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भारत सरकार रेल मंत्रालय

GOVERNMENT OF INDIA
MINISTRY OF RAILWAYS

FUEL CELL TECHNOLOGY FOR INDIAN RAILWAYS

REPORT NO.MP-MISC-159
July 2004

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1.0 INTRODUCTION

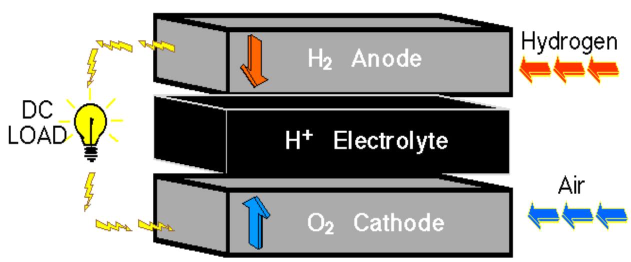
Fuel cells have been around since 1839 but it took 120 years for NASA to demonstrate their potential applications as a power source during a space flight. The last two decades have seen a lot of fuel cell demonstrations and fuel cell technology has reached a point where it is now being accepted as a commercially viable energy source across different Industry sectors.

Much interest has been generated in fuel cell research and development on account of it's potential as a source of clean and efficient power generation. In principle, a fuel cell operates like a battery. Unlike a battery, a fuel cell does not run down or require recharging. It produces energy in the form of electricity and heat as long as fuel is supplied. Conventional combustion engines rely on conversion of heat into mechanical energy, the efficiency of which is limited by the temperatures of the source and sink (Camot cycle). The fuel cell is an electrochemical device and does not rely on heat conversion: its efficiency is 2-3 times that of an internal combustion engine.

2.0 THE PRINCIPLE

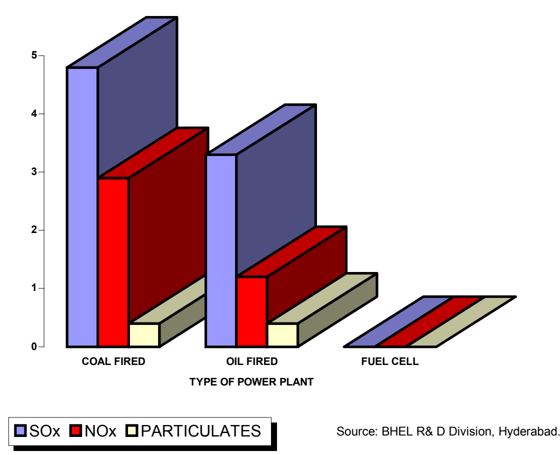
Fuel cells are power-generating devices having a wide range of applications including stationary power generation, portable power generation and transportation. The chemical energy of a fuel is converted to electricity by electrochemical means. Figure 1 shows the schematic of a fuel cell. The fuel, typically hydrogen, is sent to the anode and oxygen from air is sent to the cathode. The electrons generated at the anode due to dissociation of hydrogen pass through an external circuit to the cathode, thereby generating electricity. At the cathode, the hydrogen ions, electrons, and oxygen react to form water. Several such cells are stacked in series to get the required power output.

Fig.1 – Schematic of a fuel cell



Overall Reaction: $H_2 + 1/2O_2 = H_2O$ + Electricity

Fig 2 **Comparison of exhaust emissions (kg/1000kWh)**



3.0 ADVANTAGES OF FUEL CELLS

The key advantages of the fuel cell are high efficiency and the lack of emissions; the other advantages that make this technology attractive include modularity, fuel flexibility, and high power density. The high efficiency arises from the electrochemical nature of energy conversion, which is not limited by the Carnot cycle, unlike in gas turbines and internal combustion engines. The efficiency of fuel cells for generating electricity is 40%–60% and can reach 85%–90% in a CHP (combined heat and power) mode, i.e. if the heat generated from the fuel cell is also used.

