THE PROMISE OF A GREENER FUTURE – "FUEL CELLS"

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ABSTRACT:

Fuel cells use hydrogen and oxygen to generate electricity as oil resources are fast depleting over the entire world, and the increasing emphasis on reducing emissions and increasing efficiency, there is a need to develop and adopt non-conservative fuel systems for the fast moving world. This alternative fuel cells are used as fuels in automobiles Use of hydrogen as an alternative fuel to these problems would cut down India's shortfalls by a significant measure. A fuel cell generates electricity from a chemical reaction usually involving hydrocarbon fuels which produce hydrogen and an oxidizing agent. Fuel cells differ from batteries in that batteries store the reactants, and must be recharged or discarded once consumed. Fuel cells have many advantages as well as disadvantages. Fuel cells are suitable for small scale applications like portable power and transportation. Since vehicles running on fuel cells run only on hydrogen, they emit only water and heat thus reduces pollution. Materials for fuel cell components are expensive. A fuel cell car could cost almost ten times as much as a regular Internal Combustion Engine powered one. There are many agencies pursuing research and development on fuel cells. India has two hydrogen fuelling-stations. Thus as natural resources have begun to get depleted it is high time that IC engine powered vehicles are replaced by electrical vehicles.

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INTRODUCTION:

Fuel cells use hydrogen and oxygen to generate electricity. With the accelerating depletion of oil resources turning into a grave crisis looming over the entire world, and the increasing emphasis on reducing emissions and increasing efficiency, there is a need to develop and adopt non-conservative fuel systems to propel the world forward, among which fuel cells offer a promising alternative. In this paper, an attempt has been made to study the science behind fuel cells, their overwhelming relevance to modern vehicle technology and identify the application of fuel cells as alternative power plants in automobiles. The scope of fuel cell technology in India has been looked at and a critical examination on India's National Hydrogen Energy Roadmap to becoming a hydrogen economy has been done. On the basis of the forthcoming arguments, an appropriate conclusion has been drawn on why only fuel cells can best support an economy in reducing its reliance on fossil fuels.

WHY FUEL CELLS?

India is burdened by a widening energy deficit. India's planning commission projects an increase in energy imports from 25% of commercial energy consumption in 2003-04 to more than double that in 2031-32. India's crude oil requirements are fulfilled by importing 80% of it, and oil imports alone account for 31% of India's total imports. India is the fourth largest consumer of energy in the world. According to CIA's world fact book, India alone consumes 3.182 bbl/day of oil. In 2009-10 alone, India imported 159.26 million tons of crude oil.

The International Energy Agency says that India's total energy consumption comprises of 40% coal, 24% oil and 6% natural gas, and that hydrocarbons account for the majority of its use. Of this a substantial amount goes into powering automobiles. This provides tremendous scope for using alternative energy sources for meeting the automotive sector's energy requirements. According to the Planning Commission's Vision 2020 Report, the Transport Sector's oil demand is expected to rise from 39 million tons to anywhere between 72 million tons (Best Case Scenario) and 105 tons (Business As Usual), which is among the largest raises. Plus, the air quality too would get affected due to the rising demand for fossil fuels and the rapid proliferation of motor vehicles. All these call for the use of stringent measures to address pollution and demand-supply problems.

Adoption of alternative energy technologies, such as hydrogen energy, to cater to these problems would cut down India's shortfalls by a significant measure. As of 2007, power generated from renewable energy resources formed only 8% of the total power generated. The National Hydrogen Energy Board of the Ministry of New and Renewable Energy, Government of India laid out the National Hydrogen Energy Roadmap in 2006, which provides a comprehensive blueprint for the blooming of India into a hydrogen economy. The roadmap has taken up two major initiatives: Green Initiatives for Future Transport (GIFT) and Green Initiative for Power Generation (GIP). GIFT aims to develop "hydrogen powered IC Engine and fuel cell vehicles" through different phases of development and GIP conceives the development of decentralized power generating systems powered by hydrogen. It is estimated that if the roadmap is implemented as envisaged, there would be one million hydrogen powered vehicles on Indian roads by 2020.

WHAT ARE FUEL CELLS?

A fuel cell generates electricity from a chemical reaction usually involving hydrocarbon fuels which produce hydrogen and an oxidizing agent. Fuel cells differ from batteries in that batteries store the reactants, and must be recharged or discarded once consumed. The recharge process involves the controlled reversal of electrochemical reactions. But in fuel cells, reactants are stored externally and only need to be refueled, which is completed in a much shorter time than recharging. Thus a fuel cell is a steady-state device whereas a battery is not one. At the anode, a catalyst – typically platinum powder – oxidizes the hydrogen molecules into hydrogen ions and electrons. The electrolyte membrane is a specially treated material, which allows only positively charged ions to pass through to the cathode. The electrons cannot pass through the membrane, and hence they are directed through an external circuit, where they perform useful work on the load (spinning a motor in the case of vehicles), and arrive at the cathode. Nickel is used as catalyst at the cathode. Oxygen sent in to the cathode combines with the incoming H^+ ions and electrons to produce water, which is then sent out through the exhaust. Thus the only emissions in a vehicle which uses fuel cells are water and the heat produced. Even though a single fuel cell can produce only 0.7 volts at full load, a higher voltage can be obtained by stacking fuel cells in series.

