Technological barriers in PEM fuel cell system development

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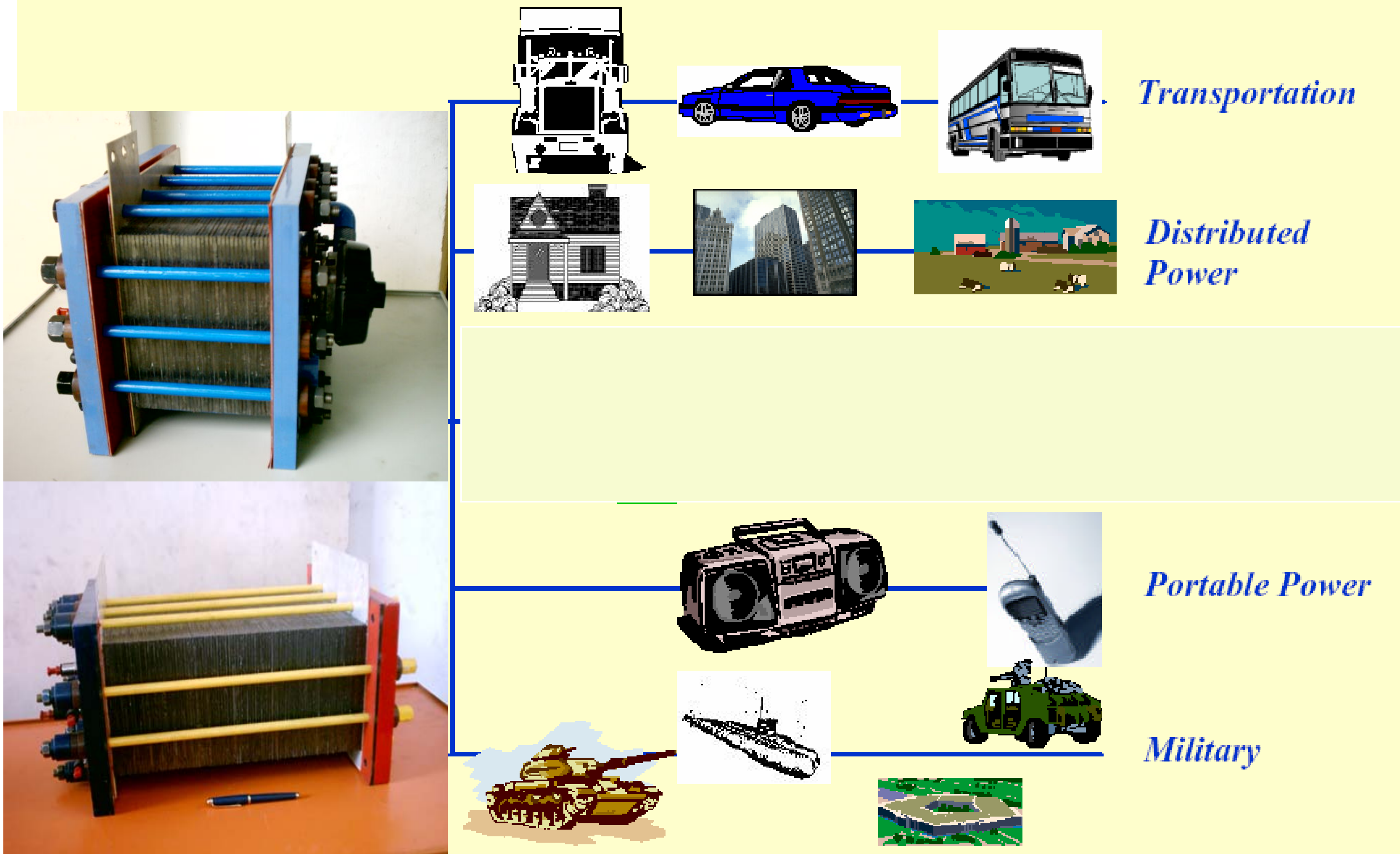
Outline of presentation

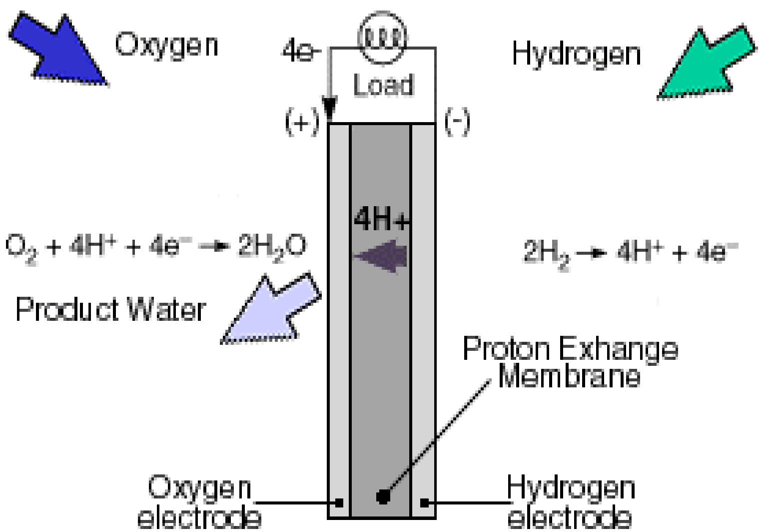
- *Brief Introduction to PEM Fuel cells*
- *PEM Fuel cell system*
- *PEM Fuel cell technological barriers*
- *Fuel cell R&D at SPIC Science Foundation*

