HYDROGEN & FUEL CELL TECHNOLOGIES

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Introduction

Fuel cells are in the early stages of development as an efficient power generation system. Use of fuel cells in power generation promises to greatly reduce greenhouse gas emissions through its relative efficient operation (when compared to conventional technologies). In addition, a fuel cell system with few/no moving parts offers a low/ noise-free operation and can operate on a variety of fuels, therefore offering several benefits while used in several of the identified applications today.

In 1970’s, fuel cells were used as power generation systems in Apollo space missions. Today, apart from space applications fuel cells are being used in stationary and vehicular power applications. Future applications being investigated today include laptops, mobile phones and other remote communication applications.

![Figure 1: Comparison of power overall efficiency vs. plant capacity (Source: Fuel Cells for Distributed Generation, A Technology and Marketing Summary, March 2000, Energy Centre of Wisconsin, U.S)](image-url)
A fuel cell consists of an electrolyte sandwiched between an anode and cathode. The anode and cathode form the electrodes of the fuel cell. In a typical fuel cell, fuel is fed continuously to the anode (negative electrode) and an oxidant (often oxygen from air) is fed continuously to the cathode (positive electrode). The electrochemical reactions take place at the electrodes to produce an electric current through the electrolyte, while driving a complementary electric current that performs work on the load. Although a fuel cell is similar to a typical battery in many ways, it differs in several respects. The battery is an energy storage device in which all the energy available is stored within the battery itself (at least the reductant). The battery will cease to produce electrical energy when the chemical reactants are consumed (i.e., discharged). A fuel cell, on the other hand, is an energy conversion device to which fuel and oxidant are supplied continuously. In principle, the fuel cell produces power for as long as fuel is supplied. The working of a fuel cell can explained with the below governing equations,

At anode,

\[ 2\text{H}_2 \rightarrow 4\text{H}^+ + 4e^- \]

At cathode,

\[ \text{O}_2 + 4e^- + 4\text{H}^+ \rightarrow 2\text{H}_2\text{O} \]

Therefore overall reaction is,

\[ \text{H}_2 + \frac{1}{2} \text{O}_2 \rightarrow \text{H}_2\text{O} \]

At the anode, the fuel (hydrogen) is oxidized to produce electrons and H\(^+\) ions (or protons) and the oxidant (oxygen) is reduced to form water at the cathode, i.e. the oxygen molecules react with the electrons from the anode and H\(^+\) ions from the electrolyte to form water. The electrons travel through an external circuit, while the protons travel through the ion-conducting electrolyte. The reactions occur simultaneously and proceed continuously at the electrode surfaces as long as the gases are supplied and the movement or migration of e\(^-\) and H\(^+\) ions is not restricted.
Research and development activities on fuel cell technology for the last couple of decades following its use in terrestrial applications has primarily focused on development and analysis of a key physical component, the catalyst. The catalyst, usually, Platinum (Pt) plays an important role in the electrochemical reactions that take place inside a fuel cell. Pt catalyst acts as a promoter of the ORR which is a sluggish electrochemical reaction in comparison to the HOR occurring at the anode. Research with regard to fuel cell catalyst has concentrated on two key areas—development of newer catalysts (alloys that are comparatively cheaper) and Pt catalyst size reduction. Other areas of current research concentration include development of stable electrolyte and carbon support material, efficient water and gas transport inside the fuel cells.

Below a brief description of the different types of fuel cells is provided.
Alkaline electrolyte fuel cell (AFC)

The electrolyte of an alkaline fuel cell can be either sodium hydroxide or potassium hydroxide. Potassium hydroxide is used quite often as the electrolyte due its stable characteristics. The operating temperature is about 250°C with an electrolyte concentration of 85wt% (and <1200°C with a concentration of 35-50wt %)

An alkaline fuel cell has three main advantages, 1) the activation over voltage at the cathode is lower that that of a PEM fuel cell, 2) It uses relatively cheap electrolytes and electrodes materials, 3) demands less water management then a PEM fuel cell. The electrochemical reactions occurring at the electrodes are,

Anode: $2H_2 + 4OH^- \rightarrow 4H_2O + 4e^-$

Cathode: $O_2 + 4e^- + 2H_2O \rightarrow 4OH$

However, the oxidant (usually air) and the fuel have to be free from impurities. Even a small amount of carbon dioxide can destroy the fuel cell.

Direct Methanol Fuel Cell (DMFC)

Methanol can be used directly as a fuel in a fuel cell with any kind of electrolyte. Problems of storage of hydrogen can be eliminated with this type of fuel cell. In addition, the complexity of the system is reduced as direct feeding of the fuel is possible.

However, many other disadvantages challenge the widespread usage of this type of fuel cell. The oxidation of methanol at the anode is a complex three-step process that reduces the overall performance of the DMFC fuel cell considerably. In addition to this disadvantage, fuel crossover also poses another major problem. The electrochemical reactions occurring at the electrodes are,

Anode: $CH_3OH + H_2O \rightarrow 6H^+ + 6e^- + CO_2$

Cathode: $1 \frac{1}{2} O_2 + 6H^+ + 6e^- \rightarrow 3H_2O$
Phosphoric Acid Fuel Cell (PAFC)

Phosphoric acid fuel cell is one of the most developed high temperature fuel cells. The operating temperature ranges from 150-2200 C. The electrolyte is Phosphoric acid (H₃PO₄), which is an inorganic, highly stable electrolyte with very low volatility. The electrolyte solution is contained inside a silicon carbide matrix. The Phosphoric acid fuel cell, even though it operates a relatively high temperature, requires a substantial amount of noble metal catalysts. The catalyst materials used here have to be protected against poisoning like in any other low-temperature fuel cells. The electrochemical reactions occurring at the electrodes of a PAFC, similar to PEM fuel cell reactions are,

Anode: \( \text{H}_2 \rightarrow 2\text{H}^+ + 2e^- \)

Cathode: \( \frac{1}{2} \text{O}_2 + 2\text{H}^+ + 2e^- \rightarrow \text{H}_2\text{O} \)

Molten Carbonate Fuel Cell (MCFC)

The electrolyte of this type of fuel cell is a mixture of alkali metal and carbonate (usually, a binary mixture of lithium and potassium or lithium and sodium carbonate). At high operating temperatures, the alkali carbonates form a highly conductive solution with carbonate \( \text{CO}_3^{2-} \) ions providing the ionic conduction. The electrolyte solution is contained in a matrix of LiAlO₂.