There are different kinds of fuel cells, such as

- Polymer Electrolyte Membrane Fuel Cells (PEMFC)
- High Temperature Proton Exchange Membrane Fuel Cells (HT – PEMFC)
- Direct Methanol Fuel Cells (DMFC)
- Alkaline Fuel Cells (AFC)
- Phosphoric Acid Fuel Cells (PAFC)
- Molten Carbonate Fuel Cells (MCFC)
- Solid Oxide Fuel Cells (SOFC)
- Regenerative Fuel Cells (RFC)
- Zinc Air Fuel Cells (ZAFC)
- Protonic Ceramic Fuel Cells (PCFC)
- Microbial Fuel Cells (MFC)

Of these, the Polymer Electrolyte Membrane (PEM) Fuel Cells have been found to be particularly suited for automotive applications since they can offer efficient energy conversion in a compact and robust package. The majority of all vehicular fuel cells are based on PEMFC technology (PEM Fuel Cells for Road Vehicles – Paul Adcock, Ashley Kells and Chris Jackson).

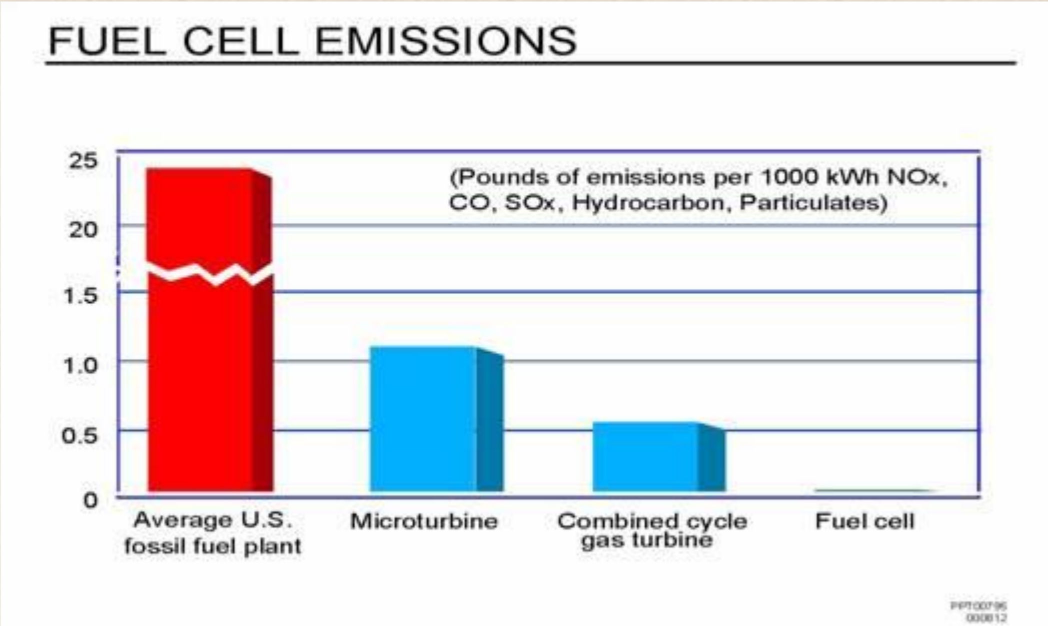
PEM fuel cells use polymer electrolyte membranes (such as fluorinated sulphonic acid polymer or others) which conduct protons well.

ADVANTAGES OF USING FUEL CELLS IN VEHICLES:

Fuel cells are suitable for small scale applications like portable power (backup and stationary) and transportation, as they possess certain desirable characteristics such as uninterrupted operation without recharging (only refueling is necessary), compact size with low weight and volume, fast booting, orientation insensitiveness, no moving parts, good power to weight ratio, high power density (3.8 – 6.5 kW/m^3) and operation at low temperatures. PEM Fuel cells operate at low temperatures of around 80 degree Celsius. Their operating temperature is limited by the polymer electrolyte membrane. They are not prone to corrosion since they use only water (Fuel Cell Handbook, Fifth Edition, EG&G Services, Parsons, Inc., Science Applications International Corporation).