PEM Fuel cells

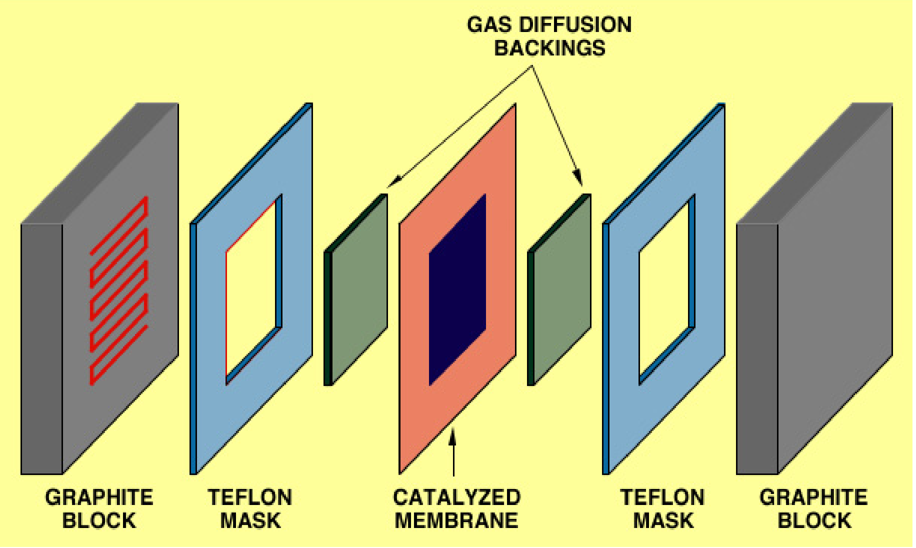
Wide range of applications



PEM Fuel Cell



SINGLE CELL HARDWARE

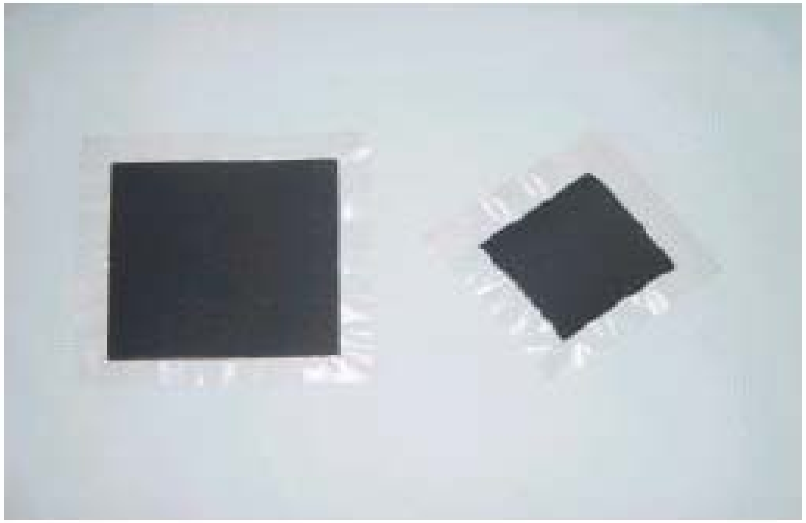


H2 + O2-----→ H2O + electricity (+ heat)