The operating temperature of a molten carbonate fuel cell is in the range of 600-700 C. In a molten carbonate fuel cell, CO₂ gas is supplied along with O₂ at the cathode side. Important advantages of this type of fuel cell are, noble metal catalysts are not required, and a wide range of fuels can be utilized. For example, hydrocarbons and even carbon monoxide are used, as they can be internally reformed to produce H₂ or CO gas. The electrochemical reactions occurring at the electrode are,

Anode: \( 2\text{H}_2 + 2\text{CO}_3 \rightarrow 2\text{H}_2\text{O} + 2\text{CO}_2 + 4e^- \)

Cathode: \( \text{O}_2 + 2\text{CO}_2 + 4e^- \rightarrow 2\text{CO}_3 \)
Solid Oxide Fuel Cell (SOFC)

Here the electrolyte consists of an ion-conducting ceramic material, Zirconia doped with 8-10 mole% of yttria (yttria-stabilized zirconia). The cell operates at a temperature of about 1000°C and the ionic conduction takes place with the aid of oxygen ions. Solid oxide fuel cell is simpler in concept and design, even when compared to MCFC. Recycling of CO2 is not required. Various hydrocarbons and carbon monoxide can be used as a fuel. The electrochemical reactions occurring at the electrodes are,

Anode: \(2H_2 + 2O \rightarrow 2H_2O + 4e^-\)

Cathode: \(O_2 + 4e^- \rightarrow 2O\)

Hydrogen energy and Fuel Cell technology in India

For over a decade, the Ministry of New and Renewable Energy (MNRE) has supported research and demonstration activities to develop hydrogen and Fuel Cell technologies and their applications in the country. The Ministry recently setup the National hydrogen Board to draft the National Hydrogen Energy Road Map and presented the same to key stakeholders during a National Meeting on 4th June 2007 in New Delhi. The main objective of the National Hydrogen Energy Road Map is to identify the path that would lead to a gradual introduction of Hydrogen Energy in the country. The Road Map also aims to accelerate commercialization efforts and facilitate creation of Hydrogen Energy Infrastructure in the country.

The National Hydrogen Energy Road Map will provide a comprehensive approach to the development of the components of the hydrogen energy system, ranging from production, storage, transport, delivery, applications, safety and standards, education and awareness among others. The Road Map recommends that a strong public-private partnership covering the total hydrogen energy system for the implementation of its proposal be developed.
Priorities and targets

India has identified two major projects in the field of transport and power generation for the development of hydrogen and fuel cell technologies; (1) Green Initiative for Future Transport (GIFT) and (2) The Green Initiative for Power Generation (GIP). The GIFT programme aims to develop and demonstrate hydrogen powered IC engine and fuel cell based vehicles (from small 2/3 wheelers to heavy vehicles) and the GIP programme aims to develop and demonstrate hydrogen powered IC engine/turbine and fuel cell based decentralized power generating systems ranging from small milliwatt capacity to MW size systems through different phases of technology development and demonstration.

The GIFT programme will involve extensive research and development in hydrogen powered IC engine and fuel cell vehicles. The first phase of development would concentrate on public transport vehicles such as city-buses, three wheelers, vans and taxis. The next phase of development would cover passenger vehicles. In the third phase the number of vehicles on road would be substantially expanded, while intensive R&D work improves the cost competitiveness of hydrogen fuel production and storage. The GIP programme will involve the development and demonstration of small capacity generators (50-100 kW) and fuel cell power packs. Later as the technology develops, field-testing of stand-alone and grid interactive fuel cell power plants will be undertaken. The IC engine based generators would continue to be used for rural, remote and congested locations. With the development of coal gasification technology, Integrated Gasification Combined Cycle (IGCC) technique would be used for power generation using turbines with hydrogen as a fuel. It is expected that by 2020 an aggregate capacity of 1,000 MW would be set up in the country, which will use hydrogen as the fuel.

Hydrogen production & Co2 capture and storage

At present, hydrogen is produced on a large scale in fertilizer and petroleum refining industries across the country. The production of hydrogen is mainly based on steam reforming of naphtha and natural gas. Hydrogen is also produced as a by-product in the chemical industry. Several methods of hydrogen production such as biomass gasification, dissociation of methanol or ammonia, thermo-chemical and electrochemical splitting of water, biological photosynthesis or fermentation etc., are still at different stages of development in the country. Production of
hydrogen through available non-renewable energy resources has been identified as an important step towards ensuring energy security.

The road map suggests that apart from setting up of central hydrogen production facilities, the technology for on-site generation of hydrogen by reformation of hydrocarbons needs to be further improved and demonstrated, as this would reduce the high cost of the hydrogen fuel in the short to medium term. It also recommends that suitable policies are formulated to support research, technology development and demonstration of various hydrogen production technologies in a cost effective manner to enable the development of hydrogen production network and infrastructure in the country.

Realizing that coal will play a major role in the energy mix of the country, it was envisaged that research work has to be undertaken to develop technology for production of hydrogen from coal.

**Hydrogen storage, transportation and distribution**

Fuel storage, transportation and distribution are the backbone for the energy system of a country. Its efficiency, safety, reliability, etc, are as critical as energy security itself. At present the limited infrastructure to transport and supply hydrogen fuel in India in a cost effective, safe and reliable manner is a major barrier to the large-scale introduction of hydrogen as an energy carrier. The existing pipelines are unreliable and thus the Road Map recommends that new transportation and delivery facilities be developed.

The road map identifies that development of suitable hydrogen pipelines as the key to the deployment of hydrogen technology in the country. It recommends that advanced research efforts be carried out to develop the necessary technology and later demonstrate the technology.

The Road Map envisages that the focus should be on solid storage. It recommends that on-site production of hydrogen and delivery systems be developed. Advanced storage methods such as high compression storage in cylinders/tanks, hydrides, carbon nanostructures will have to be developed to achieve system storage efficiency of > 9 weight percent, reduce over all size, improve recycle life and ensure safe transportation and refuelling.
Applications in IC engines and fuel cells

Across the world, fuel cell technologies are still in the early stages of development. Several technological issues concerning choice of materials, improvements in design and performance of fuel cell stacks and systems are yet to be fully resolved. Advanced research, technology development and demonstration of fuel cell technology is required India.

The Road Map recommends that public-private partnerships be established to move from the research labs to industries for eventual commercialization of different technologies in India. In addition, it also recommends that demonstration projects are quickly taken up which would not only provide operating experience in key hydrogen applications such as decentralized power generation and use in automobiles, but also facilitate creation of support infrastructure through public-private partnership. Such demonstration projects would also facilitate development of low cost, safe and reliable technologies for production of hydrogen, its storage and safe transport and delivery.

Hydrogen safety and codes and standards

The use of hydrogen as an energy carrier is yet to be exploited in the country. However, the industrial use of hydrogen has been taking place for a long time. As a result several safety codes and standards have been developed. These standards are concerned with the industrial applications of hydrogen. And the present regulations are focused on transportation of hydrogen to and from the sites. The Bureau of Indian Standards (BIS) has issued specification for compressed gaseous hydrogen storage (IS – 1090). The Department of Explosives is entrusted with the administration of Explosives Act, 1884, Petroleum Act, 1934, Inflammable Act, 1952 and other rules framed under these acts which also includes static and mobile pressure vessel (unfired) rules, 1981 and the gas cylinder rules, 1981. The Oil Industry Safety Directorate (OISD) has formulated and coordinated implementation of a series of self-regulatory measures aimed at enhancing the safety in oil and gas industry in India. However, with the absence of relevant codes and standards, it is felt that the acceptance and commercialization of new technologies such as fuel cells development of codes and standards are imperative. The Road map recommends that codes and standards for the entire range of hydrogen energy be developed. In addition, the Road map suggests that relevant acts
concerning transport sector, environment and air quality will require amendments to encourage safe use of hydrogen.