Since vehicles running on fuel cells run only on hydrogen, they emit only water and heat, which bodes well for air quality. Some fuel cell vehicles use reformers to extract hydrogen from hydrocarbon fuels such as methanol, but even then emissions from such fuel cell systems are substantially lesser than those from gas-powered vehicles as can be seen from the table below. As can be seen, gasoline powered car emits more than 415 grams of carbon dioxide per mile whereas a hydrogen powered fuel cell vehicle emits no carbon dioxide at all.

Engine Type	**Water Vapor g/mile**	**CO2 g/ mile**	**CO g/ mile**	**NOx g/ mile**	**Hydro Carbons g/mile**
Gasoline ICE Passenger Car1	176.90	415.49	20.9	1.39	2.80
Gasoline ICE Light Truck1	N/a	521.63	27.7	1.81	3.51
Methanol FCV2	113.40	68.04	0.016	0.0025	0.0034
Hydrogen FCV2	113.40	0.00	0.00	0.00	0.00
Low Emission Vehicle (LEV)3	N/a	N/a	4.20	0.1	0.09
Ultra Low Emission Vehicle (ULEV)3	N/a	N/a	2.1	0.07	0.055
Super Ultra Low Emission Vehicle (SULEV)3	N/a	N/a	1.0	0.02	0.01



Source: www.fuelcells.org

Fuel cell engines produce less than one ounce of pollution from 1000 kWh of electricity produced, whereas fossil fuel engines produce more than 20 pounds per 1000 kWh. Thus fuel cells are the best alternative to traditional gas-powered vehicles.

Fuel cell vehicles operate at low load, and have a high efficiency of around 60 – 65% wherein around 20% of the energy is lost in conversion of hydrogen fuel into electricity, and another 20% is lost in conversion of the electricity into mechanical work required to turn the wheels. An efficiency of 60% is considerably high, compared to gasoline and diesel operated vehicles which have an efficiency of 20%.

Another way in which fuel cells are advantageous is that they are quiet in operation. The desired voltage is achieved by stacking fuel cells together, and even megawatt power outputs can be produced. The fuel used to run fuel cells – hydrogen is ubiquitous and can be produced from a wide variety of sources including fossil fuels, non-carbon hydrogen compounds, and from electricity produced from solar, wind and hydraulic power plants. Fuel cells have a longer life than batteries, and the power output per unit weight of fuel cells is higher than that of batteries.

CHALLENGES FACED:

- **Cost**

Materials for fuel cell components are expensive. Fuel cells which run on platinum catalysts can be operated at room temperature, but they are expensive. Bipolar plates, Proton exchange membranes, catalysts and diffusion layers account for three-fourths of a fuel cell system's cost. Therefore, the amount of platinum consumed for hydrogen production must be reduced through improved technology or an alternative for the platinum catalyst must be found. Cheaper ones, such as molybdenum sulphide – whose potential as a catalyst for hydrogen production was discovered by scientists at the University of Denmark – or iron based catalysts developed by scientists at INRS, Quebec – are being contemplated as possible substitutes.

A fuel cell car could cost almost ten times as much as a regular Internal Combustion Engine powered one. According to www.fuelcells.org, automotive fuel cell systems cost around `10000 per kW with the best technology available, whereas IC Engine systems cost only around `1500 – 3000 per kW. The synthesis of hydrogen fuel is costly, and hence even if infrastructure and storage problems are solved, it would still reflect in high pricing, making subsidizing a necessity.

- **Durability**

A vehicle is used cyclically, that is, it is started and stopped frequently. The proton exchange membranes used nowadays degrade under such cyclic operation of fuel cells. This is due to the rapid heating of the fuel cells to the operating temperature and cooling down to the room temperature. Therefore, the materials used in vehicles which use fuel cells must be durable and stable. Fuel cells should operate at a wide range of temperatures from sub—zero temperatures to very high temperatures, and hence impurities which raise the temperature of the fuel cell must be avoided.

- **Hydration**

The proton exchange membrane used in the fuel cell must be hydrated properly, and the quantum of hydration should stay above a minimum level. Therefore, a high pressure hydration system must be used. At extreme temperatures, hydration level fluctuates and the membranes become ineffective. Therefore, fuel cell systems that can operate at varying temperatures while still retaining the appropriate hydration level must be developed.

- **Infrastructure**

Even though there are various methods for the production of hydrogen fuels, sustainable infrastructure for production, storage and deliverance is costly and demands an immense scale of investment. Only when a vehicle which can equal the performance and cost of current gasoline and diesel run vehicles in terms of range and running costs is developed, can the money infused as investment be justified. Such infrastructure must include pipelines, hydrogen generation and transport systems and fuel stations.

