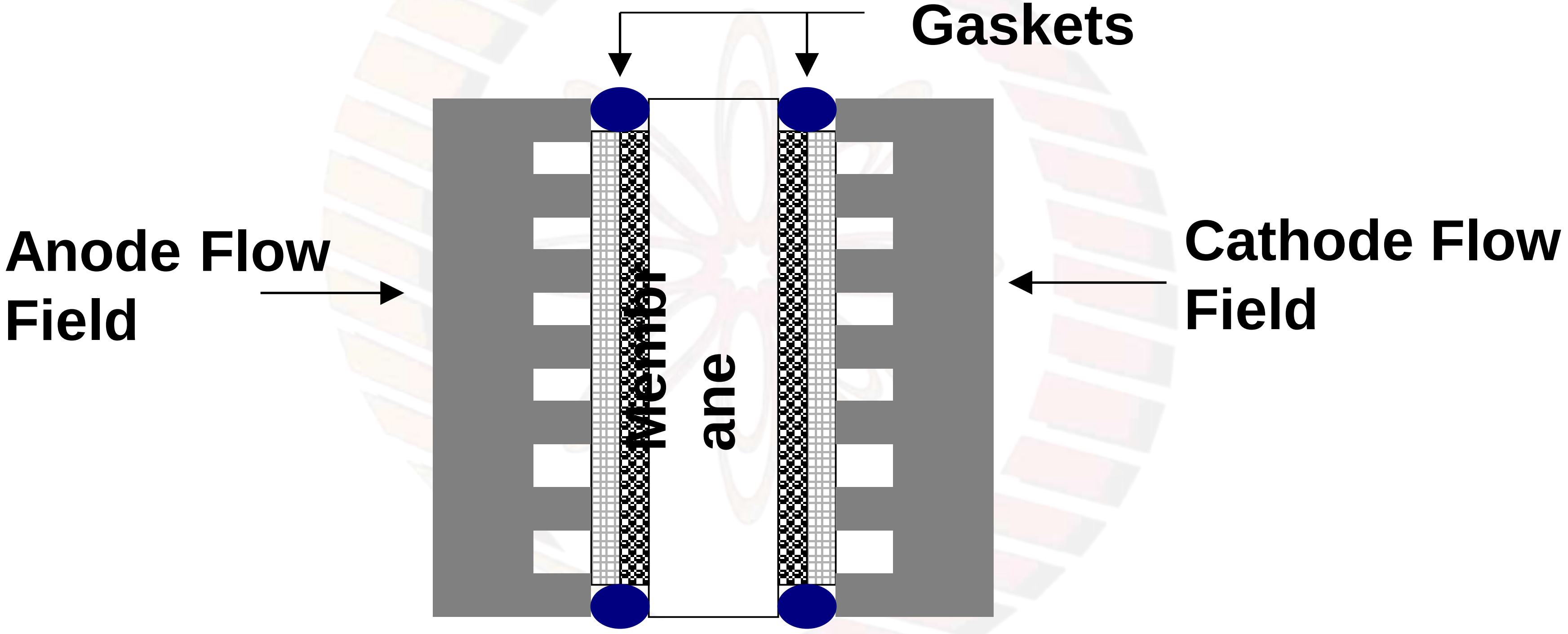

Catalyst layer
Polymer electrolyte
Gas flow channel
A
B

Gas diffusion layers (GDLs)