### Overview of Hydrogen and Fuel Cell industry in India

A majority of R&D activities on Hydrogen and Fuel Cell technologies is being undertaken by public research institutions like CSIR, BHEL Ltd and some relatively few private industrial houses such as SPIC (Southern Petrochemical Industrial Corporation).


In the India context, a large amount of research is focused on developing small stationary applications using fuel cells, which offers the greatest potential at present. Industrial users have long used conventional sources to supply their own distributed power and are now looking towards fuel cells to provide either stationary backup power or the main source of power in future. With the prevalent situation of irregular supply of power, power outages even in major cities, stationary fuel cell systems could help meet the necessary demand effectively. The automotive sector is the next most common application focus of fuel cell manufacturers in India.
Figure 4: Application focus of Indian industries and research institutions. (Source: Fuel Cells in India: A survey of current developments, 2007, Fuel Cells Today)

Over the last few years activities in this has reasonably increased. This year, three separate workshops on fuel cells took place in Indian Institutes of Technology (IITs). Fuel cell technology is taught as a subject at several Indian universities, although there is perceived to be a skills shortage, particularly for fuel cell manufacture and maintenance. However, despite the strong R&D base in Indian universities, there is currently little fuel cell manufacturing expertise. Several companies in the stationary power and automotive sectors are said to be looking for international collaborations on fuel cells for distributed generation and transport applications.

The Department of Science and Technology (DST) has established a Centre for Fuel Cell Technology (CFCT) in Chennai, Tamil Nadu with the specific objective of demonstrating and validating commercial applications of PEM fuel cells in collaboration with national and international industry. CFCT has created 1-10 kW stacks for remote power generation which are expected to be available for commercialization before the project’s end in early 2009. The Council for Scientific and Industrial Research (CSIR), an industrial R&D arm of DST comprising of different institutes including the National Chemical Laboratory (NCL) and the Central Glass & Ceramic Research Institute (CGCRI), are actively involved in researching PEM and other FC technology.
The Working Group on R&D for the 11th Five Year Plan recently recommended that research should be carried out on system as well as materials development for low temperature fuel cells (alkaline and PEMFC); high temperature fuel cells (MCFC and SOFC); high temperature reversible fuel cells; and DMFCs. In particular membranes, bipolar plates, catalysts and electrodes need to be researched. Other materials that are being proposed for development are low cost hydrogen sensors and heat exchangers.

There are plans at the Indian Institute of Technology (IIT) Madras and Vellore Institute of Technology (VIT) to develop PEMFC based technology for decentralized power generation. At the Central Glass and Ceramics Research Institute (CGCRI), a new generation of high temperature SOFCs is under development. The Institute is working on SOFCs and is planning activities in collaboration with Bharat Heavy Electrical Ltd., one of India’s leading companies. Indian Institute of Science, Bangalore is working on the development of alkaline and DMFCs. The Council for Scientific and Industrial Research has a mission project involving a number of laboratories including the National Chemical Laboratory (NCL), Pune, Central Electrochemical Research Institute (CECRI), Karaikudi and others. NCL and CECRI have developed a PEMFC stack which they report is set for commercialization.

### Technologies- current status and development targets in India

The table below provides a detailed description of the targets and proposed time-frame to achieve the targets set by MNRE.

