Figure 1.

Future of Electric Mobility and Polymer Electrolyte Membrane Fuel Cells

Fascinating World of Invisible Polymers

As the debate on electric mobility attains higher decibels in India, we should leave the choice of technology (PEM fuel cells or lithium ion battery) to the market forces so that the best one can or will survive. Irrespective of which technology ultimately becomes viable, there is one sure winner; the article highlights these unique functional polymers that are needed for both, an efficient fuel cell and a battery!

Dr. S. Sivaram
Former Director, CSIR-NCL
Honorary Professor and
INSA Senior Scientist
Indian Institute of Science
Education and Research
(IISER), Pune

The use of fuel cells for mobile power needs is an area which has attracted major R&D investments in the past decade. Fuel cells have been seriously considered for electric vehicles as a source of electrical energy, instead of the stored energy in lithium ion batteries. Hydrogen when used as a fuel produces only water in the tail pipe of a car! Today, in select geographies, you can buy or lease a fuel cell powered car (Figures 1 and 2).

Figure 1 : Toyota Mirai with a fuel cell powered electric engine.

The Techno-Commercial Challenge

The application of a polymer electrolyte membrane (PEM) based fuel cell in automobiles is also very challenging in terms of both, technology and engineering[1]. Over and above the standard performance requirements of a fuel cell such as chemical, mechanical and thermal stability, low permeability of hydrogen and oxygen across the polymer and high proton conductivity at around 120°C, automotive application requires quick start up, adequate low temperature performance (cold-start) and ability to perform at less than 50% relative humidity in the circulating gases. The cost target is also very daunting. The entire fuel cell system must cost less than USD 50 per kW. For purpose of comparison, an internal combustion engine costs about USD 60 per KW of power delivered. The Department of Energy, USA has set targets for proton exchange polymer membranes for transport applications as highlighted in Table 1[2].

Unfortunately, there is no polymer membrane available at present that fulfills all the desirable features that are mentioned in Table 1. PEM fuel cells that operate below 80°C and use perfluorinated ionomer membranes have low tolerance to fuel impurities (require ultra pure hydrogen), require specialised cooling technologies for heat removal which cannot be realised using the conventional radiator design used in automobiles and require constant humidification as well as water management systems to prevent either flooding or drying out, both of which lead to loss in performance. All this adds to cost. PEMs that operate at higher temperatures and use acid doped polybenzimidazoles as membrane materials can overcome many of these issues. They can tolerate higher level of impurities in the hydrogen feed, operate without humidity, produce water in the vapour phase and the waste heat is of a higher quality which can be used for combined heat and power or for on-board reforming of hydrocarbons or methanol (for generating hydrogen). However, their optimum performance can be achieved only above 160°C. Another serious drawback of these PEMs is that the doped phosphoric acid tends to leach out at elevated temperatures leading to loss in performance and loss of durability. Additionally, the electrocatalyst tend to undergo sintering and agglomeration at higher temperatures leading to loss in activity. The start-up time for such fuel cells can be as long as 40 minutes, the time required for heating the system, which is unacceptable.

Figure 2: Honda Clarity with a 40 kW fuel cell.

Table 1: Target of Performance for Proton Exchange Polymer Membranes for Automotive Applications

Characteristic	Target (2015)
Maximum operating temperature	120°C
Start-up temperature	- 40°C
Conductivity	0.1 S/cm at 120°C and 0.01 S/cm at -20°C
Relative humidity / inlet water vapour partial pressure	50% / 1.5 kPa
Hydrogen / oxygen crossover at 1 atm	2 mA cm^{-2}
Durability with cycling	5000 hours
Cost	USD 50 per kW