The only emission from fuel cells is water when hydrogen is fed to the fuel cell. The option of generating hydrogen renewably from water using wind or solar energy and using it in a fuel cell is, therefore, a very attractive zero-emission option. However, due to the economics of the process, currently fuels such as natural gas and biogas are used to generate hydrogen through a process called reforming. The reforming process produces some emissions, but these are significantly lower than those produced by conventional technologies. Virtually no sulphur oxides and volatile organic compounds are emitted. Fuel cells also have the ability to reduce the greenhouse gas carbon dioxide as they are more efficient and consume lesser fuel. Capturing them for use in a fuel cell can also reduce methane emissions from landfills.

Fuel cells are an attractive technology option for India because of their economic, environmental, and energy-management advantages. In the Indian context, they have the following benefits.

- Highly efficient, can deliver more power per unit of fuel consumption
- Least polluting than coal-based power generation
- Low gestation periods due to modularity for setting up new power plans
- No transmission and distribution losses because of dispersed generation
- Suitable for powering vehicles (especially buses) to reduce urban pollution and diesel import.

4.0 APPLICATIONS OF FUEL CELLS

Applications of fuel cells are expected to be in 3 broad categories:

- **Portable** (laptop computers, hearing aids, cellular phones)
- **Stationary** (power plants and backup power installations for military applications, hospitals and factories)
- **Transportation** (buses, trains, marine and submersible transport).

5.0 FUEL CELL TYPES

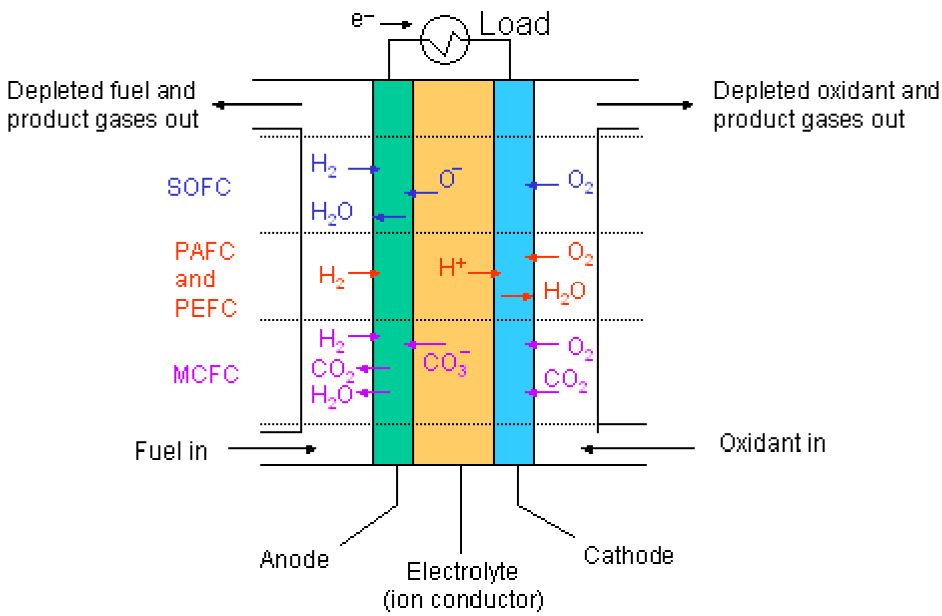
Fuel cell types are generally characterized by electrolyte material. The electrolyte is the substance between the positive and negative terminals, serving as the bridge for the ion exchange that generates electrical current.

While there are dozens of types of fuel cells, there are six principle kinds in various stages of commercial availability, or undergoing research, development and demonstration. These six fuel cell types are significantly different from each other in many respects; however, the key distinguishing feature is the electrolyte material.

They are:

1. Alkaline Fuel Cell (AFC)
2. Molten Carbonate Fuel Cell (MCFC)
3. Phosphoric Acid Fuel Cell (PAFC)
4. Proton Exchange Membrane Fuel Cell (PEMFC)
5. Solid Oxide Fuel Cell (SOFC)
6. Direct Methanol Fuel Cell

Fig 3 – Fuel Cell Reactants and Products



The following sections describe each of these fuel cell types.