<table>
<thead>
<tr>
<th>Technology</th>
<th>International Status</th>
<th>National Status</th>
<th>Technology Gaps</th>
<th>Proposed Time Frame for bridging the gaps</th>
</tr>
</thead>
<tbody>
<tr>
<td>By-product hydrogen</td>
<td>By-product is hydrogen is available from chemical industry</td>
<td>By-product hydrogen is available from chemical industry</td>
<td>Purification, pressurization and storage of by-product hydrogen</td>
<td>2005-10</td>
</tr>
</tbody>
</table>
| Steam Reformation (natural gas naptha etc.)/ | Technology is proven and commercially available | Used in oil refineries and fertilizer industry | - Indigenisation of technology  
- Efficiency improvement  
- Hydrogen purity (>99.9%)  
- Carbon sequestration | 2005-15 |
<table>
<thead>
<tr>
<th>Technology</th>
<th>International Status</th>
<th>National</th>
<th>Technology Gaps</th>
<th>Proposed Time Frame for bridging the gaps</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrolysis of water</td>
<td>Technology is proven and commercially available</td>
<td>Technology is proven and commercially available</td>
<td>Improvement in efficiency and reduction in energy consumption through development of new materials, components, sub-systems etc. for conventional alkaline and PEM electrolyser involving high temperature electrolysis, using renewable energy sources like small hydro and wind energy etc.</td>
<td>2005-15</td>
</tr>
<tr>
<td>Gasification of coal and heavy residues</td>
<td>Technology is commercially available</td>
<td>Efforts under-way for development of technology</td>
<td>- R &amp; D for pilot scale FBG for producing hydrogen through coal gasification for Indian coal - Gas clean-up technology - CO2 separation (PSA &amp; membrane) - Conversion to methanol (Fischer Tropsh process) - Integrated Gasification Combined Cycle - Carbon sequestration</td>
<td>2005-15</td>
</tr>
<tr>
<td>Biomass Gasification /Pyrolysis</td>
<td>In pre-commercial stage</td>
<td>In R &amp; D stage</td>
<td>R &amp; D for pilot scale gasifiers for producing hydrogen through biomass</td>
<td>2005-15</td>
</tr>
<tr>
<td>Biological Routes</td>
<td>In pre-commercial</td>
<td>In pre-commercial</td>
<td>- Scale up - Purification recovery</td>
<td>2005-15</td>
</tr>
<tr>
<td></td>
<td>Stage</td>
<td>Stage</td>
<td>- Compression - Screening of microbes - Bio-reactor design Specific energy consumption</td>
<td>2005-20</td>
</tr>
<tr>
<td>Photo-electrochemical, Photocatalytic</td>
<td>In R &amp; D stage</td>
<td>In R &amp; D stage</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Thermo-chemical splitting of water using nuclear/ solar heat</td>
<td>In R &amp; D stage</td>
<td>In R &amp; D stage</td>
<td>Thermo-chemical process: - Technology development for reactions &amp; separations etc. - Materials, Catalyst, Membranes development - Development of Special processing methods &amp; equipment - Measurement and control instruments &amp; methods development - Close loop operations and stability - Solar thermal assisted thermo chemical splitting of water - Integration with Nuclear reactor - High temperature nuclear reactors: - Special materials development - Corrosion and oxidation resistant coatings development</td>
<td>-</td>
</tr>
<tr>
<td>Technology</td>
<td>International Status</td>
<td>National</td>
<td>Technology Gaps</td>
<td>Proposed Time Frame for bridging the gaps</td>
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<tr>
<td>High Pressure Gaseous Storage</td>
<td>Several companies involved in development of high pressure gaseous storage (350-700 bar)</td>
<td>No high pressure gaseous storage technology exists in the country.</td>
<td>- High temperature &amp; High performance fuel related development&lt;br&gt;- Technology development for passive reactor safety system&lt;br&gt;- Technology development for passive reactor safety system&lt;br&gt;- Technology development for passive high flux heat removal system&lt;br&gt;- Liquid metal related technologies&lt;br&gt;- High temperature instrumentation</td>
<td>2005-10</td>
</tr>
<tr>
<td>Liquid hydrogen</td>
<td>Technology is commercially available</td>
<td>Liquid hydrogen plant is installed near Trivandrum by ISRO, used in space programme</td>
<td>No experience of using liquid hydrogen - for vehicular transport power generation</td>
<td></td>
</tr>
<tr>
<td>Hydrides</td>
<td>R &amp; D efforts are in progress in Japan, USA and other countries. Hydrogen storage capacity 1.5-2.0 wt% for ambient conditions and 5-6 wt% for high temperature hydrides achieved.</td>
<td>Research groups at BHU, IIT, Madras and ARCI, Hyderabad engaged in development. Hydrides with 2.42wt% storage capacity developed.</td>
<td>Hydrides with (a) storage capacity up to 3 through 6 to 9wt%, and (b) cycle life of greater than 1500 are required to be developed for transport application.</td>
<td>2005-15</td>
</tr>
<tr>
<td>Other new Hydrogen Storage Materials and complex hydrides (carbon nanotubes, sodium alanates, etc.)</td>
<td>In R &amp; D stage</td>
<td>In R &amp; D stage. BHU, IITM and other upcoming institutions</td>
<td>R &amp; D efforts need to supported and strengthened</td>
<td>2005-2020</td>
</tr>
<tr>
<td>Unusual Routes</td>
<td>Efforts being made on several unusual routes such as storage in zeolites, glass microspheres, chemical hydrides.</td>
<td>R &amp; D efforts to be initiated. Geological Survey of India to map out depleted mined</td>
<td>R &amp; D exploration efforts to be initiated</td>
<td>2005-2020</td>
</tr>
<tr>
<td>Hydrogen use in IC Engine</td>
<td>CNG-Hydrogen blends used in IC engines</td>
<td>In R &amp; D and initial demonstration stage</td>
<td>- To gain experience in CNG-hydrogen blending for use in IC engines&lt;br&gt;- To overcome problems of per-</td>
<td>2005-10</td>
</tr>
<tr>
<td>Technology</td>
<td>International Status</td>
<td>National</td>
<td>Technology Gaps</td>
<td>Proposed Time Frame for bridging the gaps</td>
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</tr>
<tr>
<td><strong>Fuel Cells</strong></td>
<td></td>
<td></td>
<td>Ignition, backfire and reduced output</td>
<td></td>
</tr>
<tr>
<td><strong>Phosphoric Acid Fuel Cell (PAFC)</strong></td>
<td>Commercially available. More than 200 units of 200 kW capacity each deployed world over.</td>
<td>Technology for development of units up to 25 kW capacity developed and demonstrated by BHEL.</td>
<td>The Expert Group on Power Generation has indicated that there is declining interest in this technology world over. However, the relevance of PAFC has to be assessed in the context of requirements in the country and our experience and achievements in it so far.</td>
<td></td>
</tr>
</tbody>
</table>
| **Polymer Electrolyte Membrane Fuel Cell (PEMFC)** | Commercially available. Number of companies are engaged in manufacturing such fuel cells. | Fuel Cell stacks up to 5 kW developed and demonstrated by SPIC Science Foundation (SSF). SSF and BHEL are presently involved in development | - To develop indigenous low cost proton exchange membrane.  
- To develop low cost bipolar plates (graphite based, high conductivity, impervious) preferably with flow grooves incorporated during moulding itself. Assembled stacks with imported materials for performance data.  
- To develop higher CO-tolerant anode catalyst  
- To develop cheaper cathode catalyst.  
- To develop cheaper cathode catalyst.  
- To develop electrode support substrate (graphite paper) | 2005-2012 |
| **Alkaline Fuel Cell (AFC)**     | Mature technology for space application                                                | In R & D stage. CECRI worked in this area earlier. Currently BHEL is working on development and supply of a 500 W power pack. | - To develop compact, low power electrolyte re-circulation system.  
- To develop low cost CO2 scrubber & alkali-water heat exchanger.  
- To develop low cost catalysts (Ni-Co spinel, MnO2/C).  
- To develop suppliers for low cost resin based mono-plates/ cell enclosures. | 2005-2020 |
| **Solid Oxide Fuel Cell (SOFC)** | In R & D and demonstration stage                                                       | In initial stages of R & D CGCRI, BHEL and NAL are engaged in development                            | - To generate long term performance data & operational experience.  
- To develop indigenous sources for raw materials required for SOFC | 2005-17 |
| **Molten Carbonate Fuel Cell (MCFC)** | Technology developed in USA. Presently in demonstration and early commercialization phase | In early R & D stage. CECRI was involved in development. NTPC is keen to pursue this technology  | Technology yet to be developed in India even in R & D stage. Technological gaps can be identified after some progress is achieved in R & D efforts | 2005-20 |
### Table 2: Targets and activities (Source: Ministry of New and Renewable Energy, Government of India)

<table>
<thead>
<tr>
<th>Area</th>
<th>Year</th>
<th>Activities</th>
</tr>
</thead>
</table>
- Pilot demonstration plant for hydrogen production from hydrocarbons (Natural gas etc.) dedicated for emerging applications as energy carrier  
- Pilot scale reactors for production of hydrogen through biological, biomass routes  
- R&D on electrolyzers including high pressure electrolyzers  
- R&D on small reformers suitable for onsite and on-board reformation  
- R&D on gasification of coal for hydrogen production  
- R&D on carbon dioxide sequestration  
- R&D on thermo chemical methods of hydrogen production (Nuclear, Solar)  
- R&D on emerging methods of hydrogen production  
- Improvements in electrolysis process  
- Demonstration of small reformers |
|                               | FY 2007-2012 | - Centralized hydrogen production from hydrocarbons  
- Pilot plant production of hydrogen production from renewable methods for on-site hydrogen production with a cost of Rs. 160 per kg at the production plant from electrolysis and Rs. 125 per kg from biomass  
- Design and development of coal gasification plant for hydrogen production  
- Carbon dioxide sequestration demonstration projects suitable for Indian conditions |
|                               | FY 2012-2017 | - Large centralized hydrogen production facilities from hydrocarbons, cost of hydrogen to be progressively reduced to Rs. 70 / kg at the fuelling station or actual point of use  
- Hydrogen production using locally available renewable sources including on-site hydrogen production  
- Hydrogen Production from Electrolysis  
- Production of hydrogen reformers suitable for different feed stocks  
- Development and demonstration of thermo chemical water splitting methods  
- Hydrogen production through coal gasification  
- Large scale carbon dioxide sequestration |
| Hydrogen storage, transportation and distribution | FY 2005-07 | - Pilot plant for production of Intermetallic hydrides  
- R&D for improving hydride storage efficiency to 3 weight %, cycle life- 1,000  
- R&D in other novel solid-state storage materials like carbon nanostructures.  
- R & D on complex hydrides like Alanates, Amides, Clathrates etc.  
- R & D on liquid hydrides, glass microspheres, zeolites, etc.  
- Development of high pressure hydrogen storage tanks and their testing (300 Bar) |
|                               | FY 2007-2012 | - Large scale production of intermetallic hydrides  
- R&D for improving solid state storage efficiency to 5 weight %, > 1,000 cycles  
- Development of Nano and other Storage Systems (Carbon and other nano- |
## 17 Hydrogen & Fuel Cell Technologies