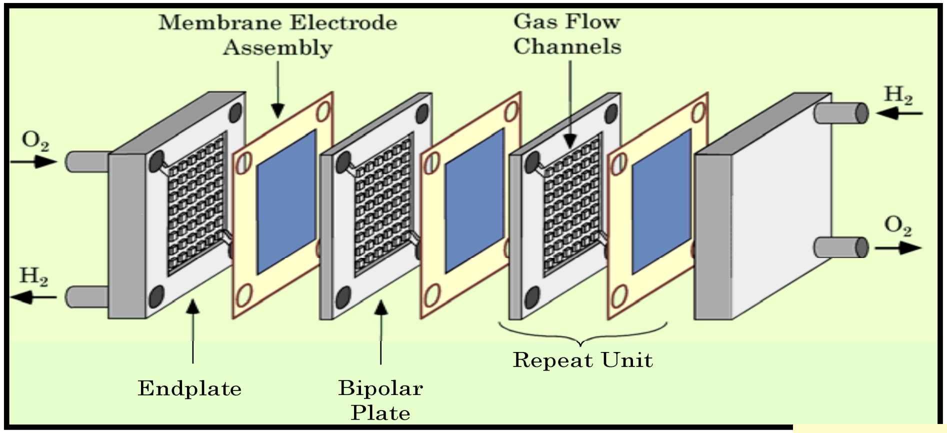
PEM Fuel Cell - Major Components

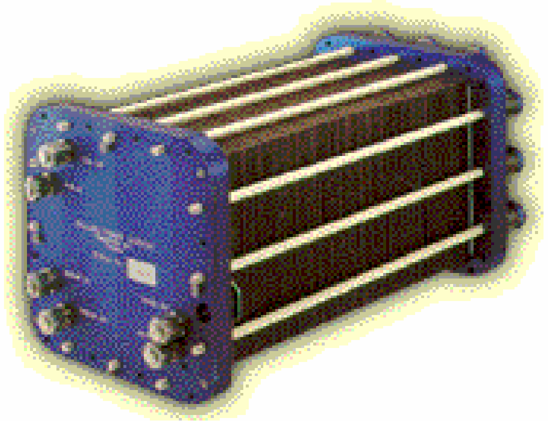
- ***Electrode – Pt catalyst used***
- ***Membrane- "NAFION" most commonly used***
- ***Bipolar plate- Graphite***

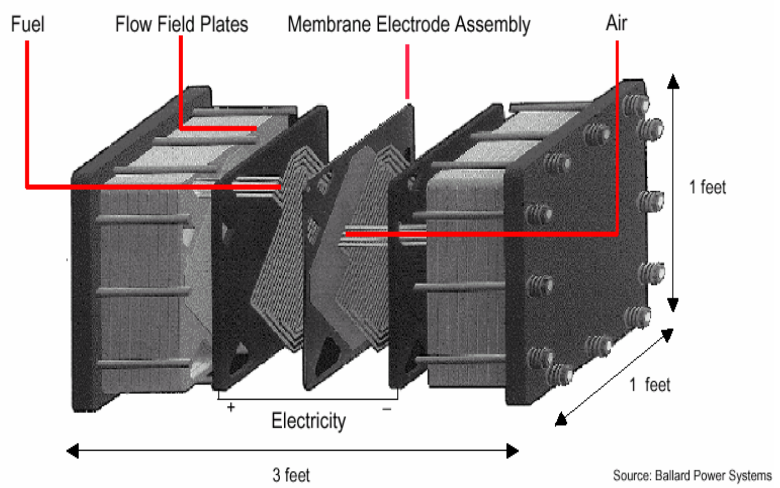
Membrane and Electrode assembly (MEA)