Alkaline

Alkaline Fuel Cells (AFCs) were the first type of fuel cell to be widely used for manned space applications. AFCs contain a potassium hydroxide (KOH) solution as the electrolyte. AFCs operate at temperatures between 100°C and 250°C (211°F and 482°F). Higher temperature AFCs use a concentrated (85wt%) KOH solution while lower temperature AFCs use a more dilute KOH solution (35-50wt%). The electrolyte is contained in and/or supported by a matrix (usually asbestos) which wicks the electrolyte over the entire surface of the electrodes. A wide range of electro-catalysts can be used in the electrodes (e.g., Ni, Ag, spinels, metal oxides, and noble metals). The fuel supplied to an AFC must be pure hydrogen. Carbon monoxide (CO) poisons an AFC and carbon dioxide (CO2) reacts with the electrolyte to form potassium carbonate (K2CO3). Even the small amount of CO2 in the atmosphere (about 370 ppm) must be accounted for operation of an AFC (Hirschenhofer et al., 1998).

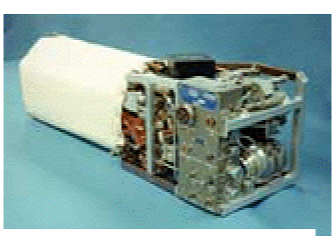


Fig.4 A lkaline fuel cell

Molten Carbonate

Full-scale demonstration plants are now testing molten carbonate fuel cells (MCFCs).

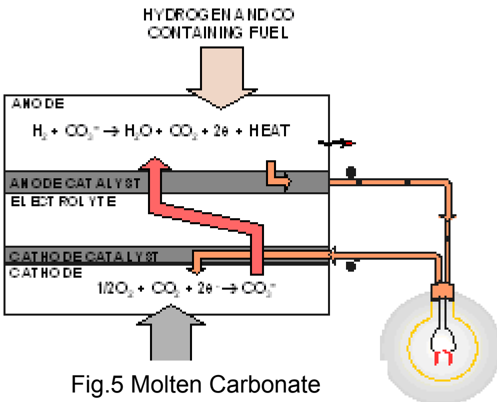


Fig.5 Molten Carbonate

The electrolyte in an MCFC is an alkali carbonate (sodium, potassium, or lithium salts, i.e., Na2CO3, K2CO2, or Li2CO3) or a combination of alkali carbonates that is retained in a ceramic matrix of lithium aluminum oxide (LiAlO2). An MCFC operates at 600 to 700°C where the alkali carbonates form a highly conductive molten salt with carbonate ions (CO_3=) providing ionic conduction through the electrolyte max. Relatively inexpensive nickel (Ni) and nickel oxide (NiO) are adequate to promote reaction on the anode and cathode respectively at the high operating temperatures of an MCFC (Baker, 1997).

MCFCs offer greater fuel flexibility and higher fuel-to-electricity efficiencies than lower temperature fuel cells, approaching 60 percent. The higher operating temperatures of MCFCs make them candidates for combined-cycle applications, in which the exhaust heat is used to generate additional electricity. When the waste heat is used for co-generation, total thermal efficiencies can approach 85 percent.

Phosphoric Acid

Phosphoric Acid Fuel Cell (PAFC) technology is the most mature of the types in use today. PAFCs use a concentrated 100% phosphoric acid (H3PO4) electrolyte retained on a silicon carbide matrix and operate at temperatures between 150 and 220°C. Concentrated H3PO4 is a relatively stable acid, which allows operation at these temperatures. At lower temperatures, problems with CO poisoning of the anode electro-catalyst (usually platinum) and poor ionic conduction in the electrolyte become problems (Hirschenhofer et al., 1998). The electrodes typically consist of TeflonTM-bonded platinum and carbon (PTFE-bonded Pt/C).

PAFC fuel cells produced by UTC Fuel Cells (previously named ONSI and International Fuel Cells) were the world's first commercially available fuel cell product (King and Ishikawa, 1996). Turnkey 200-kilowatt plants are now available and have been installed at more than 200 sites in the United States, Europe, and Asia (principally Japan). Operating at about 200°C, the PAFC plant also produces heat for domestic hot water and space heating, and its electrical efficiency is 36-40 percent. The development and implementation of this commercial fuel cell product is a result of several years of research development and demonstration by the U.S. Department of Energy, U.S. Department of Defense, Gas Research Institute.