<table>
<thead>
<tr>
<th>Area</th>
<th>Year</th>
<th>Activities</th>
</tr>
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</table>
|      | FY 2012-2017 | - Expanding production facilities for metal hydrides  
- R&D for improving storage efficiency to 7.5 weight %, cycle life - 1500  
- Enlarging network of hydrogen pipeline linked to hydrogen production plants to areas having concentrated users of hydrogen  
- Production of high pressure hydrogen storage tanks (300 – 700 bar) for transportation of hydrogen  
- Use of other solid state hydrogen storage systems for vehicular application |
|      | FY 2017-2020 | - R&D for improving storage efficiency to 9 weight %, cycle life > 1500  
- Enlarging network of hydrogen pipeline linked to hydrogen production plants to areas having concentrated users of hydrogen  
- Production of high pressure hydrogen storage tanks (up to 700 bar) for transportation of hydrogen  
- Production and large scale use of other solid state hydrogen storage systems (up to 9 wt%) for vehicular application |
| Applications in IC engines and fuel cells | FY 2005-2007 | - Extensive testing of hydrogen based IC Engine for evaluating their performance and limited demonstration for (i) in automotive engines, (ii) decentralized power generation; in selected locations  
- Demonstration of CNG-Hydrogen blend in three/four wheelers and buses  
- Development and demonstration of PEMFC for automotive and decentralized power generation  
- Development and demonstration of PAFC for decentralized power generation  
- Demonstration of PEM fuel cell-battery hybrid vehicles (vans/mini-buses)  
- R&D in other types of fuel cells (both low and high temperature type)  
- Development of micro fuel cells for power supplies of air-borne systems |
|      | FY 2007-2012 | - Expanded demonstration of hydrogen based IC Engine in automobiles and for decentralized power generation in areas having hydrogen supply or on site hydrogen production facilities  
- Widening the user base of CNG-Hydrogen blend in four wheelers and buses  
- Improvements in performance and cost of PEMFC for automotive and decentralized power generation  
- Expanded demonstration programme on fuel cell systems for decentralized power generation  
- Demonstration of fuel cell-battery hybrid vans/mini-buses and large buses  
- Development and demonstration of fuel cell vehicles  
- Development and demonstration of other fuel cell technologies for combined heat and power application and also of DMFC and DEFC  
- Demonstration of fuel cell systems for mobile applications |
<table>
<thead>
<tr>
<th>Area</th>
<th>Year</th>
<th>Activities</th>
</tr>
</thead>
</table>
|                         | FY 2012-2017 | - Expanded demonstration of hydrogen based IC Engine in automobiles and for decentralized power generation in areas having hydrogen supply or on site hydrogen production facilities  
                      |              | - Expanding the user base of CNG-Hydrogen blend in three/four wheeler and buses  
                      |              | - Improvements in performance and reduction in cost of PEM fuel cells for automotive applications to Rs. 5,000 per kW  
                      |              | - Improvements in performance and reduction in cost of fuel cells for decentralized power generation to Rs. 40,000 per kW with >50,000 operating hours  
                      |              | - Expanded demonstration programme on high temperature fuel cell systems for decentralized power generation and heat management  
                      |              | - Demonstration and large scale use of fuel cell vehicles  
                      |              | - Improvements in performance and reduction in cost of other fuel cell technologies for combined heat and power application and also of DMFC and DEFC  
                      |              | - Expanding the use of fuel cells for mobile applications  
                      |              | - Commercial production of IC engines/turbines suitable for hydrogen fuel  
                      | FY 2017-2020 | - Large scale use of hydrogen based IC Engine and fuel cells in automobiles and for decentralized power generation  
                      |              | - Production of fuel cell systems for automotive and decentralized power generation to increase their demand.  
                      |              | - Large scale use of hydrogen based IC Engine and fuel cells for (i) decentralized power generation, and (ii) automobiles  
                      |              | - One million vehicles on road by 2020  
                      |              | - 1,000 MW aggregate capacity for power generation  
| Hydrogen safety and      | FY 2005-2007 | - Study the specific safety requirements for hydrogen production, transport, storage and applications  
                      | codes and     |              | - Develop safety devices, sensors and systems for various hydrogen applications  
                      | standards     |              | - Study the present Indian standards and international standards and identify the areas where additional / new standards are required  
                      | FY 2007-2012 | - Study the specific safety requirements for hydrogen production, transport, storage and applications  
                      |              |              | - Develop safety devices, sensors and systems for various hydrogen applications  
                      |              | - Study and incorporation of international safety standards for Indian conditions to improve existing standards  
                      |              | - Development of new standards and codes  
                      | FY 2012-2017 | - Develop and adopt new standards and codes in harmony with international standards and codes  
                      |              | - Develop and adopt safety regulations for vehicles  
                      |              | - Publish documentation for all stakeholders on recommended practices on safety  
                      | FY 2017-2020 | - Develop and adopt standards and codes in harmony with international standards and codes  
|                         |              |                                                                                                                                                                                                                                                                         |
International targets and R&D activities in Hydrogen and Fuel Cell technology

Stationary Power Application

Over the last year, the fuel cell systems in large stationary applications sector have moved forward. Internationally, the main developments have focused around the drive to commercialization. Almost all companies in this sector is specifically developing large (>10kW) fuel cells for stationary use. This trend is set to continue over the next few years with developers such as Fuel Cell Energy, UTC Fuel Cells and Siemens moving into the multi-MW market.

Figure 5: Annual and cumulative new units (Source: 2007 Large Stationary Survey, 2007, Fuel Cells Today)
Figure 6: Purcell Mode 200 Power Solution (Source: http://www.utcpower.com/fs/com/bin/fs_com_Page/0, 11491, 0104, 00.html)

North America is still dominant, and within it California and Connecticut account for areas with a large majority of installed capacity in the country. Within Asia, including Japan, it is only Korea that has any real focus on large stationary units. China and Japan are both more interested in transport and small stationary units.

Figure 7: Region of operation (Source: 2007 Large Stationary Survey, 2007, Fuel Cells Today)

Vehicular Applications
The transport sectors have had another very positive year. A handful of companies have been making commercial strides.
Technological adoption continues to be varied with the full suite of electrolytes being used in various capacities. In recent years, several more countries are adopting fuel cells in niche transport applications. The reasons for this interest include: lower barriers to entry that most other applications, the ability of the “hobbyist” to make a real contribution, increasing legislation driving many areas forward and economics of adoption hitting sweet spots.

In terms of numbers of units produced there has been a declining trend. There has been an increase in the development of forklifts and floor-shop cranes by several companies in the U.S and EU. Development of trains, although being an area of increasing focus, like aerospace, it is not an application where new projects will see new units quickly. This year has been about the increase in interest and gaining a better understanding of the costs and benefits rather than new hardware. Therefore although the actual numbers are not as high as expected, it is still very positive.