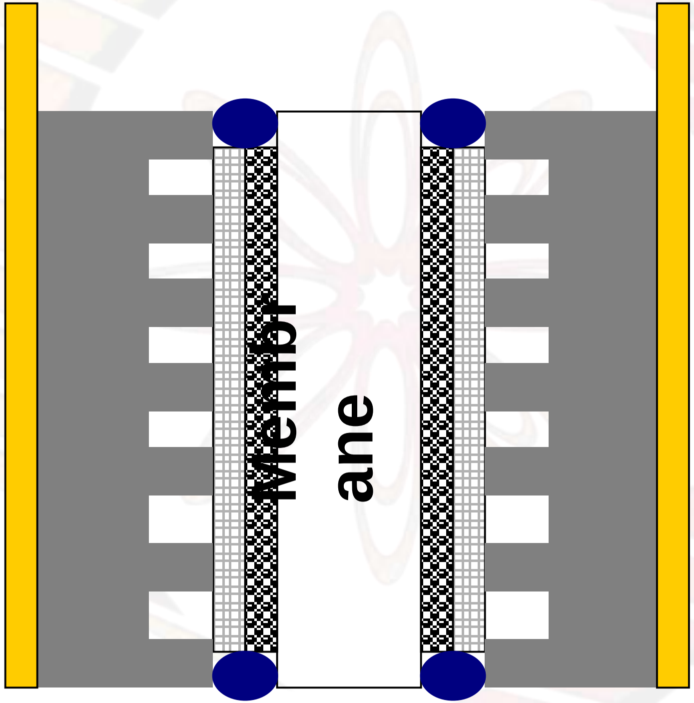



Catalyst layer
Polymer electrolyte
Gas flow channel
A
B
Gas diffusion layer

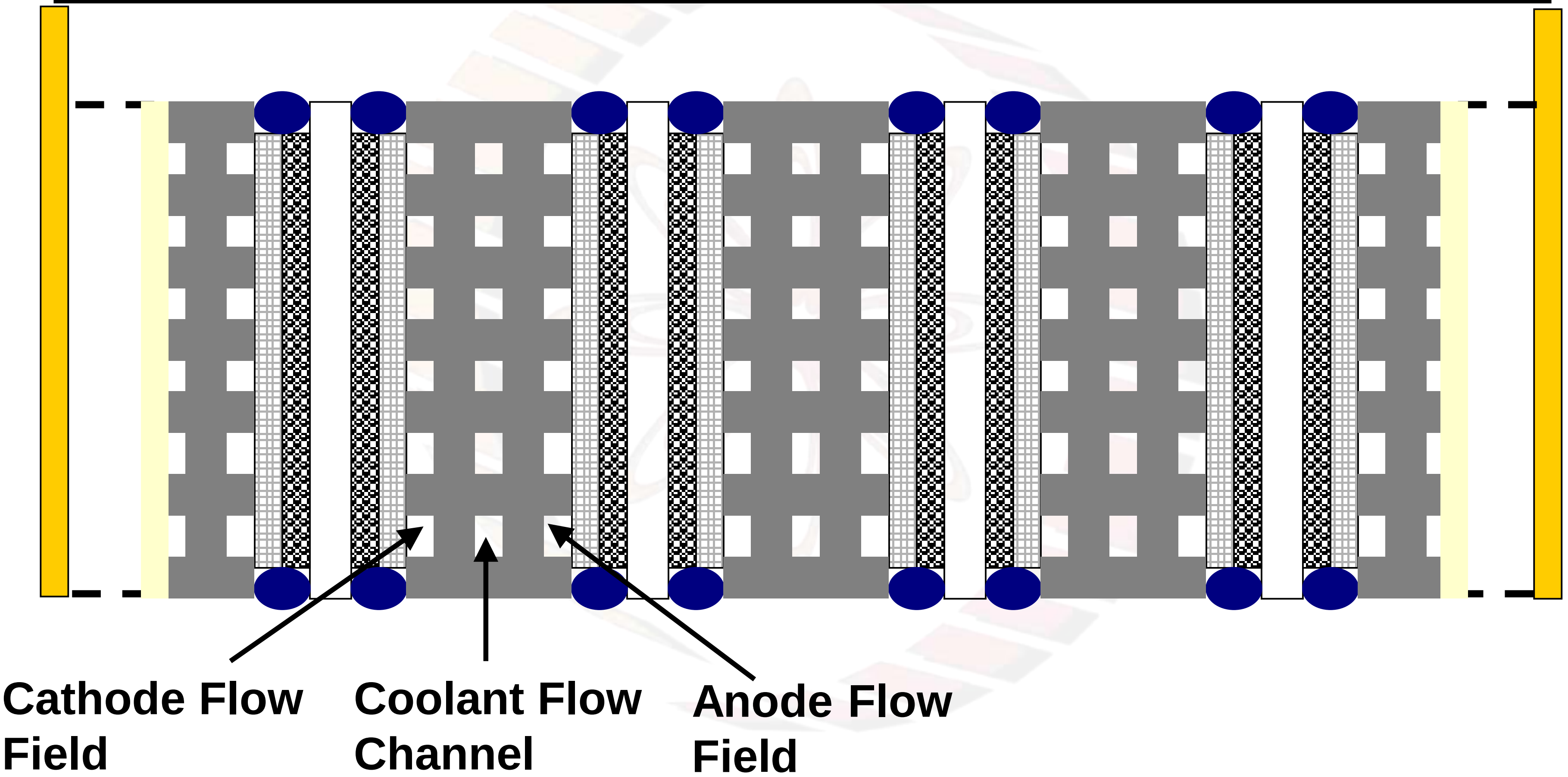
Cross section of a typical PEM Fuel Cell