Proton Exchange Membrane

The proton exchange membrane fuel cell (PEMFC) is also known as the solid polymer or polymer electrolyte fuel cell. A PEMFC contains an electrolyte that is a layer of solid polymer (usually a sulfonic acid polymer, whose commercial name is NafionTM) that allows protons to be transmitted from one face to the other (Gottesfeld and Zawadinski, 1998). PEMFCs require hydrogen and oxygen as inputs, though the oxidant may also be ambient air, and these gases must be humidified. PEMFCs operate at a temperature much lower than other fuel cells, because of the limitations imposed by the thermal properties of the membrane itself (Appleby and Yeager, 1986). The operating temperatures are around 90°C. CO, reducing the performance and damaging catalytic materials within the cell, can contaminate the PEMFC. A PEMFC requires cooling and management of the exhaust water to function properly (Gottesfeld and Zawadinski, 1998).

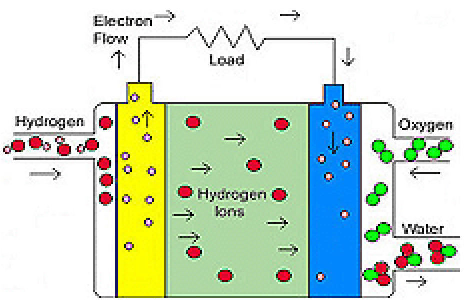


Fig.6 Proton Exchange Membrane

Solid Oxide

Solid Oxide Fuel Cells (SOFCs) are currently being demonstrated in sizes from 1kW up to 250-kW plants, with plans to reach the multi-MW range. SOFCs utilize a non-porous metal oxide electrolyte material. SOFCs operate between 650 and 1000°C, where ionic conduction is accomplished by oxygen ions (O=). Typically the anode of an SOFC is cobalt or nickel zirconia (Co-ZrO2 or Ni-ZrO2) and the cathode is strontium-doped lanthanum manganite (Sr-doped LaMnO3) (Singhal, 1997; Minh, 1993).

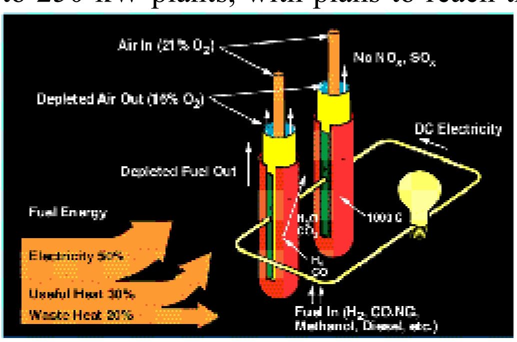


Fig.7 Solid Oxide fuel cell

SOFCs offer the stability and reliability of all-solid-state ceramic construction. High-temperature operation, up to 1,000°C, allows more flexibility in the choice of fuels and can produce very good performance in combined-cycle applications. SOFCs approach 60 percent electrical efficiency in the simple cycle system, and 85 percent total thermal efficiency in co-generation applications (Singhal, 1997).

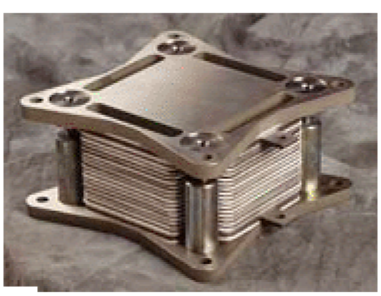


Fig.8 Planar SOFC - Courtesy of Siemens Westinghouse Power Corp.

The flat plate and monolithic designs are at a much earlier stage of development typified by sub-scale, single cell and short stack development (kW scale). At this juncture, tubular SOFC designs are closer to commercialization

Direct Methanol

The direct-methanol fuel cell (DMFC) is similar to the PEM cell in that it uses a polymer membrane as an electrolyte. However, a catalyst on the DMFC anode draws hydrogen from liquid methanol, eliminating the need for a fuel reformer. While potentially a very attractive solution to the issues of hydrogen storage and transportation (particularly for portable applications), the principal problem facing the commercial application of the DMFC today stems from its relatively low performance in comparison to hydrogen fueled PEMFCs.