Figure 8: New Units installed in 2007 (Source: 2007 Niche Transport Survey (!), Fuel Cell Today)
Figure 9: Fuel cell Technologies in 2007 *(Source: 2007 Niche Transport Survey (!), Fuel Cell Today)*

Figure 10: HyFish-Jet *(Source: Horizon Fuel Cells)*
In terms of adoption, North America (USA and Canada combined) still dominates this sector. This has been explained to be because of the development and testing of forklift, as its sale to the industrial is expected to kicking off by the end of this year. Conversely scooters and other two- and three-wheeled vehicles appear to be of very limited interest in American continent, whilst of high interest to countries like China and Japan. Some goals and proposed R&D activities of the European Union and U.S. is provided in the table below.

Industry focus has heavily centered on the development of forklifts, the application that is believed to be closest to commercial. It is expect that there will a steady growth in most areas with forklifts showing faster uptake and trains attracting
increased political interest. The military is a key adopter, and driver, in this area, especially in the UAV sector.

Hydrogen production and storage technologies

It is estimated that more than 95% of generated hydrogen is produced by reforming conventional hydrocarbon fuels or from coal. Electrolysis – the splitting of water using electricity, accounting for the remaining 5%, is the oldest of the hydrogen production technologies. This technology has full blown commercial systems for industrial use. The chemical electrolyte used in the electrolysis is being replaced by proton exchange membrane (PEM). PEM eliminates the need for mechanical compression to achieve desirable pressure levels.

Unlike the conventional fuels, the inherent properties of hydrogen make it a difficult commodity to produce, store and handle on a large scale. However several companies and researchers at top Universities are inching ahead by proposing solutions to the problems in Hydrogen technologies. Today the technologies for hydrogen production and storage are at various stages of commercial development. Some companies are contemplating on using solar power to break the water molecule to liberate hydrogen. PEM electrolysis and the solar hydrogen production are in the pathway to commercialization. These hydrogen production technologies find applications such as back up power sources and to power automobiles when used in concert with a fuel cell. There are technologies which produce hydrogen using electrolyser in automobiles to feed internal combustion engines along with the conventional hydrocarbon fuels. This technology eliminates the need for fuel cells as hydrogen is generated as and when required by the automobiles.

Compressed and gaseous hydrogen storage technologies are anticipated to set trends in fuelling stations or for on board vehicle storage. However, the success of these technologies depends on the development of hydrogen infrastructure and the development of internal combustion engines for automobiles. Metal hydride and chemical hydride hydrogen storage technologies are proposed for portable applications like mobile phones, laptops personal digital assistants etc.

The metal hydride technologies have to compete on the compactness and the chemical hydrides storage technologies
have to prove its environment friendliness while recycling the reacted chemicals back as raw materials. The research community is on its innovative path to propose solutions in hydrogen production such as solar reactors for co-producing hydrogen and carbon black, oxidative reforming of ethanol over platinum catalysts, solid state reactions, and solar energy. Hydrogen storage researchers are working on materials such as boron nitride, carbon nanotubes, dry sodium borohydride, nonporous organic materials, nanoscale materials and nickel magnesium hydride batteries.

By 2008, we should see a lot of automobiles using hydrogen (produced by electrolysis) along with the conventional hydrocarbon fuels in the internal combustion engines of vehicles. Backup power sources using electrolysis and military portable applications would become cost competitive by 2010. The following figure shows the time line of the evolution of various hydrogen powered applications. Apart from

<table>
<thead>
<tr>
<th>Table 3: International targets and R&amp;D activities</th>
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<tr>
<td><strong>Country</strong></td>
</tr>
<tr>
<td>United States of America</td>
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**Proposed R&D activities**

**Production:**

- Reduce the cost of distributed production of hydrogen from natural gas to $2.50/gge (delivered, untaxed) at the pump (without carbon sequestration) by 2010, and reduce the cost of distributed hydrogen production from biomass-derived renewable liquids to $2.00 - $3.00/gge (delivered, untaxed) at the pump by 2015.

- Verify grid-connected distributed water electrolysis at a projected delivered hydrogen cost of $2.85/gge by 2010, and by 2015, verify central hydrogen production from renewable energy sources at a projected cost of $2.75/gge delivered.

- Reduce the cost of hydrogen produced from biomass to $1.60/gge at the plant gate ($2.60 delivered) by 2015.

- Develop advanced renewable photo-electrochemical and biological hydrogen generation technologies. By 2015, verify the feasibility of these technologies to be cost-competitive in the long term.

- Research and develop high-temperature thermo-chemical cycles driven by concentrated solar power processes to produce hydrogen with a projected cost of $3.00/gge at the plant gate ($4.00 delivered) by 2015.

**Hydrogen Delivery:**

- By 2010, develop technologies to reduce the cost of hydrogen delivery from
Country | Goal | Proposed R&D activities
--- | --- | ---

Hydrogen Storage:

- Central and semi-central production facilities to the gate of refuelling stations and other end users to <$0.90/gge of hydrogen and to reduce the cost of compression, storage and dispensing at refuelling stations and stationary power facilities to <$0.80/gge of hydrogen.

- Develop enabling technologies to reduce the cost of hydrogen delivery from the point of production to the point of use in vehicles or stationary power units to <$1.00/gge of hydrogen by 2015.

Hydrogen Storage:

- By 2010, develop and verify on-board hydrogen storage systems achieving 2 kWh/kg (6 wt%), 1.5 kWh/L, and $4/kWh. By 2015, 3 kWh/kg (9 wt%), 2.7 kWh/L, and $2/kWh.

Fuel Cells:

- Develop a 60% peak-efficient, durable, direct hydrogen fuel cell power system for transportation at a cost of $45/kW by 2010 and $30/kW by 2015.

- Develop a distributed generation polymer electrolyte membrane (PEM) fuel cell system operating on natural gas or liquid petroleum gas that achieves 40% electrical efficiency and 40,000 hours durability at $400-$750/kW by 2010.

Technology Validation:

- Validate hydrogen vehicles that have greater than 250-mile range and 2,000-hour fuel cell durability, with hydrogen infrastructure that results in a hydrogen production cost of less than $3.00/gge (delivered, untaxed). By 2015, vehicles that have 300+ mile range and 5,000 hours fuel cell durability, with a hydrogen production cost of $2.50/gge (delivered, untaxed).

- Validate an Electrolyzer that is powered by a wind turbine at a capital cost of the Electrolyzer of $400/kWe and 65% efficiency, including compression to 5,000 psi, (when built in quantities of 1,000) by 2008.

- Validate an integrated biomass/wind or geothermal Electrolyzer system to produce hydrogen for $2.85/gge at the plant gate (untaxed) by 2011.

Codes and Standards:

- Support and facilitate the drafting and adoption of model building codes for hydrogen applications by the National Fire Protection Association and the ICC by 2007.

- Support and facilitate the completion of the ISO standards for hydrogen refuelling and on-board storage by 2007.

- Support and facilitate development of Global Technical Regulations (GTR) for hydrogen vehicle systems by 2010.