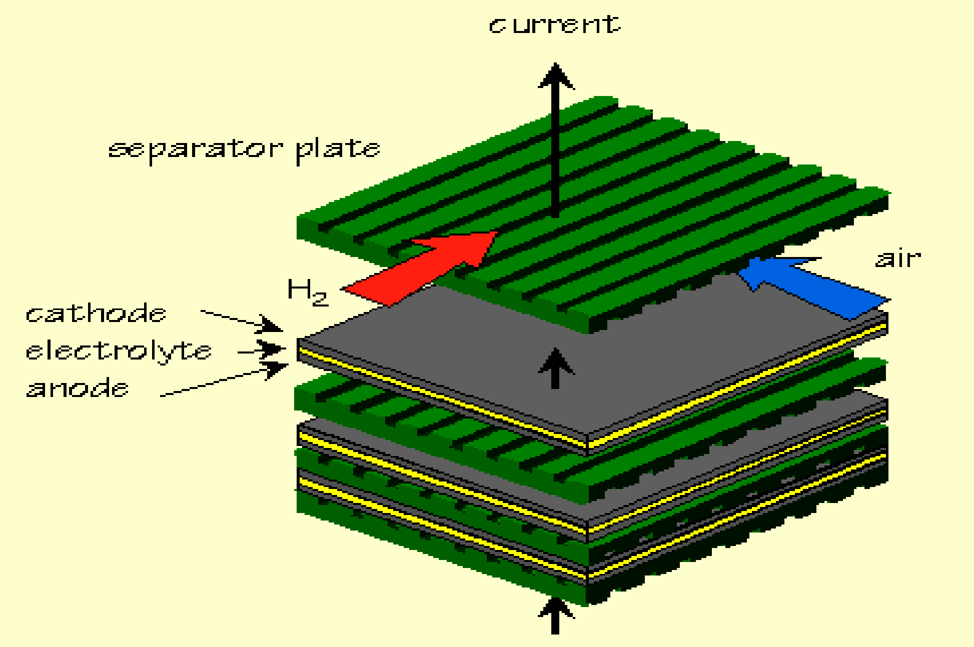


PEM Fuel cell stack





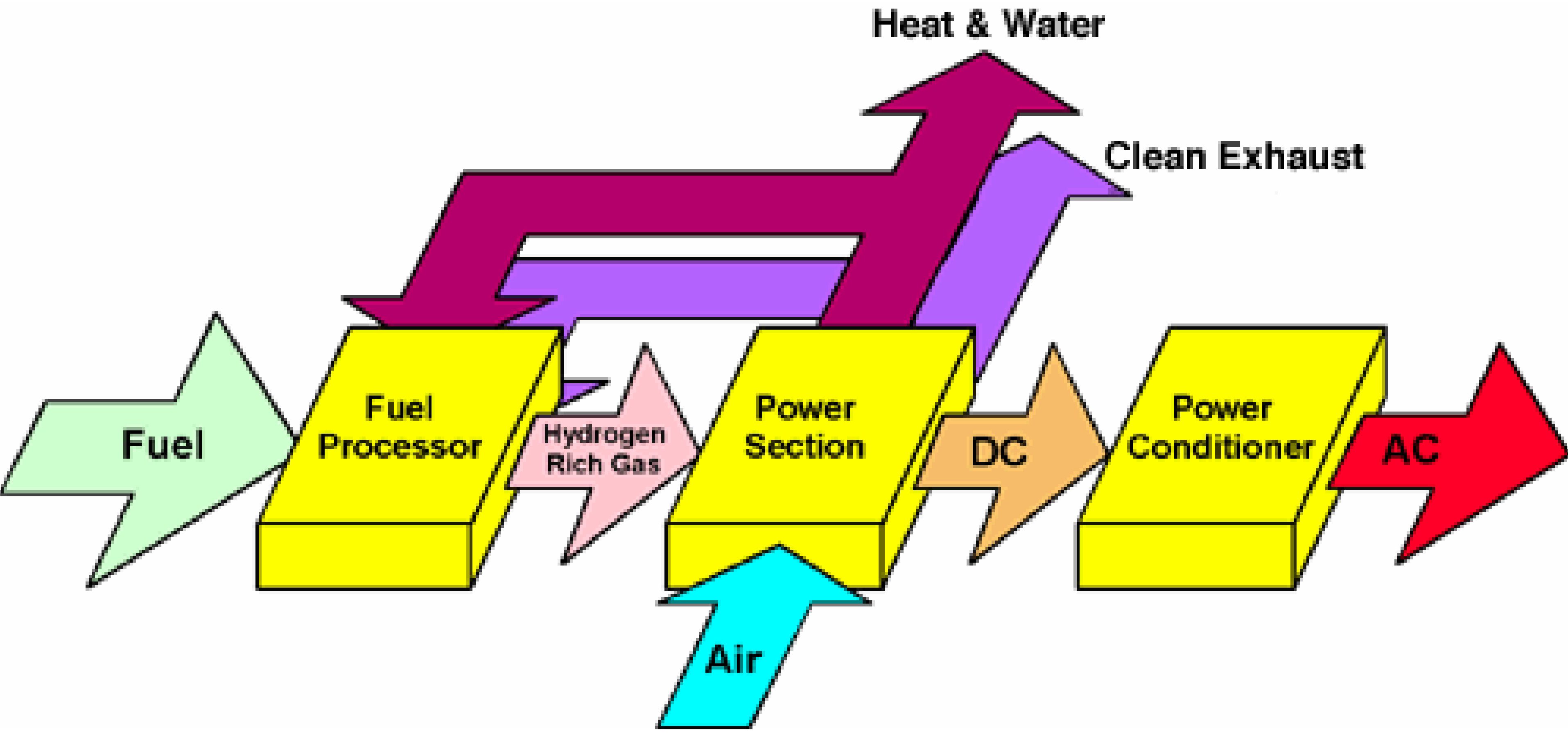




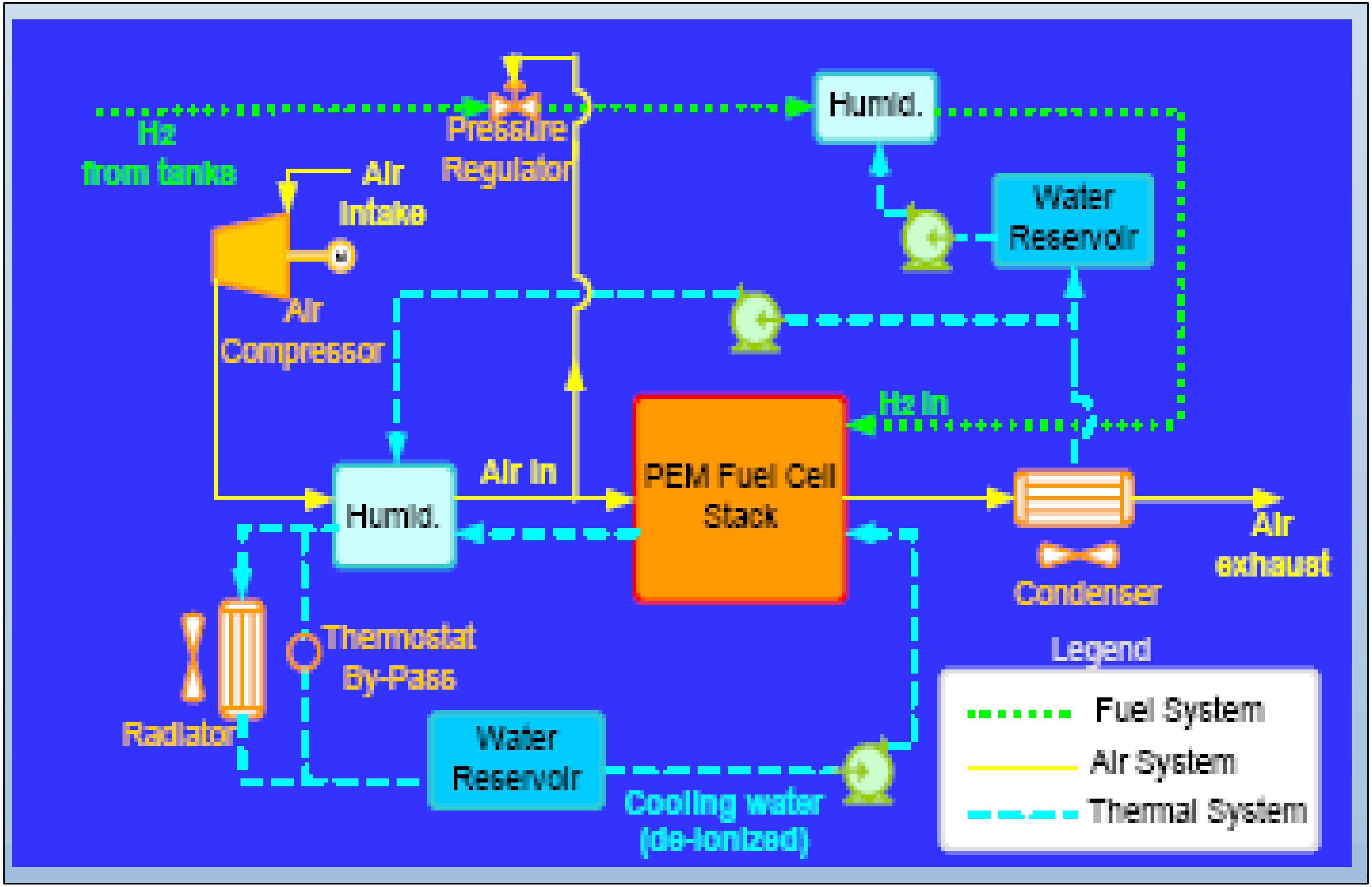
Components of Fuel cell system (fuel cell power plant)

- ***Fuel cell stack & accessories***
  - ***Gas humidifier***
  - ***Gas feed system***
  - ***Stack cooling system***
- ***Oxygen/air supply system***
- ***Fuel / Fuel processor***
- ***Power conditioner***
- ***Control & monitoring system***

Schematic of Fuel Cell system



Schematic of Fuel cell system



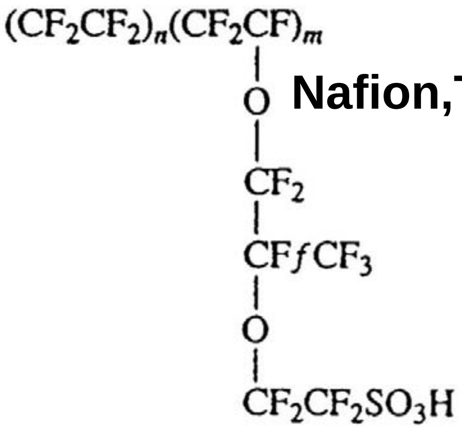
Technological barriers –

Challenges in PEM Fuel cells

PEM fuel cell membrane

Desirable features of PEM membrane

- ***Good proton conductivity***
- ***Zero electronic conductivity***
- ***Low gas permeability***
- ***Chemical & electrochemical stability***
- ***High mechanical strength***



Nafion,TM

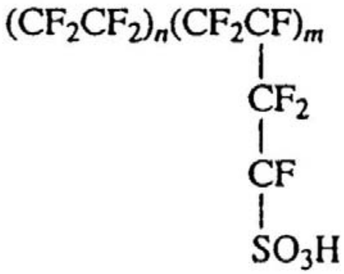
Membranes for PEM fuel cell

-Perfluorosulfonic acid (PFSA) membranes-

- ***Nafion Membrane (Du Pont, USA)***
- ***Dow membrane***
- ***Asahi membrane***
- ***Gore membrane***

-Aromatic sulphonic acid membranes

sulfonated poly(sulfones)
sulfonated poly (ether ketones)
sulfonated poly(trifluorostyrenes)



