Challenges in PEMFC System Integration

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at the
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Presentation Outline

- Development at CFCT
- Issues and Challenges
  - BoP challenges
  - Integration challenges
- Conclusions

Centre for Fuel cell Technology
Advanced Research Centre – International (ARCI)

Objective:

Development of PEM Fuel cell Technology for use in

- **UPS Systems**
- **Transportation application**
- **Decentralized Power Generation**

System Integration
Field Trials
Cost reduction

Significant Milestones achieved:

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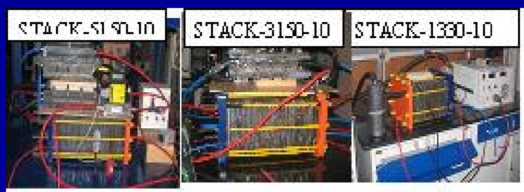
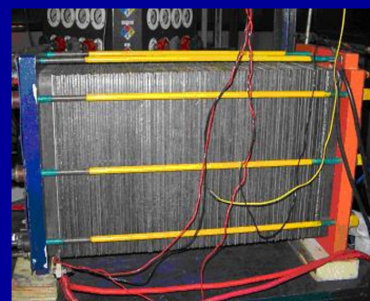
1& 4.5 kW water cooled Fuel cell stacks (UPS & DPG))



Water cooled 1 kW PEMFC stacks

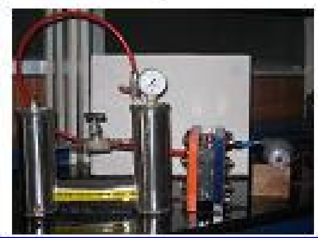


Air cooled stack (Transport)

Miniature Flat plate stack (Portable)

Grid independent Power system (300 watts)

Chemical Hydrogen Generator



Pedal powered Hydrogen generator

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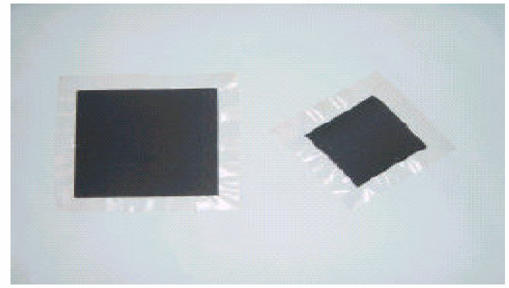
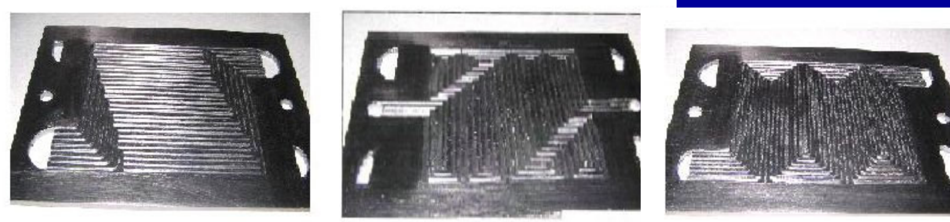
Significant Milestones achieved: Fuel cell components