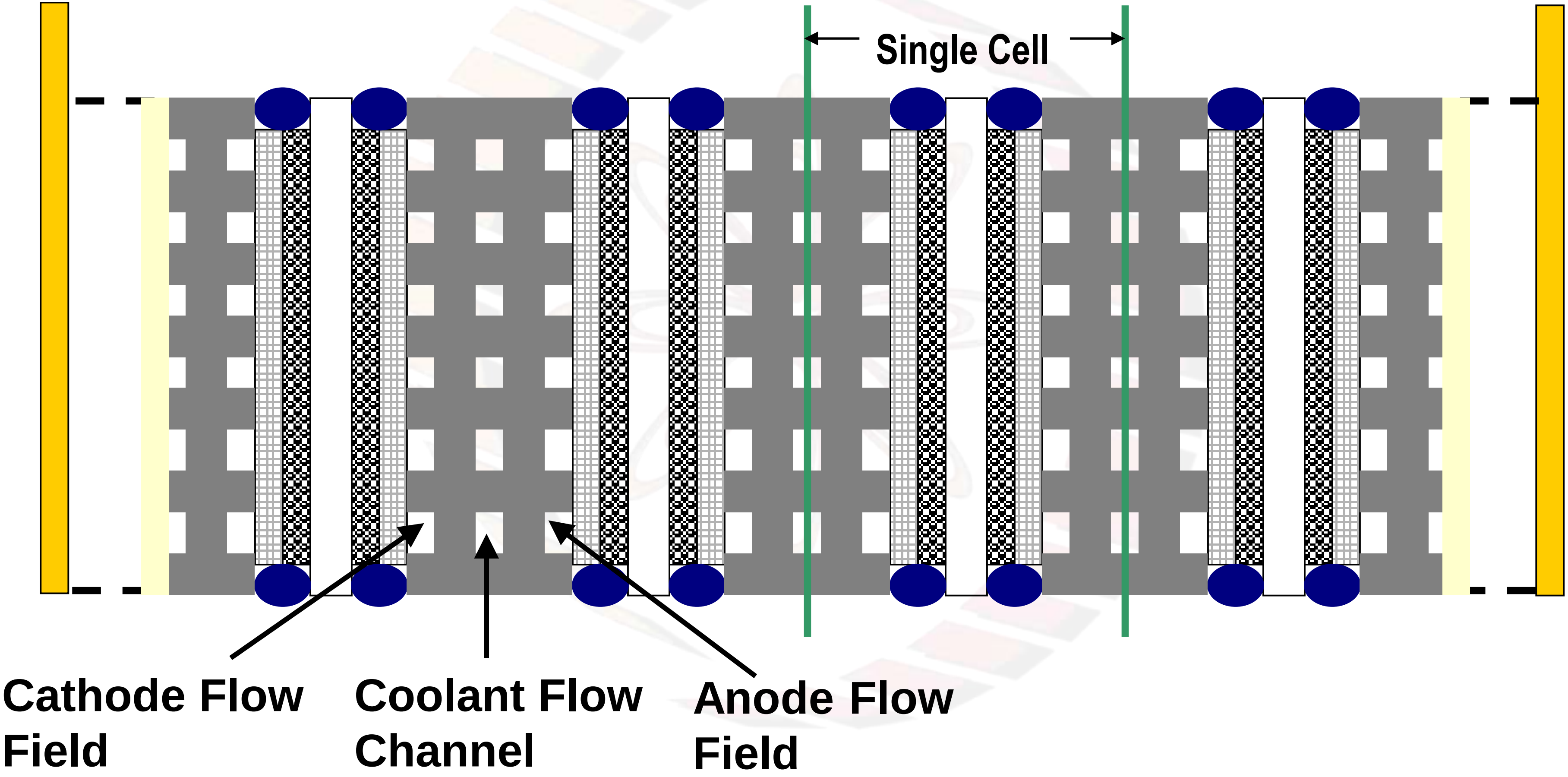
Cross section of a typical PEM Fuel Cell