- **Storage and delivery**

In order for fuel cell run vehicles to match the range of traditional gasoline and diesel run vehicles, which is approximately 300 miles, there must be a lightweight, convenient, safe and impregnable system of storage for hydrogen. Hydrogen can be stored either in solid, liquid or gas forms, and among these storage in solid form is considered to be the safest. Even though fuel cell storage systems have turned lighter and smaller, they are too large for use in conventional vehicles.

Hydrogen is usually stored in pressurized tanks as a compressed gas. But hydrogen being a light gas having a low-energy density, poses a problem to on-board storage, since for fuel cell vehicles to travel 300 miles, there must be enough hydrogen stored in compressed form. But the air compressor technologies currently available are unsuited for widespread use. If high energy-density fuels such as hydrocarbon fuels are stored, there will be the reformer which extracts hydrogen from those fuels. All these increase costs of storage and maintenance significantly.

- **Problems in efficiency**

The efficiency of a fuel cell is affected primarily by energy losses due to oxygen splitting at the cathode. Resistance of the membrane to the flow of hydrogen ions is also a problem, but can be minimized by using thin membranes of the order of micrometers.

Other problems include new legal systems to be put into place to process accident complaints involving vehicles running on fuel cells. Also, the reformers used for hydrogen extraction emit carbon dioxide, which threatens air quality.

FUTURE IN INDIA

Even though infrastructural and technological problems still imperil the future of hydrogen run vehicles in India, the fact that research and development are still in their infancy provides some respite. Among the agencies pursuing research and development of fuel cells are

- Ministry of New and Renewable Energy Sources (MNES)
- Delhi Transport Corporation (DTC)
- Indian Railways
- Indian Institute of Science
- Central Glass & Ceramic Research Institute
- Tata Energy Research Institute (TERI)
- Bharat Heavy Electricals Ltd. (BHEL), and
- Reva Electric Car Company

(Source: www.indiafuelcell.com)

India has two hydrogen fuelling-stations. India's first hydrogen fuelling station is an Indian Oil Corporation owned one at Delhi. The other one is the Hydrogen Fuelling Station at the Indian Oil Corporation's Research and Development center at Faridabad. It denotes the first phase of India's blooming into a hydrogen-propelled economy, and uses a HCNG (a mixture of compressed natural gas and 4–9 percent hydrogen by energy) mixing unit and dual dispensing unit in order to run vehicles with either pure hydrogen gas or a blend of HCNG.

India had tied up with the United Kingdom in September 2010 to identify areas of research to address problems in existing fuel cell technologies and in the development of new ones. The EPSRC (UK Energy Programme Engineering and Physical Sciences Research Council) and the Department of Science and Technology (DST) called for joint projects worth £6 million for the development of futuristic and eco-friendly fuel cell technologies. The India-UK research programme recommended funding of four projects: Performance Optimization of IT-SOFCs by Inkjet printing on Porous Metal Substrates (JETCELL), Mind the Gap, Advancing Biogas Use through Fuel-Flexible SOFCs, Modeling Accelerated Ageing and Degradation of Solid Oxide Fuel Cells (MAAD-SOFC).

CONCLUSION:

Though electric vehicle technologies have been existing since the advent of self-propelled vehicles, they lost out to IC engine powered vehicles on the basis of the performance they offered in a compact package. But as natural resources have begun to get depleted alarmingly, it is high time that electric vehicles hit the roads again. Considering the advantages that fuel cells offer over batteries: longer lifetimes, lesser maintenance, and a wider temperature range, it is clear that fuel cells provide the best of opportunities to pave the way for a clean and green future.

REFERENCES:

- http://knowledgefaber.com/index.php?option=com_content&view=article&id=33&Itemid=42
- Fuel Cell Engines by Matthew. M. Mench, Wiley Publications
- www.fuelcells.org
- Fuel cells for the future, The Hindu, 21 September 2010.
- http://electrochem.cwru.edu/encycl/art-f04-fuel-cells-pem.htm
- http://blogs.wsj.com/indiarealtime/2011/03/09/indias-widening-energy-deficit/
- http://www.eia.gov/cabs/india/Full.html

- http://aboutfuelcells.wordpress.com/2007/07/18/indian-govt-targets-one-million-hydrogen-cars-on-the-road-by-2020/
- PEM Fuel Cells for Road Vehicles - Paul Adcock, Ashley Kells and Chris Jackson, Intelligent Energy, The Innovation Centre, Epinal Way, Loughborough, Leics, England
- www.howstuffworks.com
- http://www1.eere.energy.gov/hydrogenandfuelcells/fuelcells/fc_types.html
- http://knowledgefaber.com/index.php?option=com_content&view=article&id=33&Itemid=42
- http://electrochem.cwru.edu/encycl/art-f04-fuel-cells-pem.htm
- http://www.nano.org.uk/news/1397/
- http://www.sciencedaily.com/releases/2011/08/110810133118.htm
- http://www.fuelcellenergy.com