- By 2015, ensure necessary codes and standards are completed that
European Union

<table>
<thead>
<tr>
<th>Year</th>
<th>New car on H2</th>
<th>Fleet on H2</th>
</tr>
</thead>
<tbody>
<tr>
<td>2020</td>
<td>5</td>
<td>2</td>
</tr>
<tr>
<td>2030</td>
<td>25</td>
<td>15</td>
</tr>
<tr>
<td>2040</td>
<td>35</td>
<td>32</td>
</tr>
</tbody>
</table>

- **Advanced Energy Initiative:**
  - The Advanced Energy Initiative proposes significant new investments and policies in three promising areas: (1) advanced batteries; (2) cellulosic ethanol; and (3) hydrogen vehicles.

- **Short and medium term (to 2010):**
  - Intensify the use of renewable energy sources for electricity, which can be used to produce hydrogen by electrolysis or fed directly into electricity supply grids.
  - Improve the efficiency of fossil-based technologies and the quality of fossil-based liquid fuels.
  - Increase the use of synthetic liquid fuels produced from natural gas and biomass, which can be used in both conventional combustion systems and fuel-cell systems.
  - Introduce early applications for hydrogen and fuel cells in premium niche markets, stimulating the market, public acceptance and experience through demonstration, and taking advantage of existing hydrogen pipeline systems.
  - Develop hydrogen-fuelled IC engines for stationary and transport applications, supporting the early deployment of a hydrogen infrastructure, provided they do not increase the overall CO2 burden.

- **In the medium term (to 2020):**
  - Continue increasing the use of liquid fuels from biomass.
  - Continue using fossil based liquid and gaseous fuels in fuel cells directly and reforming fossil fuels (including coal) to extract hydrogen. This enables transition to a hydrogen economy, capturing and sequestering the CO2. The hydrogen thus produced can then be used in suitably modified conventional combustion systems, hydrogen turbines and fuel cell systems, reducing greenhouse gas and pollutant emissions.
  - Develop and implement systems for hydrogen production from renewable electricity, biomass; continue research and development for other carbon-free sources, such as solar thermal and advanced nuclear.

- **In the medium to long term (beyond 2020):**
  - Demand for electricity will continue to grow, and hydrogen will complement it. Use both electricity and hydrogen together as energy carriers to progressively replace the carbon based energy carriers by the introduction of renewable energy sources and improved nuclear energy.
  - Expand hydrogen distribution networks. Maintain other environmentally...
Japan

The Japan Hydrogen & Fuel Cell Demonstration Project (JHFC) aims to demonstrate the every-day usability of fuel cell cars.

The project is funded by the Japanese Ministry of Economy, Industry and Trade (METI) and supported by the Japan Automobile Research Institute (JARI) and the Engineering Advancement Association of Japan.

Several vehicle manufacturers, including Toyota, Hino, Mitsubishi, Honda, Nissan, DaimlerChrysler, Suzuki and General Motors (GM) are running their cars and buses to gain important information. Furthermore, utility, energy and oil companies are supporting the project by installing and running various hydrogen filling stations across Japan. Companies include Nippon Oil (ENEOS), Cosmo Oil, Showa Shell, Tokyo Gas, Iwatani International, Japan Air Gases (joint-venture of Air Liquide and Osaka Sanso Kogyo), Nippon Sanso, Nippon Steel, Kurita Water Industries, Sinanen, Itochu Enex, Idemitsu Kosan and Babcock-Hitachi.

**Fuel cell introduction targets:**

<table>
<thead>
<tr>
<th>Year</th>
<th>2010</th>
<th>2020</th>
<th>2030</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel cell vehicles</td>
<td>50,000</td>
<td>5 million</td>
<td>15 million</td>
</tr>
<tr>
<td>Stationary Fuel Cell Systems</td>
<td>2100 MW</td>
<td>10,000 MW</td>
<td>12,500 MW</td>
</tr>
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</table>

**Development of Fundamental Technologies in the Safe Utilization of Hydrogen:**

A follow-up project after Phase II of WE-NET project called the Development of Fundamental Technologies in the Safe Utilization of Hydrogen is envisioned to last until 2020 and focus on the gradual diffusion and penetration of the hydrogen energy infrastructure in Japan.

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**Key players working on Hydrogen and Fuel Cell technology in India**

A brief description of the efforts undertaken by both public and private sector organizations in the development of fuel cell and hydrogen technologies is provided below.
Benaras Hindu University (BHU)

BHU is carrying out R&D activities on metal hydride storage systems for hydrogen and also the use of hydrogen in internal combustion engines. In 2001, BHU has conducted field trial and testing of 10 motorcycles. Recently in 2004, field trials on a three-wheeler running on hydrogen were conducted.

Bharat Heavy Electricals Limited (BHEL)

BHEL has been working on the development of PAFC and MCFC technologies for distributed power generation. The company also focuses on developing catalysts and fuel reformers for use in fuel cell power plants. A recent development pertains to the work being done on the development of 50 kW stack PAFC technology.

Indian Institute of Technology (IIT)

Indian Institute of Technology (IIT), Madras is involved in the development of a 250 watt DMFC stack. IIT Madras has conducted advanced studies on hydrogen storage in carbon nanotubes.

Extensive work is being undertaken at IIT Madras on the development of new catalysts, catalysts metal-alloys and membranes for use in PEM fuel cells.

Indian Institute of Technology (IIT), Bombay is involved in the development of CFD models of fuel cell systems.

Southern Petrochemical Industries Corporation Science Foundation (SPIC-SF)

Southern Petrochemical Industries Corporation Science Foundation (SPIC-SF) is engaged development of PEMFC technology for applications that range from stationary (UPS systems, etc), portable and transportation. The centre is also involved in designing PEM electrolyser and hydrogen sensors. They have also demonstrated a fuel cell battery hybrid vehicle using a 10 kW PEM power plant.

National Chemical Laboratory (NCL), Pune:
NCL has synthesised proton-conducting membranes using surface fictionalization. Membranes having good proton transport behaviour have been identified for use as electrolytes in batteries and fuel cells.

Indian Oil Corporation Limited

Indian Oil Corporation is participating in a project to introduce hydrogen-CNG blends on a trial basis in existing CNG vehicles in the capital city. The company operates a hydrogen dispensing facility at its R&D centre in Faridabad. The proposed project aims to optimise the hydrogen-CNG blend for maximum performance and minimum emissions in major Indian cities.

Indian Institute of Science (IISc), Bangalore and Central Glass & Ceramic Research Institute (CGCRI), Kolkata

IISc and CGCRI are involved in developing SOFC technology for stationary applications. A methanol reformer was developed and integrated with a fuel cell system by IISc, Bangalore. Work on developing a DMFC is underway at IISc.

Mahindra & Mahindra Ltd

Mahindra & Mahindra Ltd is the second largest automotive manufacturer in India. The company is currently working on alternative fuel technologies for automotive applications. It is believed that they are also working on fuel cell and hybrid vehicles.

Tata Motors

Tata Motors, India's third largest maker of passenger cars, is currently in talks with manufacturers of hybrid engines and fuel cells, such as Ballard Power Systems for introducing fuel cell technologies in their passenger car models.

Telecommunications Consultants India Ltd (TCIL)

Telecommunications Consultants India Ltd (TCIL) has entered into a non-exclusive agreement with US fuel cell manufacturer
Plug Power to market, distribute and service Plug Power’s GenCore product line to government entities and companies requiring telecoms power in India.