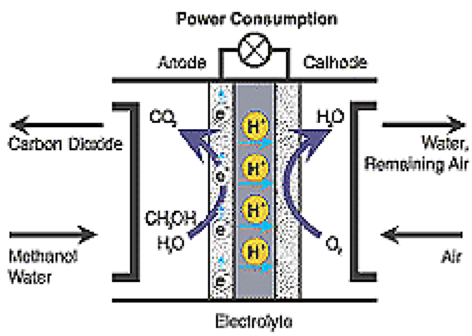


Fig.9 Direct Methanol fuel cell

6.0 FUEL-CELL R&D IN INDIA

In India, development of fuel cells is primarily supported by the MNES (Ministry of Non-conventional Energy Sources). Several universities and research organizations are involved in the areas of fuel cells, reformers, and hydrogen storage.

Bharat Heavy Electricals Ltd. (R&D), Hyderabad. They are involved in the development of Phosphoric Acid Fuel Cells (PAFCs) and have developed a 50-kW stack. They have also installed a 200 kW fuel cell bases power plant. The fuel used is LPG and besides generation of electricity, it also produces hot water which is uses in their canteen.

TATA Energy Resources Institute (TERI) has in the past demonstrated the use of digester gas (biogas) for generating electricity from a 2.5-kW PAFC stack imported from ERC (Energy Research Corporation), USA.

MNES has funded the import of a 200-kW PAFC system made by the ONSI to evaluate its operation.

SPIC-SF (SPIC Science Foundation) is working on Proton Exchange Membrane (PEM) fuel cells and has developed stacks. They have also demonstrated a fuel-cell battery hybrid vehicle using a 10-kW PEM power plant.

Work on an MCFC stack is underway at TERI and the Central Electrochemical Research Institute. TERI has tested the operation of an MCFC monocell on simulated coal gas. Development of a kW-level stack is currently underway with the aim of integrating it with a coal gasifier.

Work on developing a DMFC (direct methanol fuel cell) is underway at IISc (Indian Institute of Science). In addition, research on SOFC is being done at IISc and CGCRI (Central Glass and Ceramic Research Institute). Research and development on metal hydride storage is ongoing at BHU (Banaras Hindu University).

7.0 GLOBAL DEVELOPMENTS – TRANSPORTATION

In transportation, the area of commercial passenger transportation, viz. buses and trains are most promising. An initiative in this direction has already been made in Delhi, where 6 fuel cell buses will run. This project has great potential to be replicated in several other large cities in India, where vehicular pollution is a serious concern. Fuel costs for running a bus are expected to be as low as Rs.0.25 per kilometer distance covered. This and other reductions due to environmental credits, maintenance savings etc. are expected to compensate for the high cost of the bus itself and make the fuel cell bus a strong economic proposition in the future.

Locomotive applications

Two major undertakings of fuel cell trains are currently on: one in USA, the other in Japan. Both predict at least 5 years project life cycle before train is ready. The US train claims a requirement of a 1MW plant, where as the Japanese claims a requirement of 500 KW. The selection of fuel cell type in both the cases in PEM fuel cell. An extract of the news clippings on the subject is given below:

August 1, 2003, Fuel cell locomotive for Military and commercial Railways

An international consortium is developing the world's largest fuel cell vehicle, a 109 metric ton, 1MW (1340 hp) locomotive. The five-year project, which commenced 27 May 2003 will develop and demonstrate the first fuel cell powered locomotive for military and commercial railway applications.

The project was conceived, organized, and is led by vehicle projects LLC of Denver,USA,and is funded and administered by the US Army Tank-automotive and Armaments Command (TACOM),National Automotive Center (NAC), Warren (MI), USA, via prime contractor Jacobs Engineering Group Inc, Pasadena, USA. Vehicle Projects previously developed and demonstrated a fuel cell mine locomotive and is also developing a 23 metric- ton, 100 kW fuel cell- battery hybrid mine loader (see www. Fuelcellpropulsion.org), both projects are supported by the US Department of Energy and Natural Resources Canada.