Dow

Limitations of available membranes

- ***High membrane cost (> 25% cost of Fuel cell stack)***
- ***Dependence on water for conduction***
- ***Limited stability at temperatures >80^{o}C (This restricts operating temp of PEM fuel cell stack)***
- ***sensitivities of membranes to contaminants from the fuel (e.g. NH_3, H_2S), from air (e.g. SO_2) and from materials in FC system (e.g. metal ions)- care must be taken to get high durability***
- ***No fuel cell membrane manufacturer in India***

Bipolar plates-

Desirable features

- ***High electronic conductivity***
- ***Low gas permeability***
- ***High chemical & electrochemical stability***
- ***Good mechanical strength***
- ***Low cost***

Barriers / Limitations-

- *High cost (>20% cost of Fuel cell stack)*
  - *- high cost mainly due to low volume of production*
- *Bipolar plate accounts for majority of stack weight, volume – Hence very thin and low density bipolar plate is required- graphite plate is commonly used whose density is relatively high (2 g/cc)– and mechanical strength of very thin plate is poor.*
- *Technology for alternate bipolar plate materials is required- metallic bipolar plates, grafoil based bipolar plates to be developed*
- *Lot of R&D required on Hydrogen /air/ water Flow field plate design on bipolar pates.*

Fuel cell performance improvement

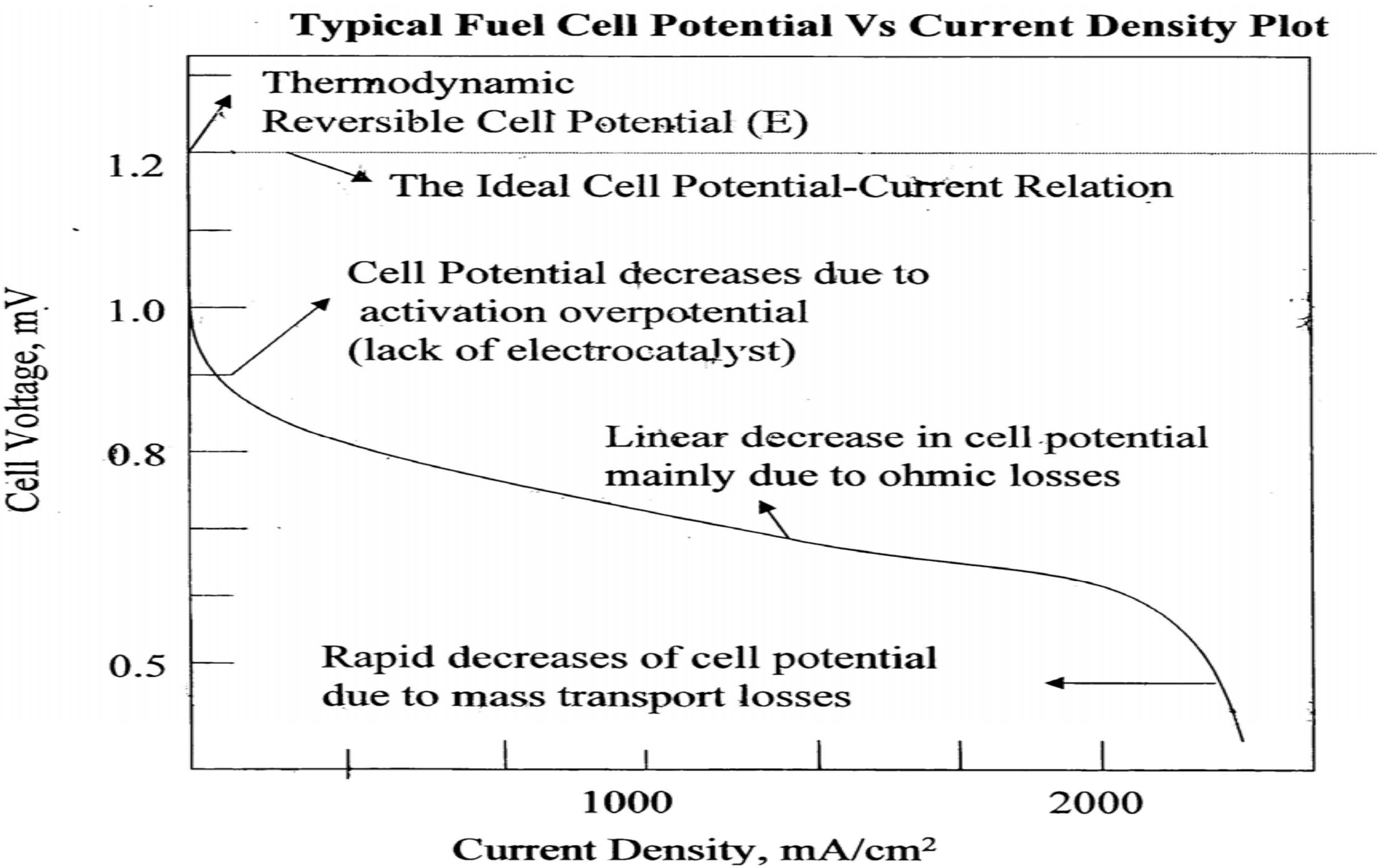
Factors affecting PEM fuel cell performance