Non Noble Metal catalyst-Anode successfully replaced

Fuel cell Control system



MEAs - 30-730 sq. cm



Low Cost bipolar plates 90-400 sq.cm

Modeling Taguchi analysis

Other Fuel cell types

DMFC BHFC DAC MFC AFC SOFC

Fuel Cell Power Plant

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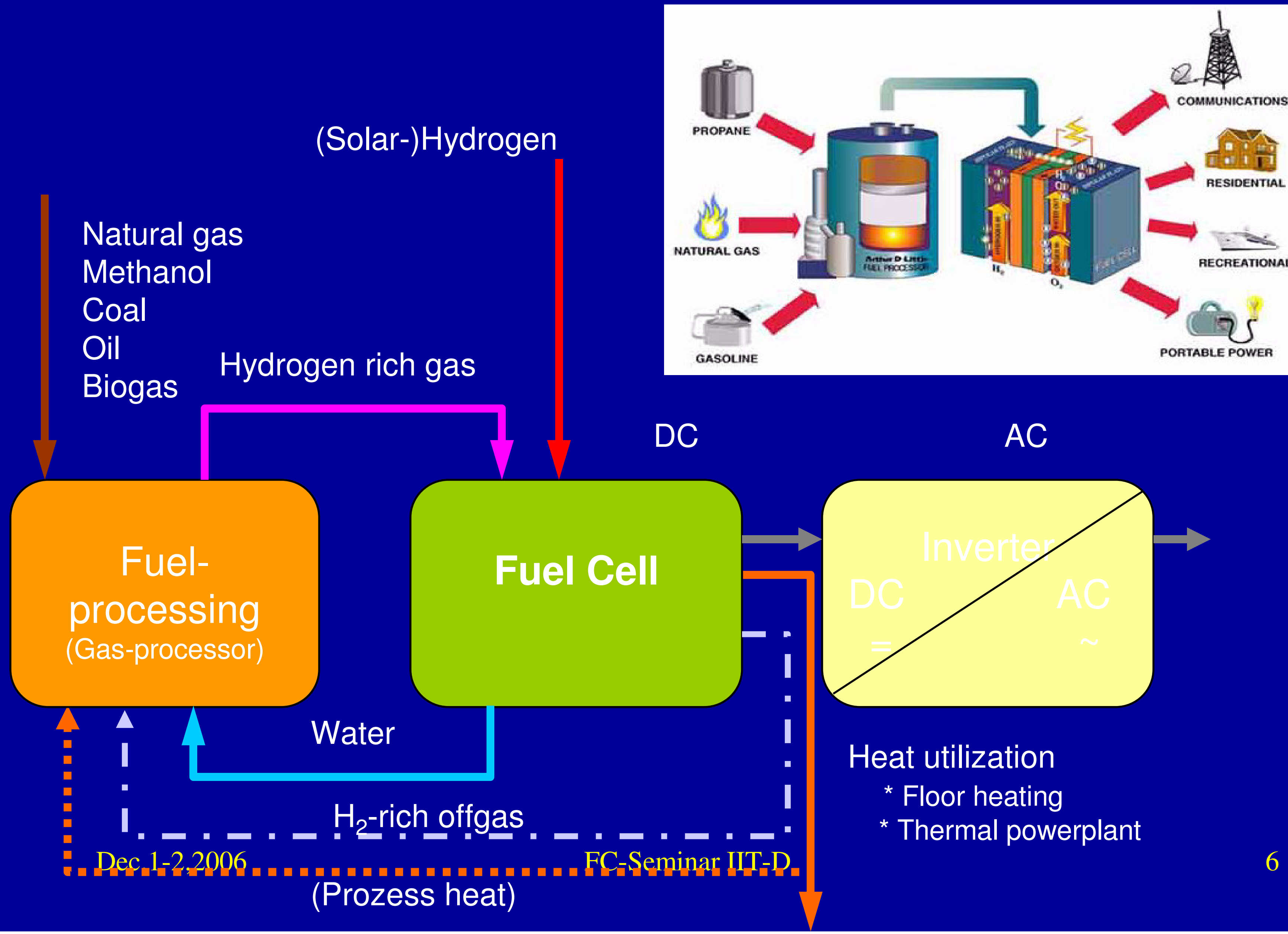

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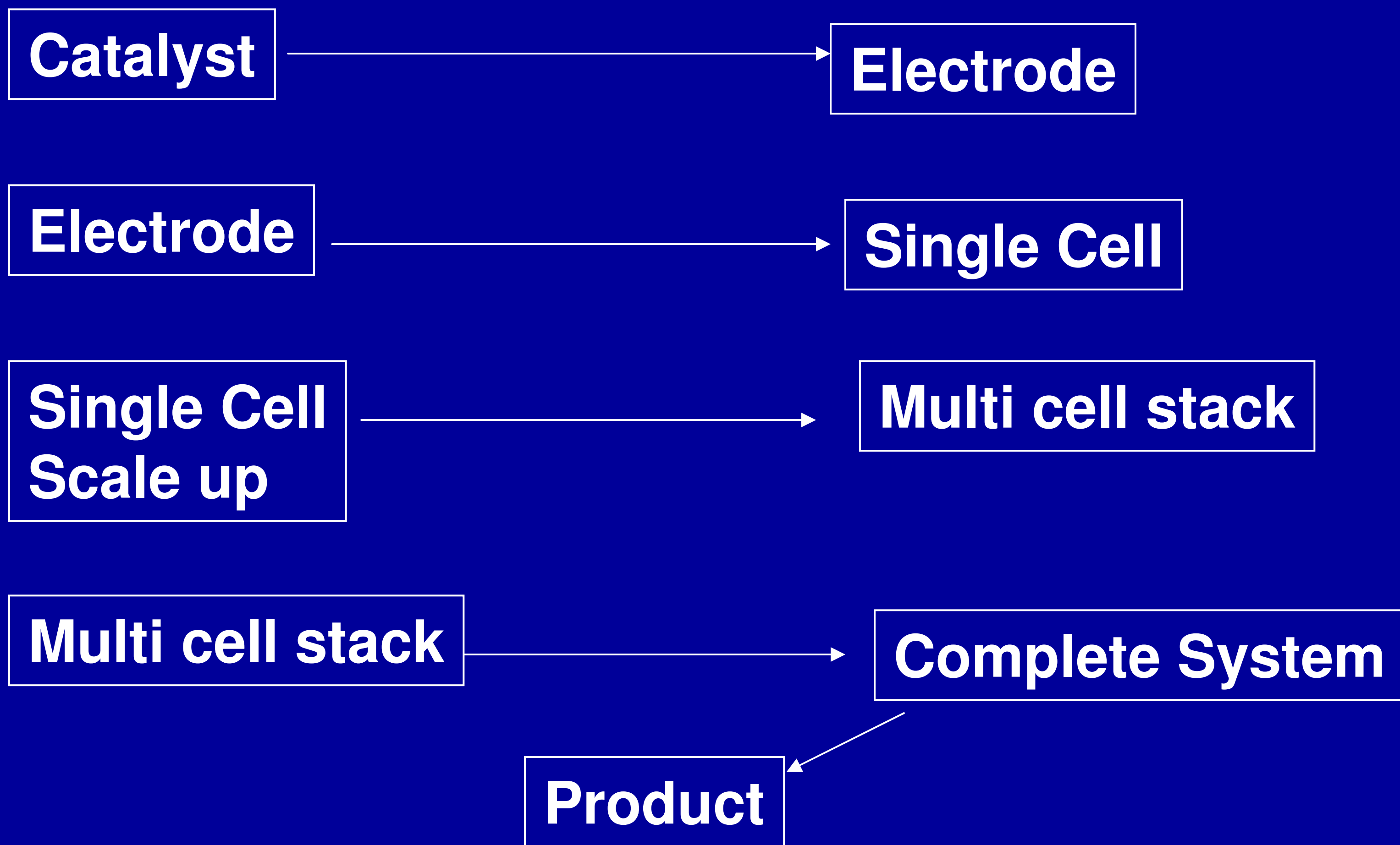
Challenges