Application of PEM in the Automotive Sector

Automobile manufacturers have demonstrated the performance of several fuel cell powered prototype vehicles and have driven such vehicles for several thousand kilometres to test their performance. Inspite of the massive effort, penetration of PEM fuel cell powered cars has been modest (Figure 3). As with any new product which is yet to achieve economies of scale, costs are high (A Toyota Mirai on the road costs about USD 60,000). A typical PEM fuel cell powered car has a stack consisting of > 350 individual cells, delivering about 40 - 50 kW energy, stores about 5 kg of hydrogen on board, has a driving range of 500 km with one tank of hydrogen and a refueling time

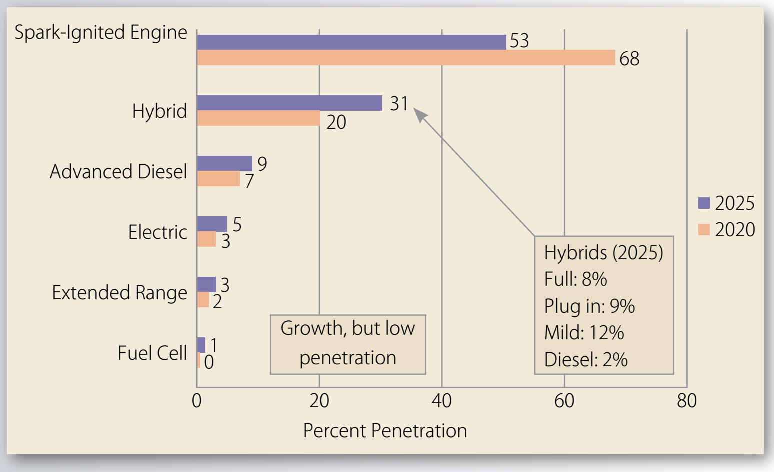

Figure 3: Percent penetration of passenger car automotive engines (IC, hybrid and electric). (Courtesy: Professor Saied Taheri, Virginia Tech, Blacksburg, Virginia , USA)

of < 5 minutes. Fuel cells are also being explored for public transport vehicles like buses. It has found widespread use in multi-utility vehicles like fork lifts in warehouses.

Lithium ion batteries are the most important competitors in automotive application for energy storage. In contrast to fuel cells, lithium battery has a driving range of < 250 km and has a recharging time anywhere between half an hour to eight hours. There is an intense debate today in the media regarding the future of electric mobility. Will future mobility be centered on vehicles where energy for locomotion is stored in batteries, which are chargeable using electricity or powered by fuel cells which does not require any large charge storage systems (batteries), but needs a continuous supply of fuel, namely, hydrogen? Automobile manufacturers are hitching their wagons on one or the other technology. Tesla is the most vociferous proponent of an electric vehicle with lithium ion battery storage. Toyota (Mirai), Hundai (Tuscon) and Honda (Clarity) have unveiled fuel cell driven electric vehicles. Apart from the relative cost of either a battery or the fuel cell, there is another important dimension related to infrastructure that may lock in one or the other technology with very little possibility of both technologies co-existing.

Battery powered vehicles need extensive public charging infrastructure, whereas, fuel cell vehicles will require large scale hydrogen refueling facilities. Japan is on the way to build a chain of hydrogen filling stations. Over 50,000 fuel cell powered cars may ply on the roads in Japan within the next 3 - 5 years. Both the infrastructure is expensive to create. It is inconceivable that there may not be sufficient incentives to create two parallel set of infrastructure facilities. Consequently, only one of these technologies will survive in the long run in a given geography.

The Road Forward

As the debate on electric mobility attains higher decibels in India, a few words of caution maybe in order. We should leave the choice of technology (PEM fuel cells or lithium ion battery) to the market forces so that the best one can or will survive. Human ingenuity and innovation is the safest bet for a sustainable solution. It is dangerous on the part of the Government to pick a technology choice or winner. This will have unintended consequences and will be detrimental to the emergence of optimum technology solutions.

Irrespective of which technology ultimately becomes viable, there is one sure winner. These are the unique functional polymers that are needed for both, an efficient fuel cell and a battery!

References

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