- *Type, thickness, properties of the PEM*
- *Electrode kinetics, i.e., electrode structure, catalyst loading and catalyst utilization*
- *Type of backing layer, its structure, thickness, porosity, tortuosity, hydrophobicity*
- *Hardware resistance (contact resistance)*
- *Gas flow field configuration*
- *Operating conditions (temperature, pressure, flow rates, humidification of reactant gases)*

Barriers/ Challenges:

- *Though high performance achieved in single cells, it is difficult to achieve high performance in multi cell stacks- requires more stack design studies*
- *Power density of stacks to be improved-for lighter, smaller, less expensive fuel cell stacks*
- *Fuel cell efficiency to be improved- Fuel cell Performance low at high cell voltage > 0.6-0.7V. High performance at higher cell voltage is required for higher efficiency- More R&D on Fuel cell catalyst is required*

Polarisation curve for a Fuel Cell



Water management

- ***Water plays an important role in PEM Fuel cells. Water is required for humidification and stack cooling and it is produced by the fuel cell during power generation.***

- ***PEM Fuel membrane conductivity depends on membrane humidity, hence water has to be fed into the stack for good fuel cell good performance. – gas humidification by bubbling through water, or using membrane gas humidification is adopted usually- new methods to be explored.***

- ***Excess water has to be removed to avoid flooding of the electrode pores, for good performance.***

- ***Maintaining optimum water balance in the fuel cell stack and entire system requires proper design, control strategies.***

Thermal management

- *Fuel cell produces lot of heat- Effective Utilization of waste heat is a challenge- due to low operating temp of PEM Fuel cell*

- *Due to low operating temp of PEM Fuel cell operation (hence small difference between the operating and ambient temperatures) large heat exchangers are required for heat removal.*

Radiator fans, pumps for radiators use part of the power that produced reducing overall system efficiency. Better heat removal systems for PEM Fuel cells to be explored.

Fuel –
Fuel Flexibility, availability, storage

- *Low cost Fuel, Fuel availability, fuel infracture, fuel storage is one of the most important technological barrier facing Fuel cell technology commercialization*

- *With current production technologies, H_2 is still currently three to four times as expensive as gasoline.*

- *PEM Fuel cell gets poisoned by impurities in fuel – mainly by carbon monoxide*

- *Small multi-fuel reformers for hydrogen production to be developed- with fast start-up, low CO*
- *Renewable fuel processing for hydrogen generation to be developed*
- *More R&D required on water electrolysis- for reduction of energy consumption- Water electrolysis using renewable energy wind, solar, etc to be given priority.*

Other barriers

- *Air management- suitable compressors/blowers for fuel cell applications- with high efficiency and low cost is not available-*
- *High efficiency inverters suitable for fuel cells (with wide input voltage and low cost) is not available off the shelf*

- *Low cost mass flow controllers / gas feed systems, load-matching gas feed systems not available commercially.*

- *Lot of R&D required for Control and safety system for fuel cells*
- *System integration / System packaging difficult due to non-availability of small, light weight , low cost accessories required for high density Fuel cell system- More R&D required.*

High manufacturing cost and Specific areas of cost reduction

- ***Material requirement reduction***
- ***Lower-cost material***
- ***Reducing the complexity of an integrated system***
- ***Minimizing temperature constraints (which add complexity and cost to the system)***
- ***Streamlining manufacturing processes***
- ***Increasing power density***
- ***Scaling up production to gain economies through increased market penetration***

Present high cost is mainly due to low volume of production !!

