Disruptive potential of fuel cell technology in transportation sector in India

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Speaker:
Prof Prakash Chandra Ghosh
Department of Energy Science and Engineering, IIT Bombay

Moderator:
Shravani Sharma
WRI India
DISRUPTIVE POTENTIAL OF FUEL CELL TECHNOLOGY IN THE INDIAN TRANSPORTATION SECTOR

Dr.-Ing P. C. Ghosh
Professor
Department of Energy Science and Engineering
Indian Institute of Technology Bombay
Mumbai – 400076
pcghosh@iitb.ac.in
Outline

• Introduction
• Overview of fuel cell technologies
• Fueling options for fuel cells
• Challenges for fuel cell vehicles
• Conclusions
About IITB and DESE

• Dept. of Energy Science and Engg was established in 2006
• Involved in energy related teaching and research
• Total of 23 faculties and > 400 students
• Offers Dual Degree (B.Tech-M.Tech and M.Sc.-Ph.D.), M. Tech and Ph.D. degrees
Introduction

Clean Environment
Clean water

Energy demand
Total: 43 kWh/day
Electricity: 6.65 kWh/day
Food: 67 Year @ 2500 kCal/day
Number: 6602 Million
# Threats and consequences

## CONSEQUENCES

- Reserved fossil fuel is limited
- Depletion of fossil fuel
  - Coal 300 Years
  - Petroleum 40 years
- Future energy crisis
“The Stone Age did not end because we ran out of stones and the oil age will not end because we run out of oil”

Don Huberts
What is fuel cell

• Electrochemical devices which convert chemical energy directly to electrical energy

• Higher efficiency

• Higher lifetime

• No moving parts

• Extremely quite in operation

• Less emission
Efficiency

BAU

NON-CONVENTIONAL PRACTISE

75%

25%

19%

100%

65%
Efficiency comparison

Conventional systems
- Direct greenhouse gas emission
- High temperature operation
- Lower efficiency
- Lower efficiency at partial load
- Loud operation
- Low investment cost
- Well established technology

Fuel cell based systems
- Indirect/lower emission
- High and low temp. operation
- Higher efficiency
- Higher efficiency at partial load
- Quiet operation
- High investment cost at present
- Under R&D
Efficiency comparison

Carnot: \( \frac{T_h - T_c}{T_h} \times 100 \)

Fuel cell: \( \frac{\Delta G^o}{\Delta H^o} \times 100 \)
Fuel cells: Basics

Products
Fuel cells: Basics

\[ \text{Fuel + Oxydant} \rightarrow \text{Products} \]

Diagram showing the process of a fuel cell, with hydrogen ions (H+) and oxygen molecules (O2) reacting to produce water (H2O) and electrons (2e\textsuperscript{-}).
Fuel cells: Basics
Fuel cells: Basics

H₂ + O₂ → H₂O + 2e⁻ + \text{Products}

Fuel  \rightarrow  2e⁻  \rightarrow  O₂  \rightarrow  H₂O  \rightarrow  Products

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Fuel cells: Basics

\[ \text{Products} \]
\[ \text{H}_2 \text{O} \]
Fuel cells: Basic configurations
Fuel cells: types

<table>
<thead>
<tr>
<th>Fuel Cells</th>
<th>Fuel in</th>
<th>Oxidant in</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>SOFC</td>
<td>H₂</td>
<td>O₂</td>
<td>750-900 °C</td>
</tr>
<tr>
<td>MCFC</td>
<td>H₂</td>
<td>O₂</td>
<td>~ 650 °C</td>
</tr>
<tr>
<td>PAFC</td>
<td>H₂</td>
<td>O₂</td>
<td>~ 220 °C</td>
</tr>
<tr>
<td>AFC</td>
<td>H₂</td>
<td>O₂</td>
<td>100-200 °C</td>
</tr>
<tr>
<td>DMFC</td>
<td>CH₃OH; H₂O</td>
<td>O₂</td>
<td>90-120 °C</td>
</tr>
<tr>
<td>PEFC</td>
<td>H₂</td>
<td>O₂</td>
<td>60-90 °C</td>
</tr>
</tbody>
</table>
Fuel cells: types

Based on electrolyte
- Alkaline Fuel Cell (AFC)
- Polymer Electrolyte Fuel Cell (PEFC)
- Phosphoric Acid Fuel Cell (PAFC)
- Molten Carbonate Fuel Cell (MCFC)
- Solid Oxide Fuel Cell (SOFC)