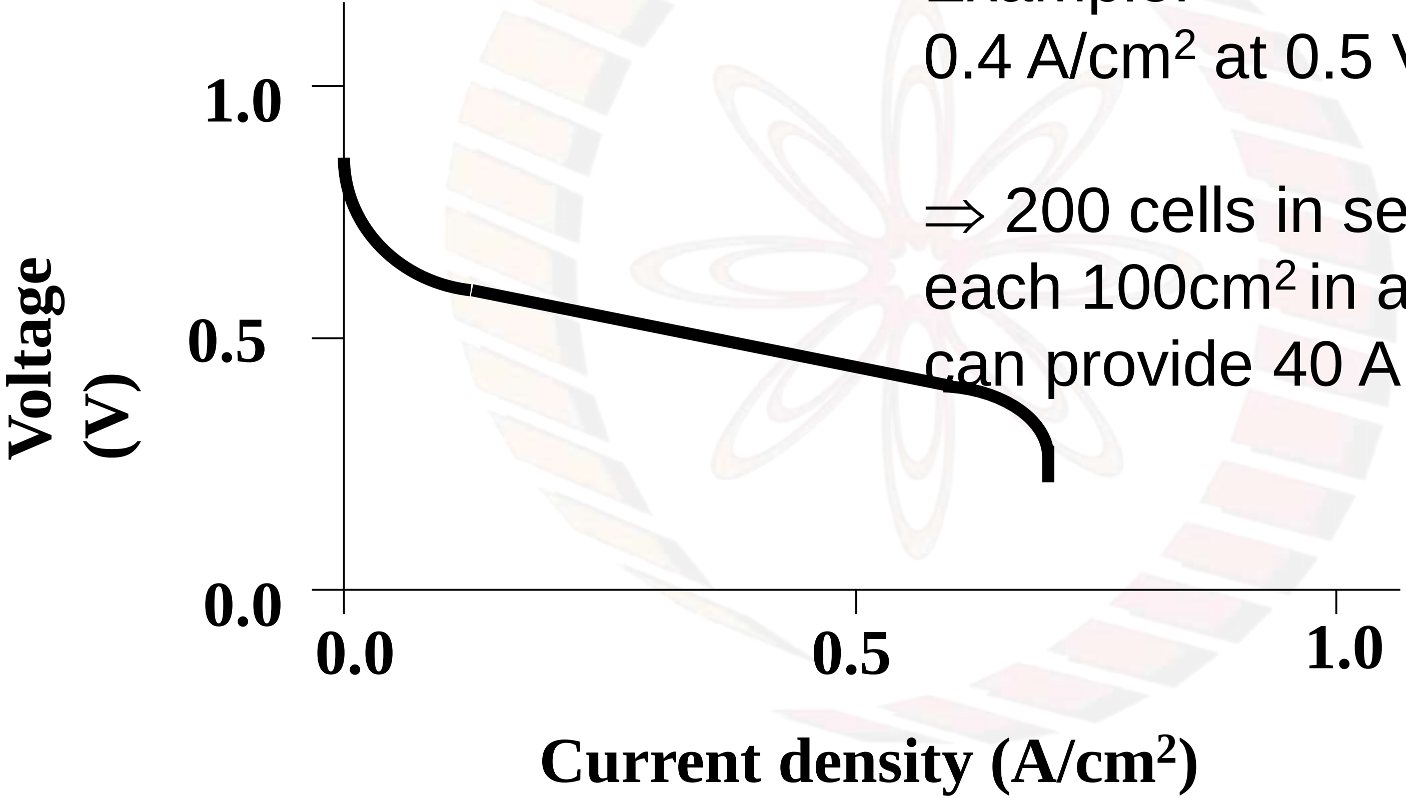
Cross section of a typical PEMC stack



Cross section of a typical PEMC stack