- Materials challenges
- BoP challenges
- Integration issues and challenges

Application Dependent

The system integration calls for many compromises



System Integration

Applications of PEMFC technology

➔Stationary ➔Transport ➔Portable

Design options w.r.t application

Stationary

1. Grid connection
2. Load following
3. Installation
4. Cogeneration

Transportation

1. FC+ Battery hybrid
2. FC+ Supercap hybrid
3. FC+ICE

Portable

1. Series in Plane
2. Series like in battery
3. Air breathing / forced air

BoP requirements differ depending on the application ,operating conditions and also on the power output from the system

1.Choice of fuel and supply
2.Oxidant supply
3.Power conditioning
4.Heat removal
5.Size and weight
6.Noise level
7.Start up time
8.Life time

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Materials challenges
BoP challenges
Integration issues and challenges

- **Catalysts**
- **Membrane**
- **GDM**
- **GDL**
- **Bipolar plates**
- **Gasketing**
- **Corrosion Issues**

Materials challenges
BoP challenges & Integration issues and challenges

- **Operating conditions**
  - ✓ **Humidification**
  - ✓ **Operating temperatures**
  - ✓ **Thermal management**
  - ✓ **Fuel and oxidant supply**
  - ✓ **Sensors**
  - ✓ **Power controller**
  - ✓ **System controller**
- **Stack capacity**

Humidification

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PEM Fuel cells requires well controlled humidification of reactants

In a lab operation one could use Bubble humidifier or more Sophisticated / complicated setups

In a practical system these are cumbersome:

- ✓ Parasitic loses
- ✓ Increased volume and weight
- ✓ Maintaining water level

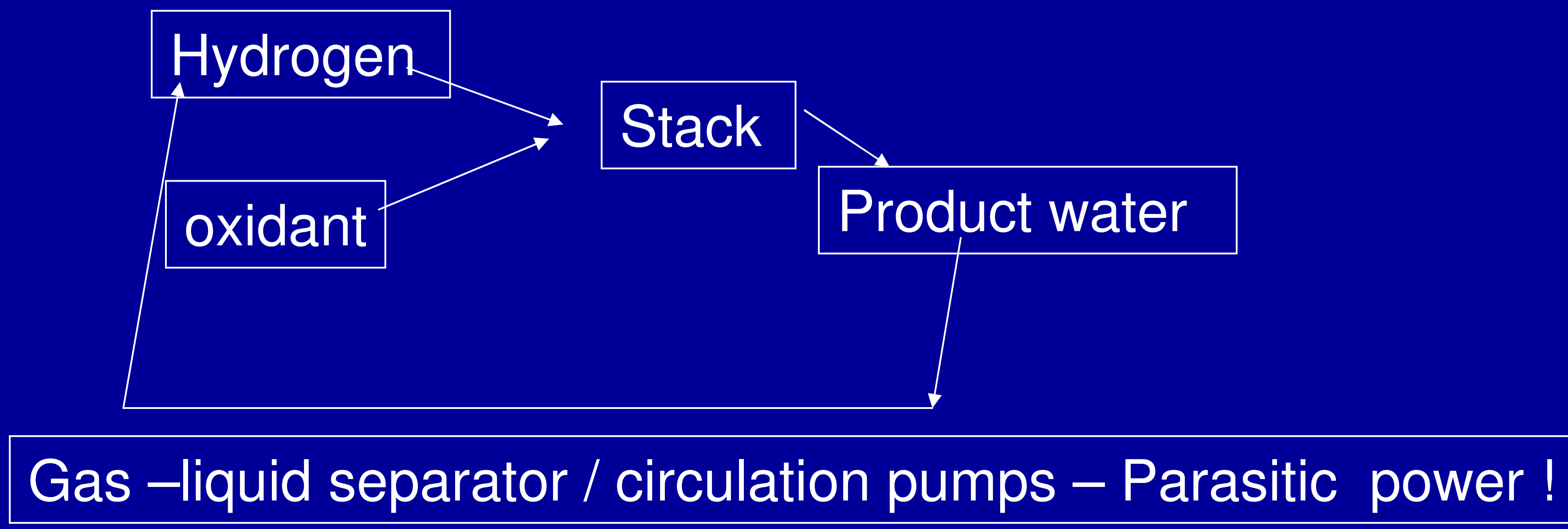
Options:

Membrane humidification (external or integral)

Issues: expensive, complicated engineering, increase in stack size

Not suitable for peak power as the response of the stack is normally poor

Bubble type humidifier may be suitable for higher capacity stacks - issue of topping water still remains



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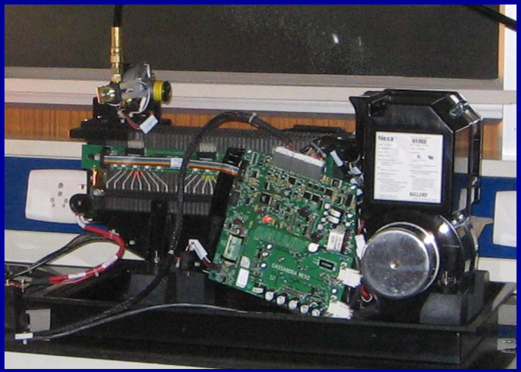
Can we run the stack with out humidification of hydrogen or use other strategies ?

- Back diffusion of water from cathode to anode
  - ➔Materials and electrode characteristics
  - ➔Differential pressure

e.g; Ballard's NEXA stack

-No hydrogen humidification
-Air humidified !!!! (contradictory to general belief - product water is expected to take care of humidification)
-Is it due to the type of membrane?
- if so what should be its characteristics?
- How should the electrode design change?



Another Issue: Similar air supply system not available readily and/or expensive

Reactant supply –Hydrogen

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PEM Fuel cells work best with pure hydrogen gas .

Hydrogen from reformation of hydrocarbons and alcohols requires excessive cleaning steps.

Choice of fuel determines application

Requirement of fast response ➔ use pure hydrogen
Fuel cell as base power provider ➔ can use purified reformate Hydrogen

Reactant supply

- Pressure control regime
- Flow control regime

Reactant supply –Oxidant

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Best efficiency of PEM Fuel cell can be obtained when pure Oxygen can be used ➔ expensive!

Air is commonly used in normal applications

Higher stoichiometry required ➔ electrode structure!

Higher pressure of air can improve performance

BUT

Compressors consume lot of energy
They do not scale up/down well,
Variable speed units not easy to find/expensive
This is a major issue with low capacity stacks

Reactant supply –Oxidant

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The other option is use Air blowers.

Issues :

We can not get high pressure

➔The flow field design becomes critical

For operational reasons DC powered air blowers would be ideal

➔not available easily/expensive

AC powered blowers – load following is difficult- complex electronic

Humidification of large volume of air is a major challenge

➔ bubble humidifiers not suitable or too bulky

➔ pressure drop is a major issue

Reactant supply –Oxidant

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CLAIM:

FUEL CELL SYSTEMS ARE SILENT

FACT:

➔THEY CAN BE SILENT ONLY WHEN THE AIR SUPPLY SYSTEM IS KEPT AWAY FROM THE AREA OF OPERATION

➔ AIR BLOWERS MAKE LOT OF NOISE

Grouping of FC components

Group	Components
Air Management	Compressor/expander, humidifier, filter, mass flow sensor, water separator
Auxiliaries	Pumps, piping, valves, pressure regulator
Control	Supervisor, anode, cathode, thermal, power electronics
Thermal management	Radiator, off-gas burner, flash back, cooling fan, HEX