Based on fuel
- Direct Alcohol Fuel Cell (DAFC)
- Direct Methanol Fuel Cell
- Direct Ethanol Fuel Cell
- Direct borohydride fuel cell (DBFC)
- Direct Carbon Fuel Cell (DCFC)
- Direct Formic Acid Fuel Cell (DFAFC)
- Microbial Fuel Cell (MFC)
Polymer Electrolyte Fuel Cells

- \( \text{H}_2 \) is oxidized on the anode side of the fuel cells in presence of platinum catalyst and produces \( \text{H}^+ \) and \( \text{e}^- \)

- Proton exchange membrane allows \( \text{H}^+ \) to move through it. However electron can not move through membrane

- Electron flows through external circuit and produces external work

- On the cathode side \( \text{H}^+ \), electron in presence of oxygen and produce water

- In this way the oxidation tendency of \( \text{H}_2 \) is used to convert the chemical energy of hydrogen directly into electricity
Fuel cells: thermodynamics

\[ \Delta G^o = \Delta H^o - 298 \cdot \Delta S \]

\[ \Delta G = \Delta G^o - \frac{RT}{nF} \ln Q \]

Heating value (\(\Delta H^0\))

Free energy (\(\Delta G^0\))

Nernst energy (\(\Delta G\))

Potential (v) = Energy/nF

Energy (kJ/Mole)
Electrode kinetics & losses

Electrode Kinetics

- Overpotential
- Polarisation
- Irreversibility
- Losses
- Voltage drop

Losses:
- Activation losses
- Internal losses
- Ohmic losses
- Concentration losses
Electrode kinetics & losses

\[ V_i = A \ln \left( \frac{i_n}{i_o} \right) \]

\[ V = E - V_i \]

\[ V_{ohm} = IR = i \cdot \rho \cdot l \]

\[ V = E - V_{ohm} \]

\[ V_{con} = -B \ln \left( 1 - \frac{i}{i_i} \right) \]

\[ V = E - V_{con} \]
Characteristics: losses

Potential (v) = Energy/nF

Current density (mA/cm²)

E₀
E₀
Eₙ
Characteristics: combined losses

Potential (v) = Energy/nF

Current density (mA/cm²)
Characteristics: I-V

- Activation
- OMIC
- Contraction

Potential (v) = Energy/nF

Current density (mA/cm²)

$E^0_h$

$E^0$

$E_n$
Typical I-V characteristics
Components

- Electrolyte
- Electrode
- Supporting layer
- Bipolar/interconnect plate
- Gasket/sealant
- Endplate
Electrode

- Electrodes are made of high surface area (235 m²/gm) carbon and Platinum
- Carbon provides high surface to Pt catalyst
- Pt sizes are around 2-3 nm
- Carbon sizes are 20-40 nm
- Porous carbon electrodes on both side of membrane
  - provide the interface between reactant gases and the electrolyte
  - allow wet gases to diffuse and reach the electrolyte surface
  - allow electron to conduct from anode to cathode
- Platinum catalyst between membrane and electrode
  - used for high electrochemical activity, stability and electrical conductivity
  - loading is critical for cost (Typically: 0.4-0.6 mg/cm²)
- MEA provides integral sealing
Electrode morphology

- **Electrolyte**
  - $H^+$
  - Pores (20-40 nm)

- **Diffusion layer**
  - Carbon (20-40 nm)
  - Catalyst (2-4 nm)

- **Electrons ($e^-$)**
  - $H_2$ to $H_2O$

- **Oxygen ($O_2$)**

The diagram illustrates the flow of hydrogen ($H_2$) from the carbon layer, through the electrolyte, and into the diffusion layer where it reacts to produce water ($H_2O$) and oxygen ($O_2$). Electrons ($e^-$) flow in the opposite direction, from the catalyst layer to the carbon layer.
Reactant distributors: flow field and bipolar plate

- Reactant gases are supplied to the electrodes on both sides of MEA through flow field
- Flow field consists of single or multiple gas channels
- Design of flow field is very important for
  - uniform power generation
  - stable performance
  - water management
- Flow field material must be highly conductive
- Generally graphite is used for this purpose
- Flow field design is machined or pressed on graphite plate
Flow field: serpentine

- Commonly used in PEFC
- Water content in cathode reactant gases increases with length
- Causes water flooding at high current densities
- Degradation in performance
Unit cell assembly

End plate | BPP | Gasket | Backing layer | MEA | Backing layer | Gasket | BPP | End plate

Fuel in | Coolant in | Fuel in | Coolant out | O₂ out | O₂ in | Coolant out | O₂ in
Multiple cell assembly
Historic Pt production and projected demand

Source: TIAX report to DOE, 2004