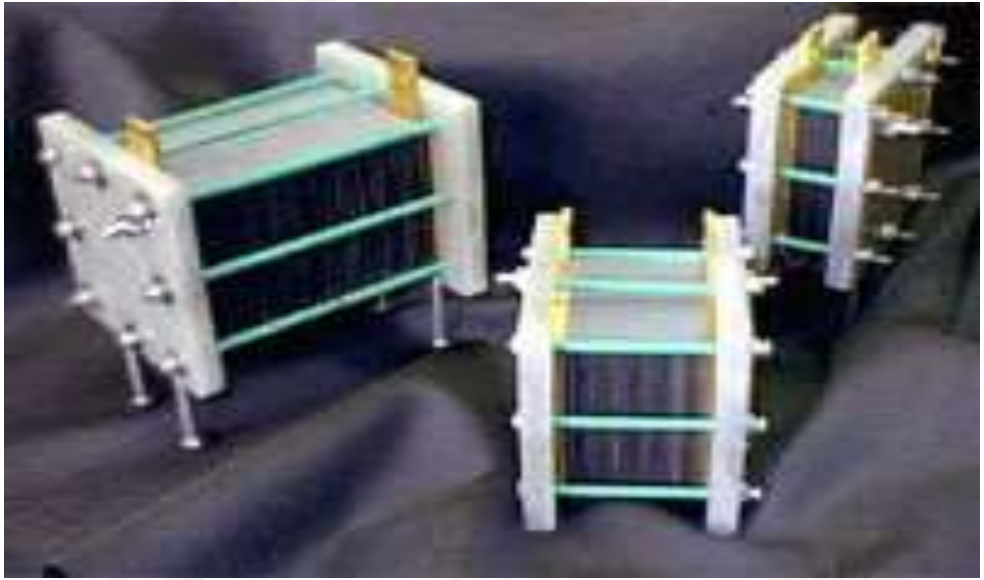


Schematic of polarization curve from a fuel cell

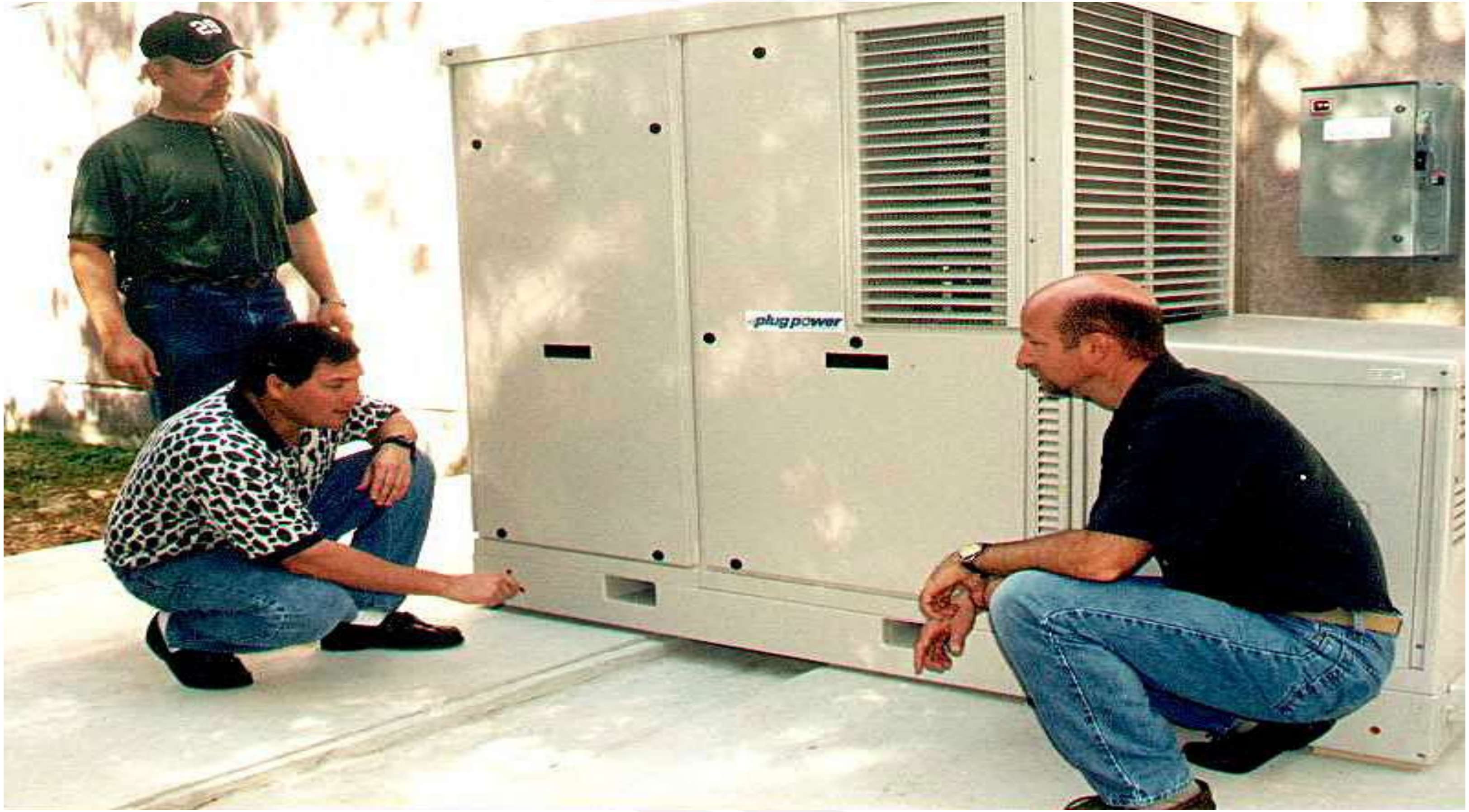


Example:
0.4 A/cm^2 at 0.5 V

$\Rightarrow$ 200 cells in series,
each 100cm^2 in area
can provide 40 A at 100 V (DC)