Component function /selection in system Integration

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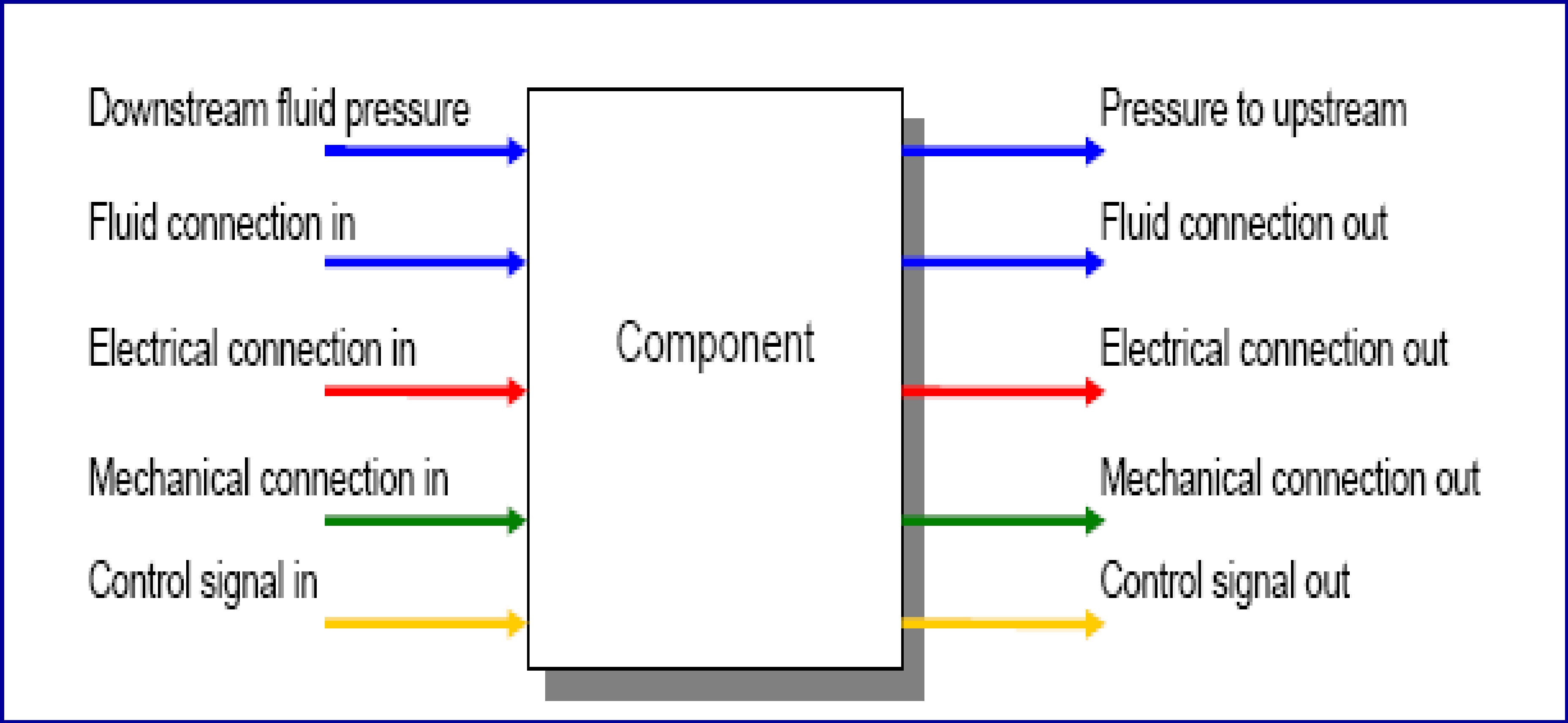

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Thermal management / Cogeneration

- Sources of heat
  - Fuel cell stack
  - Fuel processor
  - Unused hydrogen
- Rejection of heat
  - Heat Exchangers
  - Heat dissipation
- Use of Rejected heat
  - For heating domestic hot water
  - Room heating combined with heat pump

Load following controls

Important as it can save fuel, reduce parasitic losses if Provided with variable speed devices

but

- Strongly depends on the mechanical devices like Pumps, blowers or compressors used
- Depends on the inertia and time lag in responding to change of rate
- Difficult to operate reformer in a transient/ variable load mode

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Sizing of Fuel cell stack

Facts:

- **Higher operating voltage leads to better efficiency, but increased stack size**
- **Higher current densities complicate heat removal, brings in humidification issues – application dependent**

Do we design the FC to generate rated power output + all the parasitic power including power conversion losses or use different concepts ?

Use of an auxiliary stack vs. battery or super cap

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Power conditioning

- To convert DC power into usable AC power
- Voltage design has to be made in the range 2:1
- Should be able to handle high current and low voltage
- Provide interface for powering parasitic loads
- Provide interface with auxiliary power devices within the system and with grid
- Power conditioning design depends operating mode like grid parallel, grid support, stand alone or back up
- Ability to carry unbalanced load due to switching characteristics of the electronics circuitry due to unequal load

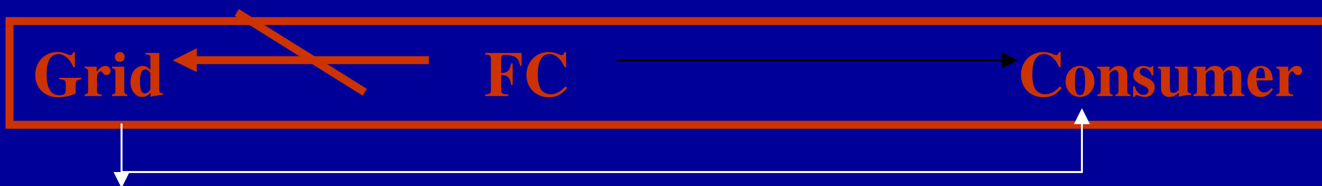
Design of power conditioning Module

- Grid parallel- - allows power from grid to consumer and not from FC to grid.