SPIC SCIENCE FOUNDATION
Centre for Energy Research
Focus of Research

1. Fuel Cells

2. Fuel cell based application development

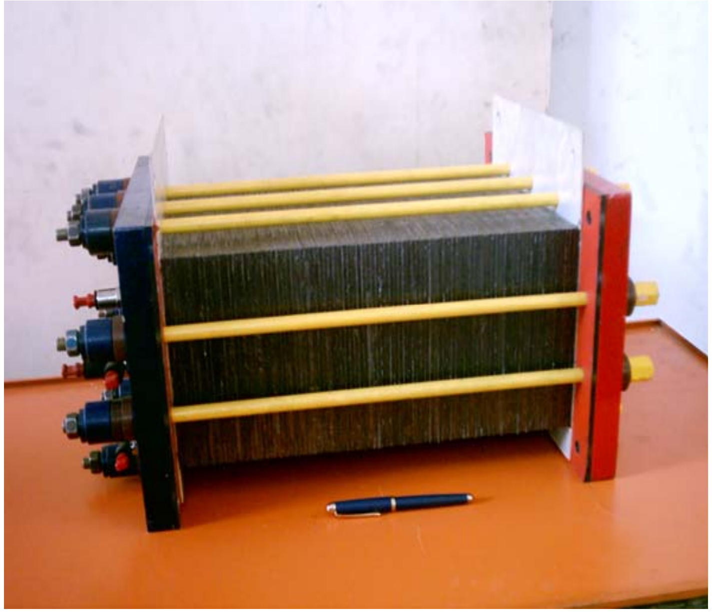
3. Hydrogen production

Research on Fuel Cells stack development

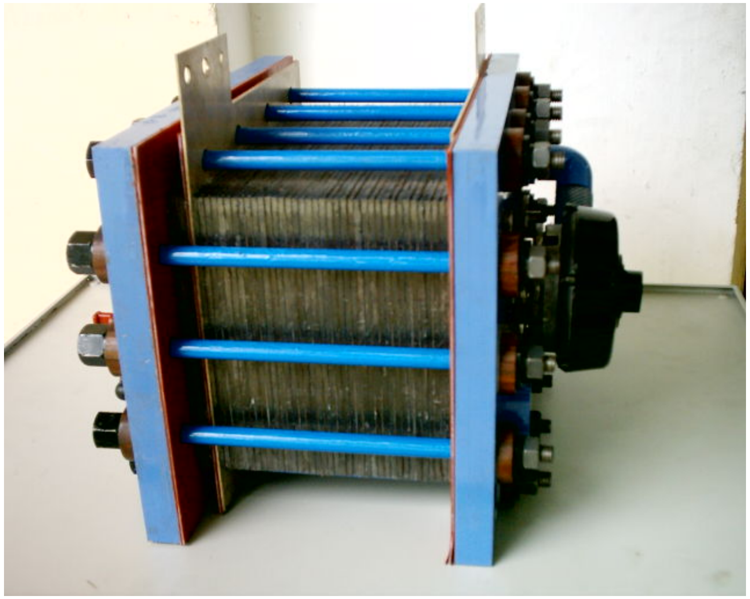
- ***Polymer Electrolyte Membrane (PEM) Fuel Cell***
  - ***Developed technology for PEM Fuel cell stacks (5kW)***

- ***Direct Methanol Fuel Cell (DMFC)***
  - ***Developed 250 DMFC stack***
  - ***R&D being carried out on alternate fuels***

3-5 kW PEM Fuel Cell stack Developed at SSF



Hydrogen-air PEM Fuel Cell stack Developed at SSF



Fuel cells components and accessories development:

- ***Developed <u>very low Pt electrodes</u>***
  - ***R&D in progress on improving electrode performance, development of CO tolerant electrodes***
- ***Developed <u>Pt/CNT catalysts</u>***
- ***R&D being carried out on <u>new membranes</u>***

- ***Developed <u>membrane gas humidifier</u>***
- ***Developed <u>load- matching gas flow controller</u>***
- ***Developed <u>Hydrogen gas sensor (leak detector)</u>***

PEM Fuel cell Battery Hybrid vehicle (12 seater van) Developed by SPIC Science Foundation - under MNES Funded project

PEM Fuel cell based Uninterrupted power supply (UPS)

PEM Fuel cell based Uninterrupted power supply (UPS)

Hydrogen production

- ***Water Electrolysis-***

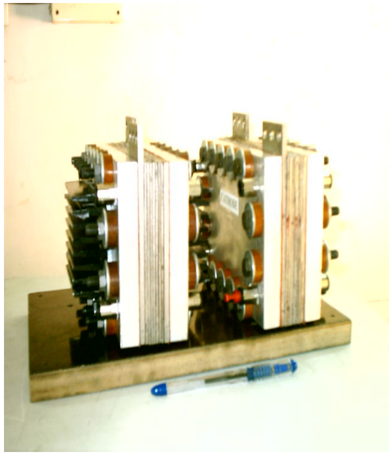
-developed PEM water electrolysers of capacity 500 lit/hour (0.5Nm3/hour) Hydrogen and 1000 lit/hour(1 Nm3/hour) Hydrogen, under DST- TIFAC funded project

- ***Electrolysis of aqueous methanol-***

developed 60 lit/hour hydrogen generator, with very low power consumption , (1/3rd) compared to water electrolyser (MNES funded project)

PEM water electrolyser

Hydrogen production 0.5Nm3 /hour



Hydrogen production 1Nm3 /hour

Methanol electrolyser for hydrogen production
60 lit/hour hydrogen

Low power consumption , (1/3rd) compared to water electrolyser

Future Programs

- *Development of Fuel cell stacks with high Power density*
- *Materials development for Fuel cells*
- *Reduction of precious metal requirement in Fuel cell electrodes*
- *Development of CO tolerant catalysts*
- *High temperature membrane development for better water management, increased tolerance to CO*
- *Bipolar plate development*
- *Development of Water electrolyses with high efficiency*
- *Development of compact Reformers for hydrogen production*
- *Cost reduction*
- *Development of Fuel cell based systems for*
  - *portable,*
  - *Stationary – Fuel cell based UPS, and*
  - *Transport applications -Fuel cell EV*

- *Collaboration with research institutes/ industries for further advancement of Fuel cell technology*

Thanks