Some commercially available fuel cell stacks

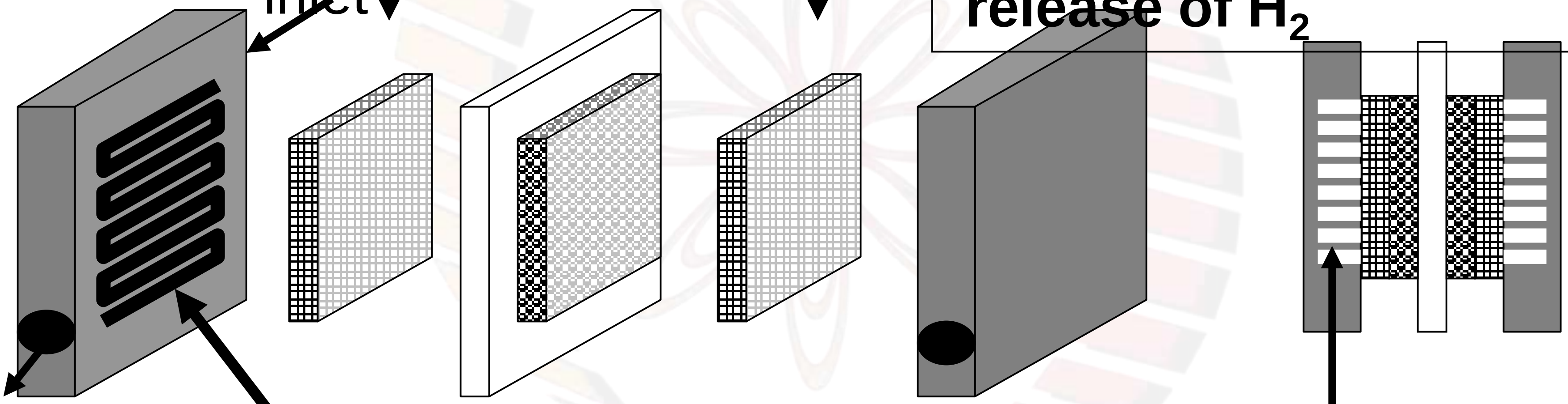

plug power


necar 5
necar 5
FINISH

Challenges and Trends

Research Issues

- Reformer
- Control and Diagnosis
- Inverter design
- Storage and controlled release of H_2



Other important design Issues:

Safety!

Hazard from use of pure H_2 and pure O_2

Replacements:

Air for O_2

Natural gas / other fuel that can be reformed to a H_2-rich fuel stream just before use

Technology Issues

- System integration
- Robustness
- Modularity
- Scalability
- Locally available fuels
- Turndown ratio
- Load following capability

Technology Issues

System integration

- Production more than consumption
- Mean time between failures
- Commercially available auxilliaries

Technology Issues

<u>Robustness</u>

Range of operating points

- Temperature
- Pressure
- Humidity

Technology Issues

Modularity

- Varying needs of customers

- Focus on a limited number of products

Technology Issues

<u>Scalability</u>

- Area of cell
- Number of cells

Technology Issues

<u>Locally available fuels</u>

- Addressing local requirements

- Acceptability and success of product

Technology Issues

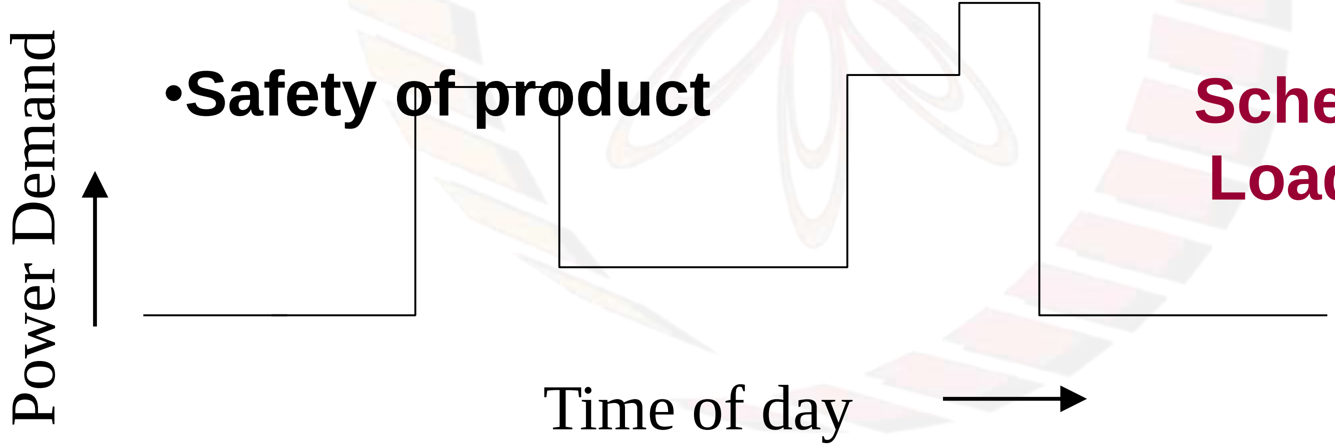
Turndown ratio

Single product, wide range of uses

User dependant

Controls and Diagnostics

- Load following and reformer response time
- Critical for practical applications
- May be auxiliaries limited
- Safety of product



Schematic of Load Profile

Technology Issues

<u>Serviceability</u>

- Drawback in existing designs
- Critical for success of product
- Must be addressed in early stages of development itself

Business Issues

- Software model
- Auto industry model