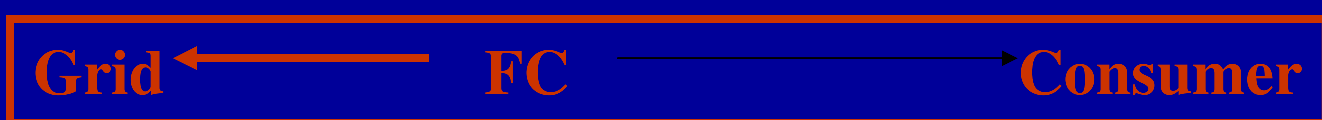
  Sized according to consumer needs

  Used to meet short term demands

  No need of battery bank



- Grid Interconnected– Power flows in both directions



  Can be designed as load following or constant power

- Stand alone – Providing power without grid
  - Capable of load following
  - Battery bank is required for load following
- Back up power- capable of quick start up
  - Combined with battery bank or other devices
  - Batteries for low power, low duration
  - Fuel cells for higher power, long duration(several kW, more than 30 mts)

Grid connection

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Design of power conditioning Module depends on the type of grid connection

- PEMFC as only power source in the areas not covered by Grid
- As a supplemental power source working in parallel with Grid, covering either base load or peak load
- In combination with Renewable energy sources, when these cannot meet the demand.
- As a back up or emergency power generator providing power when the grid is down.

Installation

- Indoor installation needs more demanding codes and standards
- Outdoor installation requires weatherproof system design
- Split system consists of fuel (processing) supply ,fuel cell systems installed outdoor and control & power conditioning sections at indoor.

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Components and System Configuration

- Fuel processor – SR,POX,CO Removal
- Fuel cell stack
- Balance of Plant

  Pumps

  Valves

  Heat Exchangers

  Fans

  Instrumentation

  PLC controllers

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Transport applications

System design for vehicle depends on

1. Required power output
2. Electric motor
3. Space considerations
4. Field of application
5. Energy recuperation facility
6. Driving comfort
7. No of occupants
8. Vehicle weight

A Typical Fuel cell Vehicle system

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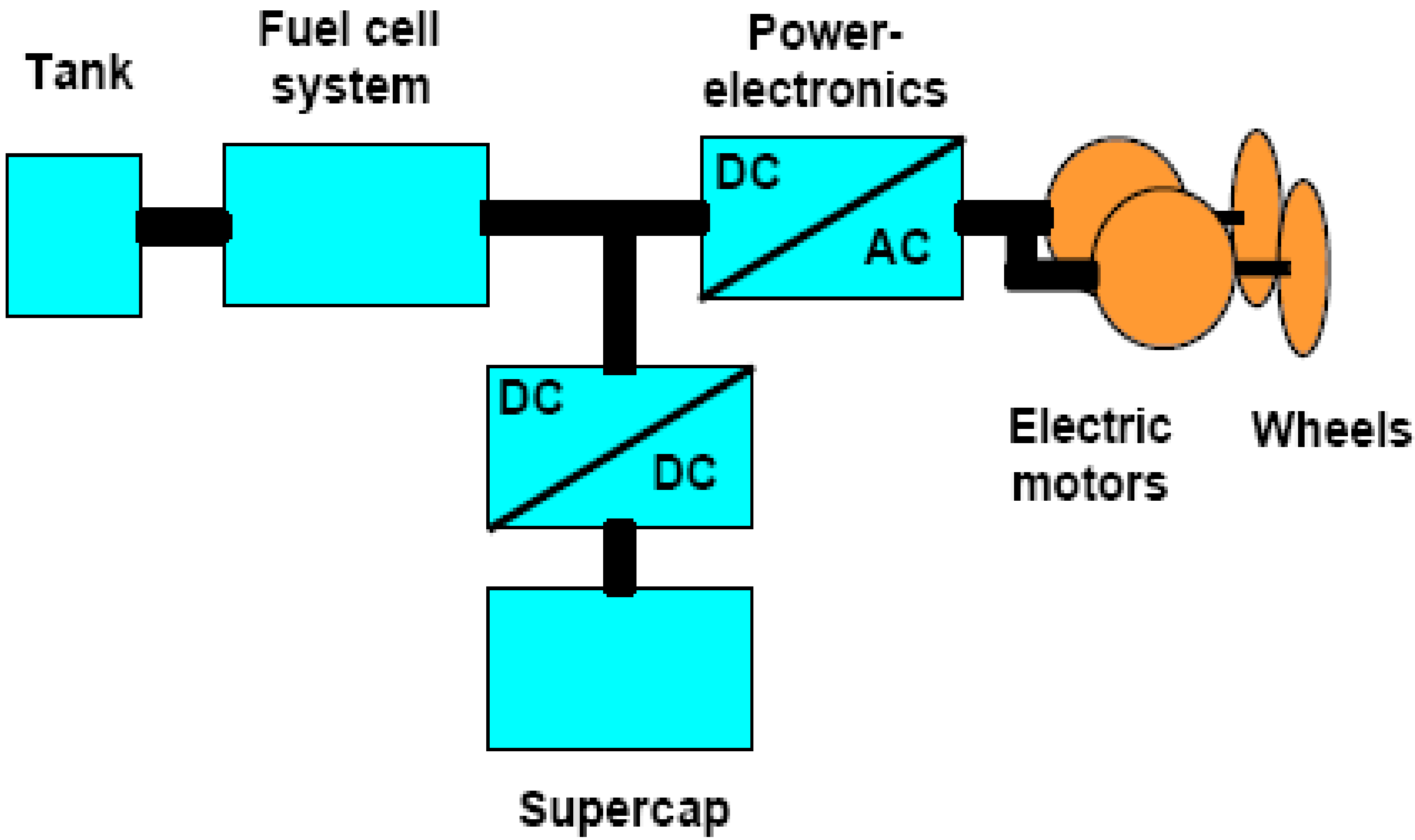