**Key international players and their projects on Hydrogen and Fuel Cell technology:**

Below a brief description of projects by key international players is provided. The description below is categorized by application.

**Railways**

**East Japan Railway, Japan**

East Japan Railway has announced the test runs of its newly designed fuel cell-powered train. This event is expected to take place later this year (2007). The train will be tested on the route across the Yatsugatake mountain range in central Japan. This train will be the first hydrogen-fuelled train to travel on a regular passenger train track.

**The National Science and Technology Museum, Taiwan**

The National Science and Technology Museum successfully tested a mini-train using power generated by a hydrogen fuel cell. The train is one of the first of its kind in the world and forms part of the museum’s efforts to promote environmental protection.

**Japan’s Railway Technical Research Institute (RTRI), Japan**

The Institute announced that it conducted a trial run of what is claimed to be the world’s first fuel cell-powered railway vehicle. According to the institute, a 100 kW fuel cell system was tested following two years of development. The prototype train used a polymer electrolyte fuel cell (PEFC) manufactured by US-based Nuvera Fuel Cells.

**Aerospace and Space**
Aerospace is considered as the most challenging avenue for fuel cell based applications. However, with increasing pressure being put on the airline industry to decrease its carbon footprint this industry is actively looking at all its options.

**Aerovironment**

Aerovironment has announced that it is to run further tests on its fuel cell-powered unmanned plane as part of its efforts to improve mobile communications. The firm will trial the technology as part of an initiative backed by the Japanese government and the European Union, as it explores the potential for high-altitude platform (HAP) technology.

**Boeing, U.S.**

Boeing researchers and industry partners throughout Europe plan to conduct experimental flight tests in 2007 of a manned (single seat) propeller-driven airplane powered only by a fuel cell and lightweight batteries.

The systems integration phase of the Fuel Cell Demonstrator Airplane research project has been completed. The Boeing demonstrator uses a Proton Exchange Membrane (PEM) fuel cell/lithium-ion battery hybrid system to power an electric motor, which is coupled to a conventional propeller. The fuel cell provides all power for the cruise phase of flight. During takeoff and climb, the flight segment that requires the most power, the system draws on lightweight lithium-ion batteries. The proposed flight tests will take place in Spain.

**Horizon Fuel Cell Technologies, Singapore**

Singapore-based Horizon Fuel Cell Technologies announced the successful demonstration of its newly-developed hydrogen fuel cell-powered jet. The unmanned aircraft completed a test flight near Bern in Switzerland following 18 months of development. Designed primarily for the Unmanned Aerial Vehicle (UAV) market, the aircraft was developed in cooperation with the German Air and Space Centre along with other international partners. The vehicle has been named the HyFish, and has a total weight of 6 kg, with a fuselage length of only 1.2 metres.
Israeli Aerospace Industries (IAI)

Israeli Aerospace Industries developed the Inter-City Aircraft (Enfica). The aircraft is powered by fuel cells and has been developed in conjunction with the European Union and independent aerospace firms.

Protonex, U.S.

Protonex is jointly developing a fuel cell system for long-endurance UAV missions. The company, a contractor for the US Air Force Research Laboratory is developing a UAV power system that will integrate hydrogen battery technology with a high power fuel cell system designed to increase current UAV flight times from under two hours to over six hours.

Quantum Fuel Systems Technologies, U.S.

Quantum Fuel Systems Technologies is developing a fuel storage system designed for a stratospheric airship application. The company will develop hydrogen and oxygen fuel storage tanks capable of withstanding extreme conditions.

Sandia National Laboratories, U.S.

Sandia National Laboratories and Boeing are jointly researching the possibility of using a polymer electrolyte membrane (PEM) fuel cell as a source of back-up power in aircraft.

Two- and Three- Wheeled Vehicles

Two- and three- wheeled vehicles are once thought to be the most likely candidate for the first commercial applications of fuel cell technology.

GR Grafica, Italy

GR Grafica, an Italian company, is currently developing a new hydrogen fuel cell-powered scooter. The company’s “Hysyrider” is currently in the research and development stage.

Masterflex Brennstoff zellentechnik, Germany
The company has developed a fuel cell-powered “cargobike”. The bike, which is designed for use in city-based logistics tasks such as postal delivery and street cleaning, operates on a 250W fuel cell system which provides auxiliary power for lighting and other purposes as well as drive power.

Valeswood, U.K

Valeswood released a fuel cell power assisted bicycle into the UK market in early 2007. The H-Bike is a retrofit electric bike which has been imported from China and fitted with a HydroCell alkaline fuel cell.

Yamaha

Yamaha launched its new FC-AQEL in 2006. The new version of its bike FC-me runs’ in compressed hydrogen and is a hybrid. Apart from showing this new vehicle it appears that the earlier optimistic commercialisation timetable is slowing down and moving outwards from its original 2007 date.

Forklift and Industrial Vehicles

The players in the Fuel Cell powered forklifts arena have seen a large amount of movement this year.

Energy Conversion Devices (ECD Ovonics)

Energy Conversion Devices (ECD Ovonics) is developing a hydrogen-powered airport tow tractor. The company is expected to further develop its Ovonic metal hydride fuel cell technology. ECD Ovonics will develop and demonstrate the hydrogen-powered tractor, featuring on-board hydrogen storage, designed for use in US airports.

H2logic, Denmark

As well as working on trains and automobiles they have been carrying on the work on the H2 Truck. The test project has seen seven of the trucks sent to various organizations within Demark for day-to-day running.
University and Academic Institutions

Imperial College, London

The Imperial College, London set up a multidisciplinary teaching project to design and build a fuel cell hybrid go-cart. The university announced its Imperial Hybrid Racing programme, a teaching project at the university’s Faculty of Engineering aimed at creating the zero emissions go-cart using a battery and a super capacitor together with a fuel cell in 2006.

Ohio State College of Engineering

A fuel cell-powered land speed racing car attempted a new land speed record for electric vehicles in 2007. The Buckeye Bullet 2 car, designed and built by students at Ohio State College of Engineering set out to beat the land speed record of its battery-powered predecessor, currently standing at 315 mph.

Georgia Institute of Technology

Researchers based at the Georgia Institute of Technology have conducted new research into fuel cell-powered aircraft. Using grants from NASA and the US Defence Department, the research engineers have spent the last two years constructing and testing a hydrogen fuel cell-powered aircraft.

Tennessee Tech University, U.S

Researchers at the Tennessee Tech University are planning to develop fuel cell-based distributed generation systems for military ships and other naval war fighting platforms. Funding for the programme is to be provided by the Office of Naval Research.

Polytechnic of Turin, Italy

The Polytechnic of Turin has been involved in an international initiative to develop a new form of unmanned aerial vehicle (UAV) called the Heliplat. The Heliplat will be powered by both solar panels and fuel cells, running on solar power by day and on fuel cell power by night. The vehicle, designed as a surveillance plane, will be able to run for up to four months without stops.
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7. UTC Power (Fuel Cell manufacturer)
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8. Fuel Cell Today.com (Fuel Cell and Hydrogen consultancy organization),
   http://www.fuelcelltoday.com/jsessionid=0EC1B8B89EB9C6661C47A24EB41D4554