April 16, 2001, Japan To Test Fuel-Cell- Power Train, Diesel Fuel News

Railway Technical Research Institute aims to develop fuel cell powered trains by 2010, according to a report by Nikkei news agency. The institute aims to investigate 500-kilowatt (670 hp) polymer electrolyte membrane (PEM) fuel cells to replace diesel locomotives, mostly on Japan's northern and southern islands. Electric trains are more common in Japan than diesel locomotives.

August 29, 2003, The Engineer, Tubular cells, By Helen Knight

Hydrogen could be used to power London Underground trains following a US-led project to develop a fuel cell locomotive.

Tube lines, the infrastructure company responsible for the Jubilee, Northern and Piccadilly lines on the London Underground, is providing commercialization guidance to the project team as a potential customer of fuel cell locomotive, said Amold Miller, president of Vehicle Project LLC. The customers are providing us with guidance so that the technology evolves in the way the operating companies want. This will be the nucleus *for spin –off project (to find commercial applications), and one of these will be to utilize fuel cell locomotive on the Underground.*

Fuel cell trains are likely to be used initially to replace the 30 battery and 15 diesel powered locomotives used for early morning maintenance work on the underground, when the electrified third rail is shut down. With fewer trains using the tunnels to push the air through and provide ventilation, the pollution created by the diesel cannot be cleared, while the battery- equipped locomotive are unable to store much power.

Comments: Based on the 3 major global developments described above, it is clear that the development of the first fuel cell powered locomotive shall take place in the next 5-10 years. These locomotives will nevertheless be of low hp (1400 hp approx or less) and hence high horsepower fuel cell powered locomotives are likely to be developed only after success is attained in the above.

8.0 HOW MUCH DO FUEL CELLS COST

One company commercially offers fuel cell power plant for about $3,000 per kilowatt. At that price, the units are competitive in high value, "niche" markets, and in areas where electricity prices are high and natural gas prices low.

A study by Arthur D. Little, Inc., predicted that when fuel cell costs drop below $1,500 per kilowatt, they will achieve market penetration in USA. Several Companies are selling small units for research purposes. Prices vary. Fuel cells will have to be much cheaper to become commercial in vehicles. Conventional car engines cost about $3,000 to manufacture and more research is needed to bring the cost of fuel cells down to that level.

9.0 POSSIBLE APPLICATIONS ON INDIAN RAILWAYS

Railways in the transportation sector are a major user of energy in India. Railways are reported to be using as much as 5% of the total Diesel oil consumption within the country. Railways are also using near about 1.5% of the electrical energy consumed in India. So there exists a need for alternate energy sources and devices.
The non-conventional energy sources like solar photo voltaic cells and devises based on hydrogen (FUEL CELLS) could from an important and attractive alternative for meeting some of the energy needs of railways. The following areas (other than the locomotives) in railways have the potential to use non- conventional energy sources and devices:

Stationary Applications

- Supplement power source in Production Units
- Supplement power source in Workshops

Non-Stationary Applications

- Passenger coaches – Lighting and fans
- Air –conditioned coaches
- Power for Diesel-Elec Multiple Units
- Power source for shunting engines operating in metros

It is suggested that to begin with stationary applications may be considered. An ideal choice would be Diesel Locomotive Works.

At DLW power for specific applications, can be generated using fuel cells. It is proposed to install a solid oxide fuel cell or a phosphoric acid fuel of 250 – 500 Kw capacity for generating power at DLW.

Subsequently a project can be undertaken for developing fuel cell powered vehicles viz. DEMU or even shunting locomotives.

It is recommended that for this, MoU be signed with internationally reputed firms which are developing fuel cells.

Details of some firms who have developed fuel cells are given below:

Ballard Power Systems Inc.
4343 North Fraser Way
Burnaby, British Columbia
Canada – V5J5J9
www.ballard.com

Stuart Energy Systems Corporation
5101 Orbitor Drive, Mississauga
Ontario, Canada
L4W 4V1
www.stuartenergy.com

MTU Friedrichshafen GmbH
88040 Friedrichshafen
Germany
www.mtu-online.com

RDSO is in contact with the above and some other firms for literature survey and is exploring the feasibility of implementing fuel cell technology for specific applications.