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Technology Challenges

- Startup with cold start(-25C) and start-stop ability
- Driving operation
  - Maximum driving speed
  - Mountain driving with inclines
- Driving Cycles

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Possible vehicle drive conditions

Start --- cold start, warm start

Start up – At lights, slope,

Braking - Braking on operation, braking during descend, braking with service break, stop at lihghts

Driving -- Constant driving, cornering, Accle, overtaking, Reversing, Mountain slop<10%, Ramp slope >10%, icy road,Tunnel, Off road, Convoy driving, Emergency operation, Towing

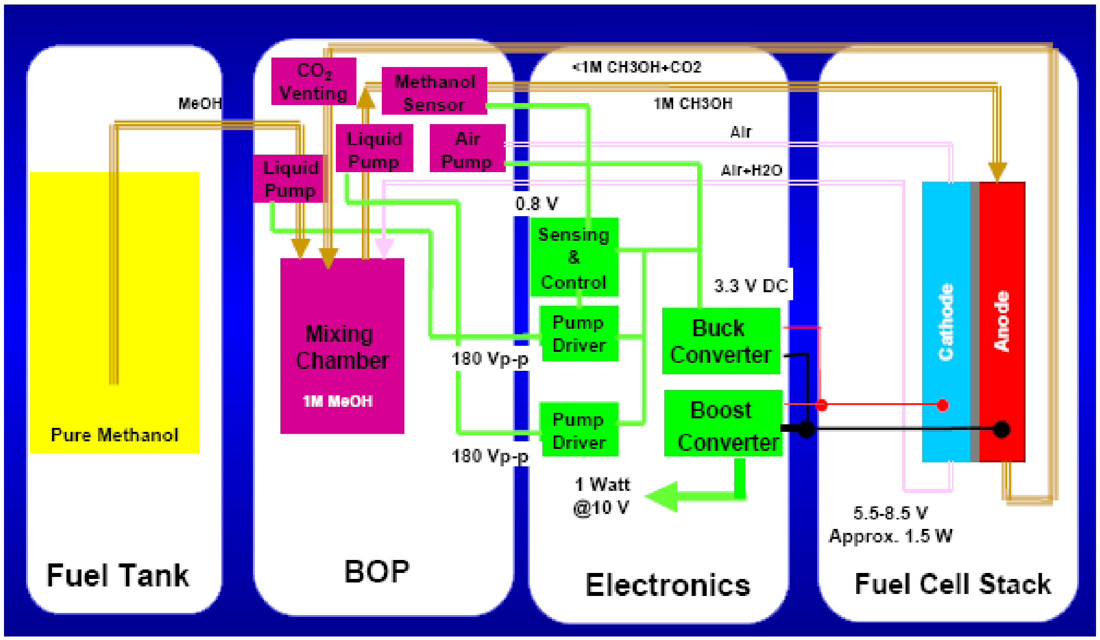
Stop – Outdoor parking, Garage parking<24h, Garage parking>24h

The relevant time constants for an automotive propulsion-sized PEMFC stack system are:

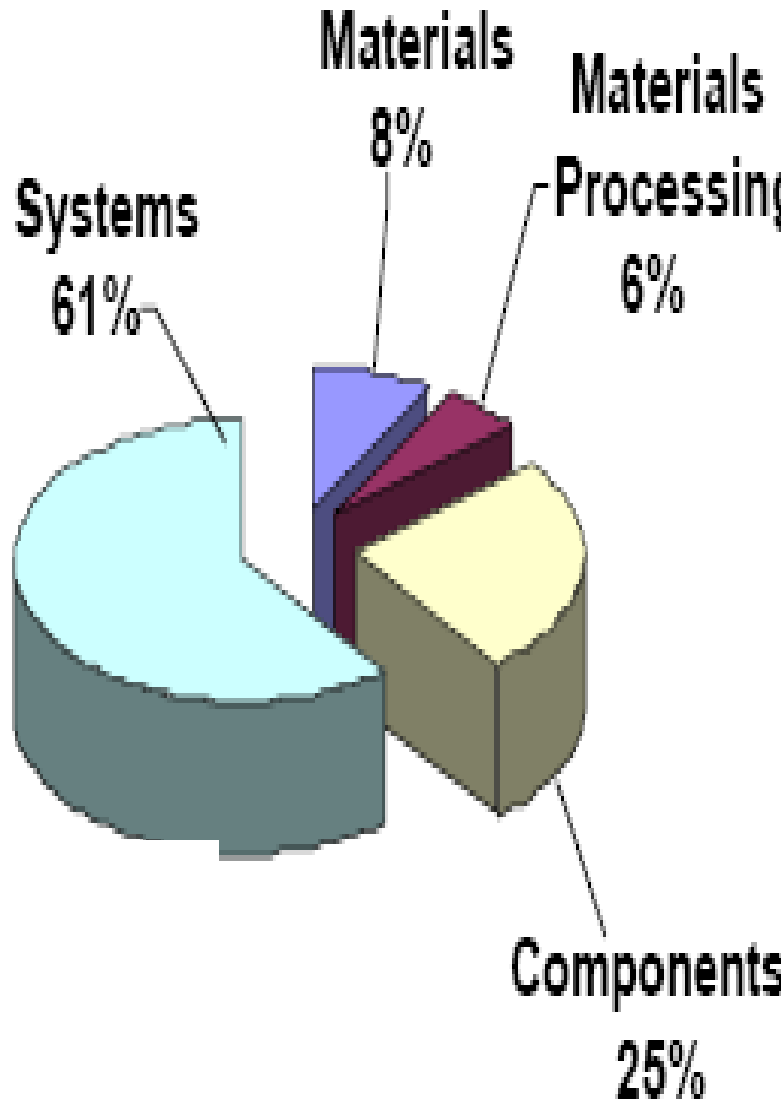
- Electrochemistry -10^{-19} sec
- Hydrogen & air manifolds 10^{-1} sec
- Membrane water content 10^{2} sec for the cathode

  and 10^{1} sec for the anode
- Flow control/supercharging devices 10^{2} sec
- Vehicle inertia dynamics 10^{1} sec
- Cell and stack temperature 10^{2} sec

Portable application



Resource Allocation



Conclusion

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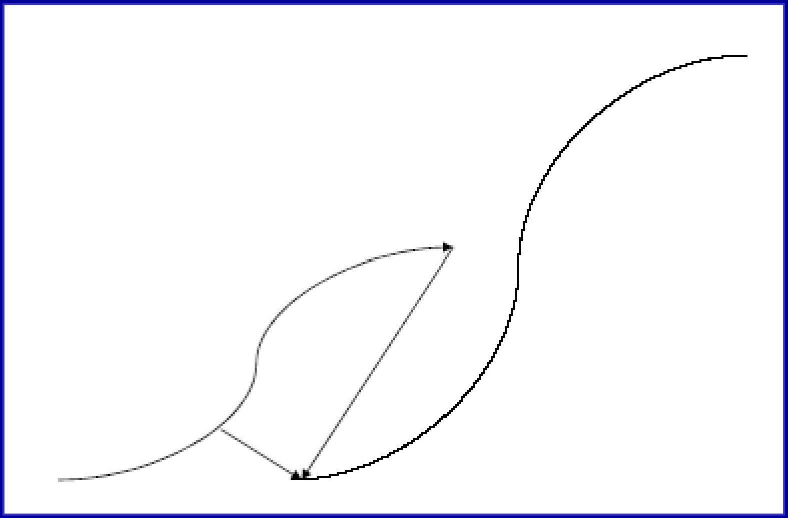
- ❖Concerted effort is required to make success of fuel cells
- ❖Besides the materials for the stack ,BoP requirement should be urgently understood and efforts made to make them
- ❖The Fuel cell system integration calls for many compromises



Learning curves of conventional and potentially more efficient technology
When to make a transition?

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Thank you very much for your attention